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Review Article

Forecasting infant mortality rates in Turkey between 2024 and 2035 with Facebook prophet model a time series study

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Highlights

- Infant mortality rates remain high in Turkey.
- Over the next ten years, these rates are projected to decline to an average of 7.69.
- Improved healthcare services and increased expenditures will play a crucial role in achieving this reduction.

Abstract

Background: The infant mortality rate is often used as an indicator to assess the overall health status of a society, measure the level of development in countries, and reflect their socioeconomic and demographic conditions. It is recognized as one of the most critical indicators of development.
Aim: This study utilizes data on infant mortality rates per thousand from 2009 to 2023, sourced from the TUIK database, to estimate changes in Turkey's future infant mortality rates over time.
Method: The study employs time series analysis using the Facebook Prophet model to project infant mortality rates in Turkey from 2024 to 2035. The primary objective is to analyze the trends in infant mortality rates and provide long-term forecasts to inform health policies.
Results: The findings indicate that the infant mortality rate in Turkey could decrease to 7.69 per thousand by 2035. Additionally, projections suggest that the infant mortality rate may range between a minimum of 6.53 per thousand and a maximum of 8.95 per thousand during this period.
Conclusion: To reduce infant mortality rates, it is recommended to increase health expenditures, enhance the availability and qualifications of healthcare professionals, and implement effective and evidence-based care practices.
Keywords: Forecasting, infant mortality rate, time series analysis.

Introduction

The infant mortality rate is defined as the probability of dying within the first year of life, expressed as the number of infant deaths per thousand live births. It serves as a key indicator of social development, national progress, and public health (WHO, 2024). Health indicators, including infant mortality rates, are frequently used to measure the development and welfare levels of countries. Lamichhane et al. emphasize that the infant mortality rate is a sensitive and significant metric for assessing a country's physical quality of life and overall welfare (Lamichhane et al., 2017:2).

Research worldwide classifies the causes of infant mortality into three primary categories: biological, socioeconomic, and environmental factors (Mosley and Chen, 2003:140-142). Additionally, underlying factors such as social and economic conditions, education, health literacy, and health-related behaviors significantly contribute to infant mortality. For instance, urban-rural disparities influence infant mortality rates due to challenges in providing and accessing healthcare services in rural areas (Carol, 1996).

Globally, there are stark differences in infant mortality rates between developed, developing, and underdeveloped countries. While infant mortality rates-an essential indicator of economic development-have significantly declined since the early 1900s, they remain high in many underdeveloped and developing nations.

In Turkey's case, notable advancements have been achieved in social, health, and economic sectors, especially over the past two decades. Turkey has shown remarkable progress in reducing infant and child mortality rates. According to UNICEF (United Nations Agency for Children), Turkey achieved a 72% reduction in under-five mortality rates between 1990 and 2007, ranking first globally for this achievement (UNICEF, 2009). However, despite this progress, Turkey's infant mortality rate remains higher than the OECD (Organisation for Economic Co-Operation and Development) average. This discrepancy, especially when compared to other countries in similar income groups, highlights critical areas for further investigation.

This study aims to analyze trends in infant mortality rates in Turkey over time and provide long-term projections to guide health policy development. Understanding the factors behind Turkey's infant mortality rates and devising targeted strategies to address them are essential for aligning with global health standards and improving overall child health outcomes.

Literature review

There are a limited number of studies in the literature focusing on forecasting infant mortality rates for the future. To address this gap and contribute to the body of

knowledge, a retrospective data analysis and time series modeling study on infant mortality rates in Turkey has been conducted. Below is a review of studies from both Turkish and international literature that share common themes with this research.

Seçin (2009) examined factors affecting infant mortality rates in Turkey, analyzing data from a survey conducted with 8,075 women between 2003 and 2004. The study revealed a positive relationship between poverty and infant mortality. Additionally, it emphasized the role of breastfeeding in reducing the risk of death within the first two months of life and the significant impact of clean drinking water on improving infant survival rates.

