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| 2021 | 58/184 | Q2 | 68.75 |
| 2020 | 45/177 | Q2 | 74.86 |
| 2019 | 57/177 | Q2 | 68.08 |
| 2018 | 71/176 | Q2 | 59.94 |

Article

Infant Mortality Trends and Determinants in Kazakhstan

Nurbek Yerdessov, Olzhas Zhamantayev, Zhanerke Bolatova, Karina Nukeshtayeva, Gaukhar Kayupova and Anar Turmukhambetova



Article

Infant Mortality Trends and Determinants in Kazakhstan

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Abstract: Infant mortality rate (IMR) is a crucial indicator of healthcare performance and a reflection of a country's socioeconomic development. We analyzed the trends of IMR in Central Asia (CA) countries and its determinants in Kazakhstan, which is a middle-income country. Linear regression was used for IMR trend analysis in CA countries from 2000 to 2020 and for exploring associations between IMR and socioeconomic factors, health service-related factors, and population health indicators-related factors. A gamma generalized linear model was applied to define associations with various determinants. Our analysis revealed that IMR has decreased in all CA countries, with Kazakhstan having the lowest rate in 2000 and 2020. Our results suggest that socioeconomic indicators, such as total unemployment, Gini index, current health expenditure, gross domestic product (GDP), proportion of people living in poverty, and births by 15–19-year-old mothers, were associated with increased infant mortality rates. Improving socioeconomic conditions, investing in healthcare systems, reducing poverty and income inequality, and improving access to education, are all potential issues for further development. Addressing these factors may be critical for improving maternal and child health outcomes in the region.

Keywords: infant mortality; health determinants; middle-income country; Kazakhstan; Central Asia



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1. Introduction

Infant mortality rate (IMR) is widely considered as a major public health criterion and a reflection of a country's socioeconomic development. It is closely linked to maternal health and is a key determinant of a nation's health [1,2]. For countries with limited resources, infant mortality remains a relevant and easily calculable measure of population health [3]. The IMR is a standardized measure of children's deaths under one year of age per thousand live births. Achieving a reduction in IMR is a crucial milestone in attaining Sustainable Development Goal 3, with the purpose of providing healthy and active lives for every human being. The global infant mortality rate (IMR) has shown a significant decline, from 65 infant deaths per 1000 live births in 1990 to 29 infant deaths per 1000 live births in 2018 [4].

Kazakhstan has witnessed a notable reduction in mortality rates among all age groups, including infants, since 2000 [5]. Nevertheless, despite considerable investments in the health sector, Kazakhstan continues to fall behind OECD countries when it comes to key health indicators. The population of the country, which faced a decline between 1992 and 2002, has experienced a subsequent growth of 20%. As of 2019, Kazakhstan's gross domestic product (GDP) was estimated at USD 180.2 billion, with a per capita gross national income of USD 8810. These figures are significantly lower compared to the per capita gross national income of USD 40,115 observed in other OECD countries [6]. According to time-series analysis conducted by Thomas, the transition to a market economy in the 1990s temporarily alleviated environmental degradation but also resulted in socioeconomic challenges and a decline in living standards [7]. Some credibility issues have been raised regarding infant mortality data, including underreporting/misreporting in the Central Asian region and Eastern European countries [8,9]. However, in 2021, Kazakhstan, Kyrgyzstan, Uzbekistan,

and Tajikistan were among the 36 countries with high quality national data used for child mortality estimation by UN experts [5]. Furthermore, Kazakhstan implemented international criteria for live births and stillbirths in 2008, leading to increased attention and resources for the care of low weight newborns [10]. Over the past decade, mortality rates in Kazakhstan have declined across all age groups, including infants [11]. Regions such as Kostanay, Akmola, and Almaty have observed relatively high neonatal mortality rates [12]. In the Central Asian countries, neonatal mortality has experienced a 66% decline between 1990 and 2021, with an average annual reduction of 3.4% [5].

Uzbekistan has also achieved a decline in the death rate across all age groups, thanks to improvements in the healthcare system and an enhanced focus on maternal and child health [13]. Despite its relatively low GDP level, Kyrgyzstan has made significant progress in reducing infant mortality, which was successfully reduced by 46% over the last two decades [14].

Official data provide consistent evidence that IMR has decreased steadily in the EU and its member states over the past few decades, particularly in Baltic states and some East European countries. However, some developed countries have seen an increase or plateau in IMR in the last decade [15]. In the mid-2000s, it was found that South Korea was managing infant mortality levels relatively well. The IMR in South Korea was 3.2 in 2009, which was lower than the average IMR of OECD nations (4.7 in 2008) and the USA (6.3 in 2009), but higher than Japan's IMR (2.8 in 2009). This difference was attributed to the healthcare service system in Korea. Recommendations were made to improve perinatal, neonatal, and infant healthcare, such as establishing new policies for caring for preterm and high-risk pregnancies, and research driven perinatal facilities [16]. Meanwhile, in Japan between 1999 and 2017, the IMR differed based on household occupation types. The IMRs for farming households almost doubled (1.96), and for unemployed households, it increased 6.5 times compared to occupation types with the highest income [17]. In the USA, between 1999 and 2017, the IMR dropped from 736.0 to 567.0 per 100,000 live births, while the age of women giving birth increased [18,19]. In Chile, between 1990 and 2011, the IMR declined rapidly with an annual percent change (APC) of -5.4 . However, from 2001 to 2016, the rate of decline slowed down (APC -1.6) [20]. In Scotland, between 2000 and 2018, IMR and stillbirth rates decreased. Nonetheless, socioeconomic disparities continue to exist, and there are indications that mortality rates among the disadvantaged communities might be deteriorating [21]. All the countries mentioned above belong to the group of high-income countries [22].

We also looked at the IMR situation in some middle-income countries. In Hungary, between 1963 and 2012, a notable seasonal (end of winter) impact on neonatal and infant mortality was identified. This effect was more pronounced among infants with low birthweight and mothers with lower levels of education. It is suggested that respiratory infections may be linked to this observed phenomenon [23]. In Venezuela, achievement in managing the IMR came to a halt around 2009. Despite previous success in reducing infant mortality, the IMR in Venezuela reached 21.1 deaths per 1000 live births in 2016, which was almost 1.4 times higher than the rate in 2008. This represents a significant setback for public health efforts to improve maternal and child health in the country [24]. While India has made significant strides in reducing IM over the last decades, the country still faces challenges in ensuring the survival and well-being of all children. IMR varies widely across different states and socioeconomic groups [25]. A study in China analyzing the IMR from 1999 to 2019 suggested that inflation has an impact on infant mortality [26].

1.1. Determinants

The World Health Organization (WHO) emphasizes that maternal and child health is influenced by various social determinants of health that extend beyond access to healthcare. In addition to health policies, addressing socioeconomic factors and living conditions is equally crucial for infant survival [27]. Various social determinants, including gender, ethnicity, socioeconomic status, urban/rural disparities, work opportunities and conditions, and the broader context (such as state regulations and policies, and culture), significantly

impact infant health outcomes. For instance, economic development at the country level, measured by GDP per capita, seems to have an impact on IM to some extent during particular stages of human life [28,29]. Per capita government expenditure on healthcare emerged as the primary factor influencing infant mortality rates in Asia. Asian nations that allocated higher per capita funds to healthcare experienced notably lower levels of IMR [30]. The Gini index, which measures income distribution across a population, indicates the level of inequality present. A higher Gini index suggests greater inequality [31]. There was a positive and significant correlation observed between infant mortality and the Gini index [29]. Higher human development is strongly correlated with decreased infant mortality [32]. Additionally, income inequality is found to be positively associated with IMR, while mean household income and female educational attainment are negatively correlated with IM. The unemployment rate is found to be independently associated with IM [28,33]. In Italy, despite the availability of universal healthcare, differences in IM were linked to unemployment and income level [29].

Recent research found that adequate funding of healthcare systems is crucial. These studies demonstrated that, for every 1 percent increase in public health expenditure, there is a corresponding decrease in the IMR of approximately 0.6 to 1 percent [34,35].

Additionally, healthcare policies and actions have a significant impact on the reduction of IM. In Brazil, establishing the unified health system and the family health strategy were important factors in reducing infant mortality [33]. Other factors affecting rates of infant mortality were found to be income, poverty, nutritional status, housing, and educational attainment. Decreasing fertility rates were also associated with decreasing infant deaths [36].

Environmental factors also play a role in infant mortality rates. For instance, poor working environments and industrial pollution are significantly related to infant mortality, while urbanization, employment in the service sector, and economic wealth are not [37]. Furthermore, research indicates that domestic violence poses a risk to infant survival, as infants born to women who have encountered two or more incidents of domestic violence face increased rates of IMR [38].

1.2. The COVID-19 Period

Although the COVID-19 pandemic has had little direct effect on IM, its indirect impacts on the economy and the effectiveness of the health system are anticipated to result in higher death rates among this vulnerable population in low- and middle-income nations. In cases where the mother is positive for SARS-CoV-2 PCR, the baby is at increased risk of complications and adverse outcomes, which may include specialized neonatal care and prolonged hospitalization [22,39].

Previous research reported difficulties in delivering healthcare services to families, particularly in rural areas, and a disrupted referral chain, resulting in a decrease in stillbirth and infant mortality rates, during the COVID-19 pandemic. However, the pandemic has also led to a reduction in the number of follow-up visits during pregnancy, and pregnant women have had their regular antenatal care disrupted [40,41]. In addition, the lockdown policy due to the pandemic, coupled with patients' concerns about becoming infected in hospital, may have contributed to the higher stillbirth rate [42].

Strict preventive efforts implemented by the government at the outset of the pandemic have led to a comparatively low prevalence of COVID-19 in Kazakhstan, a middle-income country in CA [43,44]. A rise in unemployment, a reduction in economic development, and aggressive inflation were all occurring at the same time. Access to healthcare has decreased despite attempts to preserve basic services [45]. Given these complex factors, our aim is to estimate infant mortality rate trends from 2000 to 2020 in Kazakhstan and CA and identify the IM determinants in Kazakhstan.

2. Materials and Methods

2.1. Data Sources

A retrospective analysis of secondary data was conducted.

Data on the numbers of live births and infant deaths were obtained from the published nationwide population register.

Monitoring of IM cases in Kazakhstan is conducted on a daily basis, with the following three levels of information collection and analysis: at the health organization level, the territorial branch level of the Republic Center for Health Development, and the central office of the Republic Center for Health Development.

At the health organization level, data are collected from newborns based on hospital records, or in cases of stillbirth or death of children under one year old. At the territorial branch level of the Republic Center for Health Development, data are collected from all medical organizations, and output forms are generated for each region, including districts and health organizations within them. At the central office of the Republic Center for Health Development, data are collected from the entire republic, and output data are generated at the country level, including regions and districts.

Each health organization designates responsible individuals for monitoring and analyzing incoming data on a daily, monthly, or yearly basis. Trained medical personnel with expertise in examining documents related to live births, stillbirths, and deaths of children under one year old ensure the reliability of the registers and transmit the data to the next level. The compiled data are made available to the public in annual compilation reports entitled "Population Health and Healthcare Organizations' Performance in the Republic of Kazakhstan" from 2000 to 2020.

The mandatory documentary evidence for infant mortality cases includes the medical certificate of death and the conclusion of perinatal death. These documents must be promptly completed, regardless of where the death occurs (in a maternity hospital, during childhood illness, or at home). The doctor responsible for handling the death observation must possess the necessary medical knowledge and qualifications [46].

IMR data, socioeconomic, health service-related, and population health-related indicators of Kazakhstan were obtained from the annual statistical reports "Population Health and Healthcare Organizations' Performance in the Republic of Kazakhstan" from 2000 to 2020. These reports contain country- and region-level data on health services and population health. Kazakhstan's health data collection policy adheres to international guidelines to guarantee statistical data comparability. The IMRs of Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan were derived from World Bank databases [47].

2.2. Statistical Analysis

Data were analyzed with IBM SPSS Statistics version 26.0. Linear regression was used for IMR trend analysis in CA countries from 2000 to 2020 and for exploring associations between IMR and socioeconomic factors, health service-related factors, and population health indicators-related factors. Due to the non-normal distribution of the IMR variable, a gamma generalized linear model was used. For the regression, the dependent variable used was the infant mortality rate, which is calculated as the ratio of the number of children who died before the age of 1 year in a given year to the number of live births in the same year, multiplied by 1000. However, to ensure more accurate calculations, the authors adopted the methodology proposed by the German statistician Johannes Rathes [48]. Before fitting the regression model, the authors performed a cross-correlation analysis among 69 variables. The regression analyses included 39 indicators, which were further divided into two groups, socioeconomic factors and population health-related factors (Appendix A, Table A1).

3. Results

3.1. IM Situation in CA Countries and Its Trends

A decline in IMR is observed in all CA countries. The lowest IMR in the CA countries, in 2000 and 2020, was in Kazakhstan and was 36.7 per 1000 live births and 8.9 per 1000 live

births, respectively. In 2000, Tajikistan had the highest IMR among CA countries (67.6 per 1000 live births), while in 2020, IMR was highest in Turkmenistan (36.1 per 1000 live births; Figure 1).

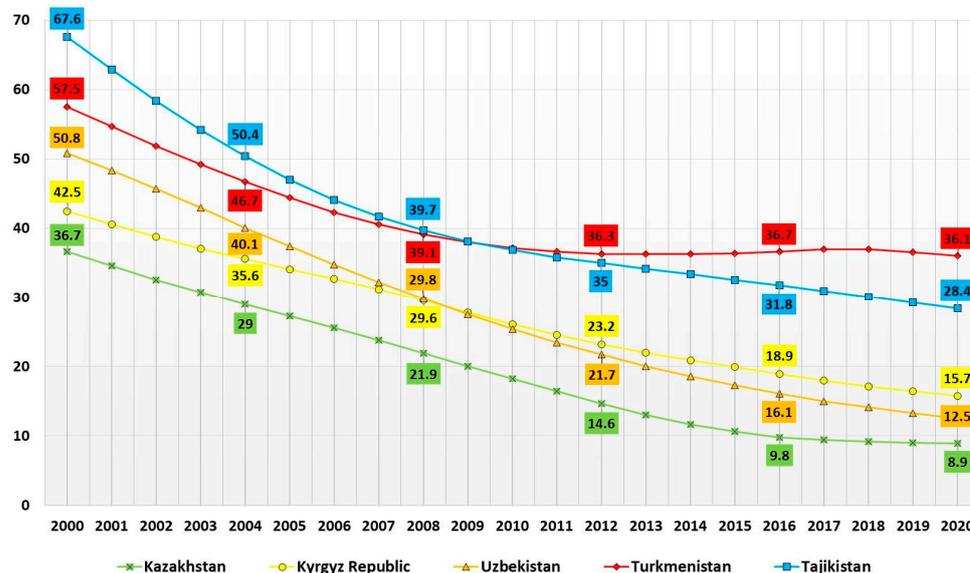


Figure 1. Infant mortality rate in CA countries per 1000 live births, 2000–2020.

In general, in all CA countries, a 20-year decreasing trend of IMR is observed. Thus, a regression analysis of IMR in the CA over 20 years showed that the largest annual decline in IMR was detected in Uzbekistan. The annual value of IMR in Uzbekistan decreased by an average of 1.97 ($b = -1.97$, intercept = 3979.82; 95% CI: $-2.13, -1.79$; p -value < 0.001), and the infant mortality rate in 2020 decreased by 75% compared to 2000. The annual IMR reduction in Turkmenistan over 20 years was on average 0.94 ($b = -0.94$, intercept = 1936.6; 95% CI: $-1.21, -0.68$; p -value < 0.001), and IMR in 2020 decreased by 37% compared to 2000, which is the lowest in CA. The annual IMR, decreasing in Kazakhstan over 20 years, was on average 1.49 ($b = -1.49$, intercept = 3023.44; 95% CI: $-1.69, -1.36$; p -value < 0.001), and IMR in 2020 decreased by 76% compared to 2000.

3.2. Description of Socioeconomic and Population Health Indicators-Related Factors

The study included 21 observations collected between 2000 and 2021. Among the socioeconomic factors analyzed, the Gini index, which measures income distribution, ranged from 27.00 to 40.00, with a mean value of 30.04 ± 3.72 . The average gross enrollment in tertiary education, calculated as the number of postsecondary students divided by the corresponding population and multiplied by 100, was 52.47 ± 6.49 , ranging from 38 to 67. Health expenditure, expressed as total per capita at the average exchange rate, averaged 223.75 ± 105.88 , ranging from 51 to 378. GDP ranged from 3.00 to 4.00, with a mean value of 3.22 ± 0.47 . The mean income per capita, a measure of economic well-being, was $USD 216.93 \pm 105.98$, ranging from USD 45.00 to 371.00. The proportion of people living below the poverty line ranged from 3.00 to 47.00, with a mean value of 14.44 ± 15.29 . The number of births to mothers aged 15–19 ranged from 2.00 to 10.00, with a mean value of 5.08 ± 1.94 .

Moving on to population health-related factors, the average bed density per 1000 children was 5.08 ± 1.94 , ranging from 3.49 to 5.34. Maternal mortality ratio (MMR), defined as the number of maternal deaths per 100,000 live births within a specific period, averaged 29.50 ± 16.12 , ranging from 12 to 61.00. The mortality rate from respiratory system diseases per 1000 live births ranged from 5.00 to 52.90, with a mean value of 18.39 ± 15.19 . The average mortality rate from acute upper respiratory infections, influenza, and pneumonia per 1000 live births was 17.66 ± 15.09 , ranging from 4.44 to 51.80. Infectious and parasitic

diseases had an average mortality rate of 6.72 ± 4.03 per 1000 live births, ranging from 3.07 to 17.00. The mortality rate from intestinal infectious diseases per 1000 live births ranged from 0.10 to 7.70, with a mean value of 1.86 ± 2.09 . The mortality rate from congenital malformations per 1000 live births ranged from 15.61 to 38.90, with a mean value of 25.95 and a standard deviation of 6.81. Mortality rate from injury, poisoning, and other external causes per 1000 live births ranged from 2.64 to 10.30, with a mean value of 6.26 ± 2.01 . The average malnutrition rate was 26.48 ± 19.26 , with a range of 3.30 to 57.80. For the remaining indicators, please refer to Table A1 in Appendix A.

3.3. IMR and Its Associated Factors

Regression analysis showed that socioeconomic indicators (Table 1), such as total unemployment (0.163; 0.0001), Gini index (0.725; 0.005), current health expenditure (0.187; 0.0001), GDP (0.187; 0.0001), the proportion of people living below the poverty line (0.072; 0.0001), and babies born to 15–19 years old mothers (0.25; 0.0001) were associated with increased IMR. However, the next indicators from this category individuals using the internet (−0.006; 0.0001), mean age of the population (−1.45; 0.001), total divorce rate (−0.753; 0.0001), gross enrollment in tertiary education (18–22 years) (−0.042; 0.002), health expenditure in USD (−0.003; 0.003), THE (−0.001; 0.001), mean income per capita in USD (−0.002; 0.0001), and the value of the subsistence minimum (−0.008; 0.0001), were associated with decreased IMR.

Additionally, bed density (−0.008; 0.0001) was associated with decreased IMR. All population health-related factors were associated with increased IMR. Thus, MMR (0.009; 0.0001), the infant communicable diseases morbidity rate (0.012; 0.001), intestinal infectious diseases (0.015; 0.0001), sepsis (1.524; 0.001), diseases of the blood and blood-forming organs (0.005; 0.0001), nutritional anemias (0.005; 0.0001), endocrine disorders (0.007; 0.0001), malnutrition (0.018; 0.0001), disorders of the central nervous system (0.012; 0.0001), respiratory diseases (0.001; 0.0001), acute upper respiratory infections (0.001; 0.0001), digestive system diseases (0.013; 0.0001), diseases of the genitourinary system (0.034; 0.0001), certain conditions originating in the perinatal period (0.003; 0.0001), injury, poisoning and certain other consequences of external causes (0.118; 0.0001), mortality rate from diseases of the respiratory system (0.031; 0.0001), mortality rate from acute upper respiratory infections, influenza and pneumonia (0.031; 0.0001), mortality rate from intestinal infectious diseases (0.042; 0.0001), mortality rate from congenital malformations (0.107; 0.012), and mortality rate from injury, poisoning and certain other consequences of external causes (0.148; 0.0001) were associated with increased IMR.

