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Research Article

Non-monetary dynamics of well-being in transition economies: A multi-dimensional analysis of life expectancy in Kazakhstan

Geçiş ekonomilerinde refahın parasal olmayan dinamikleri: Kazakistan örneğinde yaşam beklentisinin çok boyutlu belirleyicileri

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Abstract

This study empirically examines the economic (real GDP per capita and unemployment), demographic (infant mortality and fertility rates), health (hospital bed capacity and vaccination coverage), and environmental (PM2.5 air pollution) determinants of life expectancy in Kazakhstan over the period 1991–2023. A quantitative approach is employed to investigate both short- and long-run relationships using the Augmented Autoregressive Distributed Lag (A-ARDL) cointegration framework. Long-run coefficients are further validated through Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) estimators. The empirical findings reveal that economic growth and improvements in health infrastructure significantly increase life expectancy. In particular, real GDP per capita and hospital bed capacity exhibit positive and statistically significant effects. In contrast, higher fertility rates and infant mortality significantly reduce life expectancy. The results also indicate a positive and statistically significant association between PM2.5 air pollution and life expectancy. This finding diverges from conventional expectations and may reflect the simultaneous expansion of economic activity and healthcare investments during the study period. By contrast, the effects of vaccination coverage and unemployment are not statistically significant. Overall, the findings highlight the multi-dimensional determinants of life expectancy and underline the importance of economic development, demographic dynamics, and health infrastructure in shaping population health outcomes in transition economies such as Kazakhstan.

Keywords: Life Expectancy, Transition Economies, Kazakhstan, Health Economics, Economic, Demographic, and Environmental Determinants

Jel Codes: I1, O1, O53, J11

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Öz

Bu çalışma, 1991–2023 döneminde Kazakistan'da yaşam beklentisinin ekonomik (kişi başına reel gelir ve işsizlik), demografik (bebek ölüm oranı ve doğurganlık oranı), sağlık (hastane yatak kapasitesi ve aşılama oranı) ve çevresel (PM2.5 hava kirliliği) belirleyicilerini ampirik olarak incelemektedir. Çalışmada kısa ve uzun dönemli ilişkileri analiz etmek amacıyla Augmented Autoregressive Distributed Lag (A-ARDL) eşbütünleşme yaklaşımı kullanılmıştır. Uzun dönem katsayılarının sağlamlığı ise Fully Modified Ordinary Least Squares (FMOLS) ve Canonical Cointegrating Regression (CCR) tahmin yöntemleri ile doğrulanmıştır. Ampirik bulgular, ekonomik büyüme ve sağlık altyapısındaki iyileşmelerin yaşam beklentisini anlamlı biçimde artırdığını göstermektedir. Özellikle kişi başına reel gelir ve hastane yatak kapasitesi değişkenlerinin yaşam beklentisi üzerinde pozitif ve istatistiksel olarak anlamlı etkilere sahip olduğu tespit edilmiştir. Buna karşılık, yüksek doğurganlık oranları ve bebek ölüm oranlarının yaşam beklentisini anlamlı biçimde azalttığı belirlenmiştir. Bulgular ayrıca PM2.5 hava kirliliği ile yaşam beklentisi arasında pozitif ve istatistiksel olarak anlamlı bir ilişki olduğunu göstermektedir. Bu sonuç, literatürdeki genel beklentilerden farklı olup, incelenen dönemde ekonomik faaliyetlerdeki genişleme ile sağlık altyapısına yapılan yatırımların eş zamanlı artışıyla ilişkili olabilir. Buna karşın aşılama oranı ve işsizlik değişkenlerinin yaşam beklentisi üzerindeki etkilerinin istatistiksel olarak anlamlı olmadığı görülmektedir. Genel olarak bulgular, yaşam beklentisinin çok boyutlu belirleyicilere sahip olduğunu ortaya koymakta ve Kazakistan gibi geçiş ekonomilerinde nüfus sağlığı sonuçlarının şekillenmesinde ekonomik gelişme, demografik dinamikler ve sağlık altyapısının önemini vurgulamaktadır.

Anahtar Kelimeler: Yaşam Beklentisi, Geçiş Ekonomileri, Kazakistan, Sağlık Ekonomisi, Ekonomik ve Demografik Belirleyiciler

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Introduction

The sudden collapse of the Soviet Union was not only one of the greatest geopolitical transformations of the 20th century but also an unprecedented social rupture that deeply affected the daily lives of millions. Kazakhstan was among the countries where this rupture was felt most sharply (Shkolnikov & Cornia, 2000). After gaining independence in 1991, the country faced a 40% decline in production capacity, hyperinflation, and the collapse of social safety nets (World Bank, Kazakhstan Overview, 2021). The health services, which the state had strictly controlled during the Soviet era, became inaccessible as a result of sudden privatisations and budget cuts; the closure of clinics and shortages of medicine, particularly in rural areas, led to severe and lasting public health losses (Cabinet of Ministers of the Republic of Kazakhstan, 1992). Meanwhile, the closure of industrial enterprises and the rapid rise in unemployment deepened social vulnerabilities; growing alcohol dependency and suicide rates among men became some of the most evident socio-economic determinants of the sharp decline in life expectancy (Voroshilin, 2012).

During this period, not only the healthcare system but all areas of social life became fragile; income losses and rising poverty led to a dramatic deterioration in life expectancy (UNDP, Human Development Report Kazakhstan, 2000). Indeed, statistics clearly reveal the human dimension of this collapse. The average life expectancy, which was 71 years in 1990, fell below 60 years for men within only five years, one of the most extraordinary demographic crises ever recorded in peacetime (Cornia & Paniccia 2000). Although women lived longer, the gender gap in life expectancy exceeded 12 years, making it one of the widest in Europe (WHO, Kazakhstan Health Profile, 2020). The increase in maternal and child mortality was among the most dramatic consequences of this process; in rural areas, infant mortality rates exceeded 60 per 1,000 live births in the mid-1990s (UNICEF, State of the World's Children, 1996). The collapse of the healthcare system, combined with economic contraction and social inequalities, led to a sharp rise in mortality rates, leaving deep marks on health and life expectancy in Kazakhstan as one of the most vulnerable transition economies.

Beyond these socio-economic factors, historical and environmental issues also played a critical role in the decline of life expectancy. The heavy industrialisation policies and unregulated mining activities during the Soviet industrialisation period exposed Kazakhstan to toxic waste, heavy metal pollution, and radiation, all of which posed serious threats to public health (News dalla rete ITA, 2026). In particular, the ecological disaster in the Aral Sea basin became not only an environmental tragedy but also a public health crisis, leading to sharp increases in respiratory diseases and immune system disorders (White, 2013). Furthermore, the damage caused by the Semipalatinsk nuclear test site resulted in genetic disorders and cancer rates far above the global average in the affected region (Grosche et al., 2015). Therefore, the increased mortality rates in the early years of independence were the outcome of a complex process in which economic policies intertwined with historical and environmental problems (Pomfret, 1995)

Thus, the case of Kazakhstan demonstrates that the turbulence experienced by transition economies has not only financial and institutional dimensions but also deeply human consequences. The sharp decline in life expectancy reveals that economic growth figures alone are insufficient to understand social welfare; health, environmental quality, and social stability are also indispensable components of the development process (Sen, 1999). For this reason, international organisations have long considered life expectancy as one of the key indicators in development and human development indices (UNDP, 2000; OECD, 2020).

In this context, the relationship between economic growth and life expectancy has been extensively examined in the literature, which concludes that it is strong but non-linear. Preston's well-known "Preston Curve" demonstrates that as income levels rise, life expectancy increases, but at higher income levels this increase slows down (Preston, 2007: 488). This finding suggests that income growth alone does not guarantee longevity; the strength of health infrastructure and social policies plays a decisive role (Bloom & Canning, 2000: 1208). Indeed, WHO data show that in countries with relatively low per capita income but strong health policies, life expectancy surpasses that of many developing nations (WHO, World Health Statistics, 2012). In this regard, it has been emphasised that the health reforms implemented in Kazakhstan since the mid-2000s have contributed to a partial recovery in life expectancy (WHO, 2015).

Life expectancy is also considered a sensitive indicator of environmental conditions. Air pollution, water contamination, and climate change-related risks directly increase mortality rates, making environmental factors one of the main determinants of life expectancy, especially in transition economies that inherited severe environmental issues from industrialisation (Dasgupta, 2021). In

Kazakhstan, the ecological collapse of the Aral Sea basin, water scarcity, and heavy metal contamination are among the key threats to public health, particularly associated with high rates of respiratory diseases and cancer in rural areas (Feshbach, 1995).

On the other hand, demographic structures directly influence life expectancy. Fertility rates, the share of the elderly population, and migration dynamics are crucial determinants of the average lifespan of societies (Lee, 2003). In Kazakhstan's case, the emigration of hundreds of thousands of ethnic Russians and the migration of young people to Europe in the post-Soviet period rapidly altered the demographic structure, deepening both labour market challenges and regional inequalities in access to healthcare (Schmidt, 2008: 88).