Ertekin et al. (2016) investigated the relationship between economic growth, unemployment, and infant mortality in Turkey, utilizing time series data spanning from 1960 to 2013. Their findings indicated that an increase in income levels reduces infant mortality in the long term, while a rise in unemployment leads to higher infant mortality rates. Moreover, the study emphasized that per capita income plays a more significant role in reducing infant mortality compared to unemployment rates.

Kılıç Yıldırım (2020) conducted a study to determine the risks of infant mortality across provinces in Turkey between 2009 and 2017 using the integrated nested Laplace approach. The study found a significant decrease in high-risk provinces during this period, with the highest relative risks concentrated in Eastern and Southeastern Anatolia. It highlighted that as GDP increased, the risk of infant mortality decreased. Provinces such as Erzurum, Van, Siirt, Bingöl, and Bitlis were identified as the most at-risk regions. The study concluded that increasing income levels is crucial for reducing infant mortality risks in these areas.

Koncak and Konat (2022) explored the relationship between the causes of infant mortality and socioeconomic indicators in Turkey. Their research concluded that factors such as childbirth under the age of 15 and income inequality increase infant mortality rates, while higher education levels are associated with lower mortality rates. The authors recommended policies aimed at improving public health, increasing women's education levels, boosting per capita income, encouraging education, and preventing early pregnancies to mitigate infant mortality.

Açıksöz (2023) analyzed changes in infant mortality rates in Turkey between 2009 and 2019, focusing on differences by gender, region, and province. Using data from TUIK, the study identified Southeastern Anatolia as the region with the highest infant mortality rate in 2019, at 12.88%. The research highlighted a decline in infant mortality rates in Turkey over the decade, attributing this improvement to better maternal and child health services, higher parental education levels, and improved quality and accessibility of healthcare services.

By reviewing these studies, this research aims to further understand the factors influencing infant mortality in Turkey and to build on existing knowledge through retrospective analysis and time series modeling.

Güleryüz and Köse (2017) conducted a time series analysis using data from 1960 to 2015 in Turkey, revealing a significant negative relationship between unemployment and infant mortality rates. Akcan and Üçler (2022) applied a Granger Causality Test on data from 1991 to 2019 in Turkey and discovered a unidirectional causal relationship between infant mortality and various economic and social variables. Similarly, Ateş (2022) conducted a Granger Causality Test using data from 1990 to 2021 in Turkey and concluded that advancements in health technologies can enhance efficiency in the healthcare sector and significantly reduce infant mortality.

Examining studies on infant mortality rates in the international literature, it is evident that time series analyses are relatively limited. Maria Caporale and Gil-Alana (2015) performed a time series analysis using data from 24 countries obtained from the Human Mortality Database, covering the years 1950 to 2006. Their findings indicated that countries such as Czechia, Japan, Portugal, Austria, and Slovakia were projected to experience the most significant reductions in infant mortality rates. In contrast, countries like the United States, the Netherlands, Norway, Denmark, and Sweden were expected to see less substantial declines.

Onambele et al. (2019) analyzed changes and trends in infant mortality rates across the European Union and its 28 member countries using data from the Eurostat database for the years 1994 to 2015. Their regression analysis revealed a substantial decline in infant mortality rates in the EU, from 8.3 to 3.6 per 1,000 live births during the study period. They also identified Romania and Bulgaria as having the highest infant mortality rates, while Scandinavian countries, particularly Finland and Sweden, had the lowest rates. Additionally, the study highlighted a notable increase in infant mortality rates in Greece in recent years and stabilization in the United Kingdom and Ireland.

Taylor-Robinson et al. (2019) investigated the impact of rising child poverty on infant mortality using data from 2014 to 2017 across 324 local governments in nine regions in England. Using fixed-effect regression models, they found that the unprecedented rise in infant mortality during this period was unevenly distributed across the population. Specifically, low-income local authorities experienced a reversal in the previous downward trend, with infant mortality rates rising to 24 deaths per 100,000 live births annually. The study emphasized the growing disparity in infant mortality rates between low- and high-income local governments.