Table 1. Regression model coefficient estimates.

| Variable | B | 95% Wald Confidence Interval | | p-Value |
|-----------------------|--------|------------------------------|--------|---------|
| | | Lower | Upper | |
| Socioeconomic factors | | | | |
| TU | 0.163 | 0.121 | 0.206 | 0.0001 |
| INTERNET | −0.006 | −0.007 | −0.006 | 0.0001 |
| G—INDEX | 0.725 | 0.215 | 1.235 | 0.005 |
| AGE | −1.45 | −2.47 | −0.43 | 0.005 |
| TDR | −0.753 | −0.841 | −0.664 | 0.0001 |
| GENROLL | −0.042 | −0.07 | −0.015 | 0.002 |
| CHE | 0.187 | 0.095 | 0.28 | 0.0001 |
| HE USD | −0.003 | −0.005 | −0.001 | 0.003 |
| THE KZT | −0.001 | −0.002 | 0 | 0.001 |
| GDP KZT | 0.187 | 0.095 | 0.28 | 0.0001 |
| INCOME USD | −0.002 | −0.003 | −0.002 | 0.0001 |
| POVERTY | 0.072 | 0.057 | 0.086 | 0.0001 |
| SUBMIN USD | −0.008 | −0.01 | −0.006 | 0.0001 |
| YOUNG | 0.25 | 0.142 | 0.358 | 0.0001 |
| MOTHER | | | | |

Table 1. Cont.

| Variable | B | 95% Wald Confidence Interval | | p-Value |
|-----------------------------------|--------|------------------------------|-------|---------|
| | | Lower | Upper | |
| Population health-related factors | | | | |
| BED | −0.008 | 0.574 | 0.891 | 0.0001 |
| MMR | 0.009 | 0.006 | 0.013 | 0.0001 |
| MORBIDITY | 0.0004 | 0.0004 | 0.001 | 0.0001 |
| COMD | 0.012 | 0.01 | 0.013 | 0.0001 |
| INTESTID | 0.015 | 0.013 | 0.017 | 0.0001 |
| SEPSIS | 1.524 | 0.6 | 2.448 | 0.001 |
| BLOOD | 0.005 | 0.004 | 0.007 | 0.0001 |
| ANAEMIA | 0.005 | 0.004 | 0.006 | 0.0001 |
| ENDOCRINE | 0.007 | 0.007 | 0.008 | 0.0001 |
| MALNUTRITION | 0.018 | 0.017 | 0.019 | 0.0001 |
| CNERVE | 0.012 | 0.01 | 0.015 | 0.0001 |
| NERVE | 0.011 | 0.01 | 0.011 | 0.0001 |
| RESP | 0.001 | 0.001 | 0.001 | 0.0001 |
| ARESP | 0.001 | 0.001 | 0.001 | 0.0001 |
| DIGESTIVES | 0.013 | 0.012 | 0.014 | 0.0001 |
| GENITS | 0.034 | 0.023 | 0.045 | 0.0001 |
| CERTAIN | 0.003 | 0.003 | 0.003 | 0.0001 |
| INJURY | 0.118 | 0.085 | 0.151 | 0.0001 |
| MRRESP | 0.031 | 0.026 | 0.035 | 0.0001 |
| /MRARESP | 0.031 | 0.026 | 0.035 | 0.0001 |
| MRINFECT | 0.331 | 0.239 | 0.422 | 0.0001 |
| MRINFECT | 0.42 | 0.209 | 0.63 | 0.0001 |
| MRMALFORMATIONS | 0.107 | 0.024 | 0.19 | 0.012 |
| MRINJURY | 0.148 | 0.122 | 0.173 | 0.0001 |

4. Discussion

In this study, we analyzed trends in infant mortality rates in CA countries and its determinants in Kazakhstan. We found that all CA countries have successfully decreased their IMR from relatively high levels, with Kazakhstan having the lowest rate in 2000 and 2020. Our results suggest that socioeconomic indicators, such as total unemployment, Gini index, current health expenditure, GDP, the proportion of people living in poverty, and births by 15–19-year-old mothers, were associated with increased infant mortality rates in Kazakhstan, which is consistent with findings from other studies conducted in middle-income countries [49–51]. Higher national income and increased public health expenditure have been found to significantly improve health outcomes and reduce infant mortality rates [34,35,52]. Maternal mortality emerges as a notable risk factor for infant mortality, followed by inadequate access to sanitation, water, and lower female education. In Europe, towards the end of the study period, out-of-pocket health expenditure emerged as a significant determinant, deviating from the global trend, which aligns with our research findings [9]. Schell et al. found that income equality (Gini index) was an influential predictor of IMR in middle-income countries, which is consistent with the findings of our study conducted in Kazakhstan. Therefore, extrapolating health policies from high- to low-income countries poses challenges [53]. At the same time, in recent years, Kazakhstan has seen a steady increase in nominal cash income per capita. From 2013 to 2017, this increased by 47.1%, almost 1.5 times. Also, in Kazakhstan, there is a slight decrease in the level of poverty (the share of the population with incomes below the subsistence level) [54]. Our findings imply that poverty levels relate to greater IMR, which is consistent with previous research. Furthermore, regardless of specific maternal socio-demographic, health, and obstetric characteristics, excessive poverty relates to IM [55]. These findings support the idea that major efforts are required to minimize the fraction of individuals living on less than the subsistence level. It is also crucial to consider the influence of government expenditure on healthcare requirements. Increased per capita health spending in high

mortality areas is said to play a significant influence in lowering infant mortality. Medical facilities, on the other hand, are more essential in lowering the death rate of children under the age of five [56].

Uzbekistan's socio-demographic development during the years of independence has resulted in a decline in mortality across all age groups. The country has improved its healthcare system and focused on enhancing maternal and child health [13]. Despite its relatively low GDP level and limited investments in the health sector, Kyrgyzstan has successfully reduced newborn mortality rates by 46% [14].

Access to healthcare resources is another major element in lowering IMR. It has been found that the risk of infant mortality lowers in higher income families, i.e., those with the best access to healthcare services. At the same time, the risk of IM is higher in rural households than in urban ones, which can be explained by the difficulty of obtaining health services in rural regions [57]. In recent years, Kazakhstan implemented various measures to manage IMR. These include the regionalization of prenatal care, establishment of additional perinatal clinics, and equipping them with modern technology. Additionally, training centers have been set up across the country to ensure efficient prenatal care, integrated management of childhood diseases, and effective coordination of perinatal care through the involvement of regional coordinators [11]. The great majority of pregnant women in Kazakhstan received specific prenatal care, according to the 2015 Kazakhstan Multiple Indicator Cluster Survey. Thus, 99.3% of women of reproductive age who gave birth to a live child in the previous two years received care from a competent health provider at least once, and 95.3% received care from a qualified health provider at least four times. Over the last two years, 99.4% of births took place in the presence of trained medical staff and within a medical facility [54].

Rising income and access to safe water are some of the reasons for improved health outcomes in low- and middle-income countries [58]. However, the relative importance of major health determinants varies between income levels, and extrapolating health policies from high-income to low-income countries can be problematic [53]. In our study, we found that indicators such as individuals using the internet, mean age of the population, total divorce rate, gross enrollment in tertiary education, health expenditure in USD, total health expenditure, mean income per capita, and value of the subsistence minimum were associated with decreased IMR in Kazakhstan.

It is important to acknowledge the limitations of our study. One of the main limitations is that we did not take into account the impact of the COVID-19 pandemic on infant mortality rates in Kazakhstan. The pandemic has had direct and indirect effects on infant mortality rates, especially in low- and middle-income countries [39]. Disruptions in antenatal care and follow-up visits due to the pandemic may have contributed to increased rates of stillbirth and infant mortality [40,41]. Future research could examine the impact of the pandemic on infant mortality rates in Kazakhstan. Additionally, maternal factors such as preterm births, birth spacing, multiple/single gestation, type of delivery, and number of abortions were not included in our study and should be considered when analyzing IMR [59–62].

Sudden infant death syndrome (SIDS) used to be one of the major causes of death of infants [63]. Even though the incidence of SIDS has steadily declined due to adoption of recommendations such as a supine sleeping position, avoiding maternal smoking during pregnancy, and several others, the exact mechanism of the development of this syndrome still remains unclear. The triple-risk model, which was first put forth by Filiano and Kinney, appears to provide the most comprehensive explanation of SIDS pathophysiology [64,65]. While it was out of the scope of our study, discovery of the etiological factors of sudden infant death syndrome would be a significant input towards reducing IM.

It is worth noting that data quality and accessibility of vital and health statistics are important considerations in IMR. While data quality and accessibility are generally good in Kazakhstan, other countries in the CA region may face some difficulties in this regard [66]. In conclusion, while our study provides valuable insights into the trends and patterns of

infant mortality rates in Kazakhstan, it is important to take into account these limitations and factors for future research in this area.

5. Conclusions

The decline in infant mortality rates in CA countries over the past two decades is encouraging. However, significant challenges remain in reducing IMR in the region further. This study identified various social determinants of infant health that require attention for improving infant health outcomes in a middle-income country from the region. Improving socioeconomic conditions, investing in healthcare systems, reducing poverty and income inequality, improving access to education, reducing fertility rates, addressing environmental factors, and reducing domestic violence are all potential avenues for further improvement. Furthermore, the study identified several population health and health service-related factors that were associated with increased infant mortality rates. Addressing these factors may be critical for improving maternal and child health outcomes in the region.

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Appendix A

Table A1. Socioeconomic factors.

| Factors | Acronym |
|-------------------------------------------------------------------|--------------|
| Socioeconomic factors: Total unemployment, % of total labor force | TU |
| Individuals using the internet, % of population | INTERNET |
| Gini index | G—INDEX |
| Mean age of the population | AGE |
| Total divorce rate | TDR |
| Gross enrollment in tertiary education (18–22 years) | GENROLL |
| Current health expenditure, % of GDP | CHE |
| Health expenditure in USD, per capita | HE USD |
| Total health expenditures in KZT, in millions | THE KZT |
| GDP in KZT, % | GDP KZT |
| Mean income per capita, in US dollars | INCOME USD |
| Proportion of people living below poverty | POVERTY |
| Value of the subsistence minimum, in USD | SUBMIN USD |
| Born to 15–19 years old mothers, % | YOUNG MOTHER |

Table A2. Population health—related factors.

| Factors | ICD-10 Code | Acronym |
|---------------------------------------------------------------------------------------------------------------|------------------------|-----------------|
| Beds density, per 1000 children | | BED |
| Maternal mortality rate | | MMR |
| Antenatal death, per 1000 live and death birth | | ANDEATH |
| Infant morbidity rate, per 1000 infants | | MORBIDITY |
| Infant communicable diseases morbidity rate | | COMD |
| Intestinal infectious diseases, per 1000 infants | (A00-A09) | INTESTID |
| Sepsis incidence, per 1000 infants | (R65.20) | SEPSIS |
| Diseases of the blood and blood-forming organs, per 1000 infants | (D50-D89) | BLOOD |
| Nutritional anemias incidence per 1000 infants | (D50-D53) | ANAEMIA |
| Endocrine disorders incidence per 1000 infants | (E00-E89) | ENDOCRINE |
| Malnutrition incidence per 1000 infants | (E40-E46) | MALNUTRITION |
| Disorders of central nervous system incidence per 1000 infants | (G96.9) | CNERVE |
| Diseases of the nervous system), per 1000 infants | (G00-G99) | NERVE |
| Respiratory diseases incidence, per 1000 infants | (J00-J99) | RESP |
| Acute upper respiratory infections incidence, per 1000 infants | (J06. 9, B97) | ARESP |
| Digestive system diseases incidence per 1000 infants | (K00-K95) | DIGESTIVES |
| Diseases of the genitourinary system incidence, per 1000 infants | (N00-N99) | GENITS |
| Certain conditions originating in the perinatal period incidence, per 1000 infants | (P00-P96) | CERTAIN |
| Injury, poisoning and certain other consequences of external causes incidence, per 1000 infants | (S00-T88) | INJURY |
| Mortality rate from diseases of the respiratory system, per 1000 live births | (J00-J99) | MRRESP |
| Mortality rate from acute upper respiratory infections, influenza and pneumonia, per 1000 live births | (J00-J06) (J10-J18) | MRARESP |
| Mortality rate from infectious and parasitic diseases, per 1000 live births | (A00-B99) | MRINFECT |
| Mortality rate from intestinal infectious diseases, per 1000 live births | (A00-A09) | MRITINFECT |
| Mortality rate from congenital malformations, per 1000 live births | (Q00-Q99) | MRMALFORMATIONS |
| Mortality rate from injury, poisoning and certain other consequences of external causes, per 1000 live births | (S00-T88) | MRINJURY |

Table A3. Descriptive statistics of socioeconomic and population health indicators-related factors.

| Variable | Minimum | Maximum | Mean | Std. Deviation |
|-----------------------------------|---------|---------|--------|----------------|
| Socioeconomic factors | | | | |
| TU | 5.00 | 13.00 | 6.77 | 2.21 |
| INTERNET | 4.00 | 66.00 | 30.24 | 24.07 |
| G-INDEX | 27.00 | 40.00 | 30.04 | 3.72 |
| AGE | 31.00 | 32.00 | 31.47 | 0.33 |
| TDR | 2.00 | 3.00 | 2.56 | 0.43 |
| GENROLL | 38.00 | 67.00 | 52.47 | 6.49 |
| CHE | 3.00 | 4.00 | 3.22 | 0.47 |
| HE USD | 51.00 | 378.00 | 223.75 | 105.88 |
| THE KZT | 108.00 | 1938.00 | 772.09 | 602.58 |
| GDP KZT | 3.00 | 4.00 | 3.22 | 0.47 |
| INCOME USD | 45.00 | 371.00 | 216.93 | 105.98 |
| POVERTY | 3.00 | 47.00 | 14.44 | 15.29 |
| SUBMIN USD | 28.00 | 109.00 | 71.76 | 23.18 |
| YOUNG MOTHER | 2.00 | 10.00 | 5.08 | 1.94 |
| Population health-related factors | | | | |
| BED | 3.49 | 5.34 | 4.39 | 0.61 |
| MMR | 12.00 | 61.00 | 29.50 | 16.12 |
| MORBIDITY | 107.80 | 342.70 | 193.18 | 85.95 |
| COMD | 20.80 | 88.30 | 48.31 | 21.28 |
| INTESTID | 9.30 | 60.90 | 31.95 | 16.60 |
| SEPSIS | 0.00 | 0.50 | 0.20 | 0.17 |
| BLOOD | 42.50 | 189.00 | 125.99 | 48.15 |
| ANAEMIA | 36.80 | 184.10 | 121.52 | 48.80 |
| ENDOCRINE | 9.30 | 129.80 | 66.40 | 43.85 |
| MALNUTRITION | 3.30 | 57.80 | 26.48 | 19.26 |
| CNERVE | 1.00 | 3.10 | 1.40 | 0.45 |
| NERVE | 76.40 | 141.60 | 101.58 | 19.13 |
| RESP | 565.90 | 1368.50 | 982.54 | 214.81 |
| ARESP | 281.40 | 943.80 | 665.77 | 221.26 |
| DIGESTIVES | 62.60 | 103.80 | 83.85 | 13.34 |
| GENITS | 9.60 | 28.50 | 17.15 | 5.16 |
| CERTAIN | 149.40 | 403.70 | 297.23 | 76.05 |
| INJURY | 4.40 | 20.90 | 8.44 | 4.34 |
| MRRESP | 5.00 | 52.90 | 18.39 | 15.19 |
| MRARESP | 4.44 | 51.80 | 17.66 | 15.09 |
| MRINFECT | 3.07 | 17.00 | 6.72 | 4.03 |
| MRITINFECT | 0.10 | 7.70 | 1.86 | 2.09 |
| MRMALFORMATIONS | 15.61 | 38.90 | 25.95 | 6.81 |
| MRINJURY | 2.64 | 10.30 | 6.26 | 2.01 |

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Relationships between infant mortality and socioeconomic and demographic factors in Kazakhstan: an analysis from a middle-income country in Central Asia

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Abstract

Background Infant mortality rate is an important indicator of a nation's overall health and development. Kazakhstan, like many Central Asian countries, has faced its fluctuating trends during the last decade influenced by various socioeconomic factors. This study aims to analyze the relationship between socioeconomic and infant mortality indicators in Kazakhstan from 2010 to 2021.

Methods We analyzed aggregated panel data from all 14 regions of Kazakhstan and 3 major cities (Astana, Almaty and Shymkent) over a twelve-year period, including socioeconomic and demographic variables obtained from the Bureau of National Statistics and the Ministry of Healthcare of the Republic of Kazakhstan. Log transformation was applied to achieve symmetrical distribution and standardization of selected variables. Multiple linear regression assessed the effect size of significant predictors on infant mortality.

Results The mean infant mortality rate was 10.22 per 1,000 live births, with higher rates in southern/western regions (e.g., Kyzylorda: 13.0) compared to northern areas (e.g., Pavlodar: 8.32). Our panel data analysis (2010–2021) revealed consistent socioeconomic patterns: unemployment rates and poverty levels showed positive relationship with infant mortality rates, while greater housing space per capita, lower income inequality (Gini coefficient), and higher living wages were correlated negatively. The regression model accounted for a substantial proportion of variance in infant mortality, emphasizing the role of economic stability, equitable resource distribution, and living conditions in improving infant health outcomes.

Conclusions The study examines the relationship of infant mortality with socioeconomic factors in Kazakhstan. Economic growth alone is insufficient, equitable wealth distribution and comprehensive social and healthcare investment may contribute to the sustained reductions in infant mortality indicators. These findings may be valuable for policymakers not only in Kazakhstan but also in other Central Asian nations facing similar public health challenges.

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Keywords Infant mortality, Socioeconomic factors, Public health, Demography, Kazakhstan, Central Asia, Middle-income countries

Introduction

Infant mortality stands as an important marker of a nation's health status, with research pointing to a notable association between infant mortality and socioeconomic factors such as income inequality, unemployment, poverty, and access to healthcare [1, 2]. It is expressed as the probability of a child's death between birth and one year of age [3]. The infant mortality rate (IMR) serves as a critical gauge of overall population health, and high IMR often signifies broad structural issues such as underlying socioeconomic conditions, inadequate healthcare services, poor sanitation, and low educational attainment [4, 5].

In Kazakhstan, which is a middle-income country in Central Asia (CA), state initiatives in healthcare development such as “Densauilyk” and “Salamatty Kazakhstan” focusing on preventive care, have shown promising results in enhancing maternal, prenatal, and infant health [6]. Kazakhstan's demographic landscape, marked by population growth from natural increase and migration, faces challenges with a lower life expectancy and higher infant mortality rate compared to developed countries. Moreover, according to the TransMonEE (Transformative Monitoring for Enhanced Equity) partnership, which monitors the situation of children and women in Europe and Central Asia, the percentage of children aged 0–17 years in Central Asian countries' populations (34–42%) is significantly higher compared to selected European nations (United Kingdom, Germany, Poland), see Additional file 1 [7]. These countries were chosen to highlight disparities in child population shares between Central Asia and Europe as regional benchmarks to highlight demographic and economic contrasts, contextualizing Kazakhstan's demographic challenges. Simultaneously, Kazakhstan boasts universal literacy and extensive educational coverage [8].

The remainder of this paper is structured as follows: Sect. “Introduction” as “Background” covers existing literature in the field, identifies research gaps, and how the research being done will add to current knowledge. Section “Background” provides a detailed description of the data and methods used in the analysis. Section “Data and methods” presents the results of the study, including descriptive statistics and regression analyses. Section “Results” discusses the findings in the context of existing literature and their implications for policy. Finally, Sect. “Discussion” concludes the paper with a summary of key insights.

Background

During the past decades, Kazakhstan achieved a remarkable sixfold reduction in the IMR from 1990 to 2017, declining from 54.1 to 8.9 deaths per 1,000 live births, outpacing other CA countries [9]. A significant contributor to this reduction was Kazakhstan's 2008 adoption of World Health Organization (WHO) criteria for defining live births and stillbirths [10]. This alignment with WHO standards helped Kazakhstan reduce infant mortality by over a third by 2015, with ongoing efforts towards further reductions by 2030. Regional disparities were reported by Bayserkina et al. and official statistics, highlighting higher IMRs in southern and western Kazakhstan from 1991 to 2012 [11]. Overall, since 1990, Kazakhstan has achieved a 64% reduction in infant mortality and a 65% reduction in child mortality, meeting United Nations Millennium Development Goal 4 ahead of schedule in 2014 [12]. From 2000 to 2020, Kazakhstan achieved a 76% reduction in infant mortality (annual average reduction rate of 1.49), while Uzbekistan was the only Central Asian country to demonstrate comparable progress, with a 75% decline over the same period [13]. This significant pace of improvement reflects the CA authorities' strong commitment to pursuing Sustainable Development Goal 3 (SDG 3), which aims to ensure healthy lives and promote well-being for all ages [14].

Socioeconomic determinants contribute to the shaping of health outcomes, particularly in infant mortality. Despite consistent investments in healthcare, education, and social sectors within the CA region, these efforts fall below the averages observed for the Organization for Economic Co-operation and Development [15]. Social determinants including poverty, access to healthcare services, and legal or social barriers significantly influence health outcomes [4]. Demographic transition theory suggests that reductions in mortality rates, including infant mortality, are closely tied to socioeconomic development and improved healthcare access [16]. Classical studies emphasize the role of maternal education and household wealth in child survival [17]. Contemporary research underscores persistent structural inequities, such as disparities in maternal healthcare utilization and wealth-related inequalities, which perpetuate disparities in infant mortality even amid economic growth [18, 19]. For instance, studies highlight how targeted policy interventions, such as expanding maternal education and strengthening healthcare infrastructure, can mitigate these inequities and accelerate progress toward child survival goals [20]. Income inequality and social policies, including maternal leave policies, may help to explain

variations in infant mortality and birth outcomes across countries, even in high-income nations [21].

Studies from Kazakhstan and other countries emphasize the association of maternal and infant health with the household composition, wealth quantiles, the absence of sanitation facilities in households and life expectancy at birth [9, 22]. In low- and middle-income countries, factors such as lower population growth, better living conditions, and improved service provision are associated with lower IMR [23]. The growing proportion of Kazakhstani people living below the living wage further adds to the complexity of socioeconomic challenges [24]. Moreover, cultural factors, including attitudes and beliefs related to medical care, may interact with socioeconomic determinants to indirectly impact children's health outcomes [25].

Reductions in government health spending can be linked to negative public health outcomes. For instance, in European Union countries, a 1% decrease in government health expenditure correlated with an increase in maternal mortality rates [26]. Total, public and private health expenditures have correlations with reducing infant mortality rates, with private health expenditure having a more substantial effect [27, 28]. Factors such as poverty and unemployment can also contribute to variations in IMR. In Italy, the Gini index and total unemployment rate correlated positively with infant mortality, while mean household income showed a strong negative correlation [29]. In Korea, parental employment status was associated with infant mortality in preterm infants, while unemployment status was linked to lower birthweights and higher rates of infant mortality [30]. Addressing disadvantaged socioeconomic status through improved access to quality healthcare and increased social expenditures can have a reflective impact on IMR [31].

The aim of this study was to analyze the relationship between infant mortality rates and key socioeconomic indicators in Kazakhstan from 2010 to 2021, with a focus on identifying the most significant determinants that can inform policy interventions. The research question of this study was "How do socioeconomic indicators influence infant mortality rates in Kazakhstan from 2010 to 2021?"

Data and methods

Study area, source, and design

The dataset used in this study was panel data, comprising aggregated data for all 14 regions of Kazakhstan and 3 major cities (Astana, Almaty and Shymkent) from 2010 to 2021. It included socioeconomic and demographic variables from the Bureau of National Statistics and IMRs from the Ministry of Healthcare of the Republic of Kazakhstan [32, 33]. The dataset comprised 196

observations across all variables, representing all regions over a 12-year period.