Many empirical studies in the literature have examined the economic, social, and environmental factors underlying life expectancy. According to World Bank data, the sharp declines in life expectancy between 1990 and 2000 resulted from the combined effects of economic crisis, weak health infrastructure, and environmental problems (World Bank, Kazakhstan Country Brief, 2003). Gulis et al. Emphasised that the inadequacy of health services in rural areas increased maternal and child mortality, pulling down life expectancy (Gulis et al., 2021: 6). The analytical report prepared by Halyk Finance highlighted that income inequality and high poverty rates deepen life expectancy disparities in Kazakhstan (Halyk Finance, 2023). Moreover, ILO reports pointed out that occupational accidents and work-related diseases are among the factors limiting male life expectancy (ILO). Thus, the literature indicates that life expectancy cannot be explained solely by economic growth; health infrastructure, education, environmental conditions, and social policies are also critical determinants. However, in Kazakhstan, holistic empirical studies systematically examining the interactions among these factors remain limited.

Kazakhstan's transition experience shows that life expectancy reflects not only historical and social vulnerabilities but also the intertwined effects of economic growth dynamics, unemployment rates, health infrastructure, and environmental conditions (Pomfret, 1995: 88; Cornia & Paniccia, 2000: 14). Therefore, this article aims to analyse, within the context of Kazakhstan, these interrelated dimensions in an integrated framework, addressing the gap in the literature, which often examines such relationships in a one-dimensional manner. The study's original contribution lies in incorporating economic indicators along with health and environmental factors into a single analytical framework. The lack of empirical research analysing life expectancy in Kazakhstan holistically across the economy, health, and environment dimensions constitutes the core motivation of this study.

Accordingly, this research seeks to answer the following questions:

(i) How do fluctuations in economic growth and unemployment rates shape life expectancy?

(ii) How does the institutional capacity and accessibility of health infrastructure affect the population's lifespan?

(iii) To what extent do environmental pollution and ecological degradation—particularly the issues inherited from the Soviet era—affect public health and average life expectancy?

The analysis developed around these questions has both academic and policy relevance, not only for understanding welfare determinants in Kazakhstan but also for transition economies in general. This study aims to illuminate both the determinants of life expectancy in Kazakhstan and the structural challenges faced by transition economies regarding sustainable development and public health policies. To achieve this, unit root tests considering structural breaks, the A-ARDL cointegration approach, and long-run estimation methods (FMOLS and CCR) were applied; in particular, the effects of the transition shocks of the 1990s and the COVID-19 break in 2020 on life expectancy were empirically tested.

Literature review

Measuring a society's real welfare requires not only examining how long individuals live, but also systematically assessing how economic growth, unemployment, income distribution, health infrastructure, and environmental sustainability affect life expectancy. Therefore, in transition economies, life expectancy functions as a key indicator that reflects not only the strength of healthcare systems but also the transformation of market institutions, the quality of employment, and the effectiveness of environmental policies (Cutler & Deaton, 2006: 100; Bloom & Canning, 2000).

Within the existing literature, the determinants of life expectancy are commonly discussed through several interconnected dimensions, including economic conditions, the performance of health systems, and environmental sustainability. In this context, a large body of research has examined the relationship between economic development and population health outcomes. The relationship between economic growth and life expectancy has long been a debated topic in the literature. Preston's classical "Preston Curve" demonstrates that as income levels increase, life expectancy also rises (Preston, 2007: 231). More recent studies show that, in transition economies, this relationship is non-linear and that investments in healthcare systems play a decisive role during periods of strong economic growth (Acemoglu & Johnson, 2007; Barro, 1996). For instance, the World Bank's panel data analysis for Central Asian countries indicates that a 1% increase in GDP per capita extends life expectancy by approximately 0.3 years (World Bank, 2003: 55).

Research focusing on transition economies has further documented the dramatic effects of socio-economic shocks on mortality and life expectancy following the dissolution of the Soviet Union. Cornia and Paniccia, using panel analysis of 20 transition economies, showed that the initial stages of market reforms resulted in significant declines in life expectancy (Cornia & Paniccia 2000: 66). Shkolnikov and Cornia analysed increases in male mortality in Russia using demographic data, identifying alcohol consumption, unemployment, and the dissolution of social networks as primary causes (Shkolnikov & Cornia, 2000). Brainerd and Cutler, using regression analysis of Russia, found that institutional collapse, unemployment, and weak healthcare systems were critical drivers of increased mortality (Brainerd & Cutler, 2005). World Bank reports likewise emphasise the role of social protection programs and health investments in mitigating this vulnerability (World Bank, 2003: 57).

Beyond economic factors, a substantial body of literature emphasises the importance of health system characteristics in shaping life expectancy outcomes. Early studies highlight that life expectancy is not only related to income but also to the quality of healthcare infrastructure. Fogel, through a historical causal analysis of nutrition and living conditions in 18th- and 19th-century Europe, determined that improvements in these factors were the primary drivers of long-term increases in lifespan (Fogel, 1994). Similarly, Anand and Bärnighausen, using panel data for 150 countries between 1960 and 1995, demonstrated that physician density and the distribution of healthcare personnel have strong effects on life expectancy (Anand & Bärnighausen, 2004: 1605). Nolte and McKee compared Western and Eastern Europe. They showed that differences in health system performance, measured through "amenable mortality" indicators, play a major role in extending lifespan (Nolte & McKee, 2004: 57). Nixon and Ulmann examined 15 European countries using panel regression and found that health expenditures increase life expectancy. However, cross-country differences remain significant (Nixon & Ulmann, 2006: 12).

More recent research focusing on Kazakhstan and transition economies further emphasises the role of health investments and healthcare accessibility. Kalyuzhnova and Nygaard, using structural break models for Kazakhstan, found that the positive effects of health investments are constrained by unemployment and income inequality (Kalyuzhnova & Nygaard, 2008). Jobalayeva et al. examined mortality data and found that insufficient healthcare infrastructure in rural regions leads to regional disparities in life expectancy (Jobalayeva et al., 2025). Consistent with these findings, Halyk Finance reported that economic crises, inadequate healthcare infrastructure, and insufficient social protection sharply reduced life expectancy (Halyk Finance, 2023).

At the same time, an important strand of the literature highlights the role of environmental sustainability in determining long-term health outcomes. Studies on environmental factors demonstrate that life expectancy is closely linked not only to economic growth and healthcare infrastructure but also to ecological sustainability. In this regard, Dasgupta analysed the destructive effects of environmental degradation on health in low-income regions through theoretical ecological-economic models, showing that environmental damage increases disease burden among poor populations and reduces life expectancy (Dasgupta, 2021: 117). Pope et al., using panel regression models for the United States, found that reductions in PM2.5 air pollution significantly increase life expectancy (Pope et al., 2009: 376–386). In a more recent study, Nica (2023) used dynamic panel GMM for 30 OECD countries and demonstrated that CO_2 emissions negatively affect health outcomes and reduce lifespan. These findings highlight the need to evaluate environmental indicators together with health expenditures.

Environmental challenges specific to Central Asia further illustrate the importance of ecological conditions in shaping population health outcomes. Studies on the ecological and demographic consequences of Aral Sea degradation reveal the significant impact of the environmental crisis on the region's population health. In particular, the works of Philip P. Micklin and Ian Small analyse ecological and demographic data from the Aral Sea basin and point to the connection between reductions in water resources, increased salinity and mineralisation of water, and the accumulation of agricultural chemicals, and the deterioration of public health indicators. According to these studies, the ecological degradation of the region contributed to increased child mortality and the spread of infectious diseases among the Aral Sea population (Micklin, 2007; Small et al., 2001, 2003). Olcott, through historicalsociological analysis, emphasised that gaps in environmental governance have created lasting negative health impacts in Kazakhstan (Olcott, 2002: 49). Epidemiological studies dedicated to the consequences of nuclear tests at the Semipalatinsk test site have revealed the serious impact of radiation exposure on public health. In particular, studies by David G. Zaridze (1994) and others have shown an increased risk of oncological diseases among residents of regions near the test site. Data from Kazakhstan's medical registries also indicate a statistically significant increase in cancer mortality and the frequency of congenital anomalies among the population exposed to radiation.

Furthermore, the COVID-19 pandemic has created a new turning point, demonstrating the impact of sudden shocks on life expectancy. Aburto et al. (2022), using time-series decomposition for high- and middle-income countries, reported a dramatic reduction in life expectancy. Similarly, Kontis et al., through demographic modelling of pandemic-related deaths in Europe, found a decline not seen since the post-war period (Kontis et al., 2020). These findings indicate heightened vulnerability in transition economies as well.

Recent studies also emphasise the growing importance of environmental sustainability, health investments, and social policy in shaping life expectancy outcomes. Bilgili et al. (2016) used panel ARDL for transition economies and demonstrated that renewable energy use increases life expectancy (Bilgili, Koçak & Bulut, 2016: 840). OECD's comparative report concludes that environmental quality and institutional capacity play a decisive role in life expectancy gains, and Kazakhstan lags behind EU averages due to environmental risks and institutional vulnerability (OECD, 2022).

Despite the growing body of literature examining the economic, health system, and environmental determinants of life expectancy, several important gaps remain. In particular, existing studies often focus on either cross-country comparisons or single-factor explanations. At the same time, relatively few analyses examine the multi-dimensional interactions among economic conditions, health infrastructure, and environmental sustainability in the context of transition economies. Moreover, empirical studies specifically focusing on Kazakhstan remain limited, despite the country's unique historical experience of institutional transition, environmental shocks, and structural economic transformation. In this context, a comprehensive analysis that simultaneously evaluates economic, health system, and environmental determinants of life expectancy can provide important insights into the dynamics of well-being in transition economies and contribute to the existing literature.