Prinja et al. (2021) evaluated the overall impact of the National Rural Health Mission (NRHM) on infant mortality in India at both national and state levels. Using annual data on infant mortality rates from 1990 to 2016 obtained from Sample Registration System bulletins, they conducted a two-stage segmented time series regression analysis. Their findings estimated that 248,212 infant deaths were prevented between 2005 and 2017 due to the NRHM. They also observed significant declines in infant mortality rates across 13 of the 17 largest states, with Andhra Pradesh demonstrating particularly sharp reductions.

These studies highlight the multifaceted factors influencing infant mortality rates and underscore the importance of socioeconomic, technological, and policy interventions in addressing this critical public health challenge.

In their study, Trinh et al. (2022) conducted a regression analysis of monthly infant mortality rates using data from the French National Institute of Statistics and Economic Research for the period 2001 to 2019. Their findings revealed a sharp decline in infant mortality rates between 2001 and 2005, followed by a significant increase starting in 2012. Sensitivity analysis indicated that the rise was largely attributable to an increase in neonatal mortality. The authors emphasized the urgent need for in-depth research

to understand the underlying causes of this historical increase in infant mortality rates in France since 2012 and to develop appropriate corrective actions.

Bishai (1995) analyzed infant mortality rates in Sweden, the United Kingdom, and the United States using the Dickey-Fuller Test. His findings suggested that improvements in the UK's GDP per capita during the 20th century had a more pronounced impact on infant survival than similar improvements in the US GDP per capita.

Hajat et al. (2007) explored the effects of outdoor air pollution on infant mortality in 10 major cities in the United Kingdom, utilizing time series analysis with data from 1990 to 2000. Their study found a weak relationship between infant mortality and air pollution, suggesting that other factors may play a more significant role in determining infant survival.

Şamkar and Güner (2018) examined under-five mortality rates in OECD countries using biased estimation techniques. Their findings highlighted that women play a crucial role in reducing child mortality and emphasized the importance of increasing the share of national income allocated to health expenditures to achieve further reductions in mortality rates.

Ata and Eryer (2024) studied the impact of health expenditures and income distribution on infant mortality rates using panel data analysis of 26 OECD countries for the period 2000 to 2019. They concluded that a 1% increase in public health expenditures in OECD countries could reduce infant mortality rates by 0.54%, while a 1% increase in private health expenditures could result in a 0.20% reduction. These findings underline the critical role of public health spending in improving infant survival rates across OECD countries.

These studies collectively underscore the multifactorial nature of infant mortality, highlighting the interplay between economic growth, public and private health investments, and environmental factors. They also emphasize the need for targeted policies to address disparities and improve infant survival globally.

Method

Design

This study is a retrospective data analysis and time series modeling study designed to analyze infant mortality rates in Turkey from 2009 to 2023 and forecast potential trends until 2035. By leveraging historical data, the study aims to identify patterns and provide long-term predictions to inform health policy development. Specifically, it seeks to examine changes in infant mortality rates over time and generate forecasts to support decision-making in public health strategies.

Data collection

The data used in this study were sourced from the Turkish Statistical Institute (TurkStat), the official statistical agency of Turkey. TurkStat provides comprehensive demographic data, including infant mortality rates. The dataset comprises annual infant mortality rates for all 81 provinces of Turkey from 2009 to 2023. For national-level analysis, city-based values were used to calculate average and median infant mortality rates for Turkey.

Data evaluation

The data were evaluated in multiple stages, as outlined below:

Calculation of basic statistics

Average and median infant mortality rates for each city were calculated for the period 2009-2023. Additionally, annual average infant mortality rates were computed for Turkey as a whole. Provinces with the highest and lowest rates during the study period were identified to understand regional disparities.

Time series analysis

Time series modeling methods were employed to forecast future infant mortality rates. The following approaches were tested during this process:

Exponential smoothing state space (ETS) model

While the ETS model was applied, its predictions were inconsistent with observed data and therefore excluded from the final analysis.