Variables and definitions

Variable selection was based on previous literature and data availability [32, 33]:

- *Housing space per capita* measures the average living space available per individual, expressed in square meters per person. This variable represents housing conditions and living standards by indicating how much housing area is allocated to each resident.
- *Living wage (minimum wage)* refers to the legally mandated lowest monthly remuneration that employers may pay workers. It is designed to ensure a minimum standard of living for employees, covering basic needs such as food, housing, and other essentials. Defined annually by the government in tenge (KZT).
- *Average monthly salary* represents the typical gross income received by employees on a monthly basis before taxes and deductions. It serves as an indicator of general economic well-being and the standard of living for the workforce.
- *Average monthly salary in healthcare* measures the typical earnings of healthcare professionals on a monthly basis. This variable reflects investment in human resources within the health sector, impacting the quality and availability of healthcare services.
- *Gross Domestic Product (GDP)* represents the total economic output of Kazakhstan, signifying overall economic performance. It includes the market value of all final goods and services produced within a country in a specific period.
- *GDP per capita* is the GDP divided by the total population, providing a per-person measure of economic productivity and living standards. It offers insight into the average income level and economic well-being of individuals in a country.
- *Gross Regional Product (GRP)* measures the total economic output of a specific region within Kazakhstan, expressed in millions of KZT. GRP is similar to GDP but at a regional level, including the market value of all final goods and services produced in that region over a specified period.
- *Gross Regional Product per Capita*. This indicator represents the per-person economic productivity and living standards within a specific region, expressed in thousands of KZT. It is calculated by dividing the GRP by the population of that region. This metric helps assess the average income and prosperity of individuals within the region.
- *Income below the subsistence level* reflects the proportion of people earning less than what is

necessary for basic living expenses. This variable indicates poverty levels by showing how many individuals fall below the threshold required for minimal subsistence.

- *Gini coefficient* is a measure of income inequality within a population, where 0 represents perfect equality (everyone has the same income) and 1 indicates maximal inequality (one person has all the income). It helps assess distributional fairness and economic disparity within society.
- *Unemployed population (unemployment rate)* is the total number of individuals or percentage of the labor force that is jobless but actively seeking employment. This indicator impacts economic stability and social well-being by reflecting labor market conditions and potential financial distress among households.
- *Average age of women* represents the mean age of women in the population. This demographic statistic can influence trends related to fertility, health outcomes, and social dynamics within a community.
- *Average age of mothers at birth* indicates the mean age of women when they give birth. This demographic measure can impact maternal and infant health outcomes, influencing both prenatal care practices and overall birth statistics.

Data analysis

Descriptive statistics were employed to summarize central tendencies, dispersions, and distributions. Pearson correlation analysis was conducted to identify relationships and potential multicollinearity among the variables. Variables that had a Pearson correlation coefficient (r) greater than 0.8 were excluded from further analysis to avoid multicollinearity issues [34]. We checked for multicollinearity using Variance Inflation Factors (VIFs). A VIF greater than 5 typically indicates significant multicollinearity among independent variables in a regression model [34]. Variables with $VIF > 5$ were excluded from the final model to avoid multicollinearity issues. Assumptions for multicollinearity, linearity, independence, and homoscedasticity were checked. The remaining variables included in the analysis were IMR, living wage, unemployed population, Gini coefficient, income below the subsistence level, housing space per capita, gross domestic product per capita, and average age of women.

In the analysis presented, all selected variables were subjected to a natural logarithm (\ln) transformation. Many socioeconomic and health-related variables often have right-skewed distributions, where the majority of observations are concentrated at lower values with a long tail extending to higher values [35]. Applying the logarithmic transformation can mitigate the effects of

skewness, resulting in a more symmetric distribution and data standardization [36].

Statistical analyses were performed with IBM SPSS 27.0, Standard Edition. Mean levels of infant mortality were assessed with a one sample t-test. In this study, linear regression analysis was employed to examine trends in IMR across all regions of Kazakhstan from 2010 to 2021. This approach allowed to identify statistically significant trends and quantify the average annual changes in IMR over the study period [37].

We employed a fixed effects regression model to analyze our panel data. Multiple linear regression was used to measure the effect size (B) of the previously detected statistically significant predictors in infant mortality. Significance was based on a 95% confidence interval (95% CI).

Results

The mean infant mortality rate for 2010–2021 across all Kazakhstan was 10.22 ± 3.27 (95% CI: 9.55–10.61), indicating moderate variability across the regions studied. The geographical distribution of average IMR across the study period, as shown in Fig. 1, highlights spatial variations, with regions such as Kyzylorda (average IMR: 13.0) having higher rates compared to northern areas like Akmola (average IMR: 9.15) or Pavlodar (average IMR: 8.32).

Table 1 presents the descriptive statistics for all study variables. The analysis revealed significant regional variations across socioeconomic indicators. The living wage averaged $22,657.32 \pm 7,249.51$ KZT, while unemployment stood at 23.51 ± 12.62 thousand people. Income disparities were evident in the average monthly salary ($141,097.67 \pm 65,036.44$ KZT) and healthcare sector wages (107.25 ± 44.90 thousand KZT). The Gini coefficient (0.25 ± 0.04) indicated moderate income equality, with $3.46 \pm 2.02\%$ of the population below the subsistence level. Housing conditions averaged 21.97 ± 3.08 m² per capita. Demographic measures showed women's average age at 34.22 ± 3.60 years, with mothers averaging 28.50 ± 0.83 years at childbirth and a birth rate of 81 per 1,000 women aged 15–49.

Table 2 presents the results of the IMR trend analysis across the regions of Kazakhstan and the cities of national significance (Almaty and Astana). Overall, all regions showed a decline in IMR, however, in Northern Kazakhstan, this trend is not statistically significant ($p > 0.05$). The most substantial average annual decreases in IMR are observed in the East Kazakhstan, Kyzylorda, and South Kazakhstan regions, with annual average changes in IMR of -1.13, -1.15, and -0.94 units, respectively.

Figure 2 illustrates the region-specific trends in infant mortality rate from 2010 to 2021, revealing variations in both the rate and pattern of change across Kazakhstan's

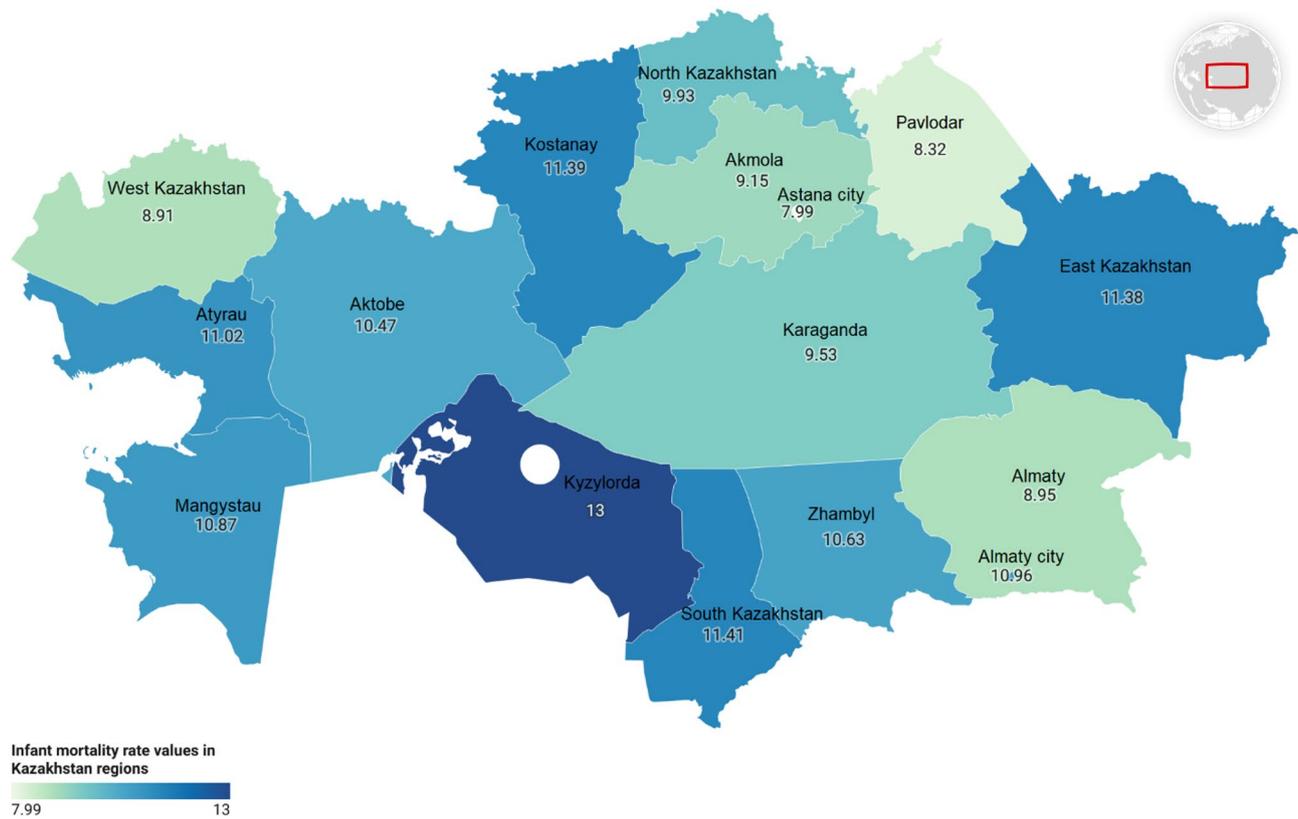


Fig. 1 Choropleth map of average infant mortality rate by region in Kazakhstan, 2010–2021

Table 1 Descriptive statistics of selected variables

| Variables | Mean | 95%CI | | SD | Skewness |
|--------------------------------------------------------|---------|---------|---------|---------|----------|
| IMR, cases per 1000 live births | 10.22 | 9.55 | 10.61 | 3.27 | 1.26 |
| Living wage, in thousands KZT | 22.66 | 21.58 | 23.95 | 7.25 | 0.69 |
| Unemployed population, in thousands people | 23.51 | 22.03 | 25.00 | 12.62 | 1.03 |
| Average monthly salary, in thousands KZT | 141.10 | 137.58 | 159.74 | 65.04 | 0.95 |
| Average monthly salary in healthcare, in thousands KZT | 107.25 | 103.21 | 117.99 | 44.90 | 1.25 |
| Gini coefficient | 0.25 | 0.25 | 0.26 | 0.04 | -0.27 |
| Income below the subsistence level, in percents | 3.46 | 3.15 | 3.76 | 2.02 | 0.92 |
| Housing space per capita, in square meters | 21.97 | 21.46 | 22.47 | 3.08 | 0.98 |
| Gross Regional Product, mln KZT | 2831.63 | 2621.81 | 3347.15 | 2048.53 | 1.56 |
| Gross Regional Product per Capita, thousands KZT | 3418.99 | 3079.89 | 3758.10 | 2046.09 | 1.19 |
| Average age of women, years | 34.22 | 33.65 | 34.79 | 3.60 | 0.07 |
| Birth rate, per 1000 women aged 15–49 | 80.16 | 76.50 | 83.82 | 24.17 | 0.37 |
| Average age of mothers at birth, years | 28.50 | 28.36 | 28.63 | 0.83 | 0.37 |

regions. Each panel represents the IMR trend for an individual region, highlighting the downward trajectories over the study period.

In the presented dataset, several indicators showed notable skewness in their distribution, and we log-transformed them to achieve a more symmetrical distribution.

In order to assess whether the average IMR (log transformed) from 2010 to 2021 significantly differs from the targeted national average for 2025 (which is 7.2 per 1000 live births [34], and the log transformed one is

approximately equal to 2.0), a one-sample t-test was conducted with a null hypothesis stating that the average IMR is equal to the desired national average (Table 3). In examining the log-transformed IMR (IMR_log), the descriptive statistics reveal an average of 2.28 ± 0.29 . A one-sample t-test comparing the average IMR_log to a specified test value of 2 yielded a substantial result ($t(195) = 13.350, p = 0.000$). The mean difference of 0.28, along with a 95% CI (0.24, 0.32), underscores the statistical significance and suggests that the average IMR_log

Table 2 IMR trend analysis results for Kazakhstan, 2010–2021

| Region | 2010–2021 average IMR | Annual average changes in IMR | 95%CI (lower; upper) | p-value |
|------------------|-----------------------|-------------------------------|----------------------|---------|
| Akmola | 9.15 | -0.85 | -1.13; -0.58 | < 0.001 |
| Aktobe | 10.47 | -0.57 | -0.92; -0.22 | < 0.01 |
| Almaty | 8.95 | -0.49 | -0.69; -0.31 | < 0.001 |
| Atyrau | 11.02 | -0.66 | -1.16; -0.16 | < 0.05 |
| East Kazakhstan | 11.38 | -1.13 | -1.47; -0.79 | < 0.001 |
| Zhambyl | 10.63 | -0.86 | -1.07; -0.66 | < 0.001 |
| West Kazakhstan | 8.91 | -0.45 | -0.74; -0.18 | < 0.01 |
| Karaganda | 9.53 | -0.45 | -0.71; -0.18 | < 0.01 |
| Kostanay | 11.39 | -0.41 | -0.62; -0.21 | < 0.01 |
| Kyzylorda | 13.00 | -1.15 | -1.62; -0.68 | < 0.01 |
| Mangystau | 10.87 | -0.74 | -1.19; -0.29 | < 0.01 |
| Pavlodar | 8.32 | -0.59 | -0.84; -0.34 | < 0.001 |
| North Kazakhstan | 9.93 | -0.29 | -0.59; 0.01 | > 0.05 |
| South Kazakhstan | 11.41 | -0.94 | -1.12; -0.77 | < 0.001 |
| Almaty city | 10.96 | -0.91 | -1.41; -0.41 | < 0.01 |
| Astana city | 7.99 | -0.53 | -0.78; -0.28 | < 0.001 |

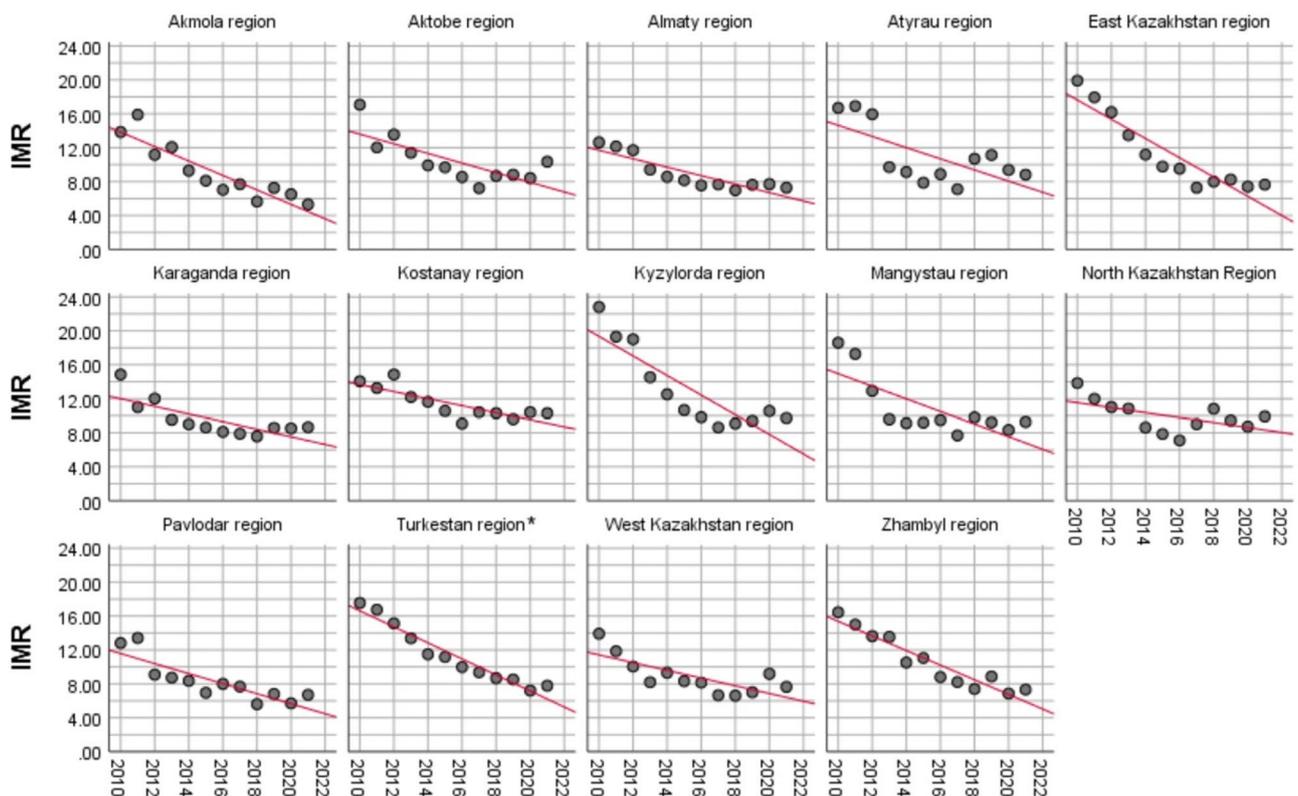


Fig. 2 Trends in infant mortality rate across regions in Kazakhstan, 2010–2021. N.B: *Until 2018 it was South Kazakhstan region

Table 3 Log transformed IMR comparison to reference of targeted log transformed IMR = 2.0

| | n = 196 | t-test | E.S. |
|---------|-------------|----------------------------|---------|
| IMR_log | 2.28 (0.29) | t(195) = 13.35 (p < 0.001) | d = 0.3 |

differs notably from the specified test value. Additionally, Cohen’s d of 0.29 indicates a small-to-medium effect, emphasizing the practical significance of the observed difference.

We conducted a Pearson correlation analysis to examine the relationships between the IMR and various factors. IMR was strongly negatively correlated with living

Table 4 Multiple linear regression determination of IMR

| Predictor | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | Collinearity Statistics | |
|-----------------------------------------------------------|-----------------------------|------------------|---------------------------|--------|-------|-------------------------|-------|
| | B | 95%CI | β | | | Tolerance | VIF |
| β_0 (Constant) | 8.971 | (6.72; 11.222) | | 7.878 | 0.000 | | |
| β_1 Unemployed population, in thousands people | 0.357 | (0.236; 0.477) | 0.412 | 5.839 | 0.000 | 0.512 | 1.955 |
| β_2 GRP per Capita, thousands KZT | 0.001 | (-0.075; 0.076) | 0.001 | 0.013 | 0.989 | 0.441 | 2.266 |
| β_3 Gini coefficient | -0.483 | (-0.833; -0.132) | -0.234 | -2.725 | 0.007 | 0.346 | 2.894 |
| β_4 Income below the subsistence level, in percents | 0.164 | (0.093; 0.235) | 0.358 | 4.581 | 0.000 | 0.417 | 2.4 |
| β_5 Housing space per capita, in square meters | -0.563 | (-0.986; -0.14) | -0.257 | -2.629 | 0.010 | 0.266 | 3.764 |
| β_6 Living wage, in KZT | -0.472 | (-0.638; -0.306) | -0.496 | -5.616 | 0.000 | 0.326 | 3.066 |
| β_7 Average age of women | -0.626 | (-1.08; -0.171) | -0.219 | -2.719 | 0.007 | 0.394 | 2.536 |

Notes: All variables were log-transformed. Dependent variable: IMR; $R^2=0.638$; adjusted $R^2=0.620$; $F_{(7,142)}=35.775$ ($p<0.001$), Durbin-Watson statistic of 1.7

wage ($r = -0.667$, $p < 0.01$), indicating that higher wages correlated with lower infant mortality levels. Similarly, average monthly salary ($r = -0.542$, $p < 0.01$) and average monthly salary in healthcare ($r = -0.664$, $p < 0.01$) both showed strong negative correlations with IMR, suggesting that increased incomes, particularly within the healthcare sector, contribute to reduced infant mortality. Additionally, housing space per capita was negatively correlated with IMR ($r = -0.584$, $p < 0.01$), signifying that better living conditions were linked to lower rates of infant death. Income below the subsistence level was positively correlated with IMR ($r = 0.287$, $p < 0.01$), highlighting that greater levels of poverty had relationship with higher infant mortality rates. Subsequent analysis, such as multiple regression, was implemented to understand the combined influence of these factors on IMR.

The multiple linear regression analysis revealed significant relationship between several socioeconomic factors and IMR in Kazakhstan from 2010 to 2021 (Table 4). Unemployment levels had a positive relationship with IMR ($B = 0.357$, $\beta = 0.412$, $p < 0.001$). Greater income inequality measured by the Gini coefficient showed negative relationship with IMR ($B = -0.483$, $\beta = -0.234$, $p = 0.007$). A higher percentage of the population living below the subsistence level correlated with higher IMR ($B = 0.164$, $\beta = 0.358$, $p < 0.001$). Increased housing space per capita was linked to decreased IMR ($B = -0.563$, $\beta = -0.257$, $p = 0.010$), while a higher living wage had negative relationship with IMR ($B = -0.472$, $\beta = -0.496$, $p < 0.001$). Additionally, an older average age of women was related to lower IMR ($B = -0.626$, $\beta = -0.219$, $p = 0.007$). GRP per capita did not show a significant relationship with IMR ($p = 0.989$).

Assumptions of linearity, independence, normality, and homoscedasticity were verified. The normality of residuals was confirmed with a P-P plot (see Additional file 2), showing close alignment to the expected distribution. Scatter plots of residuals versus predicted values indicated linearity and homoscedasticity, with no discernible

patterns (Additional file 3). The Durbin-Watson value of 1.7 suggested no significant autocorrelation.

The model had a good fit and explained a significant proportion of variance in IMR ($R^2 = 0.638$), with an adjusted (R^2) value of 0.620 and an overall F-statistic of ($F(7,142) = 35.775$) ($p < 0.001$). Collinearity statistics indicated acceptable levels of multicollinearity among predictors: VIF values ranged from a low of 1.955 for the unemployed population to a high of 3.764 for housing space per capita, while tolerance values ranged from 0.266 to 0.512.

Discussion

Understanding infant mortality in Kazakhstan contributes significantly to a broader understanding of the Central Asian region. Kazakhstan can be seen as a representative case due to its economic transition, demographic dynamics, and specific policy initiatives [38]. The country's experiences may offer insights into how similar challenges and successes play out in neighboring CA countries, because Kazakhstan's experience holds relevance for neighboring countries in CA due to shared historical and cultural ties. Regional dynamics, such as economic transition challenges, social disparities, and demographic trends, might be common across the region [39]. The sixfold reduction in infant mortality from 1990 to 2017 signals notable progress [9], raising questions about the contributing factors.