Material and method outline

Research design

This study employs a quantitative research design to investigate the determinants of life expectancy in transition economies, with a particular focus on Kazakhstan for the period 1991–2023. Econometric time-series methods are used to empirically analyse the impacts of economic, demographic, health, and environmental factors on life expectancy. The research aims to provide a robust empirical evaluation that captures both short- and long-term relationships among these multi-dimensional determinants, offering evidence-based insights for policy and academic discussions on welfare and health dynamics in transition economies.

Methodology

In this study, non-linear unit root tests were employed to determine the stationarity properties of the time series. Environmental and health indicators often exhibit asymmetric adjustment dynamics and non-linear mean reversion in response to policy shocks, demographic transitions, and environmental fluctuations. Therefore, non-linear unit root tests, including the KSS (Kapetanios, Shin, & Snell, 2003), Sollis (2009), and Kruse (2011) tests, were applied as the primary identification strategy. These tests are specifically designed to detect non-linear adjustment mechanisms that classical linear tests, such as the ADF and PP, may overlook, enabling more reliable stationarity identification in macroeconomic time series with asymmetric dynamics.

Before applying the A-ARDL bounds testing procedure, it was necessary to ensure that none of the variables was integrated of order two (I(2)), since the Augmented ARDL framework accommodates only I(0) and I(1) series. The primary objective of the unit root analysis was therefore to verify that all variables satisfied the unit root requirement.

Lag lengths in the auxiliary regressions were selected using the Modified Akaike Information Criterion (MAIC) proposed by Ng and Perron (2001), which reduces size distortions and improves lag selection in small samples. Deterministic specifications (constant or trend with constant) were selected based on the graphical properties of each series and theoretical expectations.

Logarithmic transformations were applied to variables such as GDP per capita (LGDPPC) and infant mortality (LIMR) to stabilise variance and allow interpretation of the coefficients as elasticities. Variables expressed as rates or percentages, such as fertility (FR) and the age dependency ratio (ADR), were kept at the level, as their distributions did not require transformation, and level interpretation is more intuitive.

To avoid potential multicollinearity and maintain a parsimonious model specification suitable for the available sample size, pairwise correlations among the independent variables were examined. The dataset consists of 33 annual observations, while the initial model included a relatively large set of potential explanatory variables. In small-sample time-series frameworks such as A-ARDL, including a large number of highly correlated regressors may lead to unstable parameter estimates and reduce the reliability of the results (Gujarati & Porter, 2009).

The correlation matrix showed extremely high correlations (above 0.90) between certain variables, particularly infant mortality (IMR) and maternal mortality (MMR), as well as GDP per capita (GDPPC) and urban population (UP). Including highly correlated variables simultaneously in the model can lead to multicollinearity and instability in estimation. Therefore, based on both econometric considerations and the study's theoretical framework, MMR and UP were excluded from the final specification. IMR was retained to represent the health dimension of well-being, while GDPPC remained the primary indicator of economic development affecting life expectancy.

$$LLEt = \beta_0 + \beta_1 LGDPPCt + \beta_2 LHBt + \beta_3 LIMRt + \beta_4 FRt + \beta_5 ADRt + \beta_6 PM25t + \beta_7 UNRt + \beta_8 IMZRt + \beta_9 NDt + \varepsilon t \quad (1)$$

Equation (1) represents the long-run equilibrium relationship between life expectancy and its potential determinants. In this specification, LLE denotes life expectancy at birth. LGDPPC represents the logarithm of GDP per capita and captures the effect of economic development on longevity. LHB refers to hospital beds per 1,000 people and reflects the capacity of the healthcare infrastructure. LIMR denotes the logarithm of the infant mortality rate, representing population health conditions. FR is the fertility rate, ADR is the age dependency ratio, PM25 measures particulate air pollution, UNR denotes the unemployment rate, IMZR represents immunisation coverage, and ND denotes the number of physicians per 1,000 people. The error term εt captures other unobserved factors affecting life expectancy.

Following the determination of the stationarity properties of the variables, the long-run cointegration relationship among the variables was examined using the Augmented Autoregressive Distributed Lag (A-ARDL) cointegration test proposed by Sam et al. (2019). The conventional Autoregressive Distributed Lag (ARDL) bounds testing approach developed by M. Hashem Pesaran et al. (2001) allows testing for cointegration when the dependent variable is integrated of order one, I(1), and the explanatory variables are integrated of mixed orders, I(0) and I(1).

Building on this framework, Sam et al (2019), McNown, and Soo Khoon Goh (2018) extend the ARDL bounds testing methodology by introducing an augmented specification that allows for more flexible integration properties and improves the reliability of cointegration inference.

A similar methodological framework has previously been applied in empirical research on post-Soviet economies. For instance, Gasim et al. (2025) employ the FADF-SB unit root test, the Augmented ARDL cointegration approach, and the Fourier Toda–Yamamoto causality method to analyse the dynamic relationship between economic and health indicators in transition economies. Following this established framework, the present study adopts the same methodological sequence to ensure robustness and comparability of empirical findings.

The A-ARDL error-correction representation used in this study is specified as follows:

$$\Delta LLE_t = v_0 + v_1 DUMMY_t + \sum_{i=1}^{p}\alpha_{1i}\Delta LLE_{t-i} + \sum_{i=0}^{k}\alpha_{2i}\Delta LGDPPC_{t-i} + \sum_{i=0}^{c}\alpha_{3i}\Delta LHB_{t-i} + \sum_{i=0}^{d}\alpha_{4i}\Delta LIMR_{t-i} + \sum_{i=0}^{d}\alpha_{5i}\Delta FR_{t-i} + \sum_{i=0}^{d}\alpha_{6i}\Delta LADR_{t-i} + \sum_{i=0}^{d}\alpha_{7i}\Delta PM2.5_{t-i} + \sum_{i=0}^{d}\alpha_{8i}\Delta UNR_{t-i} + \sum_{i=0}^{d}\alpha_{9i}\Delta IMZR_{t-i} + \sum_{i=0}^{d}\alpha_{10i}\Delta ND_{t-i} + \gamma_1 LLE_{t-1} + \gamma_2 LGDPPC_{t-1} + \gamma_3 LHB_{t-1} + \gamma_4 LIMR_{t-1} + \gamma_5 FR_{t-1} + \gamma_6 ADR_{t-1} + \gamma_7 PM2.5_{t-1} + \gamma_8 UNR_{t-1} + \gamma_9 IMZR_{t-1} + \gamma_{10} ND_{t-1} + \varepsilon_t \quad (2)$$

In Equation (2), Δ represents the first-difference operator, ε_t is the error term, and DUMMY_t denotes the structural break dummy capturing the COVID-19 shock in 2020. The lag orders p and k are selected according to information criteria.

Within the A-ARDL framework, cointegration is evaluated using three complementary statistics: the Foverall test, the tdependent test, and the Findependent test.

The null hypotheses are specified as follows:

$$F_{overall}\ test;\ H_0: \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = \gamma_6 = \gamma_7 = \gamma_8 = \gamma_9 = \gamma_{10} = 0$$

$$t_{dependent}\ test;\ H_0: \gamma_1 = 0$$

If the calculated F and t statistics exceed the corresponding upper critical bounds reported by Narayan (2005), Pesaran et al. (2001), and Sam et al. (2019), the null hypotheses are rejected, indicating the existence of a long-run equilibrium relationship among the variables.

The inclusion of the Findependent test provides an additional diagnostic for detecting possible degenerate cases in the ARDL bounds framework, ensuring a more robust inference regarding cointegration relationships among the variables.

To obtain consistent long-run coefficient estimates, Fully Modified OLS (FMOLS; Phillips & Hansen, 1990) and Canonical Cointegrating Regression (CCR; Park, 1992) were employed. These methods correct for potential endogeneity and serial correlation within the cointegration framework, thereby enhancing the reliability and interpretability of long-run parameter estimates.

Finally, diagnostic tests including residual normality, autocorrelation, heteroskedasticity, and model specification checks were conducted to ensure the robustness of the A-ARDL results and to confirm the reliability of both short- and long-run inferences.

Data and empirical analysis

The determinants of life expectancy are multi-dimensional and shaped by the interactions among economic, health, demographic, environmental, and social factors. Therefore, examining variables representing different domains within a single model allows for a more comprehensive understanding of long-term relationships.

First, real GDP per capita (GDPPC) is widely recognised as one of the fundamental indicators of welfare. Preston's curve shows that higher income is associated with higher life expectancy (Preston, 2007: 489). The unemployment rate, on the other hand, reflects economic instability and increases mortality through social stress mechanisms (Stuckler et al., 2009: 321).

Health infrastructure indicators form an essential component of the model. The number of physicians and hospital bed density reflect the capacity of healthcare service provision (Devebakan, 2006). OECD reports show that increases in the healthcare workforce and infrastructure effectively reduce preventable or treatable deaths (Nolte & McKee, 2004). The immunisation rate (DPT) extends lifespan, particularly by reducing infant and child mortality (Shattock et al., 2024). Maternal mortality (MMR) and infant mortality are critical indicators of health system effectiveness and have negative impacts on life expectancy (Kassebaum et al., 2016).

