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RESEARCH ARTICLE

Mortality Projections, Regional Disparities in the Burden of Neonatal Disorders, and the Status of Achieving SDG Targets by 2030 in South Asia: Insights from the Global Burden of Disease Study 2021

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Abstract

Background Neonatal disorders represent a significant public health challenge, particularly in low- and middle-income countries, where they account for 79% of global neonatal mortality. South Asia, comprising countries such as India, Pakistan, Bangladesh, Nepal, and Bhutan, bears a disproportionately high burden, contributing to 38% of the world's neonatal deaths. Despite notable progress, South Asia remains off track in meeting the Sustainable development goals (SDG). This study aims to assess the current burden, trends in neonatal disorders, and forecast mortality rates across South Asian countries, providing insights to guide investment priorities and improve neonatal outcomes.

Methods Data for this study were sourced from the Global burden of disease (GBD) 2021 study, which utilizes a Bayesian meta-regression model to estimate mortality, prevalence, and disability-adjusted life years (DALYs). Spatial maps depicting the age-standardized prevalence rate and age-standardized mortality rate for neonatal disorders in South Asia were generated using QGIS software. Mortality forecasts for the period 2022–2031, attributed to various neonatal disorders, were produced employing the Auto-Regressive Integrated Moving Average model in R software. Additionally, an analysis of overall neonatal mortality trends from 1980 to 2021 was conducted, supplemented by a heat map that compares DALYs attributable to various neonatal disorders across South Asian countries in 2021.

Results Between 1980 and 2021, South Asia experienced a substantial decline in neonatal mortality rates, with India and Bangladesh leading the progress. Mortality decreased by 40%, while DALYs fell by 35%, despite a 15% increase in the prevalence. The prevalence of neonatal encephalopathy due to birth asphyxia and trauma surged by 355%, yet its mortality dropped by 31%. Pakistan recorded the highest neonatal mortality and disease burden, particularly for hemolytic disease and other neonatal jaundice and neonatal encephalopathy due to birth asphyxia and trauma. In India and Bangladesh, neonatal preterm birth and neonatal sepsis and other neonatal infections contributed most to mortality. Neonatal encephalopathy due to birth asphyxia and trauma accounted for the highest DALYs. Forecasts predict continued reductions in neonatal mortality across South Asia, except in Pakistan, where persistently high rates are expected till 2031.

Conclusion For South Asian countries to meet the SDG target for neonatal mortality by 2030, intensified and continuous efforts are required. These efforts should focus on identifying high-risk pregnancies and improving the quality of care during childbirth to address the root causes and reduce preventable neonatal deaths.

Keywords Neonatal mortality · Sustainable development goals · Regional disparities · Neonatal outcomes

1 Introduction

A neonate is defined as an infant less than 28 days old. This period is crucial in early life, as it is associated with the highest risk of mortality [1]. In this context, Sustainable development goal (SDG) 3.2, which aims to reduce

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preventable deaths of newborns and children under five years of age by 2030, places significant emphasis on addressing neonatal mortality [2]. Neonatal disorders present a significant public health challenge, particularly in low- and middle-income countries, where they account for 79% of global neonatal mortality [3]. South Asia, encompassing nations such as India, Bhutan, Nepal, Bangladesh, and Pakistan, carries a disproportionate share of this burden, with the region accounting for 38% of the world's neonatal deaths [4]. Annually, over 1 million newborns die in South Asia, alongside another 1 million stillbirths.

Key contributors to neonatal mortality in the region include preterm birth complications, neonatal infections, and birth asphyxia [5]. These disorders not only result in immediate mortality but also contribute to long-term neurological and cognitive impairments, exacerbating the strain on already overburdened health systems and economies [1, 6].

Despite significant global progress, over 60% of deaths among children under five in South Asia occur within the first month of life. The region remains off track to meet the SDG target of reducing neonatal mortality to a less than 12 per 1000 live births by 2030 [7]. The neonatal disorders continue to pose significant challenges in South Asian countries, yet there is a limited understanding of their full burden, regional disparities, and emerging trends. This study aims to provide a thorough assessment of these aspects, delivering actionable insights to governments and funding bodies. By identifying key priorities, the research aims to facilitate optimized resource allocation, advancing progress toward international health objectives and better neonatal health outcomes.