Our analysis shows that infant mortality in Kazakhstan is influenced by a combination of socioeconomic and demographic factors. Higher levels of unemployment and a greater percentage of the population living below the subsistence level had positive relationship with IMR, suggesting that economic instability and poverty are critical risk factors for infant health. These results align with existing literature which indicate that financial hardship often limits access to essential healthcare services, adequate nutrition, and safe living conditions, all of which are crucial for infant survival [40]. Specifically, our finding that higher unemployment is linked to increased

IMR is consistent with previous research. For instance, Tejada et al. (2019) also identified a correlation between higher unemployment rates, economic discomfort, and increased child mortality rates [41]. Similarly, research in Japan by Kanamori et al. (2021) demonstrated that unemployed workers experienced higher infant mortality rates compared to other occupational groups [42], further supporting the influential role of unemployment on infant survival observed in our study. On the other hand, income inequality, as measured by the Gini coefficient, showed a negative relationship with IMR. Our findings may reflect the complexity between income distribution and healthcare access in Kazakhstan. One possible explanation is that regions with higher income inequality might also have higher overall wealth and better-funded healthcare systems, which can mitigate some adverse effects on infant health. This highlights the nuanced role of inequality, supporting Schell et al.'s (2015) assertion that the Gini index is a relevant, though complex, predictor of infant mortality in middle-income countries [43].

The negative relationship between housing space per capita and IMR ($\beta = -0.257, p = 0.010$) underscores the importance of adequate living conditions for reducing infant mortality. Greater housing space mitigates overcrowding, limits exposure to infectious diseases, and fosters healthier infant environments. While this relationship remains underexplored in public health literature, our findings align with Cage and Foster's (2002) study in Scotland, which identified housing space as a determinant of infant mortality [44]. This link is further reinforced by Fisher et al. (2024), who reported higher infant mortality in areas with household crowding in England [45], aligning with our results on the protective effect of greater housing space per capita.

Our study revealed an inverse relationship between living wage levels and IMR, underlining the potential impact of economic policies on infant health outcomes. This finding aligns with research by Komro et al., who reported that increases in state minimum wages were associated with improved infant health indicators [46]. Moreover, Kate Pickett emphasizes the important role of implementing a living wage policy as the single most impactful action that local authorities can take to reduce health inequalities [47]. Consequently, ensuring that wages meet or exceed the cost of living may enhance families' capacity to access essential healthcare services, maintain adequate nutrition, and provide a safe living environment for infants.

Interestingly, GRP per capita did not show a significant relationship with IMR. This suggests that while general economic prosperity is important, it alone does not directly translate into lower infant mortality without targeted interventions addressing disparities in access to healthcare and other essential services. Overall, this

finding contrasts with much of the existing literature, where researchers typically report a strong inverse relationship between economic indicators like GRP per capita and infant mortality rates [48, 49].

Overall, our findings highlight key areas where policy interventions could potentially mitigate adverse outcomes in infant health. Policies aimed at reducing unemployment and poverty levels could significantly impact lowering IMR. A comprehensive strategy should include initiatives aimed at enhancing public awareness regarding health monitoring, access to medical care, and existing programs dedicated to reducing mortality. Solidarity in taking responsibility for individual health should be promoted [50]. Aligning with the principles of the Adelaide Statement on Health in All Policies, it is important to recognize that addressing infant mortality issues requires not only health policies but also broader societal policies [51]. These policies should explicitly target the social determinants of health, contributing to the reduction of inequities in infant mortality and birth outcomes. A concerted effort at both the societal and individual levels, while addressing key research gaps in the social determinants of infant mortality and birth outcomes, is necessary for achieving optimal results. Recently, Kazakhstan achieved a substantial progress towards reducing its infant mortality rate and improving overall public health. The policies "Densaulyk" and "Salamatty Kazakhstan" have played a significant role in influencing maternal, prenatal, and infant health in Kazakhstan. "Densaulyk" focused on healthcare improvements, while "Salamatty Kazakhstan" aimed at enhancing public health [52, 53]. According to Abzaliyeva et al. stable reductions in cardiovascular, maternal, and infant mortality rates observed in Kazakhstan from 2015 to 2019 were attributed to increased per capita supply of general practitioners [54]. Moreover, improving health and insurance coverage can emerge as an effective strategy to reduce state IMR [55].

While our study provides valuable insights into the socioeconomic determinants of infant mortality in Kazakhstan, several limitations should be acknowledged. Our model did not account for several potentially influential factors due to data limitations and the scope of the study. Firstly, cultural factors, which can significantly impact healthcare-seeking behaviors, child-rearing practices, and attitudes towards prenatal and postnatal care, were not included in our analysis. Cultural factors, even after economic standing adjustments, can strongly predict infant deaths [56, 57]. Secondly, we did not incorporate educational attainment levels, particularly of mothers, into our model. Despite progress in education in Kazakhstan, with the average working-age individual having 15 years of education and a literacy rate of 99.9% among young people aged 15–24 years [15], challenges

persist. Thirdly, genetic predispositions and pre-existing health conditions, which can influence infant health outcomes, were not considered in our study. These factors can vary across populations and regions, potentially confounding the relationships we observed between socioeconomic factors and infant mortality.

We also acknowledge potential limitations related to data quality inherent in low- and middle-income settings like Kazakhstan. However, it's worth noting that Kazakhstan has implemented comprehensive guidelines for the collection, classification, documentation, and dissemination of medical statistics. These guidelines are in line with current international standards [58, 59]. Both the Bureau of National Statistics of Kazakhstan and the Ministry of Healthcare employ rigorous data management protocols. These include systematic audits and robust quality assurance measures. While such practices do not entirely eliminate the possibility of errors or biases in the primary data collection, they do instill a significant level of trust in the data's overall reliability and uniformity. This methodological rigor enhances our confidence in the dataset used for this study, despite the inherent limitations of secondary data analysis. Nevertheless, we acknowledge that some degree of caution is warranted when interpreting our results, given these considerations.

Conclusions

This study analyzes the relationship between infant mortality rates and various socioeconomic factors in Kazakhstan from 2010 to 2021. Our findings indicate that several key socioeconomic determinants play influential roles in infant mortality levels, highlighting both risk and protective factors. Based on these results, we recommend prioritizing policies aimed at reducing unemployment rates and alleviating poverty. Investing in housing infrastructure to decrease overcrowding and improve living conditions may positively impact infant health outcomes. Additionally, implementing and enhancing living wage policies can provide families with the financial means necessary for accessing healthcare and maintaining healthy environments. These findings may be valuable for policymakers not only in Kazakhstan but also in other Central Asian nations facing similar public health challenges.

Abbreviations

| | |
|---------|---------------------------------------|
| CA | Central Asia |
| WHO | World Health Organization |
| SD | Standard deviation |
| ES | Effect size |
| GRP | Gross regional product |
| GRP_Cap | Gross regional product per capita |
| GDP | Gross domestic product |
| KZT | Kazakhstani tenge |
| IMR | Infant mortality rate |
| IMR_log | Infant mortality rate log transformed |
| VIF | Variance inflation factor |

P-P Probability-Probability

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

O.Z. and N.S. designed the study. O.Z., K.N., G.Zh., Zh.A., and N.Sh. performed the literature searches, O.Z., G.T., and A.K., prepared the manuscript draft. O.Z. and N.S. wrote the main manuscript, G.T., A.K. and Zh.A. collected the data. N.S., O.Z. and K.N. conducted statistical analysis. All authors contributed to revising the manuscript. O.Z. and Z.K. prepared and edited the final manuscript. N.S. and Z.K. reviewed the final version.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The present study has received ethical approval from the IRB Ethics Committee of Karaganda Medical University, protocol number 09–45, November 27, 2023. The committee has granted a waiver for the informed consent, acknowledging the retrospective nature of the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Factors associated with maternal mortality in Kazakhstan: a pre- and during-pandemic comparison

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Introduction: The maternal mortality indicator serves as a crucial reflection of a nation's overall healthcare, economic, and social standing. It is necessary to identify the variations in its impacts across diverse populations, especially those at higher risk, to effectively reduce maternal mortality and enhance maternal health. The global healthcare landscape has been significantly reshaped by the COVID-19 pandemic, pressing disparities and stalling progress toward achieving Sustainable Development Goals, particularly in maternal mortality reduction.

Methods: This study investigates the determinants of maternal mortality in Kazakhstan from 2019 to 2020 and maternal mortality trends in 17 regions from 2000 to 2020, employing data extracted from national statistical reports. Stepwise linear regression analysis is utilized to explore trends in maternal mortality ratios in relation to socioeconomic factors and healthcare service indicators.

Results: The national maternal mortality ratio in Kazakhstan nearly tripled from 13.7 in 2019 to 36.5 per 100,000 live births in 2020. A remarkable decrease was observed from 2000 until around 2015 with rates spiked by 2020. Significant factors associated with maternal mortality include antenatal care coverage and the number of primary healthcare units. Additionally, socioeconomic factors such as secondary education enrollment and cases of domestic violence against women emerged as predictors of MMR. Moreover, the impact of the pandemic was evident in the shift of coefficients for certain predictors, such as antenatal care coverage in our case. In 2020, predictors of MMR continued to include secondary education enrollment and reported cases of domestic violence.

Conclusion: Despite Kazakhstan's efforts and commitment toward achieving Sustainable Development Goals, particularly in maternal mortality reduction, the impact of the COVID-19 pandemic poses alarming challenges. Addressing these challenges and strengthening efforts to mitigate maternal mortality remains imperative for advancing maternal health outcomes in Kazakhstan.

KEYWORDS

maternal mortality, global health, health determinants, Central Asia, Kazakhstan, COVID-19

1 Introduction

Mothers' and children's health are important measures of a nation's well-being. The maternal mortality ratio (MMR) reveals performance of a nation's healthcare system and its economic and social levels (1–3). The MMR is a valuable measure of the quality and organization of modern obstetrical care. The World Health Organization defines maternal mortality as “the number of maternal deaths during a given time period per 100,000 live births during the same time period.” Whereas maternal death is defined as “the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and the site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management, but not from accidental or incidental causes” (4).

Goal 3 (SDG 3) of the UN's Sustainable Development Agenda calls for a reduction in the worldwide MMR to fewer than 70 per 100,000 live births by 2030. The pandemic of COVID-19 has had a substantial adverse influence on maternal health and the progress toward reducing MMR. It has exacerbated existing disparities in healthcare access, particularly in developing countries (5, 6). Studies have revealed a substantial rise of maternal mortality at the time of the pandemic compared to pre-COVID period, even though measuring maternal mortality during pandemics can be challenging. Some results demonstrate a significant difference between high- and low-resource environments (7, 8). The impact of COVID-19 is far-reaching and influenced by various factors such as climate, societal behavior, human activities, governance, economy, and technology. To meet the goal of lowering maternal mortality and enhancing maternal health, it is critical to understand the distribution of these effects across different populations, particularly those who are more vulnerable, and address the various factors that contribute to the problem (9).

Nearly 95% of all maternal deaths in 2020, according to the WHO, took place in countries with low and lower middle incomes (10). In 2017, the MMR were 462 and 11 per 100,000 live births in low-income and high-income countries, respectively (11). Maternal mortality rates remain high in the least developed nations of the world, approximated at 415 maternal deaths per 100,000 live deliveries, more than 40 times greater than in Europe (12). According to UN inter-agency estimates the MMR decreased by 34% between 2000 and 2020, from 342 deaths to 223 deaths per 100,000 live births, indicating considerable success in lowering maternal mortality on a global scale (13). However, 92% of the 129 countries surveyed at the end of 2021 had their health services disrupted by COVID-19, resulting in a halt in progress toward universal health coverage (14).

Maternal mortality is influenced by several contextual factors including age, marital status, the number of antenatal visits, education level, divorce rates, lack of health workforce and others (15, 16). Despite significant socioeconomic development over the last two decades and the introduction of consecutive health programs aimed at improving primary care, particularly maternal health, Kazakhstan still trails behind Organisation for Economic Co-operation and Development (OECD) countries in leading health indicators (17). Healthcare expenditure in Kazakhstan saw a yearly increase from 2011 to 2020, the nation's healthcare system still suffers from substantial underfunding. Consequently, household expenditures significantly contribute to overall health spending in Kazakhstan (18).

Over the past couple of years, there's been a surge in domestic violence incidents in Kazakhstan. The majority of victims are women, making up over 77.9% of cases. The most vulnerable groups include women aged between 30–39 (37.80%) and 40–49 (41.46%) (19). In terms of education, according to a 2014 OECD study, 28% of women pursued higher education compared to 23% of men (20). Moreover, both women and men in Kazakhstan have extremely high literacy rates (99.9%). The labor force participation rate stands at 63.2% for women and 74.5% for men (21). In Kazakhstan, the percentage of births attended by skilled health personnel has been around 99.9% for the last decade, significantly higher than the global average of 86.2% in 2022 (22). All of these, which could be considered as contextual and structural factors, may contribute to maternal mortality and health. Therefore, they should be examined in this context.

In this research, we aimed to analyze the determinants which contributed to the maternal mortality in Kazakhstan between the period of 2019 to 2020.

2 Materials and methods

2.1 General information about the Republic of Kazakhstan

The study was conducted in Kazakhstan. It is a landlocked middle-income country in the center of Eurasia, with a small amount of its area belonging to Europe and the majority of it being Asia. The population of Kazakhstan is estimated at 19,644,067 by the State Statistics Committee (August 1, 2022). The area of the territory is 2,724,902 km². By territory, it holds the ninth-place position in the globe. Kazakhstan borders China, Russia, Kyrgyzstan, Uzbekistan, and Turkmenistan (23). Administratively, the Republic of Kazakhstan is split into 14 regions and three significant republican cities (Astana, Almaty, and Shymkent).

2.2 Data sources

The work of healthcare institutions and the entire population of Kazakhstan in the period from 2000 to 2020 was studied using data from the annual statistical report (24). These reports include information on population health and health care services at the national and regional levels. To ensure comparability of statistics, health data collection practices in Kazakhstan comply with international standards. Socioeconomic data of the population was obtained from the official statistical portals of the Republic of Kazakhstan.

In this study, we analyzed several key factors sourced from the annual report. These factors included healthcare service and socioeconomic predictors.

2.2.1 Healthcare service factors

Antenatal care coverage serves as a measure of the accessibility and utilization of healthcare services throughout pregnancy (25).

The volume of healthcare services provided refers to the total cost of healthcare services provided by organizations, which is derived from funds received from enterprises, organizations, and individuals (households) in exchange for those services (26).

Abortions per 100 live births, including stillbirths, is the total number of induced abortions, regardless of the method employed (27).

Number of primary health care units encompasses all healthcare facilities offering outpatient services, such as hospital outpatient departments, polyclinics, ambulatory centers, medical clinics, and medical aid posts (28).

Nursing and midwifery personnel (per 10,000 population) refers to the number of nursing and midwifery professionals per 10,000 people in the population (29).

Obstetricians and gynaecologists, per 10,000 population is a measure the density of obstetricians and gynecologists within a given population (30).

2.2.2 Socioeconomic factors

Gross Domestic Product (GDP) *per capita* is an economic indicator that measures the average wealth generated per person in a country (31).

The poverty rate is a measure that represents the proportion of individuals (typically within a specific age group) whose income levels are below the designated poverty line (32).

Average age of the population is a statistical measure that represents the central tendency of ages within a population (33).

Marriage rate is a demographic indicator that measures the number of marriages occurring within a specific population during a given year (34).

Female labor force is a demographic indicator that measures the proportion of the female population within this age group who are economically active (35).

Total divorce ratio is a metric derived from the number of divorces finalized within a single year.¹

Secondary education enrollment (11–17 years), % represents the proportion of total enrollment, irrespective of age, relative to the population within the specified age group corresponding to the indicated educational level (36).

Number of reported cases of domestic violence against women is the number of women who believe that a husband or partner is justified in physically assaulting his wife or partner under specific circumstances (37).

2.3 Statistical analysis

We conducted a comprehensive examination of the maternal mortality ratio in Kazakhstan across all 14 regions and 3 cities of republican significance spanning a 20-year timeframe. Our study investigated the relationships between MMR and various socioeconomic and healthcare service variables both before and during the COVID-19 pandemic, employing a both-direction Stepwise Linear Regression analysis. Stepwise Linear Regression was utilized to identify the optimal subset of explanatory variables for multiple regression models for the years 2019 and 2020. This method involves comparing improvements in the Akaike Information Criterion by systematically removing or adding candidate variables within the specified bounds of regressors. We identified a total of 78

variables based on a thorough review of literature and data availability pertaining to the determinants of MMR in Kazakhstan during the aforementioned years. These variables were categorized into two distinct groups: Socioeconomic and Healthcare Service factors, leading to the derivation of four multiple regression models:

MMR for the 2019-year (Group of Healthcare service indicators) = $\alpha + \beta_1^*$ obstetricians and gynaecologists, per 1,000 born + β_2^* Antenatal care coverage, including early register of pregnancy up to 12 weeks (%) + β_3^* Medical examination of the population per 100,000 population + β_4^* Abortions per 100 live births, including stillbirths + β_5^* Number of primary health care units + β_6^* Nursing and midwifery personnel per 10,000 population.

MMR for the 2019-year (Group of Socioeconomic predictors) = $\alpha + \beta_1^*$ GDP *per capita*, in dollars + β_2^* poverty rate + β_3^* Average age of the population + β_4^* Total divorce ratio + β_5^* Gross enrollment in secondary education (11–17 years) % + β_6^* Gross coverage of higher education (18–22 years) % + β_7^* Number of reported cases of domestic violence against women.

MMR for the 2020-year (Group of Healthcare indicators) = $\alpha + \beta_1^*$ Number of Obstetricians per 1,000 born + β_2^* Antenatal care coverage, including early register of pregnancy up to 12 weeks(%) + β_3^* medical examination of the population per 100,000 population + β_4^* Abortions per 100 live births, including stillbirths + β_5^* Number of primary health care units + β_6^* Nursing and midwifery personnel per 10,000 population + β_7^* obstetricians and gynaecologists, per 1,000 born.

MMR for the 2020-year (Group of Socioeconomic predictors) = $\alpha + \beta_1^*$ poverty rate + β_2^* female labor force (aged 15 and over) + β_3^* marriage rate + β_4^* Total divorce ratio + β_5^* Gross enrollment in secondary education (11–17 years) % + β_6^* Gross coverage of higher education (18–22 years) % + β_7^* Number of reported cases of domestic violence against women.

The coefficients of statistically significant variables derived from these models are outlined in Tables 1, 2.

We also described the MMR trends in Kazakhstan regions from 2000 to 2020. For statistical analysis, we applied IBM SPSS Statistics version 26.

3 Results

3.1 MMR and its trends

In 2020, the national MMR almost tripled compared to 2019 (13.7 in 2019 and 36.5 per 100,000 live births in 2020). Also, there was a dramatic increase of MMR in 2020 in all regions of Kazakhstan. Thus, in the North Kazakhstan and Pavlodar regions, where no cases of maternal mortality were registered in 2019, during the pandemic there was a sharp rise in this indicator to 76.7 and 25.7 per 100,000 live births, respectively. In terms of MMR, the Karaganda region led in 2019 with an indicator of 39.5 per 100,000 live births, while the Kostanay region led in 2020 with an indicator of 94.4 per 100,000 live births (Figure 1).

MMR trends in various parts of Kazakhstan indicate a consistent fall beginning in 2000 and continuing until 2010–2015, then increasing by 2020. Maternal mortality per 100,000 live births has dramatically increased after 2010–2015 in the Aktobe region (from 10 in 2015 to 70.3 in 2020), in the Almaty region (from 5.1 in 2013 to

¹ https://www.stat.fi/meta/kas/kok_eronneisuus_en.html

TABLE 1 Factors associated with MMR before pandemic (2019).

| Predictor variable | Coefficient | Standard error | t-value | p-value |
|----------------------------------------------------------------------------------|-------------|----------------|---------|---------|
| Healthcare service indicators | | | | |
| Intercept | 245.324 | 49.925 | 4.914 | 0.045 |
| Antenatal care coverage, including early register of pregnancy up to 12 weeks, % | -2.513 | 0.588 | -4.273 | 0.003 |
| The volume of healthcare services provided | 0.129 | 0.033 | 3.912 | 0.005 |
| Abortions per 100 live births, including stillbirths | 1.000 | 0.176 | 5.670 | 0.001 |
| Number of primary health care units | 0.043 | 0.015 | 2.833 | 0.02 |
| Nursing and midwifery personnel (per 10,000 population) | -0.891 | 0.165 | -5.403 | 0.001 |
| Model summary: R2 0.9256/ Adjusted R2 0.851/ MSE 7.54 | | | | |
| Socioeconomic indicators | | | | |
| Intercept | 178.407 | 64.805 | 2.753 | 0.028 |
| Total divorce ratio | 14.964 | 5.932 | 2.523 | 0.03 |
| Enrollment in secondary education (11–17 years), gross % | -1.461 | 0.436 | -3.354 | 0.01 |
| Number of reported cases of domestic violence against women, 1,000 | 1.528 | 0.459 | 3.323 | 0.01 |
| Model summary: R2 0.86/ Adjusted R2 0.7201/ MSE 14.18 | | | | |

TABLE 2 Factors associated with MMR during pandemic (2020).

| Predictor variable | Coefficient | Standard error | t-value | p-value |
|-------------------------------------------------------------------------------|-------------|----------------|---------|---------|
| Healthcare indicators | | | | |
| Intercept | 690.649 | 171.124 | 4.036 | 0.00496 |
| Antenatal care coverage, including early register of pregnancy up to 12 weeks | -9.464 | 2.533 | -3.736 | 0.00730 |
| Number of primary health care units | -0.215 | 0.084 | -2.563 | 0.03738 |
| Model summary: R2 0.7959/ Adjusted R2 0.5335/ MSE 10.43 | | | | |
| Socioeconomic indicators | | | | |
| Intercept | 414.879 | 91.353 | 4.542 | 0.00107 |
| Gross enrollment in secondary education (11–17 years) % | -2.399 | 0.861 | -2.786 | 0.01924 |
| Number of reported cases of domestic violence against women, 1,000 | 6.038 | 3.173 | 1.903 | 0.04623 |
| Model summary: R2 0.7006/ Adjusted R2 0.5209/ MSE 15.13 | | | | |

30.04 in 2020), West Kazakhstan region (from 7.9 per in 2013 to 21.9 per in 2020), Karaganda region (from 4.1 in 2013 to 39.5 in 2020), Kostanay region (from 15.3 in 2013 to 94.4 in 2020), Kyzylorda region (from 10 in 2014 to 56 in 2020), North Kazakhstan region (from 12.1 in 2011 to 76.7 in 2020) (Figure 2).

3.2 Factors associated with the MMR before and during pandemic

The dependent variable of the linear regression was MMR, with a mean of 12.91 and a standard deviation of 10.88, the MMR values ranged from 0 to 39.50 for 2019 (Table 3).