Demographic factors are also indispensable in the model. High fertility rates may strain healthcare resources and increase maternal and child health risks (Bloom & Canning, 2004). The age dependency ratio reflects the population's age structure and determines long-term health and social policy burdens (Bloom et al., 2010).

Environmental variables have recently gained increased importance in the life expectancy literature. Air pollution (PM2.5) directly increases mortality through respiratory and cardiovascular diseases (Pope et al., 2009). Carbon emissions reflect environmental risks associated with energy consumption and economic growth. Javanshirova's study on Azerbaijan finds that CO_2 emissions significantly affect life expectancy (Javanshirova, 2024). Urbanisation may produce both positive effects (e.g., improved access to healthcare) and negative effects (e.g., increased environmental pressure) (Vlahov & Galea, 2002).

Finally, the homicide rate as an indicator of social security directly reduces life expectancy by reflecting violence and safety issues (Wijesinghe et al., 2025). Considering all this literature, our model incorporates variables such as income level, unemployment, healthcare infrastructure, immunisation and mortality indicators, fertility and dependency rates, environmental indicators, urbanisation, and social violence measures.

Table 1: Socio-Economic, Demographic, and Health Indicators for Kazakhstan (1991–2023)

Summary of the Data Set

Abbreviation	Definition	Year	Data Source	Unit of Measurement
LE	Life expectancy at birth	1991–2023	World Bank – Health, Nutrition and Population Statistics	Year
ADR	Age dependency ratio (% of working-age population)		World Bank – Health, Nutrition and Population Statistics)	%
FR	Fertility rate, total (births per woman)			Children/Woman
GDPPC	Real GDP per capita (constant 2015 US$)			US$ (constant prices, per capita)
HB	Hospital beds per 1,000 people			Beds / 1.000 People
IH	Intentional homicides (per 100,000 people)			Per / 100.000 People
IMR	Infant mortality rate (deaths per 1,000 live births)			Deaths / 1.000 births
IMZR	DPT immunisation (% of children ages 12–23 months)			%
MMR	Maternal mortality ratio (deaths per 100,000 live births)			Deaths / 100.000 births
ND	Physicians per 1,000 people			Physicians / 1.000 people
PM2.5	Mean annual exposure to PM2.5 (μg/m³)			μg/m³
UNEM	Unemployment rate (% of total labour force, ILO estimate)			%
UP	Urban population (% of total population)			%

Source: Produced by the author.

For Kazakhstan during the period 1991–2023, life expectancy at birth averages 67.7 years. The minimum value of 63.3 corresponds to the 1990s, when the collapse of the Soviet Union led to severe economic and health crises. The maximum value is 74.4 years, reflecting improvements following the economic recovery and healthcare investments in the 2000s.

The age dependency ratio (ADR) averages 53.5, indicating a relatively high demographic burden. This reflects a large share of the young population within the total population, with significant implications for economic growth and healthcare expenditures. The fertility rate (FR) averages 2.5, ranging from 1.9 to 3.3. This shows that Kazakhstan is in a demographic transition period, but still maintains a level close to population replacement.

Real GDP per capita (constant 2015 US$) averages 7,424, with a minimum of 3,498, representing the economic collapse of the 1990s, and a maximum of 11,453, corresponding to the 2010s, when oil and natural gas revenues increased. The unemployment rate averages around 7.0%, rising during crisis periods and falling during phases of rapid economic growth. These indicators suggest that economic fluctuations indirectly influence health outcomes through both income levels and employment conditions.

Table 2: Descriptive Statistics

Variable	Mean	Median	Max	Min	Std. Dev	Jarque-Bera	Probability (p-value)
LE	67.67	66.18	74.40	63.32	3.779	3.554	0.169
ADR	53.48	53.88	60.89	46.77	5.027	3.400	0.182
FR	2.499	2.584	3.32	1.892	0.389	0.946	0.623
GDPPC	7424.4	8036.8	11453.3	3498.5	2836.2	3.527	0.171
HB	7.751	7.16	13.71	5.132	2.428	11.13	0.004
IH	10.17	11.03	16.35	3.193	4.547	3.353	0.184
IMR	24.27	22.31	45.34	7.605	14.34	3.420	0.181
IMZR	93.88	97.31	99.16	76.04	7.162	11.77	0.003
MMR	37.15	32	72	10	22.94	3.633	0.163
ND	3.721	3.797	4.127	3.213	0.238	1.841	0.398
PM2.5	19.66	19.03	27.20	16.46	2.862	5.723	0.057
UNR	7.012	5.771	13.46	0.904	3.468	1.047	0.592
UP	56.71	56.61	58.18	55.93	0.669	2.502	0.286

Observation	Count	33
LE: Life expectancy,		
ADR: Age dependency ratio (% of working-age population)		
FR: Fertility rate, total (births per woman)		
GDPPC (constant 2015 US$): Real GDP per capita (constant 2015 prices)		
HB: Hospital beds (per 1,000 people)		
IH: Intentional homicides (per 100,000 people)		
IMR: Mortality rate, infant (per 1,000 live births)		
IMZR: Immunisation, DPT (% of children ages 12-23 months)		
MMR: Maternal mortality ratio (modelled estimate, per 100,000 live births)		
ND: Physicians (per 1,000 people)		
PM2.5: Mean annual exposure to PM2.5 (µg/m³)		
UNR: Unemployment rate (% of total labour force)		
UP: Urban population (% of total population)		

Source: Produced by the author.

The hospital bed density (HB) averages 10.7 beds per 1,000 people, well above the OECD average, indicating the continuation of a strong healthcare infrastructure inherited from the Soviet era. The number of physicians (ND) averages 4.1 per 1,000 people and has remained relatively stable over the period. In contrast, maternal mortality (MMR) shows substantial fluctuations, with an average of 37 per 100,000 live births, exceeding critical thresholds in some years. The infant mortality rate (IMR) averages 24 per 1,000 and ranges between a minimum of 13 and a maximum of 47. These values indicate that infant mortality was significantly high during the 1990s, but has declined markedly in recent years. Vaccination rates (IMZR) average 93.9%, but occasional drops to 76% indicate periodic disruptions in healthcare service delivery.

Exposure to PM2.5 averages 19.7 µg/m³, which is significantly above the World Health Organisation's recommended limit of 5 µg/m³. This reflects Kazakhstan's heavy reliance on coal for energy production and the resulting industrial air pollution in urban areas. The homicide rate (IH) averages 10.1 per 100,000 people, indicating a relatively high level of social insecurity, which may directly affect health outcomes. The urbanisation rate (UP) averages 56.7%, showing that more than half of the population lives in cities, highlighting the critical role of urban healthcare infrastructure in determining life expectancy.

The descriptive statistics clearly reveal the multi-dimensional nature of the determinants of life expectancy in Kazakhstan. The economic contraction and health system crisis of the 1990s are characterised by low life expectancy, high infant and maternal mortality, low vaccination rates, and high homicide rates. In contrast, the post-2000 period shows improvements in life expectancy driven by rising income, maintenance of healthcare infrastructure, and increased vaccination rates. However, persistently high environmental pollution and ongoing social security challenges continue to affect life expectancy negatively. These findings align with the "double burden" phenomenon observed in transition economies, where economic growth and health investments improve longevity, yet environmental and social risks continue to constrain these gains.

The descriptive statistics presented in Table 2 reflect the general trends of demographic, economic, health, and environmental indicators affecting life expectancy in Kazakhstan over the 1991–2023 period. However, averages and distributional characteristics alone do not directly reveal the direction or strength of their effects on life expectancy. Therefore, a correlation analysis was conducted to understand the relationships among variables better. The correlation matrix allows examination of the strength and direction of the pairwise relationships between life expectancy and the independent variables, as well as the identification of high correlations among the independent variables, which may indicate multicollinearity. Thus, the correlation analysis following the descriptive statistics is considered a critical step for assessing theoretical consistency and anticipating potential modelling challenges.

Table 3: Correlation Matrix

Correlation	LE	ADR	FR	GDPPC	HB	IH	IMZR	IMR	MMR	ND	PM2.5	UNR	UP
LE	1												
ADR	0.138	1											
FR	0.842	0.288	1										
GDPPC	0.950	-0.089	0.845	1									
HB	-0.632	0.376	-0.281	-0.716	1								
IH	-0.953	-0.151	-0.895	**-0.929**	0.544	1							
IMZR	0.245	-0.395	-0.036	0.336	-0.660	-0.171	1						
IMR	-0.915	0.197	-0.749	**-0.983**	0.822	0.883	-0.423	1					
MMR	-0.910	0.264	-0.737	**-0.978**	0.780	0.875	-0.394	**0.988**	1				
ND	0.836	0.288	**0.919**	0.782	-0.199	-0.876	-0.133	-0.686	-0.699	1			
PM2.5	0.666	-0.015	0.588	0.626	-0.288	-0.666	0.122	-0.584	-0.605	0.684	1		
UNR	-0.577	-0.178	-0.769	-0.551	-0.108	0.666	0.359	0.422	0.489	-0.812	-0.492	1	
UP	0.946	0.128	0.860	**0.957**	-0.680	**-0.927**	0.311	-0.931	**-0.900**	0.768	0.526	-0.497	1

Source: Produced by the author.