Facebook prophet model

The Facebook Prophet model, which accounts for trend and seasonality in time series data, was used for forecasting infant mortality rates from 2024 to 2035. The Prophet model was selected due to its robustness with non-stationary datasets. Forecasts were visualized with lower and upper confidence intervals, and the trend and seasonality components were analyzed.

Evaluation of model performance

Residual analysis was conducted to evaluate the reliability of the Prophet model's forecasts. The residuals exhibited a random error distribution, with no evidence of systematic error. Additionally, confidence intervals were examined, confirming that the model provided reasonable uncertainty estimates.

Ethical statement

The study utilized publicly available and fully anonymized data from the Turkish Statistical Institute. As such, no personal or sensitive information was included, and ethics committee approval was not required. The study adhered to scientific and ethical principles throughout its execution. The data source was explicitly cited, and the findings were reported with the intent of benefiting public health and contributing to health policy development in Turkey.

Results

In this study, the averages of infant mortality rates per thousand for Turkish cities between 2009 and 2023 are presented in Table 1. Şanlıurfa recorded the highest average infant mortality rate at 16.42 (median: 16.3), followed closely by Gaziantep at 16.36 (median: 16.1). On the other hand, Kırklareli exhibited the lowest average rate at 6.57 (median: 6.57), with Edirne following at 7.13 (median: 6.9). Across Turkey, the overall average infant mortality rate during this period was 10.27 per thousand, with a median value of 9.7 (Table 1).

The study revealed that the infant mortality rate in Turkey was 13.8 per thousand in 2009 and demonstrated a downward trend until 2020. In recent years, infant

mortality rates were recorded at 9.08 in 2021, 8.94 in 2022, and slightly increased to 9.6 in 2023 (Figure 1).

In the research, various time series methods were tested to forecast future infant mortality rates. Initially, the Augmented Dickey-Fuller (ADF) test was applied to assess stationarity, which is a prerequisite for applying the ARIMA model. The test yielded a p-value of 0.99, indicating that the series was not stationary. Subsequently, the differenced series was tested, resulting in a p-value of 0.44, which also failed to demonstrate stationarity (Table 2). Based on these results, the ARIMA model was deemed unsuitable and abandoned.

Next, the Exponential Smoothing State Space (ETS) model was applied. However, the ETS model's graphs did not produce meaningful or consistent results. Finally, the Facebook Prophet model was employed for the analysis. The Prophet model was selected as it accommodates non-stationary data and incorporates trend and seasonality components, providing a robust framework for forecasting infant mortality rates.

The reliability of the Prophet model was assessed using time series performance metrics. The results indicated an R^2 value of 0.927 and a Root Mean Square Error (RMSE) value of 0.393. These findings suggest that the Prophet model demonstrates strong predictive accuracy and reliability for forecasting infant mortality rates (Table 3).

With the prophet time series test, expected infant mortality rates between 2024 and 2035 were calculated. As a result of the analysis, it was determined that infant mortality rates could decline to 7.69 per thousand by 2035. Similarly, the lowest estimate is 6.53 per thousand and the highest estimate is 8.95 per thousand (Table 4).

The forecasted infant mortality rates using the Prophet time series model are visualized in Figure 2, which displays the expected trend between 2024 and 2035. The graph illustrates the predicted trajectory of infant mortality rates, along with confidence intervals, providing insights into future changes based on historical patterns.

Discussion and conclusion

There are numerous factors influencing infant mortality, with some of the most critical being the economic and social conditions of a country, maternal and child health, education levels, environmental factors, health literacy, and the availability and quality of healthcare services (Dirican, 1990; Özdamar, 1977: 127-141). Infant mortality rates vary significantly across income groups, being approximately 110 per thousand in low-income developing countries, 65 per thousand in middle-income countries, and 8 per thousand in high-income developed nations. Schultz (1993: 337-342) found a clear inverse relationship between income and infant mortality, with rates decreasing as income rises. Similarly, Flegg (1982: 441-458) demonstrated that spending on health, hygiene, food, and related factors indirectly reduces infant mortality rates. Other studies have emphasized additional influences, such as maternal age, breastfeeding practices, cleanliness at birth, and sanitation (DaVanzo et al., 1983: 381-402). Merrick (1985: 1-24) highlighted the pivotal role of parental education in reducing infant mortality, while Kılınç (2021) identified variables like education level, family planning, number of children, and kinship relationships as significant factors.