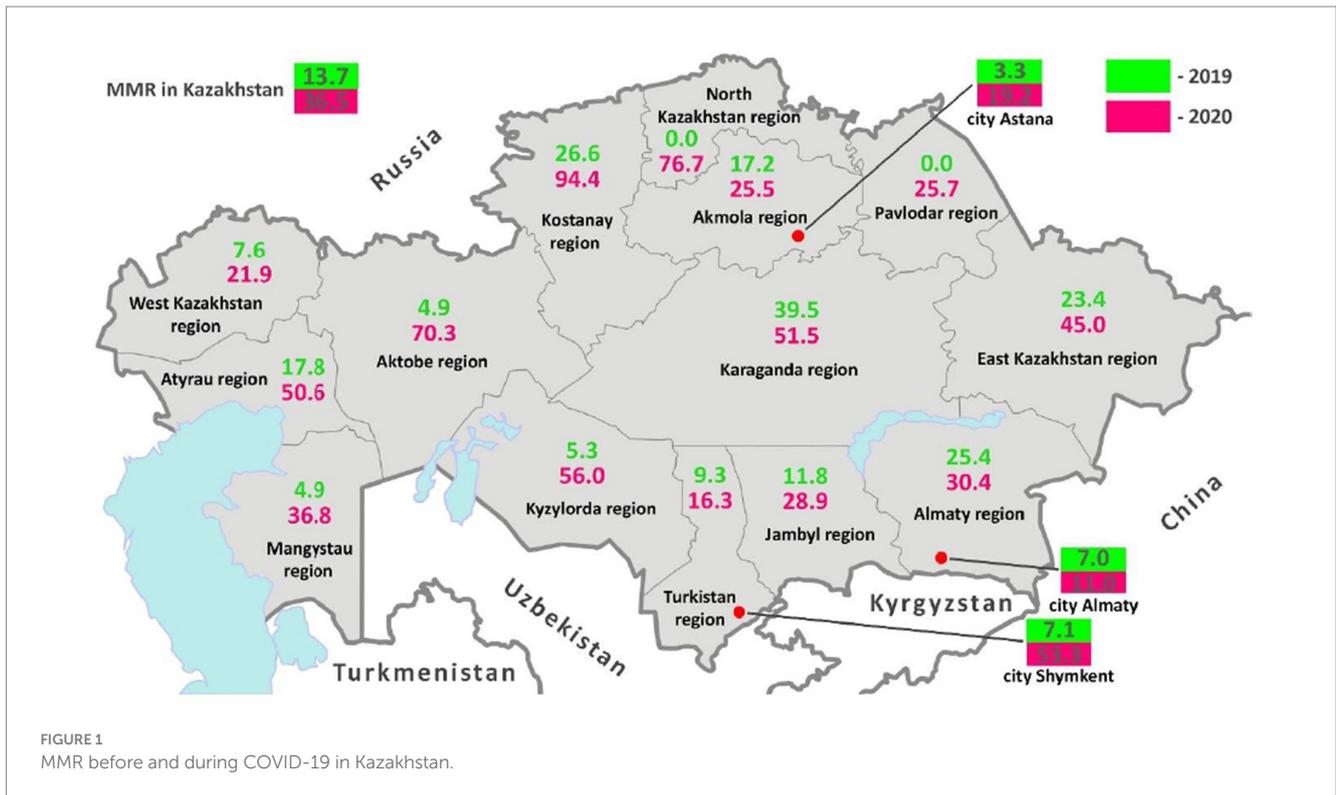
The descriptive statistics for variables of linear regression showed, that 88.20% of pregnant women received antenatal care, with a standard deviation of 2.47%. The volume of healthcare services provided ranged from 40.21 to 235.69 billion tenge and showed a mean of 83.23 with a standard deviation of 57.19 billion tenge. Abortions per 100 live births, including stillbirths, ranged from 6.70 to 50.10, with a mean rate of 22.64. The average availability of primary healthcare units indicated 115 units with a standard deviation of 76.57,

suggesting differing levels of healthcare accessibility across regions. The density of nursing and midwifery personnel per 10,000 population averaged 53.15.

According to socioeconomic indicators, the mean divorce ratio was 3.26 thousand with a deviation of 0.71. The average gross enrollment rate in secondary education was 99.9%. The indicator “violence against women and girls” averaged 5.66, with a standard deviation of 5.68.

Table 1 illustrates the factors exerting a statistically significant influence on the MMR in Kazakhstan during the pre-COVID period. Specifically, healthcare service indicators such as the antenatal care coverage ($\beta = -2.51, p < 0.01$) and the availability of nursing and midwifery personnel per 10,000 population ($\beta = -0.89, p = 0.001$) demonstrate associations with a reduction in the MMR.

An analysis of socioeconomic factors as predictors of MMR reveals notable associations in Kazakhstan for the year 2019. Specifically, divorce ratio ($\beta = 14.96, p < 0.05$) is linked with a significant rise in MMR, while a higher percentage of gross enrollment in secondary education correlates with a reduction in MMR. Additionally, it is noteworthy that instances of domestic



violence against women ($\beta=1.53, p=0.01$) contribute to an elevated MMR.

The output of linear regression indicated as MMR during pandemic time, and the average MMR was approximately 41.97 deaths per 100,000 live births, with a standard deviation of 23.27 (Table 4). On average, about 85.1% of pregnant women receive antenatal care, including early registration, up to 12 weeks, with a standard deviation of 4.11%. Moreover, this indicator ranged from 76.40 to 91.80%. The average number of primary health care units available in the population was approximately 186.41 units, with a wide standard deviation of 90.41. Almost all population within the age group of 11–17 years are enrolled in secondary education. The number of reported cases of domestic violence against women varied from 1.14 to 13.02, also the mean was approximately 3.72, with standard deviation of 2.92.

A comprehensive regression analysis focusing on healthcare indicators pertaining to MMR unveils two statistically significant factors linked with a reduction in MMR: the number of primary health care units ($\beta=-0.21, p<0.01$) and the antenatal care coverage, including early register of pregnancy up to 12 weeks ($\beta=-9.46, p<0.01$). Furthermore, it is noteworthy that the coefficient for the predictor “Antenatal care coverage, including early register of pregnancy up to 12 weeks, %” experienced a notable shift during the pandemic period, dropping to -9.46 from -2.51 observed in the pre-pandemic period.

Similar to the findings in 2019, predictors of MMR in 2020 include the percentage of gross enrollment in secondary education (11–17 years) ($\beta=-2.39, p<0.05$) and number of reported cases of domestic violence against women. Also, in 2020, the surge in domestic violence cases is significantly correlated with a notable rise in the average MMR in Kazakhstan ($\beta=6.04, p<0.05$).

4 Discussion

Our research presents the first attempt to identify and compare the healthcare and socioeconomic factors influencing MMR across different regions of Kazakhstan before and during the COVID-19 pandemic. Furthermore, our comparison reveals how the pandemic affected maternal health differently, giving important insights for targeted actions and policy adjustments during global health crises.

According to the results of this study, MMR patterns in many Kazakhstani regions showed a consistent reduction from 2000 to 2010–2015, followed by an increase by 2020, which is partially in line with the global trend of the decrease in MM during the same time period. It can be noted that in 2020 the MMR in Kazakhstan increased almost threefold compared to the previous year. Additionally, there was a sharp jump in some regions from 0 to 25.7 and even up to 76.7 per 100,000 live births in 2020. During the last 20 years, all Kazakhstani regions had MMR fluctuations except Akmola region, South Kazakhstan, and Astana city.

Furthermore, MMR was linked to measures of population health, socioeconomic status, and health services. Most of these indicators were negatively associated with MMR, while number of reported cases of domestic violence against women, total divorce ratio, the volume of healthcare services provided, abortions were positively associated with MMR. Number of primary HC units was positively associated with MMR in 2019 and negatively associated with MMR in 2020 (Tables 1, 2).

4.1 Interpretation (in light of other evidence)

The MMR and socioeconomic, medical, and morbidity indicator factors were shown to be significantly correlated in our study. Our

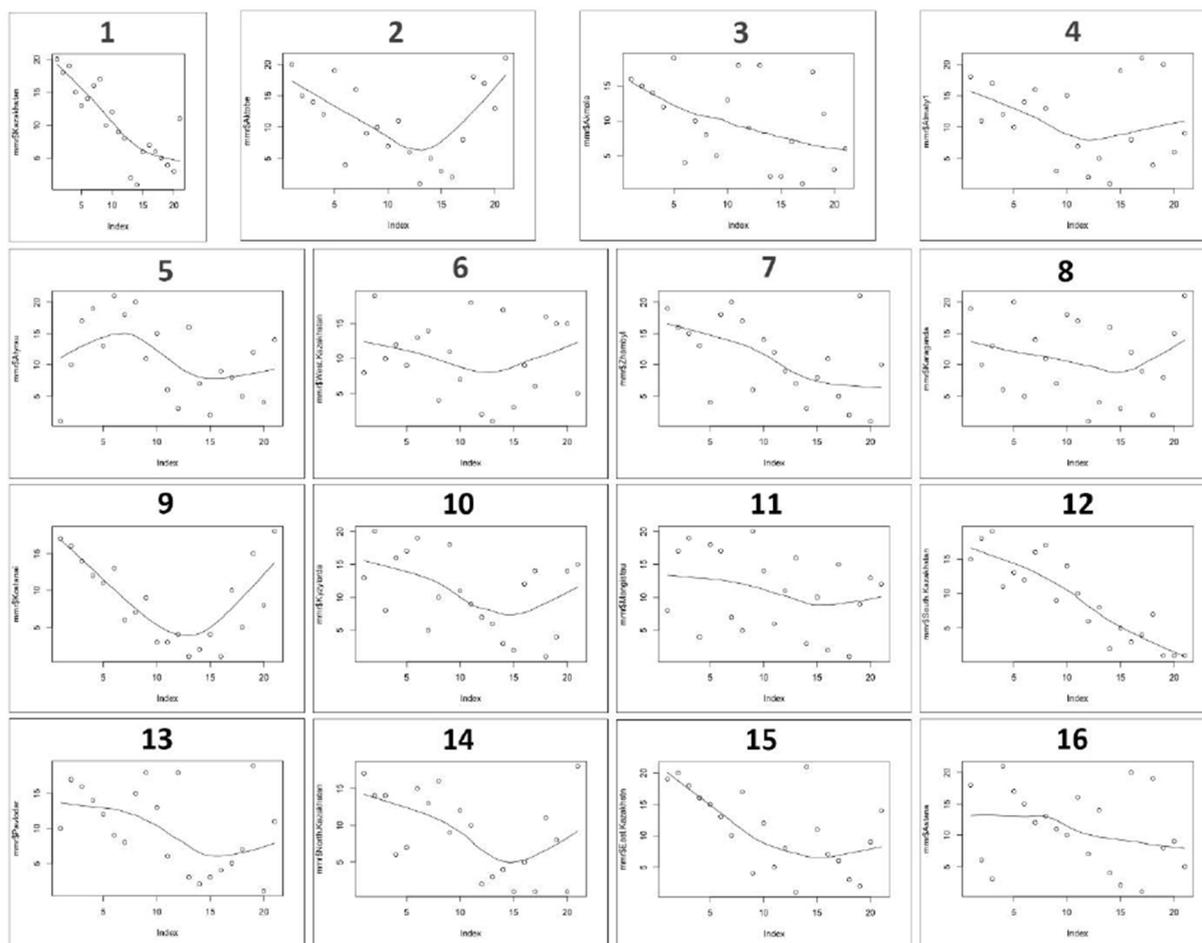


FIGURE 2 MMR trends in Kazakhstan Regions from 2000 to 2020. 1 – Kazakhstan, 2 – Aktobe region, 3 – Akmola region, 4 – Almaty region, 5 – Atyrau region, 6 – West Kazakhstan Region, 7 – Zhambyl region, 8 – Karaganda region, 9 – Kostanay region, 10 – Kyzylorda region, 11 – Mangistau region, 12 – South Kazakhstan region, 13 – Pavlodar region, 14 – North Kazakhstan region, 15 – East Kazakhstan region, 16 – Astana city.

TABLE 3 Descriptive statistics for indicators before pandemic (2019).

| Variable | Mean | Standard deviation | Minimum | Maximum |
|----------------------------------------------------------------------------------|--------|--------------------|---------|---------|
| Healthcare service indicators | | | | |
| Antenatal care coverage, including early register of pregnancy up to 12 weeks, % | 88.20 | 2.47 | 84.30 | 92.30 |
| The volume of healthcare services provided, billion teenage | 83.23 | 57.19 | 40.21 | 235.69 |
| Abortions per 100 live births, including stillbirths | 22.64 | 11.21 | 6.70 | 50.10 |
| Number of primary health care units | 115.00 | 76.57 | 28.00 | 302.00 |
| Nursing and midwifery personnel (per 10,000 population) | 53.15 | 10.92 | 37.60 | 75.90 |
| Socioeconomic indicators | | | | |
| Total divorce ratio | 3.26 | 0.71 | 1.76 | 4.24 |
| Secondary education enrollment, gross % | 99.9 | 0 | 99.9 | 99.9 |
| Number of reported cases of domestic violence against women, 1,000 | 5.66 | 5.68 | 1.52 | 25.88 |
| Outcome | | | | |
| MMR per 100,000 | 12.91 | 10.88 | 0.00 | 39.50 |

analysis revealed several key determinants influencing MMR: socioeconomic factors (total divorce ratio, enrollment in secondary education, number of reported cases of domestic violence against

women), healthcare related factors (volume of healthcare services provided, abortion rates, amount of nursing and midwifery personnel, number of primary health care units, antenatal care coverage). These

TABLE 4 Descriptive statistics for indicators during the pandemic (2020).

| Variable | Mean | Standard deviation | Minimum | Maximum |
|----------------------------------------------------------------------------------|-----------|--------------------|---------|---------|
| Healthcare indicators | | | | |
| Antenatal care coverage, including early register of pregnancy up to 12 weeks, % | 85,1765 | 4,11,180 | 76,40 | 91,80 |
| Number of primary health care units | 186,4,118 | 90,41,782 | 48,00 | 370,00 |
| Socioeconomic indicators | | | | |
| Enrollment in secondary education (11–17 years), gross % | 99.9 | 0 | 99.9 | 99.9 |
| Number of reported cases of domestic violence against women, 1,000 | 3,7,187 | 2,92,542 | 1,14 | 13,02 |
| Outcome | | | | |
| MMR per 100,000 | 41,9,706 | 23,27,031 | 11,00 | 94,40 |

findings align with the literature describing the individual-level factors (age, parity), household characteristics (location, access to clean water), community elements (socioeconomic status), and systemic aspects (healthcare facilities) as prominent influences on maternal mortality (2, 3, 38).

Since 2000, Kazakhstan's MMR was the lowest among Central Asian nations, and it had been declining for the previous 10 years. This achievement can be attributed to the realization of the Government policy of the Republic of Kazakhstan, formulated through the consistent government programs: "Salamatty Kazakhstan" (2011–2015), "Densaulyk" (2016–2019), The Concept of healthcare development of the Republic of Kazakhstan until 2026 (39). Considering the challenges the nation's healthcare system faces, the primary strategies have been established in a number of areas, with one of the top goals being the improvement of women's and children's health.

According to the Multiple Indicator Cluster Survey in the Republic of Kazakhstan, 2010–2011 99.2% of pregnant women received antenatal care at least once throughout their pregnancy, indicating a very high coverage rate for this type of care (40). In the research conducted by Dauletyarova et al. (41) 90.0% of the women expressed satisfaction with the antenatal care they received. Our research findings identified that 88.2% of pregnant women were covered with antenatal care services in 2019, whereas in 2020 this indicator dropped to 85.17%. Regression analysis revealed that the coverage of antenatal care had a higher impact on the decline in MMR in 2020 compared to 2019 (Tables 1,2).

Due to difficulties in obtaining healthcare, variations in pandemic containment strategies, and a high frequency of COVID-19 risk factors there may be an increased risk of maternal deaths as a result of COVID-19 in low- and middle-income countries affected by the pandemic (7, 42). El-Shal et al. (43) suggests that health emergencies, such as the COVID-19 pandemic, can instantly increase maternal, under-five, and neonatal mortality by 0.3, 0.3, and 0.2% and, after 1 year by 35, 80, and 26%, respectively (44). Our findings show that while Kazakhstan experienced a general decline in MMR from 2000 through around 2015, there was an alarming increase by 2020. In contrast to 2019, the MMR rapidly climbed in 2020, rising by 2.6 times to 36.5 per 100,000 live births (45). A nearly threefold rise in MMR nationally from 2019 to 2020 suggests significant systemic stressors at play. The growth of excess mortality is being observed around the world, and the pandemic contributed to it. The study from Brazil reported that, even after accounting for the anticipated excess

mortality from COVID-19, the excess maternal mortality in Brazil in 2020 was 1.40 (95% CI 1.35–1.46) (46). The pandemic also resulted in a 33.3% relative rise in maternal fatalities in the US (47). Furthermore, in the USA the number of maternal mortality cases grew with maternal age (43). A study from Kazakhstan reported that higher age associated with greater mortality risk in this period, and from 2019 to 2021 in Kazakhstan, there was a rise in mortality rates among women aged 35–39 from 0.48 to 4.37 per 100,000 individuals (48, 49). Overall, even before the pandemic, obesity and high school non-completion were identified as important contributors to maternal mortality, while access to healthcare services and resources, family factors, such as revenue and education, and ecological determinants as poverty, gender inequality, human development also played a role (3, 6, 50).

Our linear regression analysis showed that factors such as antenatal care coverage, percentage of population enrolled in secondary education, number of nursing and midwifery personnel, were statistically significantly associated with a decreased level of MMR. These findings contribute to the existing body of literature by providing specific insights into the Kazakhstani context. Thus, increasing coverage of midwife-delivered interventions potentially significantly influence the reduction of stillbirths, neonatal fatalities, and maternal mortality. 41% of maternal deaths, 39% of neonatal deaths, and 26% of stillbirths might be avoided with a significant increase in coverage. Universal coverage has the potential to make the largest impact in low- to medium-HDI countries, potentially saving up to 4.3 million lives yearly by 2035 (51). The decrease in the availability of competent healthcare professionals during childbirth due to reductions in government health spending has been found to significantly contribute to an increase in maternal mortality rates (52). A well-equipped, empowered, and effectively deployed healthcare workforce is critical for the attainment of health-related SDGs. Most high-income countries have an adequate number of health professionals to provide necessary treatment, and they generally have strong educational and regulatory systems in place. Similar trends can also be observed in upper-middle-income countries, with their policies being supportive of the healthcare sector (53–55). The Universal Health Coverage (UHC) Index for Kazakhstan has seen a steady increase from 2000 to 2021, which can be considered as a positive indicator in the context of maternal mortality. Starting at a score of 56 in 2000, the index rose gradually over two decades to reach and maintain a score of 80 by 2019 through 2021. Improvements in the UHC suggest that more people in Kazakhstan are accessing essential health services, which includes maternal and child

healthcare (56). Moreover, since universal health coverage is aligned with SDG 3.8.1, which specifically aims to achieve equity in healthcare services including reproductive, maternal, newborn, and child health, this upward trajectory correlates with efforts directed toward lowering the MMR (57). Since the mid-2000s, Kazakhstan has established youth health centers that play a significant role in enhancing maternal health among adolescents. These centers provide young women with education on prenatal care, which is essential for reducing pregnancy-related complications and maternal mortality. These centers strive to prevent unsafe abortions by guiding adolescents toward effective family planning methods and contraceptive use, thereby reducing unwanted pregnancies and associated health risks (58). In the context of maternal health and mortality, Kazakhstan's fall to 72nd place in gender equality list in 2019 highlights significant disparities affecting women's health and survival. The country's decline from 32nd since 2006 signals pressing issues like wage gaps, few women leaders, and unequal domestic workloads. Pregnant women and mothers face severe discrimination that can hinder job access and growth, leading to financial issues which negatively impact maternal healthcare availability and increase mortality risks (59). Central Asian Sample Survey on the prevalence of violence against women indicated a significant incidence of domestic abuse in Kazakhstan. Of the ever-partnered women aged 18–75 surveyed, 17% reported encountering physical or sexual violence from a partner, while 21% faced psychological abuse (60). Domestic violence had a larger influence on the rise in MMR in 2020 than it did in 2019, according to our data, even though the number of instances fell from 5.66 thousand in 2019 to 3.718 thousand in 2020. Recently, the Kazakhstan government has enacted a New Law on the Rights of Women and Safety of Children. This law aims to challenge male chauvinism embedded within society and legal frameworks by advocating for legislation that historically favors men's interests at the expense of recognizing and protecting women's vulnerabilities (61).

In low and low-middle-income countries, maternal education was revealed to be one of the most important individual factors of maternal mortality, along with the location of delivery, delays in seeking health care, prenatal care, and competent birth attendance (62). According to a 2014 OECD study, 28% of women pursued higher education compared to 23% of men (20). Furthermore, both women and men have very high literacy rates (99.9%), and the labor force participation rate in Kazakhstan stands at 63.2% for women and 74.5% for men (21).

While government revenue is crucial, the quality of governance plays an even more key role in achieving positive results for mothers and children. This impact is more pronounced in low-income countries. As government revenue reaches a level of around 5,000 USD *per capita*, the impact of governance on outcomes becomes less critical. The incidence and maternal mortality rates for COVID-19 were higher in the localities with less access to healthcare and greater socioeconomic disparities (63). In Kazakhstan, the correlation between high out-of-pocket healthcare spending and low government health investment is evident. With public healthcare expenditure at merely 2% of the GDP, it falls significantly short of the average 6.5% reported by countries in the OECD (64). Kazakhstan's recent implementation of a mandatory health insurance system, where the Social Health Insurance Fund became the purchaser of publicly funded health services in 2020, represents a significant shift in healthcare financing. These reforms aim to enhance the accessibility,

equity, and efficiency of health services. The introduction of mandatory health insurance complements the state-guaranteed basic package, diversifying funding sources for healthcare. Despite these efforts, public spending on health decreased from approximately 75% in 2009 to around 60% in 2019. Meanwhile, out-of-pocket payments rose to constitute 33.9% of total health expenditure by 2019 (65).

A greater risk of maternal morbidity and mortality exists among pregnant women who have been diagnosed with COVID-19. There are findings showing that COVID-19 during pregnancy leads to a constant and significant increase in severe maternal health issues, mortality, and neonatal complications in comparison to pregnant women who do not have COVID-19. SARS-CoV-2 infection increases the risk of unfavorable pregnancy outcomes, as do pre-existing comorbidities such as chronic hypertension, diabetes, advanced maternal age, and high body mass index (66). In Kazakhstan, living conditions and income levels have a significant association with health outcomes (67).