The correlation analysis conducted for Kazakhstan reveals that life expectancy shows the strongest relationships with economic and health indicators. The very high positive correlations between life expectancy and GDP per capita (0.95) and the urbanisation rate (0.95) reflect the impact of economic prosperity and urban development on increasing life expectancy. Similarly, physician density (0.84) also shows a strong positive correlation with life expectancy, emphasising the critical importance of human health resources.

On the other hand, infant mortality (–0.92), maternal mortality (–0.91), and intentional homicide rates (–0.95) have very strong negative correlations with life expectancy. This result indicates that child health and public safety are among the main factors limiting life expectancy in Kazakhstan. The negative associations of unemployment (–0.58) and hospital bed density (–0.63) further suggest that economic insecurity and structural issues within the healthcare system have adverse effects on life expectancy.

Conversely, variables such as fertility (0.84) and PM2.5 exposure (0.67) show positive correlations contrary to expectations. This likely reflects a historical simultaneity in which these indicators increased alongside economic growth and improvements in health outcomes.

To examine relationships among the explanatory variables and identify potential multicollinearity, a pairwise correlation matrix was constructed (Table 3). Correlation analysis provides preliminary insights into the strength and direction of linear relationships among variables. It helps identify cases in which extremely high correlations can lead to unstable parameter estimates in regression models.

The correlation matrix shows very high correlations (above 0.90) between certain variables, particularly infant mortality (IMR) and maternal mortality (MMR), as well as GDP per capita (GDPPC) and urban population (UP). Given the study's relatively small sample size (33 observations) and the need to maintain a parsimonious model structure suitable for A-ARDL estimation, including highly correlated variables simultaneously could compromise estimation stability.

Therefore, based on both econometric considerations and the study's theoretical framework, MMR and UP were excluded from the final specification. IMR was retained as a key indicator of population health, while GDPPC was retained as the principal proxy for economic development affecting life expectancy.

In conclusion, the literature-supported evaluation enhances the model's reliability. Accordingly, removing MMR while keeping IMR and excluding UP in favour of GDPPC appears to be the most appropriate strategy. This selection is consistent with the theoretical framework and helps reduce multicollinearity.

Although the correlation analysis reveals the direction and strength of relationships among variables, it does not provide direct insight into their trends and structural breaks over time. To more clearly understand the interactions between life expectancy and economic, demographic, health, and environmental indicators, long-term dynamics must be examined. Therefore, time-series graphs covering the period 1991–2023 are included. These graphs visualise Kazakhstan's post-independence economic and social transformations, changes in the healthcare system, and environmental risks. They also illustrate how crises, recovery periods, and policy interventions have influenced life expectancy. Thus, the static perspective of the correlation analysis is supported by dynamic trends.

As shown in Figure 1, life expectancy declined to around 63 years in the mid-1990s, reflecting the economic and healthcare crisis following the dissolution of the Soviet Union. From the 2000s onward, a steady upward trend is observed, with life expectancy reaching 73–74 years by 2020 due to healthcare investments and economic recovery. However, due to the impact of COVID-19, a temporary decline occurred in 2020, followed by a renewed upward trend in subsequent years.

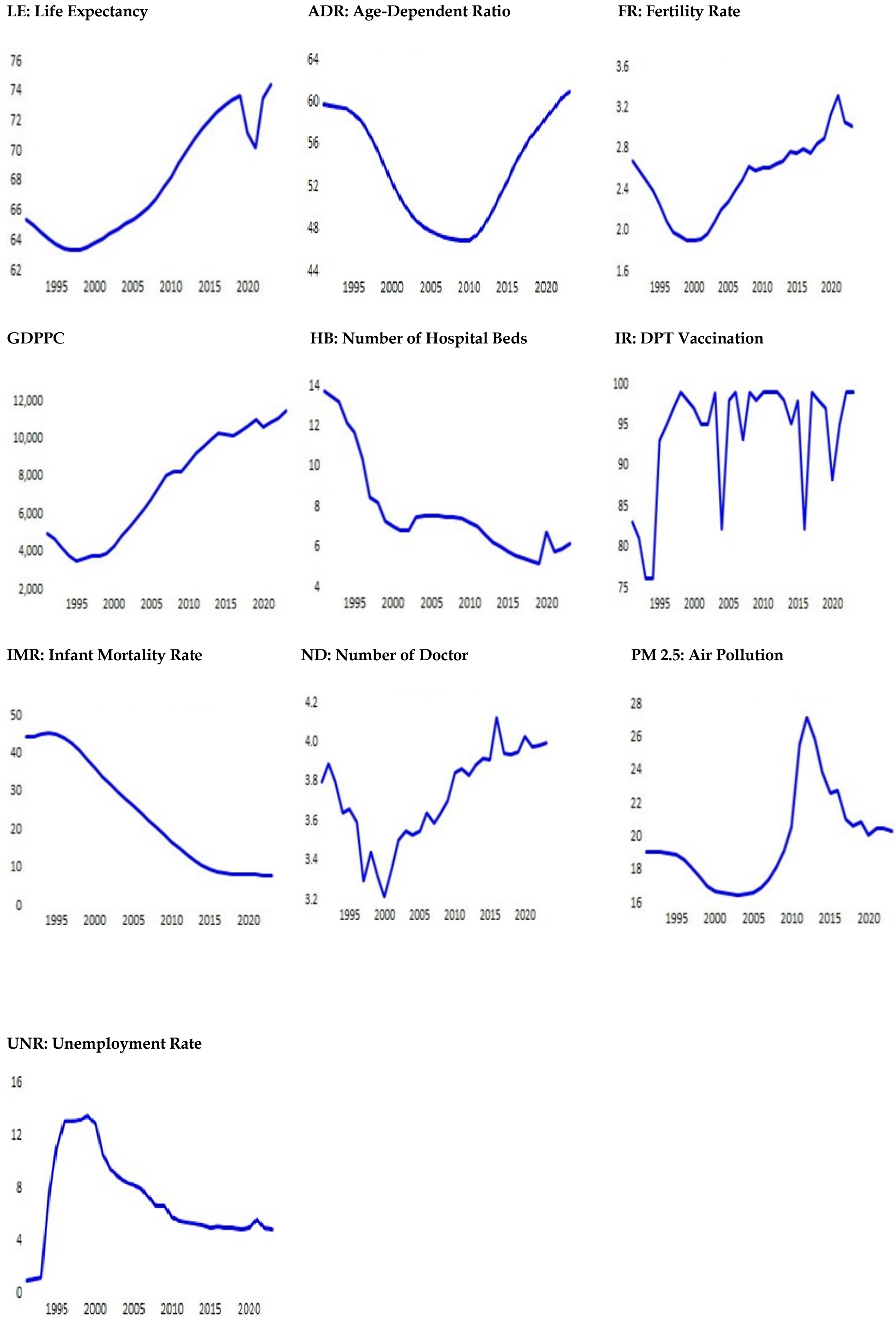


Figure 1: Time Series Graphs of the Variables

The age dependency ratio (ADR) was high in the early 1990s, declined significantly by the mid-2000s, and has increased again in recent years. This reflects the demographic transition process in Kazakhstan. The total fertility rate (FR), which was low in the 1990s, has shown an upward trend since the 2000s and has approached around 3 in recent years. This increase can be linked to family policies and economic recovery.

Real GDP per capita declined to approximately USD 3,500 in the 1990s but increased rapidly after 2000, driven by energy revenues, surpassing USD 11,000 by 2019. This trend supports the positive impact of economic growth on life expectancy.

Hospital bed density (HB) decreased from 12 beds per 1,000 population in the early 1990s to around 7 beds per 1,000 population in the early 2000s. This decline can be explained by the collapse of the Soviet healthcare system and limited resource allocation. In recent years, the number of beds has remained relatively stable. In contrast, physician density (ND), which hit its lowest point in the early 2000s, has steadily increased since then, reaching 4.0 per 1,000 population by 2020.

The infant mortality rate (IMR), which exceeded 40 per 1,000 live births in the 1990s, fell below 10 per 1,000 live births by 2020. This dramatic improvement reflects advances in access to healthcare, vaccination, and nutrition. Vaccination rates (IR) have generally remained above 90%, though sharp fluctuations in some years indicate the effects of economic crises or disruptions in the healthcare system. Maternal mortality (MMR) has also shown a long-term downward trend.

PM2.5 exposure increased sharply in the mid-2000s, reaching levels of 28–30 $\mu g/m^3$, largely associated with coal-based energy production and industrial pollution. Although there has been a partial decline in subsequent years, it remains well above the World Health Organisation's recommended threshold. The intentional homicide rate (IH) rose rapidly in the mid-1990s, gradually declined after the 2000s, and fell to around 6–7 per 100,000 people by 2020. The unemployment rate (UNR) exceeded 13% during the 1990s crisis, but steadily declined with the economic recovery and currently stands at around 4–5%.