Both domestic and international literature underline the multifactorial nature of infant mortality. In Turkey, a developing country, the infant mortality rate was 13.8 per thousand in 2009 and showed a steady decline until 2020. However, slight fluctuations were observed in recent years, with rates rising to 9.08 in 2021, decreasing to 8.94 in 2022, and rising again to 9.6 in 2023 (TUIK, Access Date: 01.12.2024).

This study aimed to forecast infant mortality rates in Turkey for the period 2024–2035 using time series analysis with the Prophet model. Reliability tests of the model produced an R^2 value of 0.927 and an RMSE value of 0.393, indicating strong predictive reliability. Based on the analysis, infant mortality rates are projected to decline to 7.69 per thousand by 2035, with the lowest and highest estimates being 6.53 and 8.95 per thousand, respectively. While not consistently linear, the overall trend suggests a steady decline, with infant mortality rates expected to fall below 8 per thousand on average by 2035.

Despite this optimistic forecast, the projected rates remain approximately twice the current average in European countries. To further reduce infant mortality, decision-makers in Turkey must address the multifaceted determinants of infant health. Efforts should prioritize improvements in education, healthcare, nutrition, and income growth. Sustainable and long-term policies are essential, including increased health expenditures, income redistribution, and greater access to healthcare services. Specific recommendations include ensuring equitable access to healthcare, addressing disparities in health service provision, and facilitating access to high-quality health technologies. By implementing these measures, Turkey can achieve more significant reductions in infant mortality and align closer to global health standards.

Table 1.
Infant mortality rates of the highest and lowest regions between 2009 and 2023.

Highest Provinces		
	Mean	**Median**
Şanlıurfa	16.42	16.3
Gaziantep	16.36	16.1
Kilis	16.03	15.0
Şırnak	15.02	15.1
Siirt	14.98	15.0
Lowest Provinces		
Kırklareli	6.57	6.1
Edirne	7.13	6.9
Karabük	7.40	7.1
Bolu	7.70	6.9