Our study revealed several socioeconomic and healthcare-related determinants associated with the maternal mortality in Kazakhstan in the pre- and during pandemic periods. To enhance the effectiveness of interventions aimed at reducing maternal mortality, it's essential to systematically address these factors. Given the amount of research showing a correlation between social and economic conditions and maternal deaths, the social and economic components should receive significant attention. Addressing domestic violence prevention and improving access to education and healthcare services are critical steps in this regard. Pregnancy care coverage, the availability of nurseries, and midwifery services are examples of health care determinants that should be guaranteed. Moreover, to inform decision-making and intervention strategies, there's a pressing need to strengthen scientific research in both public health and clinical medicine. Building a robust evidence base is fundamental for developing effective interventions and improving maternal health outcomes. By systematically addressing socioeconomic and healthcare-related determinants of maternal mortality through targeted interventions and multisectoral collaboration, significant strides towards reducing maternal mortality and improving maternal health outcomes can be done.

4.2 Strengths and limitations

Our study presents several strengths, including its comprehensive coverage of regional trends in MMR in Kazakhstan and the use of statistical methods compliant with various studies and publications in the field. We pursued to unravel the role of structural and contextual predictors of MMR. The study also benefits from using officially recognized data sources, which enhances the reliability of our findings.

There are limitations that should be acknowledged. First, as we utilized secondary data obtained from annual statistical reports, there may be inherent biases in the data collection procedure. Given the concerns regarding the potential for biases in data collection and reporting, it is important to highlight that the process of diagnosing, registering, and reporting maternal mortality cases in Kazakhstan is conducted in accordance with rigorous national standards. The Rules for the Provision of Maternal Mortality Information, as outlined by the Ministry of Justice of the Republic of Kazakhstan, ensure that each case of maternal death is thoroughly documented and reported through a structured framework. This legal document is publicly

accessible and provide guidelines that dictate how healthcare institutions should report instances of maternal mortality promptly and accurately (68). Additionally, the Standard of Pathological and Anatomical Diagnostics in the Republic of Kazakhstan issued by the Minister of Health further specifies the procedures and protocols for post-mortem examinations. This standard outlines the technical aspects of how maternal deaths are to be diagnosed pathologically (69). It includes criteria for autopsy practices as well as histological examinations when required. These documents collectively establish a comprehensive protocol ensuring that all cases of maternal deaths are not only appropriately diagnosed following medical best practices but also systematically recorded and reported in a manner consistent with legal requirements.

Second, potential confounding variables that might have influenced maternal mortality were not fully explored. Structural and contextual factors such as cultural practices, access to transportation, geographic barriers to care, and personal health behaviors could have significant implications on MMR but were not accounted for in our analysis.

Third, the generalizability of our findings beyond the study sample might be constrained due to unique socioeconomic, cultural, or health system factors present in Kazakhstan that may not be applicable elsewhere.

5 Conclusion

Various socioeconomic conditions, aspects of the healthcare system, and the prevalence of diseases significantly impact the complex issue of maternal mortality. Kazakhstan is committed to achieving the Sustainable Development Goals, which include reducing maternal mortality. However, there may have been fluctuations in maternal mortality ratios due to the nation's middle-income status and the strike of the COVID-19 pandemic. In the broader socio-political context of Kazakhstan, our findings highlight the importance of healthcare infrastructure, socioeconomic factors, and women's health services in addressing maternal mortality. In light of the significance of socioeconomic and healthcare service-related factors, it is necessary to address population dynamics and health system issues that pose a threat to mothers' health. The COVID-19 pandemic and global threats such as natural disasters and military conflicts continue to challenge the global healthcare system, further highlighting the need for governments to create a supportive environment that promotes maternal health and reduces mortalities. To effectively tackle maternal mortality, understanding key risk factors as well as determinants that contribute to this issue is important. The reduction of maternal

mortality remains a priority for all healthcare systems and public health actors should continuously assess and address these factors to achieve this goal.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: <https://www.gov.kz/memleket/entities/dsm/documents/details/246287?lang=en> <https://www.gov.kz/memleket/entities/dsm/documents/details/58654?lang=en>.

Author contributions

KN: Writing – original draft, Methodology, Formal analysis. GK: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. NY: Writing – original draft, Visualization, Formal analysis. ZB: Writing – original draft, Methodology, Formal analysis. OZ: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. AT: Writing – review & editing, Supervision, Project administration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Pre-COVID era pediatric disease incidence in Kazakhstan: regional panel data analysis of multiple disease groups (2010–2019)

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Background: While child morbidity in Kazakhstan is studied, existing research often prioritizes mortality or infectious diseases over non-communicable conditions. This study fills this gap by examining socioeconomic, demographic, and healthcare factors linked to respiratory diseases, asthma, and nervous system disorders among children aged 0–14 years across Kazakhstan from 2010 to 2019 highlighting regional context.

Methods: Panel data from 14 regions were analyzed using linear mixed models with autoregressive covariance to address regional and temporal heterogeneity. Log-transformed incidence rates of respiratory diseases (J00–J99), asthma (J45), and nervous system diseases (G00–G99) were modeled against predictors including GRP per capita, unemployment, population density, Gini coefficient, pediatrician density, and hospital resources. Other variables with variance inflation factors ≥ 5 were excluded to mitigate multicollinearity.

Results: Respiratory diseases showed the highest mean incidence (57,329.86 per 100,000), with significant regional variation. Aqtöbe, Atyrau, and South Kazakhstan had 12–25% lower incidence compared to Zhambyl (reference), while Pavlodar and North Kazakhstan had 35–61% higher rates. A 1% increase in population density correlated with a 1.05% decrease in respiratory disease incidence ($p = 0.008$), whereas unemployment was linked to a 0.41% rise ($p = 0.029$). Asthma incidence increased by 140% over the decade, with higher rates in regions with greater income inequality (0.26% increase per 1% rise in low-income households, $p = 0.032$). Nervous system disorders showed limited associations, with unemployment as the sole predictor (0.69% increase per 1% rise, $p = 0.040$). Temporal trends revealed declines in most diseases, but neoplasms, diabetes, and asthma increased significantly.

Conclusion: The study addresses the lack of localized socioeconomic and healthcare analyses for respiratory diseases, asthma, and nervous system disorders among children, providing evidence for region-specific policy interventions. Respiratory diseases and asthma among Kazakhstani children 0–14 years had associations with the regional economic conditions, healthcare utilization, and inequality. Population density and income inequality were consistent predictors, while nervous system disorders showed fewer clear associations. Our findings show distinct regional patterns in pediatric morbidity, linking health outcomes to localized socioeconomic and healthcare conditions.

KEYWORDS

pediatric morbidity, Kazakhstan, respiratory diseases, asthma, nervous system disorders, socioeconomic determinants, healthcare access, disparity

1 Introduction

The well-being of a nation's children serves as an important sign of its socioeconomic progress and a window into its future path. As earlier studies have noted, child health reveals not only the present state of public welfare but also hints at the adult population's eventual condition, since early years form habits and risks that persist through life (1). Understanding the forces behind child health thus becomes necessary for designing policies to raise societal welfare. These forces span a wide range, combining biological traits with broader social and economic elements, such as family income, parental schooling, housing quality, and access to medical care, that together leave a deep mark (2, 3).

The age range of 0 to 14 years stands out for several reasons. This period covers key phases of physical, mental, and emotional growth, where early experiences, whether poor nutrition, unsafe surroundings, or emotional strain, can cast lasting effects on health. Children in this group also tend to be more affected by outside conditions than adults, making them a clear measure of society's health gaps (4). Protecting their well-being calls for efforts that reach beyond medical care alone. It requires action from political leaders and cooperation across fields to not only address illness but also build settings that support healthy development (5).

Research on pediatric disease incidence rates is scarce in literature, with not many studies providing detailed breakdowns, particularly for non-communicable diseases (NCDs). Organizations such as the WHO and UNICEF often prioritize mortality data or focus on leading causes like infectious diseases and malnutrition, with less emphasis on NCDs or system-specific morbidity in children aged 0–14.

Globally, respiratory conditions, mainly asthma and pneumonia, are major contributors to morbidity. According to the study on asthma incidence among children 0–14 in Asia, it varies widely, with the highest in the Philippines (1,686.9 per 100,000) and the lowest in Bhutan (237.9 per 100,000) (6). Immune disorders, such as primary immunodeficiencies, are less quantified, but a U. S. study estimates a prevalence of 1 in 1,200 individuals (7). The incidence of type 1 diabetes among children under the age of 15 is increasing, with recent European data indicating an annual rate of 29.1 new cases per 100,000 population (8). Anemia affects approximately 40% of children under 5 (293 million in 2016), with urban prevalence often lower due to better nutrition but still significant in poor urban slums (9). A study from Kazakhstan found that real prevalence of asthma in Kazakhstan is estimated to be 5.33 times higher than official records, with many patients wrongfully diagnosed with COPD or obstructive bronchitis (10). Another study reporting the asthma incidence rate ranged from 67.5 to 185.9 among boys and 38.2 to 115.7 among girls per 100,000 population, with the highest rates observed in the 5–11 age group (308–351 cases) (11). Regarding nervous system disease trends in Kazakhstan, mild variability in national cerebral palsy incidence was observed in 2010–2019, ranging from 68.7 to 83.3 per 100,000 total population (12). Additionally, a significant increase in the

incidence of epilepsy was documented, rising from 26.15 in 2014 to 88.80 in 2020 per 100,000 total population (13).

Child health measures, such as rates of illness, tie closely to differences in regional economic growth, environmental quality, and the strength of schools and healthcare systems in managing disease risks (14). Everyday factors, including food availability, home stability, caregivers' working conditions, access to play areas, and the nature of schooling, can shape children's health in distinct ways across the globe (15–17). Research by Cohen and others demonstrates that a child's economic background can be associated with heart disease deaths and other specific causes later in life (18, 19). In certain areas, especially lower-income regions like Kazakhstan, unmet goals for improving child health have led to rising illness and death rates, underscoring the necessity for targeted initiatives (20, 21). Apart from socioeconomic factors, a Norwegian study showed that having more doctors in a local area is associated with better newborn outcomes, including fewer fetal deaths and higher birth weights, with this being independent of socioeconomic factors (22). In contrast, the shortage of doctors creates a significant barrier to delivering quality healthcare, intensifying disparities in health (23).

Central Asia, with Kazakhstan as a key example, offers a unique view of these patterns. Since gaining independence from the Soviet Union, the region has experienced serious economic and social transformations, resulting in significant changes in living conditions and health outcomes (24). The healthcare system in Kazakhstan has undergone significant reforms, optimizing health professional density, average days of stay at hospital, launching national screening programs, and yet gaps persist (25). Public expenditures on health care account for only 1.8–3.2% of GRP, covering just 58% of total expenditures, leading to significant out-of-pocket costs for patients, which account for approximately 38% of total healthcare expenditures, exceeding the WHO norm of 20% (26).

Our research question was “What is the relationship between socioeconomic, demographic, and healthcare indicators and pediatric disease incidence among children aged 0–14 years in Kazakhstan's regions from 2010 to 2019?”

The aim of our study was to identify statistically significant predictors of pediatric disease incidence across Kazakhstan regions using panel data regression analysis, accounting for regional and temporal heterogeneity. We also hypothesized that higher income inequality (Gini coefficient) would correlate with increased pediatric disease incidence due to disparities in healthcare access.

2 Materials and methods

2.1 Data collection and variables

We conducted a panel data analysis using data from the Bureau of National Statistics of the Republic of Kazakhstan, covering the period from 2010 to 2019. National statistics data undergoes

standard validation procedures to ensure accuracy and consistency. The dataset comprised panel data pooled across 14 regions of Kazakhstan from 2010 to 2019, yielding 140 region-year observations, except for South Kazakhstan, which contributed data until 2017 (138 observations total) (Supplementary Table 1). The selection criteria included high incidence rates, significant variability across regions and time, notable trends, and public health relevance. Quantitative data on socioeconomic, demographic, and healthcare indicators were extracted. All variables used in our analysis were continuous, except for regions which were treated as a categorical variables. Incidence rates for children aged 0–14 years were collected from national and regional statistical reference books.

The study included the following socioeconomic, demographic, and healthcare variables based on prior literature and data availability (27–30):

- GRP per capita (thousand tenge) represents the gross regional product per person, reflecting the economic output of each region adjusted for population size.
- Population density (persons per km²) captures relative differences in settlement patterns across Kazakhstan's regions, shaped by the country's vast territory (2.7 million km²), rather than serving as a direct proxy for urbanization.
- Living wage (thousand tenge) denotes the minimum income required to meet basic needs, including food, housing, and healthcare.
- Unemployed population (thousand people) refers to individuals actively seeking work but without employment, serving as an indicator of economic instability.
- Average monthly nominal salary (thousand tenge) captures the mean gross earnings before tax deductions, reflecting regional income levels.
- Gini coefficient quantifies income inequality on a scale from 0 (perfect equality) to 1 (maximum inequality).
- Population with income below the living wage (%) estimates the proportion of residents earning less than the subsistence minimum.
- Housing provision (sq. m. per resident) indicates the average living space per person, a proxy for living standards.
- Marriage rate (per 1,000 population) records the annual number of marriages per 1,000 residents, reflecting social stability.
- Divorce rate (per 1,000 population) measures the annual number of divorces per 1,000 residents, indicating family structure dynamics.
- Average monthly nominal salary in healthcare (thousand tenge) assesses the earnings of healthcare workers, influencing workforce retention.
- Number of physicians (excluding dentists) per 10,000 population evaluates the density of practicing doctors, a key metric for healthcare access.
- Pediatricians per 10,000 population specifically measures the availability of child healthcare specialists.
- Obstetrician–gynecologists per 10,000 population tracks maternal healthcare capacity.
- Nursing staff per 10,000 population quantifies the nursing workforce, critical for service delivery.
- Nursing staff (midwifery) per 10,000 population focuses on midwives, essential for maternal and neonatal care.
- Number of hospital beds for children per 10,000 population assesses pediatric inpatient infrastructure.
- Average length of hospital stay (LOS) for children 0–14 years (days) indicates the mean duration of hospitalization for pediatric patients.

In our study we analyzed childhood disease incidence categorized by the International Classification of Diseases, 10th Revision (ICD–10). Below are detailed definitions of the disease groups, including specific conditions covered under each code (31):

- All diseases (A00–Z99) category represents the total incidence of all diagnosed conditions in children aged 0–14 years, covering infectious diseases, injuries, congenital anomalies, and chronic disorders. This category serves as a comprehensive measure of overall pediatric morbidity.
- Neoplasms (C00–D49) include both benign and malignant tumors, such as leukemia, lymphomas, central nervous system tumors, and benign neoplasms of the skin.
- Diseases of the blood and blood-forming organs (D50–D89) covers disorders such as iron-deficiency anemia, vitamin B12 deficiency anemia, hemolytic anemias, coagulation defects, and thrombocytopenia. Iron-deficiency anemia (D50) specifically refers to anemia caused by inadequate iron intake or absorption, including nutritional iron deficiency.
- Endocrine, nutritional, and metabolic diseases (E00–E90) include thyroid disorders, type 1 diabetes mellitus, type 2 diabetes mellitus, malnutrition, obesity, and metabolic syndromes. Diabetes mellitus (E10–E14) focuses on chronic hyperglycemia, subdivided into insulin-dependent diabetes, non-insulin-dependent diabetes, malnutrition-related diabetes, and other specified forms (E13–E14).
- Diseases of the nervous system (G00–G99) include conditions such as meningitis, epilepsy, cerebral palsy, migraines, and neurodegenerative disorders.
- Diseases of the circulatory system (I00–I99) include rheumatic heart disease, hypertensive diseases, ischemic heart disease, and cerebrovascular accidents.
- Diseases of the respiratory system (J00–J99) cover acute upper respiratory infections, pneumonia, asthma, chronic obstructive pulmonary disease, and bronchitis. Asthma (J45) specifically refers to chronic airway inflammation characterized by recurrent wheezing, breathlessness, and coughing.
- Diseases of the digestive system (K00–K95) include gastroesophageal reflux disease, peptic ulcers, gastritis, hepatitis, and inflammatory bowel disease.
- Diseases of the musculoskeletal system and connective tissue (M00–M99) cover juvenile idiopathic arthritis, osteomyelitis, osteoporosis, and systemic connective tissue disorders.
- Diseases of the genitourinary system (N00–N99) include acute glomerulonephritis, urinary tract infections, renal failure, and disorders of the male and female genital tracts.

2.2 Data analysis

Dependent variables (disease incidence rates) were classified using ICD-10 codes as reported by the Bureau of National Statistics, with incidence rates calculated per 100,000 children aged 0–14 years.

Log transformation was applied to both dependent and independent continuous variables to address right-skewness, stabilize variance, and interpret regression coefficients as elasticities, representing the percentage change in disease incidence associated with a 1 % change in each predictor. Since no zero values were present in the incidence data, no additive constant (e.g., +1) was required for transformation.

To identify disease groups warranting detailed analysis, we evaluated incidence rates for children aged 0–14 years across 14 regions in Kazakhstan from 2010 to 2019 (South Kazakhstan until 2017). The selection criteria included high incidence rates, significant variability across regions and time, notable trends, and public health relevance.

Descriptive statistics (mean, standard deviation, and coefficient of variation) were computed for all variables to assess both disease burden and predictor variability. Temporal trends were evaluated using line plots stratified by region. Spearman's rank correlation (ρ) was employed to examine associations between log-transformed variables, as some predictors violated normality assumptions (Shapiro–Wilk $p < 0.05$). However, with panel data and sufficient observations (>100), normality is less critical due to the central limit theorem (32).

We applied linear regression analysis to examine temporal trends in childhood disease incidence across all regions of Kazakhstan from 2010 to 2019 and to quantify the average annual changes in the variables. Using regression coefficients, the analysis provided insights into both the magnitude and direction of changes in the disease burden (33).

A linear mixed model (LMM) with fixed effects for regions and years was employed to examine the proportional relationships between the log-transformed predictors and the incidence rates of respiratory diseases, nervous system diseases, and asthma. Prior to fitting the LMM, multicollinearity among the log-transformed predictors was assessed by calculating the Variance Inflation Factor (VIF) using a linear regression

model in SPSS. Initial analysis revealed high VIF values for several predictors. We removed predictors that were theoretically redundant or less relevant to the research question, including ln (Avg monthly salary), ln (Living wage), ln (Marriage rate), ln (Divorce rate), ln (Salary healthcare), ln (Physician density), ln (Obstetrician-gynecologist density), ln (Nurse density), and ln (Midwifery density). This exclusion ensured model stability but may limit insights into healthcare workforce effects, potentially underestimating their role in disease incidence. A second linear regression with the remaining predictors [ln (GRP per capita), ln (Unemployed population), ln (Population density), ln (Gini), ln (Income below living wage), ln (Housing per resident), ln (Pediatrician density), ln (Hospital beds for children), ln (Length of stay)] yielded VIF values below 5.

After running the LMM, regression residuals were examined to verify model assumptions. Residual plots (residuals vs. predicted values) were generated to check for homoscedasticity and linearity, confirming that the residuals had no systematic patterns and were approximately homoscedastic, supporting the validity of the log-transformation and model specification.

All analyses were conducted in SPSS Version 26 (IBM Corp., Armonk, NY), with statistical significance set at $p < 0.05$.

3 Results

3.1 Descriptive statistics and trends

Summary statistics (Table 1) showed that respiratory diseases had the highest mean incidence (57,329.86 per 100,000, CV = 0.40), followed by digestive system diseases (5,898.30 per 100,000, CV = 0.41) and blood diseases (3,960.85 per 100,000, CV = 0.47).

Table 2 shows a general decline in disease burden from 2010 to 2019 across most categories: Blood and blood-forming diseases; Iron-deficiency anemia; Endocrine, nutritional, and metabolic diseases; Circulatory system diseases; Respiratory system diseases;

TABLE 1 Summary statistics for diseases variables.

| Disease group | Mean incidence (per 100,000) | SD | CV |
|----------------------------------------------------------|------------------------------|-----------|------|
| All diseases (A00–Z99) | 93,233.17 | 30,242.49 | 0.32 |
| Neoplasms (C00–D49) | 164.22 | 156.13 | 0.95 |
| Diseases of the blood and blood-forming organs (D50–D89) | 3,960.85 | 1,855.84 | 0.47 |
| Iron-deficiency anemia (D50) | 3586.24 | 1,794.04 | 0.50 |
| Endocrine, nutritional, and metabolic diseases (E00–E90) | 956.19 | 492.35 | 0.51 |
| Diabetes mellitus (E10–E14) | 9.97 | 5.09 | 0.51 |
| Nervous system diseases (G00–G99) | 2,834.57 | 1,188.05 | 0.42 |
| Circulatory system diseases (I00–I99) | 327.00 | 203.60 | 0.62 |
| Respiratory system diseases (J00–J99) | 57,329.86 | 23,112.98 | 0.40 |
| Asthma (J45) | 97.11 | 70.34 | 0.72 |
| Digestive system diseases (K00–K95) | 5,898.30 | 2,435.87 | 0.41 |
| Musculoskeletal and connective tissue diseases (M00–M99) | 944.56 | 637.53 | 0.67 |
| Genitourinary system diseases (N00–N99) | 1300.15 | 509.30 | 0.39 |

TABLE 2 Trend analysis for disease incidence in Kazakhstan, 2010–2019.

| Disease group | 2010 Mean | 2019 Mean | % Change (2010–2019) | Annual average change (95%CI) |
|----------------------------------------------------------|-----------|-----------|----------------------|-------------------------------|
| All diseases (A00–Z99) | 99,987.42 | 89,070.00 | –10.92% | –910.9 (–2696.19; 874.44) |
| Neoplasms (C00–D49) | 124.45 | 199.29 | 60.14% | 10.994 (2.05; 19.93)* |
| Diseases of the blood and blood-forming organs (D50–D89) | 5,023.14 | 2,969.10 | –40.89% | –234.58 (–337.10; –132.06)** |
| Iron-deficiency anemia (D50) | 4,515.99 | 2,649.35 | –41.33% | –213.68 (–313.62; –113.74)** |
| Endocrine, nutritional, and metabolic diseases (E00–E90) | 1,372.54 | 742.99 | –45.87% | –64.37 (–91.43; –37.32)** |
| Diabetes mellitus (E10–E14) | 6.79 | 13.51 | 99.03% | 0.59 (0.31; 0.88)** |
| Nervous system diseases (G00–G99) | 2,984.52 | 2,742.87 | –8.09% | –8.29 (–78.67; 62.09) |
| Circulatory system diseases (I00–I99) | 455.27 | 245.49 | –46.07% | –20.46 (–32.02; –8.91)** |
| Respiratory system diseases (J00–J99) | 57,986.56 | 56,602.65 | –2.39% | –42.49 (–1412.01; 1327.02) |
| Asthma (J45) | 59.15 | 142.08 | 140.20% | 10.03 (6.22; 13.82)** |
| Digestive system diseases (K00–K95) | 6,468.34 | 5,887.87 | –8.98% | 8.53 (–135.79; 152.86) |
| Musculoskeletal and connective tissue diseases (M00–M99) | 1,104.11 | 1,010.88 | –8.44% | –7.57 (–45.33; 30.18) |
| Genitourinary system diseases (N00–N99) | 1,616.85 | 1,101.39 | –31.88% | –51.40 (–80.29; –22.51)** |

* p -value < 0.05, ** p -value < 0.001.