The time-series graphs show that the economic and social crises of the 1990s severely reduced life expectancy in Kazakhstan; in contrast, economic growth, investments in the healthcare system, and the sharp decline in infant mortality rates after 2000 significantly increased life expectancy. However, persistent high environmental risks (PM2.5) and only partially improved public safety conditions continue to exert pressure on life expectancy. Therefore, the graphs clearly illustrate that both gains and vulnerabilities coexist within Kazakhstan's status as a transition economy.

Although the time series graphs reveal long-term trends in Kazakhstan's economic, demographic, health, and environmental indicators, they do not provide conclusive evidence of the series' stationarity. While the graphs indicate general trends, structural breaks, and fluctuations, they are insufficient to determine whether the mean and variance remain constant over time. However, stationarity is critical in econometric analysis, because estimates from non-stationary series lead to spurious regression, producing misleading statistical outcomes (Granger & Newbold, 1973). Therefore, it is necessary to determine whether the series contains unit roots.

As observed in the graphs, some series do not exhibit linear patterns, implying that classical unit root tests may be insufficient. Hence, non-linear approaches were preferred. In this context, non-linear unit root tests such as KSS, Sollis, and Kruse were employed to capture potential asymmetric and structural-break Dynamics (Kruse, 2011). In this way, the stationarity properties of the series were identified more reliably, and possible non-linear dynamics were incorporated into the model.

The lag values reported in the tables correspond to the optimal truncation lag selected for the auxiliary regression of each unit root test and do not directly represent the stationarity decision itself. Through these tests, the stationarity of the series, whether in levels or first differences, was analysed while accounting for non-linear structures and potential structural breaks. Thus, dynamics that classical linear tests cannot capture were uncovered, and the necessary preconditions for examining long-term relationships among the variables were met.

The results in Table 4 were obtained by testing the series under models that include only a constant term and models that include both a constant and a trend. This distinction is important because some series fluctuate around a constant mean, while others exhibit clear upward or downward trends. Therefore, determining stationarity correctly requires considering whether the series contains a trend.

Table 4: Unit Root Tests

Variables	KSS (2003)		Sollis (2009)		Kruse (2011)		
	Constant						
	Test Statistic	Lag	Test Statistic	Lag	Test Statistic	Lag	Result
ADR	-4.8363***	1	11.346***	1	18.766***	1	I(0)
FR	-1.3454	0	1.2515	0	2.3281	1	I(1)
IR	-2.0028	1	3.2716	1	3.7552	1	I(1)
LGDPPC	-2.0397	0	2.7151	1	4.6204	1	I(1)
LHB	-1.8626	0	4.0585*	1	3.8001	1	I(1)
LIMR	-3.2525***	1	5.2896**	1	16.024**	1	I(0)
LLE	-0.2386	0	0.0464	0	1.2513	0	I(1)
ND	-1.8176	1	1.8505	1	3.7065	1	I(1)
PM25	-3.0849***	1	4.6066*	1	8.6255*	1	I(0)
UNR	-3.1077***	1	10.983***	1	21.280***	1	I(0)
	Constant &Trend						
ADR	-4.6085***	1	10.406***	1	17.351***	1	I(0)
FR	-2.4803	0	3.1382	1	1.8480	1	I(1)
IR	-3.1656*	1	5.1069	1	9.3438	1	I(1)
LGDPPC	-3.2628*	1	6.2005*	1	11.431*	1	I(0)
LHB	-1.4116	0	1.1124	0	2.4916	0	I(1)
LIMR	-4.6177***	1	10.297***	1	24.062***	1	I(0)
LLE	-2.7814	0	9.7130***	0	5.6532	0	I(1)
ND	-2.3887	1	2.7646	1	5.4857	1	I(1)
PM25	-3.2521*	1	5.1199	1	9.6163	1	I(0)
UNR	-4.9682***	1	10.761***	1	21.129***	1	I(0)

Note: ***, **, and * denote the rejection of the null hypothesis that the series contains a unit root at the 1%, 5%, and 10% significance levels, respectively.

When the results of the constant specification are examined, the variables ADR, LIMR, and UNR are found to be statistically significant in all three non-linear tests. They are therefore considered stationary at level (I (0)). This indicates that the age dependency ratio, infant mortality rate, and unemployment rate exhibit stable patterns over time. In contrast, the variables FR, IMZR, LGDPPC, LHB, and ND exhibit unit roots and are not stationary. This finding suggests that these indicators are strongly affected by structural breaks and economic fluctuations. The PM2.5 series, on the other hand, yields results that are sensitive to the test used; it is found to be stationary in the KSS test, whereas stationarity is rejected in the other two tests. In general terms, PM2.5 can be considered to follow an I (1) process.

The model's results, including both the constant and the trend, reveal a different picture. In this model, ADR, LIMR, and UNR are again found to be stationary at the level. However, stationarity decisions for some variables, particularly LGDPPC and IMZR, become stronger compared to the constant model. This indicates that the trend component plays an important role in Kazakhstan's long-term income, health, and demographic indicators. When the trend effect is taken into account, the stationarity characteristics of these series become clearer. For example, while LGDPPC is not stationary in the constant model, it is accepted as stationary in the constant-and-trend model. This finding shows that per capita income contains a long-term trend component and that this structure affects the test results.

Overall, when the results from both models are compared, it is seen that the ADR, LIMR, and UNR variables are stationary at the level under any assumption. In contrast, for the variables FR, IMZR, LHB, and ND, stationarity can only be achieved after differencing. The stationarity of LGDPPC and PM2.5 is sensitive to model assumptions, and these variables yield results closer to stationarity in constant and trend models. Therefore, considering both constant and constant-trend results, it can be concluded that the series have a mixed structure: some are I(0) while others are I(1). This finding confirms that the data structure is suitable for cointegration analysis. Furthermore, given the transition period the Kazakhstani economy experienced in the 1990s and external shocks such as the COVID-19 pandemic in 2020, it is necessary to use methods that account for structural breaks in the analysis of long-term relationships. In this context, the A-ARDL (Augmented Autoregressive Distributed Lag) method (Sam et al., 2019: 42), which offers the flexibility to model breaks and allows the joint evaluation of different degrees of stationarity, stands out as an appropriate choice.

Table 5: A-ARDL Cointegration Results

Model	ARDL order	Break Date	F-statistic	T-statistic	F-statistic	Results
Case III	3,0,0,1,1,1,0,0,0	2020	129.08***	9.7807***	97.824***	Cointegration
Critical Values	Peseran vd., (2001)		Narayan (2005)		Sam vd., (2019)	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
1%	2.54	3.86	3.84	5.69	3.42	5.77
5%	2.06	3.24	2.75	4.21	2.40	4.15
10%	1.83	2.94	2.30	3.61	1.95	3.48

Note: ***, **, and * indicate rejection of the null hypothesis at the 1%, 5%, and 10% significance levels, respectively.

The A-ARDL results presented in Table 5 test for cointegration under a structure in which stationary and non-stationary series coexist at the level and in first differences (I(0) + I(1)), while accounting for the structural break in 2020 (COVID-19 shock). The model was constructed under "Case III," and the lag structure was selected as ARDL (3,0,0,1,1,1,0,0,0). This selection indicates that short-term dynamics are largely driven by the lagged values of the dependent variable (LE), while most regressors require at most one period of adjustment. Incorporating the break year 2020 into the model either endogenously or exogenously is appropriate, as it reflects the structural impact of the pandemic in the long-run relationship test.

The bounds test statistics strongly support the cointegration hypothesis. The Fall = 129.08 statistic is far above the upper bounds of 3.86 (1%) for Pesaran et al. (2001), 5.69 (1%) for small-sample corrections, and 5.77 (1%) for the updated critical values (Sam et al.,2019). This magnitude indicates that the null hypothesis of "no level relationship" is rejected across all three sets of critical values, confirming the presence of a long-run cointegrating relationship in the model. Similarly, the Fbağımsız = 97.824 statistic—testing the joint level significance of the independent variables in the conditional error-correction model—exceeds the upper bounds by a wide margin, reaffirming cointegration. The value of tbağımlı = 9.7807, which is larger than the corresponding critical value, also confirms the existence of a cointegrating relationship among the variables. Overall, all three statistics consistently support the existence of a long-run equilibrium relationship among the variables.

After confirming the existence of a cointegrating relationship using the A-ARDL bounds testing procedure, the error-correction mechanism was evaluated to examine short-run adjustment dynamics. The statistically significant and negative ECM coefficient indicates that deviations from the long-run equilibrium are corrected over time. To obtain robust estimates of the long-run coefficients, the CCR and FMOLS estimators were subsequently employed as complementary approaches within the cointegration framework.

Explicitly specifying the break year (2020) highlights the advantage of A-ARDL over the classical ARDL approach. Since COVID-19 introduced a sharp (singular) regime shift affecting life expectancy and its determinants, including a dummy/trend component representing this structural break, it strengthens the power of the cointegration test. It reduces the risk of "spurious cointegration." Indeed, even when referring to critical values that account for the structural break (Sam et al., 2019: 56), both F and t statistics greatly exceed the upper bounds, indicating that the cointegration result is robust to the break.

The formation of the lag vector as (3,0,0,1,1,1,0,0,0) implies that short-run adjustment occurs mainly through the lagged values of life expectancy (LE), while determinants such as GDPPC, HB, and IMR respond with a one-period lag (or none). This structure is expected in an economy characterised by sharp regime shifts such as the 1990s crisis, the 2000s recovery, and the 2020 pandemic: shocks initially generate an inertial dynamic in life expectancy itself, while the effects of economic and health indicators persist in the long-term cointegrating component.