2 Methods

The Global burden of disease (GBD) study 2021 provides comprehensive insights into global health trends, tracking mortality, disability, and risk factors across the world [8]. It covers 371 diseases and injuries in 204 countries, offering vital data at national and sub national levels to inform health policies and priorities [9]. The study collects data on neonatal disorders from number of sources such as civil registration systems, censuses, vital statistics, and other sources. Further the data is estimated through Bayesian meta-regression tool named DisMod-MR model which has been discussed in previous studies [10, 11]. The GBD study characterizes neonatal disorders as disturbances to a newborn's normal physical state or abnormalities in organ function [12]. The specific neonatal disorders included in the GBD study are

I. Hemolytic disease and other neonatal jaundice
II. Neonatal encephalopathy due to birth asphyxia and trauma
III. Neonatal preterm birth
IV. Neonatal sepsis and other neonatal infections

2.1 Measurement of Disease Burden

The disease burden was assessed using measures such as prevalence, mortality, and disability-adjusted life years (DALYs), with the definitions and calculation methods outlined in previous studies [13]. Data was sourced via the institute for health metrics and evaluation's global health data exchange query tool (http://ghdx.healthdata.org/gbd-results-tool).

2.2 Spatial and Trend Analysis

To analyse regional disparities in the burden of neonatal disorders, we utilized QGIS software (version 3.38.0) to generate spatial maps. Boundary maps for South Asian countries, including India, Pakistan, Nepal, Bhutan, and Bangladesh, were developed to illustrate the age-standardized prevalence rate and age-standardized mortality rate for neonatal disorders in 2021. Additionally, a heat map was produced to compare the DALYs attributed to various neonatal disorders across these nations. Trends in neonatal disorders related mortality comparing males and females in these countries from 1980 to 2021 was also plotted.

2.3 Prediction Analysis

Mortality associated with neonatal disorders for India, Nepal, Pakistan, Bhutan, and Bangladesh was projected from 2022 to 2031 using the Auto-Regressive Integrated Moving Average (ARIMA) model in R software (version 4.3.1). This model was selected based on its capacity to handle time series data with non-stationary components. The analysis was performed using R software, employing the "forecast" package to fit and validate the ARIMA model. The specifics of this model have been extensively detailed in previous studies [14–16].

3 Results

Across all countries, there was a clear and consistent decline in mortality rates associated with neonatal disorders for both males and females over the study period from 1980 to 2021 except Pakistan (supplementary Fig. 1). While the mortality rates for both genders decreased, males consistently exhibited slightly higher mortality rates compared to females throughout most of the period. However, in India, the gender disparity in mortality rates diminished

significantly, particularly between 2014 and 2018, during which the rates for males and females became almost equal. India and Bangladesh demonstrated the most substantial reductions in neonatal disorder-related mortality, with significant progress observed from the early 2000s onward. Nepal and Bhutan followed a similar trajectory, although the pace of decline in these countries was slower in comparison to India and Bangladesh. Despite the disparities between individual countries, the overall trend indicates significant regional progress in reducing neonatal mortality associated with neonatal disorders.

The results demonstrate varying changes in the prevalence, mortality, and DALYs due to neonatal disorders in South Asia between 1990 and 2021. The prevalence of neonatal disorders increased by 15% (95% UI: 3%–26%) (Table 1). Despite this increase in prevalence, there was a 40% (27%–50%) reduction in mortality. Similarly, the DALYs declined by 35% (24%–46%). For specific conditions as neonatal encephalopathy due to birth asphyxia and trauma saw a sharp 355% (188%–630%) increase in prevalence, rising from 48 (27–82) to 218 (185–252). However, the associated mortality declined by 31% (14%–45%). For hemolytic disease and other neonatal jaundice, the prevalence increased by 72% (65%–80%) while mortality declined by 60% (46%–71%) The neonatal sepsis and other neonatal infections showed a 77% (28%–153%) increase in prevalence with mortality decreasing by 39% (23% to 53%) Lastly, while the prevalence of neonatal preterm birth increased slightly by 7% (−3%–18%), mortality decreased by 41% (26%–53%). These findings highlight a trend of increasing prevalence for several neonatal conditions, but significant reductions in mortality and DALYs, reflecting improved management and outcomes for neonatal health in South Asia.