Genitourinary system diseases. Trend analysis showed that the largest annual average decrease was observed in iron-deficiency anemia at –213.68 (95% CI: –313.62; –113.74), followed by diseases of the blood and blood-forming organs at –234.58 (95% CI: –337.10; –132.06) and endocrine, nutritional, and metabolic diseases at –64.37 (95% CI: –91.43; –37.32), all statistically significant. Circulatory system diseases showed a decrease of –20.46 (95% CI: –32.02; –8.91), while genitourinary system diseases decreased by –51.40 (95% CI: –80.29; –22.51), both also statistically significant. In contrast, neoplasms increased annually on average by 10.99 (95% CI: 2.05; 19.93), diabetes mellitus by 0.59 (95% CI: 0.31; 0.88), and asthma by 10.03 (95% CI: 6.22; 13.82), all with statistically significant positive trends. Some categories, such as respiratory and digestive diseases, show wide confidence intervals, indicating variability in the annual average change estimates due to non-significant statistical differences.

Based on these findings, we selected respiratory diseases for further analysis due to their high mean incidence (57,329.86 per 100,000) and moderate variability ($CV = 0.40$), making them a serious public health concern with potential socioeconomic and demographic drivers. Nervous system diseases were chosen despite a slight decline in incidence, given their relatively high incidence (2,834.57 per 100,000), variability ($CV = 0.42$), and relevance to child neurodevelopment, which may be influenced by socioeconomic factors.

Asthma was selected for further analysis due to its pronounced increasing trend, with primary incidence rising from 46.5 to 194.2 per 100,000 children aged 0–14 years between 2010 and 2019—a 140.2% increase (Figure 1). The condition also showed high variability ($CV = 0.72$).

In Figure 2, the log-transformed incidence trends of three pediatric conditions with their linear fit trends are displayed across 14 regions of Kazakhstan from 2010 to 2019. Regional variations were most evident for respiratory diseases, with significant differences

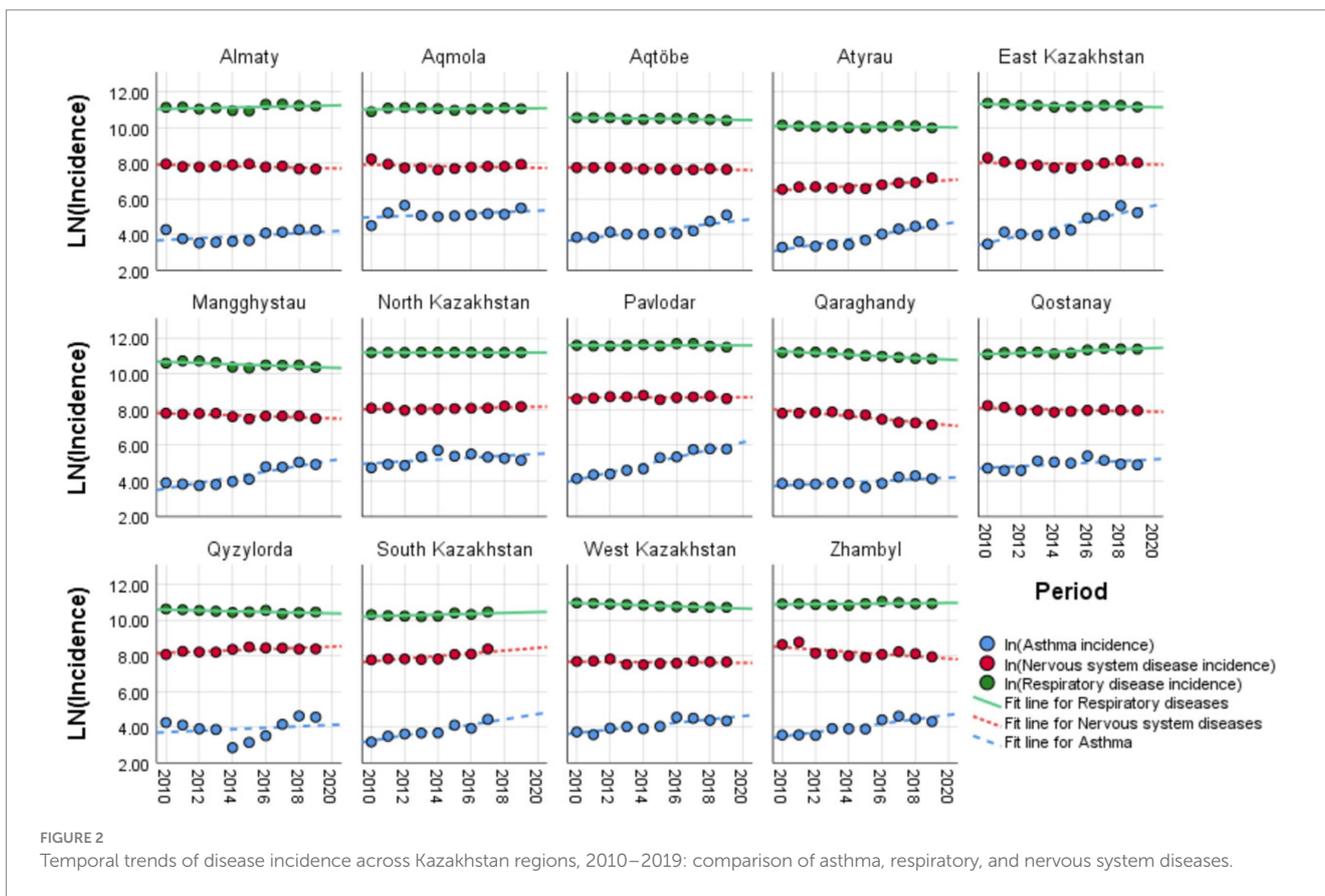
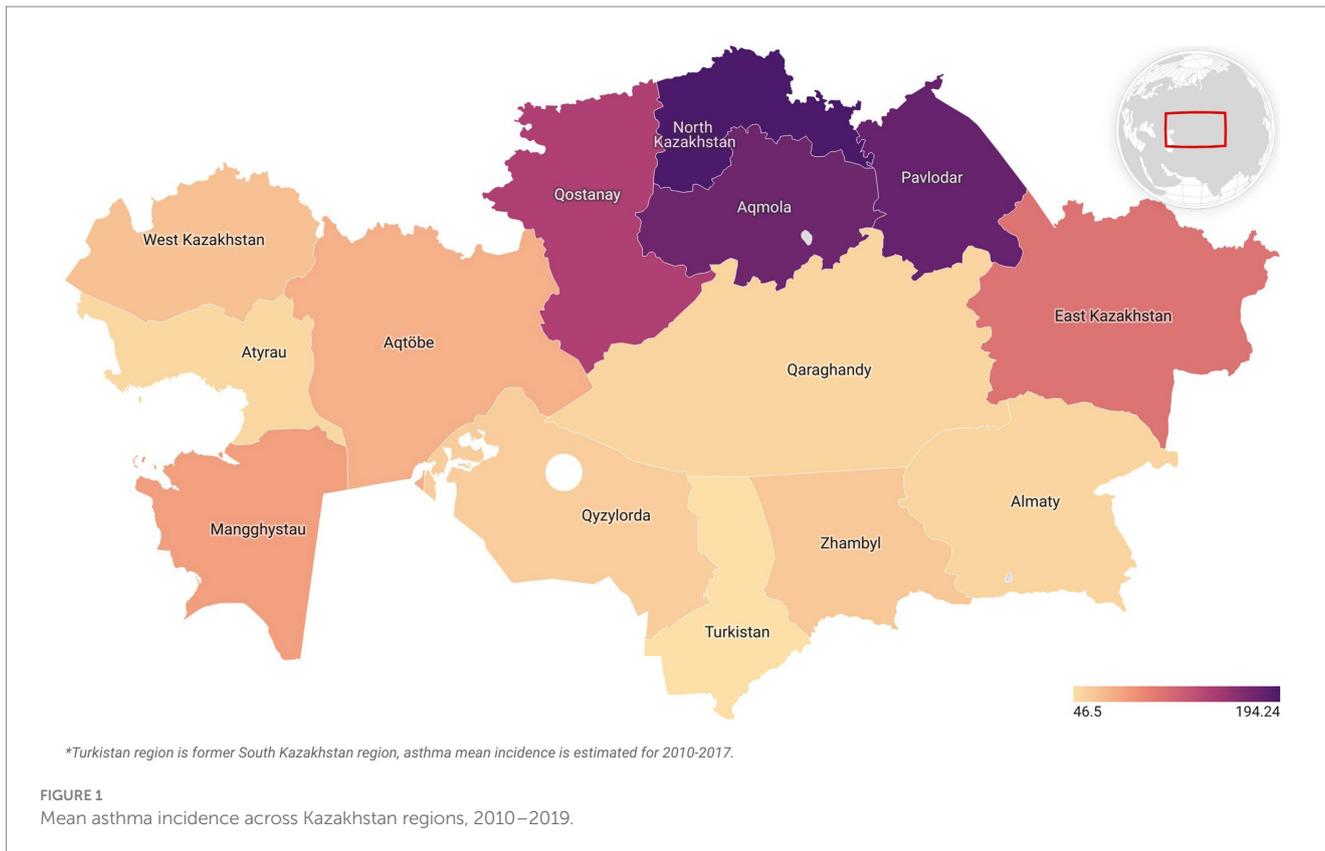
across regions, while asthma and nervous system diseases showed limited regional heterogeneity. The incidence of nervous system disorders showed mixed patterns, with some regions remaining stable and others displaying slight increases or decreases over the decade.

3.2 Regression analyses

Spearman's correlation analysis showed some associations between log-transformed disease incidence and socioeconomic/healthcare predictors. Respiratory diseases (J00–J99) had positive correlations with income inequality (Gini coefficient: $\rho = 0.59$, $p < 0.01$) and divorce rate ($\rho = 0.73$, $p < 0.01$), while showing negative associations with average salary ($\rho = -0.33$, $p < 0.01$) and GRP per capita ($\rho = -0.27$, $p < 0.01$). Asthma (J45) showed an inverse relationship with marriage rate ($\rho = -0.68$, $p < 0.01$) and pediatrician density ($\rho = -0.59$, $p < 0.01$), but correlated positively with housing provision ($\rho = 0.55$, $p < 0.01$) and living wage ($\rho = 0.39$, $p < 0.01$). Nervous system diseases (G00–G99) were inversely linked to GRP per capita ($\rho = -0.49$, $p < 0.01$) and positively associated with unemployment ($\rho = 0.23$, $p < 0.01$).

Before proceeding to the LMM, preliminary linear regression models were fitted for each log-transformed disease outcome (respiratory diseases, nervous system diseases, and asthma) using the set of log-transformed predictors to explore initial relationships. These log-log models provide elasticity estimates, where coefficients represent the percentage change in disease incidence associated with a 1% change in each predictor.

The linear regression model for respiratory diseases (adjusted $R^2 = 0.537$) identified several significant predictors (Table 3). For instance, a 1% increase in the Gini coefficient was associated with a 1.50% increase in incidence ($p < 0.001$). Similarly, a 1% increase in housing provision per



resident was associated with a 0.91% increase in incidence ($p = 0.038$). On the other hand, a 1% increase in the proportion of the population with income below the living wage was associated with a 0.20% decrease in incidence ($p = 0.011$). A 1% increase in population density corresponded to a 0.35% increase in incidence ($p = 0.016$).

For nervous system diseases (adjusted $R^2 = 0.410$), the linear regression model identified significant predictors (Table 4). A 1% increase in GRP per capita was associated with a 0.65% decrease in incidence ($p < 0.001$). In contrast, a 1% increase in the Gini coefficient was associated with a 0.12% increase in incidence ($p < 0.001$). There was a 1% increase in housing per resident, resulting in a 1.75% increase in incidence ($p = 0.001$).

The linear regression model for asthma (adjusted $R^2 = 0.525$) identified several significant predictors (Table 5). In contrast, a 1% increase in the Gini coefficient was associated with a 1.68% increase in incidence ($p < 0.001$). A 1% increase in housing provision per resident was associated with a 4.23% increase in incidence ($p < 0.001$). There was a 1% increase in pediatrician density, resulting in a 0.76% decrease in incidence ($p = 0.002$).

A LMM with a first-order autoregressive (AR1) covariance structure was fitted for the log-transformed incidence rate of respiratory, nervous system diseases, and asthma among children in Kazakhstan (2010–2019). Predictors included log-transformed GRP per capita, population density, unemployed population, Gini

TABLE 3 Linear regression results for respiratory diseases.

| Predictor | Coefficient | 95%CI | SE | p-value | VIF |
|--------------------------------|-------------|--------------|------|---------|------|
| LN(Gini) | 1.5 | 1.09; 1.90 | 0.2 | <0.001 | 1.40 |
| LN(Income below living wage) | -0.2 | -0.35; -0.05 | 0.08 | 0.011 | 1.79 |
| LN(Housing per resident) | 0.91 | 0.05; 1.76 | 0.43 | 0.038 | 1.74 |
| LN(Population density) | 0.35 | 0.07; 0.63 | 0.14 | 0.016 | 4.20 |
| LN(GRP per capita) | -0.12 | -0.27; 0.04 | 0.08 | 0.14 | 3.91 |
| LN(Unemployed population) | -0.15 | -0.39; 0.09 | 0.12 | 0.22 | 4.35 |
| LN(Pediatrician density) | -0.06 | -0.36; 0.25 | 0.15 | 0.72 | 2.81 |
| LN(Hospital beds for children) | 0.48 | -0.03; 1.00 | 0.26 | 0.06 | 2.87 |
| LN(Length of stay) | 0.58 | -0.25; 1.40 | 0.42 | 0.17 | 3.17 |

TABLE 4 Linear regression results for nervous system diseases.

| Predictor | Coefficient | 95%CI | SE | p-value | VIF |
|--------------------------------|-------------|--------------|------|---------|------|
| LN(GRP per capita) | -0.65 | -0.84; -0.46 | 0.10 | <0.001 | 3.91 |
| LN(Gini) | 0.12 | -0.36; 0.61 | 0.25 | <0.001 | 1.40 |
| LN(Housing per resident) | 1.75 | 0.72; 2.78 | 0.52 | 0.001 | 1.74 |
| LN(Population density) | -0.11 | -0.45; 0.23 | 0.17 | 0.514 | 4.20 |
| LN(Unemployed population) | -0.35 | -0.65; -0.06 | 0.15 | 0.019 | 4.35 |
| LN(Income below living wage) | -0.08 | -0.27; 0.10 | 0.09 | 0.378 | 1.79 |
| LN(Pediatrician density) | 0.25 | -0.12; 0.61 | 0.19 | 0.182 | 2.81 |
| LN(Hospital beds for children) | 0.71 | 0.09; 1.33 | 0.31 | 0.024 | 2.87 |
| LN(Length of stay) | -1.22 | -2.21; -0.23 | 0.50 | 0.016 | 3.17 |

TABLE 5 Linear regression results for asthma.

| Predictor | Coefficient | 95%CI | SE | p-value | VIF |
|--------------------------------|-------------|--------------|------|---------|------|
| LN(Gini) | 1.675 | -0.84; -0.46 | 0.32 | <0.001 | 1.40 |
| LN(Housing per resident) | 4.227 | 2.89; 5.56 | 0.67 | <0.001 | 1.74 |
| LN(Pediatrician density) | -0.756 | -1.23; -0.28 | 0.24 | 0.002 | 2.81 |
| LN(GRP per capita) | -0.241 | -0.49; 0.00 | 0.12 | 0.053 | 3.91 |
| LN(Population density) | 0.024 | -0.42; 0.46 | 0.22 | 0.913 | 4.20 |
| LN(Unemployed population) | -0.638 | -1.02; -0.26 | 0.19 | 0.001 | 4.35 |
| LN(Income below living wage) | 0.337 | 0.10; 0.58 | 0.12 | 0.006 | 1.79 |
| LN(Hospital beds for children) | -0.121 | -0.92; 0.68 | 0.40 | 0.764 | 2.87 |
| LN(Length of stay) | 0.353 | -0.93; 1.64 | 0.65 | 0.587 | 3.17 |

coefficient, income below living wage, housing per resident, pediatrician density, hospital beds for children, and length of stay. The model included fixed effects for “Region” (14 levels), “Period” (10 levels), and all predictors, a random intercept for “Region,” and an AR1 structure for repeated measures over “Period.”

The LMM for respiratory diseases identified significant fixed effects (Table 6). A 1% increase in population density was associated with a 1.048% decrease in incidence ($p = 0.008$). A 1% increase in the unemployed population was associated with a 0.406% increase in incidence ($p = 0.029$). A 1% increase in the Gini coefficient was associated with a 0.433% decrease in incidence ($p = 0.003$). A 1% increase in length of stay was associated with a 0.545% increase in incidence ($p = 0.031$). The “Region” variable was significant [$F(13, 106) = 16.134, p < 0.001$], with Zhambyl as the reference category.

Aqtöbe ($p = 0.002$), Atyrau ($p < 0.001$), Mangghystau ($p = 0.002$), North Kazakhstan ($p = 0.047$), Pavlodar ($p < 0.001$), Qaraghandy ($p = 0.033$), Qyzylorda ($p = 0.001$), and South Kazakhstan ($p < 0.001$) differed significantly from Zhambyl. The “Period” was significant [$F(9, 106) = 3.791, p < 0.001$], with 2019 as the reference category. The year 2015 differed significantly from 2019 ($p = 0.048$). Non-significant predictors included GRP per capita ($p = 0.902$), income below living wage ($p = 0.628$), housing per resident ($p = 0.262$), pediatrician density ($p = 0.223$), and hospital beds for children ($p = 0.666$).

The LMM for asthma showed significant fixed effects (Table 7). A 1% increase in income below living wage was associated with a 0.264% increase in incidence ($p = 0.032$). A 1% increase in length of stay was associated with a 1.896% increase in incidence ($p = 0.045$). Period was significant [$F(9, 106) = 1.968, p = 0.050$], with 2019 as the reference

TABLE 6 Estimates of fixed effects for respiratory diseases.

| Parameter | Estimate | SE | df | t | Sig. | 95% CI |
|-----------------------------|----------|-------|-----|--------|-------|----------------|
| Intercept | 10.652 | 1.511 | 106 | 7.051 | 0.000 | 7.657; 13.647 |
| [Region = Almaty] | 0.257 | 0.170 | 106 | 1.516 | 0.133 | -0.079; 0.593 |
| [Region = Aqmola] | -0.240 | 0.195 | 106 | -1.231 | 0.221 | -0.627; 0.147 |
| [Region = Aqtöbe] | -1.250 | 0.390 | 106 | -3.208 | 0.002 | -2.023; -0.478 |
| [Region = Atyrau] | -1.060 | 0.249 | 106 | -4.252 | 0.000 | -1.554; -0.566 |
| [Region = East Kazakhstan] | -0.112 | 0.228 | 106 | -0.492 | 0.624 | -0.565; 0.340 |
| [Region = Mangghystau] | -0.997 | 0.310 | 106 | -3.215 | 0.002 | -1.612; -0.382 |
| [Region = North Kazakhstan] | 0.345 | 0.172 | 106 | 2.010 | 0.047 | 0.005; 0.685 |
| [Region = Pavlodar] | 0.609 | 0.168 | 106 | 3.631 | 0.000 | 0.276; 0.941 |
| [Region = Qaraghandy] | -0.790 | 0.366 | 106 | -2.155 | 0.033 | -1.516; -0.063 |
| [Region = Qostanay] | -0.184 | 0.236 | 106 | -0.781 | 0.437 | -0.652; 0.284 |
| [Region = Qyzylorda] | -1.085 | 0.319 | 106 | -3.404 | 0.001 | -1.718; -0.453 |
| [Region = South Kazakhstan] | -0.682 | 0.189 | 106 | -3.614 | 0.000 | -1.056; -0.308 |
| [Region = West Kazakhstan] | -0.450 | 0.247 | 106 | -1.825 | 0.071 | -0.939; 0.039 |
| [Period = 2010] | -0.199 | 0.143 | 106 | -1.393 | 0.167 | -0.482; 0.084 |
| [Period = 2011] | -0.135 | 0.127 | 106 | -1.063 | 0.290 | -0.386; 0.116 |
| [Period = 2012] | -0.133 | 0.111 | 106 | -1.198 | 0.233 | -0.352; 0.087 |
| [Period = 2013] | -0.125 | 0.092 | 106 | -1.349 | 0.180 | -0.308; 0.059 |
| [Period = 2014] | -0.145 | 0.079 | 106 | -1.836 | 0.069 | -0.301; 0.012 |
| [Period = 2015] | -0.144 | 0.072 | 106 | -1.997 | 0.048 | -0.287; -0.001 |
| [Period = 2016] | -0.029 | 0.053 | 106 | -0.547 | 0.585 | -0.135; 0.077 |
| [Period = 2017] | 0.018 | 0.037 | 106 | 0.476 | 0.635 | -0.056; 0.092 |
| [Period = 2018] | 0.019 | 0.023 | 106 | 0.827 | 0.410 | -0.026; 0.064 |
| ln_GRPCapita | 0.010 | 0.081 | 106 | 0.123 | 0.902 | -0.151; 0.171 |
| ln_PopulationDensity | -1.048 | 0.385 | 106 | -2.720 | 0.008 | -1.812; -0.284 |
| ln_Unemployed | 0.406 | 0.184 | 106 | 2.212 | 0.029 | 0.042; 0.770 |
| ln_Gini | -0.433 | 0.144 | 106 | -3.010 | 0.003 | -0.718; -0.148 |
| ln_IncomeBelowLivingWage | -0.016 | 0.032 | 106 | -0.486 | 0.628 | -0.080; 0.048 |
| ln_HousingPerResident | -0.279 | 0.247 | 106 | -1.129 | 0.262 | -0.769; 0.211 |
| ln_PediatricianDensity | -0.089 | 0.073 | 106 | -1.226 | 0.223 | -0.234; 0.055 |
| ln_HospitalBedsKids | 0.064 | 0.147 | 106 | 0.433 | 0.666 | -0.228; 0.355 |
| ln_LOS | 0.545 | 0.249 | 106 | 2.186 | 0.031 | 0.051; 1.039 |