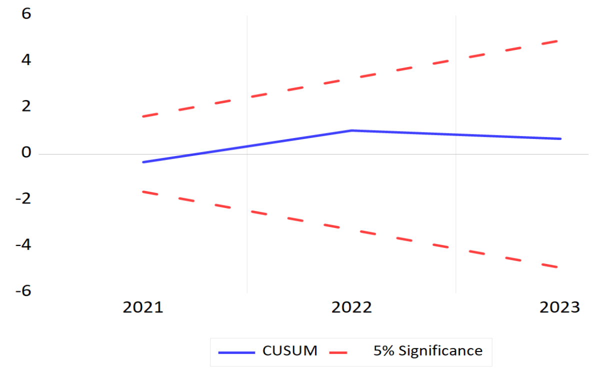
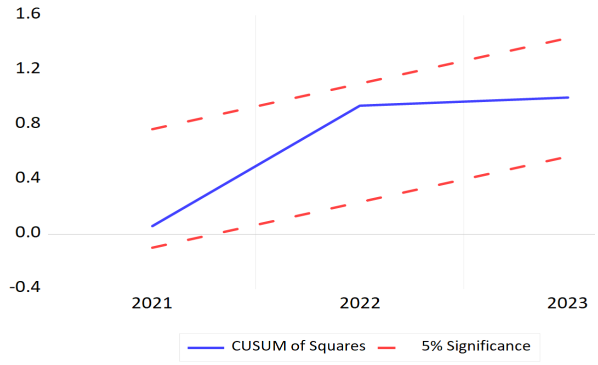
In summary, the A-ARDL bounds testing results in Table 5 provide strong evidence of cointegration, both with and without the structural break and with and without small-sample adjustments. Therefore, the next step should include (i) reporting and interpreting the long-run coefficients (checking consistency with FMOLS/CCR estimates) and (ii) evaluating the error correction mechanism (ECM) in terms of sign, magnitude, and statistical significance. A negative, statistically significant error-correction parameter indicates that deviations are corrected back to equilibrium in the short run—even after the break—thereby establishing a statistically and economically robust long-run relationship.

To assess the reliability of the long-run coefficients, identifying cointegration alone is not sufficient. The model's statistical robustness must also be verified through various diagnostic tests. In this context, the distribution of residuals, autocorrelation, heteroskedasticity, and structural stability of the A-ARDL model have been examined. Additionally, the operation of the error-correction mechanism was considered to evaluate the model's validity in both the short- and long-run.

Table 6: Diagnostic Tests for the A-ARDL Model

$\bar{R}^2$	F-stat	JB	BG-LM	White	R-R	ECM
0.9998	8685.1***	1.9949	2.0109	0.8266	0.5602	-0.3892***

Stability Tests of the Parameters

CUSUM	CUSUM SQ
	

Note: JB denotes the Jarque–Bera normality test, BG-LM refers to the Breusch–Godfrey serial correlation test, White indicates the heteroskedasticity test, R-R represents the Ramsey RESET specification test, and ECM refers to the error correction coefficient. *** indicates statistical significance at the 1% level.

The diagnostic tests presented in Table 6 largely confirm the robustness of the model. The coefficient of determination (R^2) is 0.999. The high R^2 value should be interpreted cautiously in time-series models, since macroeconomic variables often exhibit strong co-movements over time. The presence of cointegration, along with the diagnostic test results, confirms that the estimated relationship is not spurious. The F-statistic (8685.1) is significant at the 1% level, confirming that all independent variables in the model are jointly significant. The Jarque–Bera (JB) statistic (1.9949) indicates that the residuals are normally distributed, the Breusch–Godfrey LM test shows no autocorrelation, and the White test confirms the absence of heteroskedasticity. Additionally, the Ramsey RESET test verifies that the model is not subject to functional form misspecification.

The error correction mechanism coefficient (ECM = –0.3892) is negative and statistically significant, confirming the existence of a stable long-run equilibrium relationship among the variables. This finding indicates that approximately 39% of short-run disequilibria are corrected in each period, implying a relatively rapid adjustment process. Accordingly, deviations from the long-run equilibrium are gradually eliminated, and the system converges back to equilibrium within approximately 2.57 periods (1/|ECM|), corresponding to about 3 years.

The stability of the model parameters was examined using the CUSUM and CUSUM of Squares (CUSUMSQ) tests. The plots show that both statistics remain within the 5% significance boundaries. This finding indicates that the parameters are stable over time and that the model remains robust to structural breaks.

For robustness, the long-run coefficients were also estimated using the CCR and FMOLS estimators. These estimators correct for potential endogeneity and serial correlation problems in cointegrated systems and therefore provide consistent estimates of long-run parameters. Following the confirmation of cointegration, the long-term effects of the independent variables on life expectancy (LE) were estimated using the CCR method (Park, 1992) and the FMOLS method (Phillips & Hansen, 1990). The results obtained from these estimations are presented in Table 7.

When the estimation results in Table 7 are examined, it is observed that the coefficients obtained from CCR and FMOLS are largely similar in direction and magnitude, although performance criteria differ. The FMOLS method yields a higher R^2 (0.9895) compared to CCR and a lower standard error of regression (0.0057). Therefore, the FMOLS results are considered more reliable for interpreting long-run coefficients.

Table 7: Long-Run Estimation Results

Variables	CCR	FMOLS
Sabit	3.2218***	3.2996***
COVID-19	-0.0234***	-0.0240***
ADR	0.0046***	0.0044***
FR	-0.0834***	-0.0793***
IR	0.0002	0.0002
LGDPPC	0.1160***	0.1095***
LHB	0.0802**	0.0789***
LIMR	-0.0787***	-0.0811***
ND	-0.0076	-0.0091
PM25	0.0010*	0.0010**
UNR	-0.0007	-0.0006
$\bar{R}^2$	0.9892	0.9895
Reg.std.error	0.0058	0.0057

Note: ***, **, and * indicate that the null hypothesis is rejected at the 1%, 5%, and 10% significance levels, respectively.

According to the FMOLS results, the COVID-19 variable is negative and statistically significant with a coefficient of –0.024. This indicates that the pandemic reduced life expectancy by approximately 2.4%. The coefficient of the age dependency ratio (ADR) is 0.0044 and positive; that is, a one-unit increase in the dependent population raises life expectancy by about 0.44%. Although this relationship is theoretically expected to be negative, in Kazakhstan, the increase in the dependent population may have led to expanded social expenditures and healthcare support, thereby generating a positive effect.

The fertility rate (FR) has a coefficient of –0.079, indicating a strong negative impact. This shows that a one-unit increase in births per woman reduces life expectancy by approximately 7.9%. This finding is consistent with demographic transition theory, which suggests that high fertility places downward pressure on longevity (Preston, 2007: 486; Bloom & Canning, 2004: 58; Kalemli-Ozcan, 2000: 12).

The coefficient of GDP per capita (LGDPPC) is 0.109 and positive. This result implies that a 1% increase in income raises life expectancy by about 0.1%. This is consistent with the Preston curve (Preston, 2007), confirming that economic welfare has strong, positive effects on health outcomes. Additionally, Deaton (87) emphasises that economic growth increases life expectancy through higher healthcare spending and improved nutrition.

The coefficient for hospital bed density (LHB) is 0.0789 and statistically significant. This indicates that improvements in healthcare infrastructure raise life expectancy by approximately 7.9%. Similarly, Nixon and Ulmann (214) show that healthcare expenditure and infrastructure indicators have significant positive effects on longevity in European countries.

The infant mortality rate (LIMR) has a coefficient of –0.081, showing a strong negative effect. A one-unit increase in the infant mortality rate reduces life expectancy by 8.1%. This result highlights the critical role of healthcare system efficiency in shaping life expectancy. Cutler et al. (132) also argue that infant mortality rates are key indicators of health system performance and are highly correlated with longevity.

The coefficient of physician density (ND) is –0.009 and statistically insignificant. Although the expected sign is positive, the lack of significance may be due to data fluctuations or regional imbalances in physician distribution. Anand and Bärnighausen (1607) find that while healthcare worker density generally promotes longevity, regional inequalities in developing countries may weaken the effect.

The coefficient for PM2.5 air pollution is 0.001, positive and statistically significant. This result contradicts theoretical expectations, as air pollution is expected to reduce life expectancy. Pope et al. (222) show that long-term exposure to PM2.5 increases mortality and reduces longevity. In Kazakhstan, however, simultaneous increases in economic growth and healthcare spending may have masked the negative environmental effects. In this context, Chen and Chen (119) emphasise that in some developing countries, economic growth can improve life expectancy through health investment while overshadowing environmental degradation.

The coefficient for the unemployment rate (UNR) is –0.0006 and statistically insignificant. This suggests that unemployment has only a weak direct effect on life expectancy and operates mainly through indirect mechanisms. Ruhm (635) finds that increases in unemployment may paradoxically produce short-term improvements in health outcomes, although negative effects tend to dominate in the long run.