Ankara	7.82	7.6
Turkey Overall Average	10.27	9.7

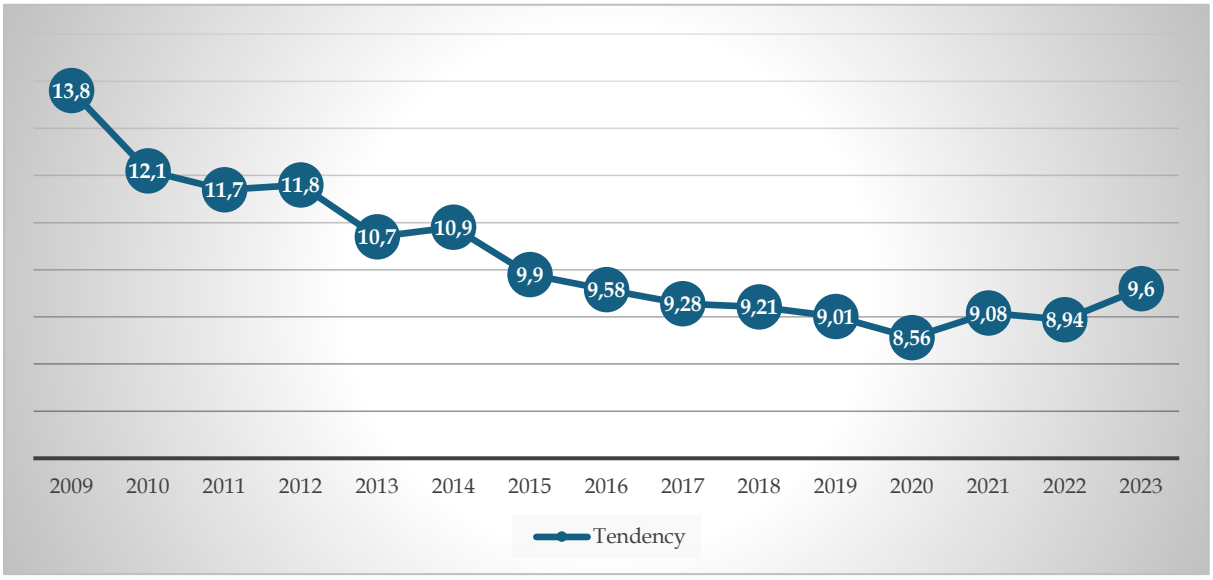

Figure 1.

Turkey's average infant mortality rates per thousand between 2009 and 2023. (Source: TUIK, https://data.tuik.gov.tr/. Access Date: 01.12.2024).

Table 2.
Time series test trial.

	Dickey-Fuller	Lag order	p value	Alternative hypothesis
Time series	2.39	2	0.99	stationary
Difference series	-2.34	2	0.44	stationary

Table 3.
Prophet model test reliability.

	R^2	RMSE	Confidence Interval Width (95% Confidence Interval)
Prophet model	0.927	0.393	1.215

Table 4.
Prophet Model 2024-2035 expected infant mortality rate projections.

Year	Average expectation	Lowest forecast	Highest forecast
2024	8.59	8.10	9.06
2025	8.77	8.25	9.30
2026	8.59	8.11	9.14
2027	8.41	7.83	8.96
2028	8.23	7.65	8.79
2029	8.41	7.77	9.06
2030	8.23	7.60	8.93
2031	8.05	7.31	8.88
2032	7.87	7.06	8.77
2033	8.05	7.11	9.06
2034	7.87	6.78	9.01
2035	7.69	6.53	8.95

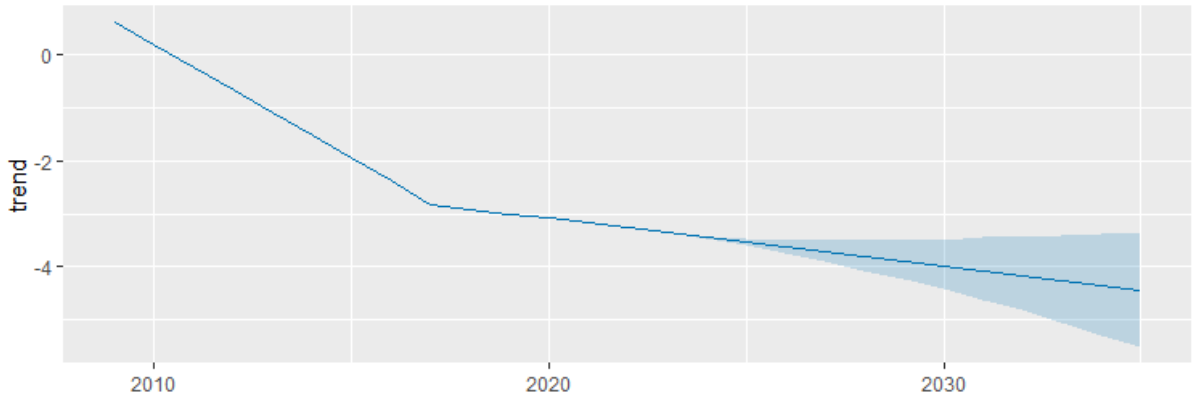

Figure 2.

Expected infant mortality rates in Turkey between 2024 and 2035 using the Prophet Model.

Ethics approval statement

I declare that this study is one of those that do not require ethics committee approval.

Patient consent statement

N/a.

Consent for publication

N/a.

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CRediT authorship contribution statement

F. Akbulut: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization.

Data availability statement

N/a.

Declaration of competing interest

The author declare no conflict of interest.

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