TABLE 7 Estimates of fixed effects for asthma incidence.

| Parameter | Estimate | SE | df | t | Sig. | 95% CI |
|-----------------------------|----------|-------|-----|--------|-------|----------------|
| Intercept | 4.115 | 5.648 | 106 | 0.729 | 0.468 | −7.084; 15.314 |
| [Region = Almaty] | −0.337 | 0.623 | 106 | −0.541 | 0.589 | −1.573; 0.898 |
| [Region = Aqmola] | 0.858 | 0.719 | 106 | 1.193 | 0.236 | −0.568; 2.284 |
| [Region = Aqtöbe] | 0.004 | 1.450 | 106 | 0.003 | 0.998 | −2.871; 2.880 |
| [Region = Atyrau] | 0.091 | 0.924 | 106 | 0.098 | 0.922 | −1.741; 1.923 |
| [Region = East Kazakhstan] | −0.196 | 0.846 | 106 | −0.231 | 0.818 | −1.872; 1.481 |
| [Region = Mangghystau] | 0.355 | 1.151 | 106 | 0.308 | 0.759 | −1.928; 2.638 |
| [Region = North Kazakhstan] | 1.397 | 0.631 | 106 | 2.215 | 0.029 | 0.147; 2.647 |
| [Region = Pavlodar] | 1.272 | 0.616 | 106 | 2.066 | 0.041 | 0.051; 2.493 |
| [Region = Qaraghandy] | −0.595 | 1.366 | 106 | −0.436 | 0.664 | −3.303; 2.112 |
| [Region = Qostanay] | 0.390 | 0.874 | 106 | 0.446 | 0.657 | −1.343; 2.122 |
| [Region = Qyzylorda] | −0.088 | 1.184 | 106 | −0.075 | 0.941 | −2.435; 2.258 |
| [Region = South Kazakhstan] | −0.487 | 0.695 | 106 | −0.700 | 0.486 | −1.865; 0.892 |
| [Region = West Kazakhstan] | 0.021 | 0.912 | 106 | 0.023 | 0.982 | −1.787; 1.829 |
| [Period = 2010] | −1.185 | 0.535 | 106 | −2.215 | 0.029 | −2.246; −0.124 |
| [Period = 2011] | −1.118 | 0.474 | 106 | −2.358 | 0.020 | −2.058; −0.178 |
| [Period = 2012] | −0.941 | 0.415 | 106 | −2.267 | 0.025 | −1.763; −0.118 |
| [Period = 2013] | −0.735 | 0.346 | 106 | −2.123 | 0.036 | −1.421; −0.049 |
| [Period = 2014] | −0.748 | 0.296 | 106 | −2.531 | 0.013 | −1.335; −0.162 |
| [Period = 2015] | −0.627 | 0.270 | 106 | −2.321 | 0.022 | −1.162; −0.091 |
| [Period = 2016] | −0.261 | 0.200 | 106 | −1.302 | 0.196 | −0.657; 0.136 |
| [Period = 2017] | −0.043 | 0.140 | 106 | −0.308 | 0.758 | −0.320; 0.234 |
| [Period = 2018] | −0.021 | 0.085 | 106 | −0.248 | 0.805 | −0.190; 0.148 |
| ln_GRPCapita | 0.072 | 0.305 | 106 | 0.236 | 0.814 | −0.533; 0.678 |
| ln_PopulationDensity | −0.567 | 1.440 | 106 | −0.394 | 0.695 | −3.422; 2.288 |
| ln_Unemployed | 0.731 | 0.689 | 106 | 1.061 | 0.291 | −0.635; 2.097 |
| ln_Gini | 0.298 | 0.540 | 106 | 0.552 | 0.582 | −0.772; 1.369 |
| ln_IncomeBelowLivingWage | 0.264 | 0.122 | 106 | 2.168 | 0.032 | 0.023; 0.505 |
| ln_HousingPerResident | −1.099 | 0.926 | 106 | −1.186 | 0.238 | −2.935; 0.738 |
| ln_PediatricianDensity | −0.382 | 0.274 | 106 | −1.396 | 0.166 | −0.926; 0.161 |
| ln_HospitalBedsKids | −0.723 | 0.552 | 106 | −1.312 | 0.192 | −1.817; 0.370 |
| ln_LOS | 1.896 | 0.935 | 106 | 2.028 | 0.045 | 0.042; 3.750 |

Zhambyl is the reference category for Region, and 2019 is the reference category for Period.

category. The years 2010 ($p = 0.029$), 2011 ($p = 0.020$), 2012 ($p = 0.025$), 2013 ($p = 0.036$), 2014 ($p = 0.013$), and 2015 ($p = 0.022$) differed significantly from 2019. Region was not significant overall [$F(13, 106) = 1.489, p = 0.133$], but North Kazakhstan ($p = 0.029$) and Pavlodar ($p = 0.041$) differed significantly from Zhambyl, the reference category. Non-significant predictors included GRP per capita ($p = 0.814$), population density ($p = 0.695$), unemployed population ($p = 0.291$), Gini coefficient ($p = 0.582$), housing per resident ($p = 0.238$), pediatrician density ($p = 0.166$), and hospital beds for children ($p = 0.192$).

The final step for log-transformed nervous system disease incidence (Table 8) showed that a 1% increase in the unemployed population was associated with a 0.692% increase in incidence

($p = 0.040$). Region variable was not significant overall [$F(13, 106) = 0.165, p = 1.000$], with Zhambyl as the reference category, and no individual regions differed significantly from Zhambyl (all $p \geq 0.953$). Period was not significant [$F(9, 101.622) = 1.106, p = 0.366$], with 2019 as the reference category, and no individual years differed significantly from 2019 (the p -values for all the individual years ≥ 0.388). Most of the predictors were non-significant, including GRP per capita ($p = 0.921$), population density ($p = 0.971$), Gini coefficient ($p = 0.963$), income below living wage ($p = 0.990$), housing per resident ($p = 0.979$), pediatrician density ($p = 0.938$), hospital beds for children ($p = 0.816$), and length of stay ($p = 0.548$).

In summary, the respiratory diseases were the most prevalent, affecting over 57,000 per 100,000 children annually in a study

TABLE 8 Estimates of fixed effects for nervous system disease incidence.

| Parameter | Estimate | SE | df | t | Sig. | 95% CI |
|-----------------------------|----------|-------|---------|--------|-------|-----------------|
| Intercept | 5.750 | 3.163 | 1.037 | 1.818 | 0.313 | −31.218; 42.718 |
| [Region = Almaty] | −0.845 | 1.585 | 0.018 | −0.533 | 0.964 | −3.998; 2.308 |
| [Region = Aqmola] | −0.056 | 1.599 | 0.018 | −0.035 | 0.995 | −2.243; 2.243 |
| [Region = Aqtöbe] | −0.367 | 1.741 | 0.026 | −0.211 | 0.973 | −2.669; 2.669 |
| [Region = Atyrau] | −0.940 | 1.629 | 0.020 | −0.577 | 0.959 | −2.527; 2.526 |
| [Region = East Kazakhstan] | −0.323 | 1.614 | 0.019 | −0.200 | 0.978 | −2.410; 1.626 |
| [Region = Mangghystau] | −0.153 | 1.677 | 0.022 | −0.091 | 0.987 | −2.740; 1.147 |
| [Region = North Kazakhstan] | 0.198 | 1.588 | 0.018 | 0.125 | 0.985 | −2.635; 1.263 |
| [Region = Pavlodar] | 0.550 | 1.586 | 0.018 | 0.347 | 0.971 | −2.706; 2.706 |
| [Region = Qaraghandy] | −0.969 | 1.711 | 0.024 | −0.566 | 0.953 | −3.701; 2.902 |
| [Region = Qostanay] | −0.187 | 1.621 | 0.019 | −0.115 | 0.986 | −2.827; 1.808 |
| [Region = Qyzylorda] | 0.271 | 1.686 | 0.023 | 0.161 | 0.979 | −2.482; 1.724 |
| [Region = South Kazakhstan] | −0.691 | 1.596 | 0.018 | −0.433 | 0.966 | −2.351; 2.782 |
| [Region = West Kazakhstan] | −0.241 | 1.632 | 0.020 | −0.148 | 0.982 | −2.445; 2.173 |
| [Period = 2010] | −0.061 | 0.270 | 98.974 | −0.225 | 0.822 | −0.597; 0.476 |
| [Period = 2011] | −0.045 | 0.240 | 98.973 | −0.187 | 0.852 | −0.521; 0.432 |
| [Period = 2012] | −0.109 | 0.210 | 99.853 | −0.518 | 0.605 | −0.525; 0.307 |
| [Period = 2013] | −0.122 | 0.175 | 100.557 | −0.697 | 0.488 | −0.468; 0.225 |
| [Period = 2014] | −0.123 | 0.149 | 101.873 | −0.827 | 0.410 | −0.418; 0.172 |
| [Period = 2015] | −0.117 | 0.135 | 104.160 | −0.867 | 0.388 | −0.384; 0.150 |
| [Period = 2016] | −0.052 | 0.100 | 104.603 | −0.521 | 0.603 | −0.249; 0.146 |
| [Period = 2017] | 0.020 | 0.069 | 105.306 | 0.290 | 0.772 | −0.117; 0.157 |
| [Period = 2018] | 0.019 | 0.041 | 105.869 | 0.451 | 0.653 | −0.063; 0.100 |
| ln_GRPCapita | −0.015 | 0.146 | 103.933 | −0.100 | 0.921 | −0.304; 0.274 |
| ln_PopulationDensity | −0.028 | 0.766 | 79.510 | −0.036 | 0.971 | −1.552; 1.497 |
| ln_Unemployed | 0.692 | 0.333 | 105.766 | 2.078 | 0.040 | 0.032; 1.353 |
| ln_Gini | 0.012 | 0.255 | 102.150 | 0.046 | 0.963 | −0.495; 0.518 |
| ln_IncomeBelowLivingWage | 0.001 | 0.057 | 101.907 | 0.012 | 0.990 | −0.113; 0.114 |
| ln_HousingPerResident | −0.012 | 0.463 | 103.732 | −0.027 | 0.979 | −0.931; 0.906 |
| ln_PediatricianDensity | −0.010 | 0.131 | 103.479 | −0.078 | 0.938 | −0.269; 0.249 |
| ln_HospitalBedsKids | −0.061 | 0.263 | 103.772 | −0.233 | 0.816 | −0.583; 0.461 |
| ln_LOS | 0.273 | 0.453 | 105.397 | 0.602 | 0.548 | −0.625; 1.171 |

Zhambyl is the reference category for Region, and 2019 is the reference category for Period.

period. Respiratory diseases were strongly linked to socioeconomic factors. Higher unemployment and longer hospital stays were associated with increased incidence, while a greater income was linked to a slight decrease, possibly due to better healthcare access in wealthier regions. Asthma incidence was higher in areas with more poverty and longer hospital stays, with significant increases observed over time, particularly in regions like North Kazakhstan and Pavlodar. Nervous system diseases, though less prevalent, were tied to higher unemployment. We identified regional differences, with respiratory diseases varying significantly across areas like Atyrau and Pavlodar, while asthma showed a consistent upward trend nationwide.

4 Discussion

This study specifically examines the pre-COVID-19 era (2010–2019), a period before the global pandemic significantly altered health indicators through both direct and indirect effects. The COVID-19 pandemic, starting in 2020, introduced unprecedented disruptions, including overwhelmed healthcare systems, delayed routine care, and socioeconomic shifts due to lockdowns, which impacted disease incidence and healthcare indicators worldwide (34, 35). For instance, a study from Italy found that pediatric emergency visits for respiratory illnesses dropped sharply during the pandemic due to reduced social contact, while Barbiellini Amidei et al. (36) and Santoli et al. (37)

reported a decline in routine vaccinations in the U.S., potentially increasing vulnerability to other diseases. In Kazakhstan, where healthcare resources were already strained with public health spending at 1.8–3.2% of GRP, the pandemic had complex effects on healthcare financing (24). While Shaltynov et al. (38) documented a decrease in out-of-pocket expenditures during 2020–2021, with catastrophic health expenditure incidence declining nearly twofold to 1.32 and 1.24% respectively, this occurred alongside reduced access to non-COVID care, suggesting potential unmet healthcare needs rather than improved financial protection. This interpretation is further supported by evidence that active tuberculosis detection in Kazakhstan decreased by 17–20% during the pandemic (35), indicating significant disruptions to essential public health services (39). By focusing on the pre-COVID-19 period, our study provides a baseline understanding of pediatric disease incidence, capturing patterns of respiratory diseases, asthma, and nervous system diseases among children aged 0–14 years without the confounding effects of the pandemic.

The high burden of respiratory diseases among children in Kazakhstan mirrors global patterns observed in other countries, with relatively stable incidence trends punctuated by periodic increases (40, 41). Beyond direct environmental exposures, our findings align with international literature reporting significant associations between pediatric respiratory outcomes and broader socioeconomic and healthcare indicators (42). We found that a 1% increase in population density was associated with a 1.048% decrease in respiratory disease incidence ($p = 0.008$). This finding contrasts with studies in Western countries where higher population density often correlates with increased respiratory morbidity due to urban pollution and overcrowding (43). However, it is important to recognize the mean population density is very low in Kazakhstan, with 5.8 people per 1 sq. km. (44). Moreover, this inverse relationship may reflect the centralized healthcare infrastructure in urban centers such as Astana, Almaty, and Shymkent, which offer better access to pediatric hospitals and early diagnosis, thereby mitigating environmental risks. It could be assessed in future studies as an interesting case to explore.

While Alam et al. (45) demonstrated that in the Eastern Mediterranean Region, a unit increase in the Gini coefficient was associated with approximately 7.2 and 3.9% increases in COVID-19 cases and deaths per million population, respectively, our study shows an inverse relationship: a 1% increase in the Gini coefficient was linked to a 0.433% decrease in respiratory disease incidence ($p = 0.003$). This finding diverges from typical associations where income inequality aggravates health disparities (46). The unexpected inverse relationship between the Gini coefficient and respiratory disease incidence may reflect regional dynamics where higher income inequality coincides with concentrated wealth in resource-rich regions like Atyrau, potentially enabling investments in healthcare infrastructure that improve disease detection and management. Also, this finding could indicate underreporting in less equitable regions with weaker health systems, masking true disparities. It's critical to acknowledge that the Gini coefficient, while widely used, simplifies the income distribution into a single metric, potentially obscuring nuanced differences in living standards between different areas (47, 48). A 1% rise in unemployment correlated with a 0.406% increase in incidence ($p = 0.029$), while longer hospital stays (+0.545%, $p = 0.031$) likely reflect respiratory disease severity. Unemployment's impact

mirrors findings in post-Soviet economies, where job loss exacerbates household stressors and worsens well-being (49, 50). Infants and young children, even those without chronic or serious underlying medical conditions, are at elevated risk for hospitalization during influenza seasons (51). However, the burden is disproportionately higher among older children with asthma, younger children with lower respiratory infections, those with chronic comorbidities, and children hospitalized in large urban hospitals (52). Moreover, insufficient infrastructure in Kazakhstan impedes the detection of less prevalent diseases such as interstitial lung disease, along with vigilance from primary healthcare providers (53).

We identified the 140% rise in pediatric asthma incidence in Kazakhstan within the study period. It may reflect a broader “double burden” in transitional economies, where industrialization and urbanization amplify NCD risks even as infectious diseases persist. Similar trends were reported in Azerbaijan, Ukraine, where post-Soviet transitions in the economy correlated with an asthma patients increase in children and adult populations (54). Our finding that income inequality drives asthma (+0.26% per 1% rise in low-income households) aligns with evidence from systematic reviews suggesting that asthma is associated with lower socioeconomic position. This highlights how economic disadvantage contributes to respiratory vulnerability through multiple pathways, including inadequate housing conditions, reduced access to healthcare, and greater exposure to environmental triggers (55, 56).

The role of unemployment in our models (+0.41% for respiratory diseases, +0.69% for nervous system disorders) suggests economic instability erodes protective factors like nutrition and parental caregiving, a mechanism observed in neighboring Russia during the 2000s, where maternal unemployment was associated with 3.4-fold higher odds of childhood asthma (57).

The potential for inter-disease effects, such as the influence of other conditions like digestive or blood disorders on the selected diseases, was not directly modeled due to data aggregation. However, asthma was analyzed separately from the broader respiratory disease category (J00–J99) to avoid collinearity, as it is a subset of respiratory conditions (J45). Future studies could incorporate other diseases as covariates to explore indirect effects.

The limited associations observed for nervous system disorders in our study, with unemployment being the sole significant predictor, contrast with findings from high- and middle-income countries, where multiple socioeconomic factors typically correlate with neurological outcomes. Robust evidence demonstrates that lower socioeconomic status, including unemployment, is associated with a higher burden of pediatric neurological conditions (58, 59). These disparities likely stem from differentials in healthcare access, educational resources, and early diagnostic capacity (60). Our findings suggest Kazakhstan's neurological health patterns may reflect either systemic under-detection of cases across socioeconomic strata, potentially due to limited specialist availability in some regions, or a more homogeneous distribution of neurological risk factors across population groups compared to other national contexts.

In Kazakhstan, ongoing reforms have focused on transitioning from a centralized, hospital-based healthcare model inherited from the Soviet era to a socially oriented, people-centered PHC system with the aim to achieve universal health coverage (61). Extensive sanitary

and anti-epidemic measures at the national level, along with supervision of childcare institutions, led to a drop in childhood morbidity and mortality in all country regions (62). Key challenges remain, such as the overall lack of public funding for primary care, poor financial protection, access to primary care in rural areas, and underdeveloped quality monitoring (63).

Based on our findings, to tackle the elevated incidence of respiratory and nervous system diseases in high-unemployment regions such as Pavlodar region, where economic constraints limit healthcare access, we see that there could be better deployment of mobile health units. These units would be equipped with pediatric specialists and diagnostic tools to deliver timely care to underserved communities, thereby reducing disease burden and improving early intervention. Strengthening socioeconomic support programs, including nutritional subsidies and community health worker initiatives, can alleviate financial barriers and promote healthier living conditions, particularly in rural areas (64, 65). In regions characterized by high income inequality, such as Atyrau, and mostly rural regions like Zhambyl, where disparities may play a role in asthma incidence due to environmental and economic factors, we advocate for the implementation of targeted asthma prevention programs. Access to and affordability of essential inhaled asthma drugs are major challenges to effective asthma control in many countries (66). These programs could include environmental monitoring, air quality regulation, and subsidies for asthma medications and devices, alongside educational campaigns targeting vulnerable populations (67, 68).

This study has several limitations that should be taken into account. First, the use of regionally aggregated data may obscure intra-regional variations or individual-level factors, limiting granularity. Due to the use of regionally aggregated data, individual-level variables were unavailable, limiting our ability to analyze age-specific variations. While the data underwent standard validation, regional underreporting bias may exist, potentially affecting the accuracy of incidence rates, and other selected variables. Second, the unavailability of data from South Kazakhstan after 2017, due to its administrative reorganization, may have impacted the analysis of regional variations when using pooled data from 2010 to 2019. This limitation could reduce the precision of estimates for this region and affect the overall assessment of regional heterogeneity. Third, the LMMs, while accounting for clustering and autocorrelation, may not capture all sources of variability, such as unmeasured environmental factors (ambient air pollution, indoor air quality, climate indicators, etc.). These environmental determinants are particularly important for respiratory conditions such as asthma, as substantial evidence links air pollutants and climate variables to respiratory symptom exacerbation and disease progression in pediatric populations (11, 69). For example, our findings show that the significantly lower incidence of respiratory diseases in industrial regions such as Aqtöbe and Atyrau contrasts with the higher burden in coal-dependent Pavlodar. The absence of these environmental metrics represents a significant gap, especially for Kazakhstan's industrial regions, where such exposures may disproportionately affect respiratory health outcomes. However, consistent reliable regional data for air pollutants were not available prior to 2019, though recent advancements in environmental monitoring systems will enable future studies to incorporate these key parameters into

statistical models. Also, we did not have some parameters, such as cases with comorbidities, parental education status, cultural aspects that may influence greatly children health outcomes (70–72). Finally, the log-transformation assumes proportional relationships, which may not hold for all predictors, potentially affecting elasticity estimates.

5 Conclusion

Using panel data from 14 regions and log-transformed linear mixed models, this study identified distinct socioeconomic, demographic, and healthcare predictors of respiratory diseases, asthma, and nervous system diseases incidence. Respiratory diseases and asthma in Kazakhstani children aged 0–14 appear closely linked to regional economic conditions, healthcare access, and inequality. Population density and income inequality were found as consistent predictors, while nervous system disorders showed weaker associations. Regional patterns in child morbidity reflect underlying socioeconomic disparities. Addressing socioeconomic disparities through place-based policies may prove effective in reducing the burden of pediatric respiratory and nervous system diseases, particularly in regions with greater income inequality and limited healthcare access. Addressing inequality and improving healthcare access may reduce the burden of pediatric disease and advance equity in health policy within the post-Soviet context.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found: data were derived from public domain resources: agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics—Main. Available online at: <https://stat.gov.kz/en/>.

Ethics statement

This study was conducted in accordance with local legislation and institutional requirements, receiving ethical approval from the IRB Ethics Committee of Karaganda Medical University (protocol number 09-45, November 27, 2023).

Author contributions

NS: Methodology, Software, Writing – original draft, Formal analysis, Data curation, Writing – review & editing, Conceptualization, Validation, Investigation, Supervision. OZ: Writing – review & editing, Conceptualization, Software, Investigation, Writing – original draft, Formal analysis, Data curation, Methodology. AA: Writing – review & editing, Conceptualization. NY: Investigation, Data curation, Writing – review & editing. KN: Data curation, Formal analysis, Writing – review & editing, Writing – original draft. ZB: Writing – review & editing, Formal analysis, Data curation, Writing – original draft. ZK: Writing – review & editing, Supervision, Conceptualization, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fpubh.2025.1615521/full#supplementary-material>

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