Discussion

This study examines the determinants of life expectancy in transition economies and provides empirical evidence on how economic, demographic, health, and environmental dynamics interact in Kazakhstan. The empirical results indicate that economic development and improvements in health infrastructure play a central role in shaping longevity outcomes. In particular, increases in real income and expansion of hospital bed capacity are found to have a positive, statistically significant impact on life expectancy. By contrast, adverse demographic dynamics, particularly higher fertility rates and infant mortality, exert a statistically significant negative effect on longevity. These findings are broadly consistent with the literature, which emphasises the importance of economic recovery and health system investments in improving population health in transition economies (Cornia & Paniccia, 2000; Olcott, 2002; Shkolnikov & Cornia, 2000).

Economic growth appears to be one of the most important structural drivers of improvements in life expectancy. Rising per capita income enhances individuals' capacity to meet basic needs such as nutrition, housing, and access to healthcare services, thereby contributing to better health outcomes and longer lives (Preston, 2007; Bloom & Canning, 2008). Similarly, improvements in healthcare infrastructure, particularly the availability of hospital beds, reflect the health system's capacity to provide effective treatment and preventive services. These results suggest that welfare improvements in transition economies are not solely associated with macroeconomic growth but are also closely linked to institutional capacity and the effectiveness of healthcare delivery systems. In Kazakhstan, the economic recovery and health reforms implemented after the early 2000s have contributed to notable improvements in life expectancy (WHO, Kazakhstan Health Profile, 2020).

Demographic dynamics also play a critical role in shaping population health outcomes. Higher fertility rates and elevated infant mortality are found to reduce life expectancy, highlighting the importance of demographic transition processes. In societies experiencing rapid demographic changes, higher fertility can place additional pressure on public resources and healthcare systems, thereby limiting the quality and accessibility of health services. Infant mortality, on the other hand, represents a key indicator of health system performance and living standards. Elevated infant mortality rates often reflect deficiencies in healthcare access, maternal health services, and socio-economic conditions, all of which can negatively affect overall life expectancy (Lee, 2003; Schmidt, 2008).

The environmental dimension presents a more complex relationship. The empirical results indicate a positive and statistically significant association between PM2.5 air pollution and life expectancy, which may appear counterintuitive compared with the conventional environmental health literature, which emphasises the adverse effects of pollution on human health (Dasgupta, 2001; Micklin, 2007). This result should therefore be interpreted with caution. One possible explanation relates to the structural characteristics of Kazakhstan's transition economy. During the post-2000 period, rapid economic growth, urbanisation, and industrial expansion simultaneously increased income levels and pollution. At the same time, improvements in healthcare infrastructure, rising public health expenditures, and broader access to medical services contributed to increasing life expectancy. Consequently, the positive association observed in the model may reflect broader economic and structural transformations rather than indicating that higher pollution levels directly improve health outcomes (Pope et al., 2009; Bilgili et al., 2016). In this context, the estimated coefficient may capture overlapping effects of economic development, healthcare improvements, and industrialisation dynamics.

Overall, these findings offer important implications for policymakers. Strengthening healthcare infrastructure, supporting sustainable economic development, and managing demographic pressures are essential components of strategies to improve population health in transition economies. In addition, effective environmental protection policies remain crucial to mitigate long-term health risks associated with industrialisation and urbanisation. In Kazakhstan, improving healthcare accessibility, particularly in rural areas, and implementing policies to reduce environmental risks may significantly reduce health inequalities and enhance life expectancy (Akın, 2018).

Finally, several limitations of the study should be acknowledged. These are mainly related to the availability and consistency of long-term data for certain socio-economic and environmental indicators. In addition, environmental variables such as PM2.5 may not fully capture all dimensions of environmental quality. Future research may address these limitations by using more detailed regional datasets, incorporating broader environmental indicators, and developing integrated health-economy models that enable a more comprehensive evaluation of the long-term determinants of life expectancy.

Conclusion

This study examined the economic, health, demographic, and environmental factors that determine life expectancy in Kazakhstan over 1991–2023, demonstrating that multi-dimensional dynamics shape longevity. The results indicate that per capita income, health infrastructure, and infant mortality are the strongest determinants of life expectancy. The positive association between economic well-being and longevity supports Preston's findings on the long-term income–life expectancy relationship (Preston, 2007) and Deaton's emphasis on the strong interaction between economic growth and health outcomes (Deaton, 2013). The significant positive effect of hospital bed density, as a measure of health infrastructure, aligns with Nixon and Ulmann's findings from European cases (Nixon & Ulmann, 2006), indicating that investments in the health system generate lasting welfare gains (Nolte & McKee, 2004).

The negative effect of infant mortality on life expectancy is consistent with the findings of Cutler, Deaton, and Lleras-Muney regarding the determinants of mortality (Cutler et al., 2006), highlighting that improvements in maternal and child health make a critical contribution to overall longevity. Conversely, the limiting effect of fertility on life expectancy aligns with Bloom and Canning's perspective on the demographic transition (Bloom & Canning, 2004) and with Kalemli-Ozcan's emphasis on the demographic burden (Kalemli-Ozcan, 2000).

One unexpected finding of the study is the positive association between PM2.5 air pollution and life expectancy. Although the literature robustly demonstrates that air pollution increases mortality (Pope et al., 2009; Chen & Chen, 2021), this result should be interpreted with caution. In the context of Kazakhstan, the observed relationship may reflect the temporary offset of environmental health risks by economic growth, improved healthcare access, and regional disparities in health infrastructure. Thus, the positive coefficient does not necessarily contradict the broader scientific evidence on the harmful effects of air pollution but may instead capture country-specific dynamics within the analysed period.

Similarly, the insignificance of physician density is consistent with the findings of Anand and Bärnighausen, who argue that uneven distribution of health workers in developing countries can weaken the observed impact of such indicators (Anand & Bärnighausen, 2004). Therefore, while physician density does not show a statistically significant effect in this study, this may reflect distributional imbalances rather than the absence of an underlying relationship. The non-significant effect of unemployment is also consistent with Ruhm's discussion of business-cycle–related health effects (Ruhm, 2000) and the context-dependent effects identified by Stuckler et al. (Stuckler et al., 2009), suggesting that its influence on life expectancy may operate indirectly through broader socio-economic mechanisms.

In conclusion, the case of Kazakhstan demonstrates that increasing life expectancy cannot be achieved solely through economic growth and health investments; demographic pressures, environmental conditions, and social vulnerabilities must also be taken into account. This finding confirms the frequently emphasised "double burden" phenomenon in transition economies. Thus, while progress in economic and health sectors contributes to longer life expectancy, environmental degradation and social inequality threaten the sustainability of these gains. Therefore, policies aimed at increasing life expectancy in Kazakhstan should not be limited to economic and health improvements, but should also include reducing environmental risks, effective management of the demographic transition, and strengthening the social security system.

Policy recommendations

The findings of this study reveal the policy priorities for increasing life expectancy in Kazakhstan from a multi-dimensional perspective. First, increasing investments in child health emerges as a critical requirement. Moreover, the strong negative association between the infant mortality rate (IMR) and life expectancy indicates the need to expand primary healthcare services. In this context, strengthening prenatal care, supporting maternal nutrition programs, and preventing fluctuations in vaccination coverage are key priorities. In this regard, the World Health Organisation also emphasises that access to healthcare services in early childhood is decisive for long-term gains in life expectancy.

Second, the healthcare infrastructure needs to evolve from quantity to quality. The positive effect of hospital bed density (LHB) on life expectancy confirms the importance of infrastructure investments. However, not only expanding capacity but also improving the quality of care, reducing regional inequalities, and strengthening intensive care capacity should be prioritised. The fact that physician density (ND) was found to be insignificant points to imbalances in the distribution of the healthcare workforce. Therefore, policies that encourage the employment of physicians in rural areas, planning that maintains a balance between specialist and general practitioners, and prioritising human resources in primary care should be adopted.

Third, environmental sustainability policies are essential for the long-term preservation of life expectancy. The positive relationship between PM2.5 in Kazakhstan suggests that the environmental costs of economic growth are being overshadowed. However, in the long run, environmental health deterioration will continue to increase mortality. Therefore, accelerating the transition from coal to natural gas, tightening emission standards, and monitoring urban air quality should be among the priority policies.

Fourth, demographic policies need to be designed in a balanced manner. A high fertility rate (FR) strains health resources and reduces life expectancy. Rather than restricting fertility, expanding access to safe childbirth services, supporting family planning, and regulating birth spacing constitute a more effective strategy. Additionally, the positive effect of the age dependency ratio (ADR) indicates that the elderly population makes additional contributions to social and healthcare systems. Therefore, healthcare services and social support mechanisms targeting the elderly population should be strengthened.

Finally, institutionalising resilience against crises holds great importance. In particular, the negative impact of COVID-19 on life expectancy clearly demonstrated the healthcare system's vulnerability to shocks. Accordingly, making pandemic preparedness plans permanent, establishing emergency medical stockpiles, strengthening digital health and telemedicine infrastructure, and expanding early warning systems are critical.

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Ethics committee statement and intellectual property copyrights

Ethical approval is not required for this study. The research was conducted in accordance with the principles of scientific research and publication ethics, and all rules regarding intellectual property and copyright have been duly observed.

Use of artificial intelligence (AI) tools

Artificial intelligence tools were used for grammar and language checking purposes.

Data availability

Data is available from the authors upon request.

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