Pakistan reported a high prevalence of hemolytic disease and other neonatal jaundice but had one of the lowest rates of neonatal encephalopathy due to birth asphyxia and trauma in 2021 (Fig. 1). It exhibited moderate rates of neonatal preterm birth and low prevalence of neonatal sepsis and other neonatal infections, reflecting better infection control. India, however, faced significant challenges with high prevalence of neonatal encephalopathy due to birth asphyxia and trauma, neonatal preterm birth and neonatal sepsis and other neonatal infections indicating serious issues with birth complications and infection management. Bangladesh showed a similar burden as India in neonatal

Table 1 Prevalence, DALYs, and mortality rates, along with total percentage change for neonatal disorders in South Asia, based on GBD data from 1990 to 2021

South Asia	1990	2021	1990 to 2021
	ASR (per 100 000) (95% UI)	ASR (per 100 000) (95% UI)	TPC (%) (95% UI)
Neonatal disorders			
Prevalence	3044 (2600−3537)	3521 (3142−3910)	15 (3−26)
DALYs	6664 (6154–7220)	4277 (3675−4995)	−35 (−46 to −24)
Mortality	70 (65−77)	42 (35−50)	−40 (−5 to −27)
Hemolytic disease and other neonatal jaundice			
Prevalence	22 (20−24)	38 (35−42)	72 (65−80)
DALYs	338 (283−410)	141 (107−179)	−58 (−69 to −43)
Mortality	4 (3−4)	1 (1−2)	−60 (−71 to −46)
Neonatal encephalopathy due to birth asphyxia and trauma			
Prevalence	48 (27−82)	218 (185−252)	355 (188−630)
DALYs	1716 (1425−2264)	1206 (958−1562)	−29 (−43 to −11)
Mortality	19 (16−25)	13 (10−17)	−31 (−45 to −14)
Neonatal preterm birth			
Prevalence	2887 (2446−3396)	3113 (2716−3515)	7 (−3 to 18)
DALYs	3142 (2770−3494)	2065 (1717−2473)	−34 (−46 to −20)
Mortality	32 (28−35)	18 (15−23)	−41 (−53 to −26)
Neonatal sepsis and other neonatal infections			
Prevalence	96 (61−136)	170 (131−211)	77 (28−153)
DALYs	541 (469−630)	356 (293−428)	−34 (−47 to −17)
Mortality	6 (5−7)	4 (3−4)	−39 (−53 to −23)
Other neonatal disorders			
Prevalence	–	–	–
DALYs	927 (681−1161)	509 (387−651)	−45 (−62 to −27)
Mortality	10 (7−13)	6 (4−7)	−45 (−63 to −27)

ASR age standardised rate, *TPC* total percentage change, *UI* uncertainty interval

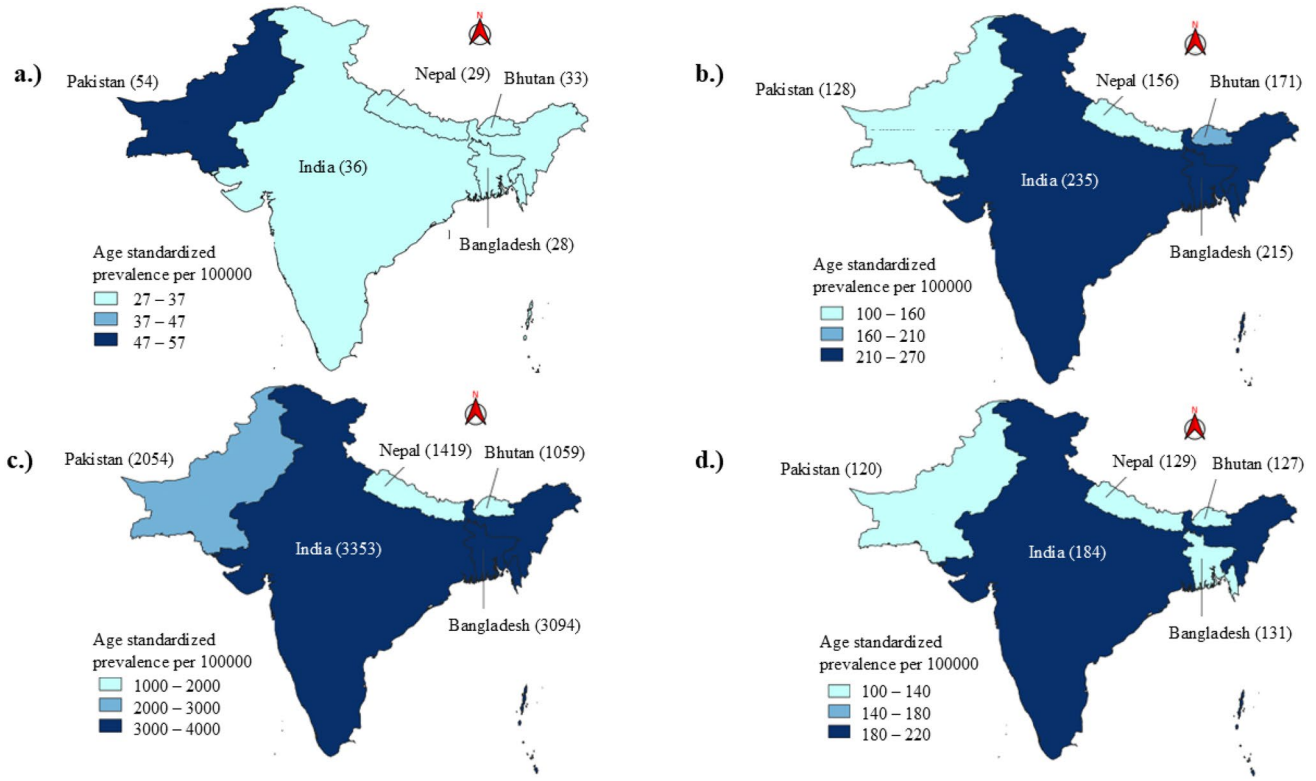

Fig. 1 Prevalence of neonatal disorders in Nepal, Bangladesh, Pakistan, India, and Bhutan in 2021 based on the GBD 2021 study: **a** haemolytic disease and other neonatal jaundice; **b** neonatal encephalopathy from birth asphyxia and trauma; **c** neonatal preterm birth; **d** neonatal sepsis and infections

encephalopathy due to birth asphyxia and trauma and neonatal preterm birth but had slightly better control of neonatal sepsis and other neonatal infections. Nepal had lower prevalence rates across most neonatal disorders, including low rates of neonatal encephalopathy due to birth asphyxia and trauma, neonatal preterm birth, and Neonatal sepsis and other neonatal infections, reflecting stronger maternal and neonatal health management. Bhutan demonstrated moderate levels of neonatal disorders, with lower rates of neonatal encephalopathy and neonatal preterm birth as well as low neonatal sepsis rates, suggesting effective control measures.

Pakistan had the highest mortality rates for hemolytic disease and other neonatal jaundice as well as neonatal encephalopathy due to birth asphyxia and trauma in 2021, suggesting a regional concentration of these conditions (Fig. 2). In comparison, other countries, including Nepal, Bhutan, Bangladesh, and India, recorded lower mortality rates. However, Nepal had notably higher rates of neonatal encephalopathy due to birth asphyxia and trauma than its counterparts. In terms of neonatal preterm birth, India and Pakistan reported the highest mortality rates, followed by Bhutan, highlighting significant challenges in managing preterm deliveries. Mortality from neonatal sepsis and other neonatal infections and other infections was highest in Bangladesh, with India and Pakistan close behind, indicating critical issues in infection control. Conversely, Nepal and Bhutan had the lowest mortality rates, reflecting more effective infection control measures in these nations.

Among all neonatal disorders, neonatal encephalopathy due to birth asphyxia and trauma accounted for the highest DALYs across all countries. For hemolytic disease and other neonatal jaundice, Pakistan reported the highest burden while Bangladesh had the lowest. Nepal, India, and Bhutan displayed similar values, which were lower than Pakistan's but higher than Bangladesh's (Fig. 3). In terms of neonatal encephalopathy, Pakistan once again had the highest DALYs with Nepal following. India had notably lower values, with Bhutan and Bangladesh reporting figures close to each other. Regarding neonatal preterm birth, Pakistan, and India both had high DALYs, with Bhutan showing a significantly lower burden. Nepal reported the lowest values which were also lower than those seen in Bangladesh. For neonatal sepsis and other neonatal infections, Bangladesh exhibited the highest DALYs while Bhutan had the lowest. The remaining countries, including Pakistan, Nepal, and India, showed intermediate values. In the category of other neonatal disorders, Pakistan had the highest burden, while Bhutan recorded the lowest. Nepal, Bangladesh, and India fell between these

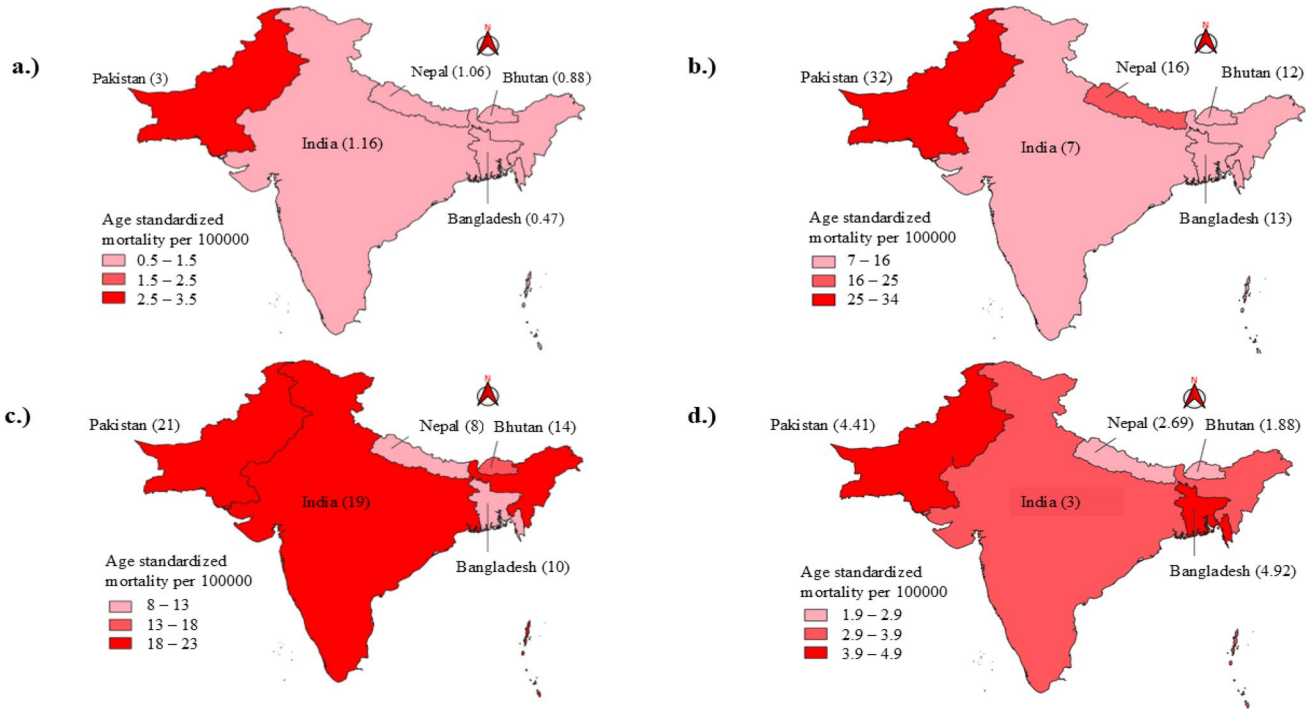

Fig. 2 Mortality due to neonatal disorders in Nepal, Bangladesh, Pakistan, India, and Bhutan in 2021 based on the GBD 2021 study: **a** haemolytic disease and other neonatal jaundice; **b** Neonatal encephalopathy from birth asphyxia and trauma; **c** neonatal preterm birth; **d** neonatal sepsis and infections

	DALYs (per 100 000) (95% UI)				
	Hemolytic disease and other neonatal jaundice	Neonatal encephalopathy due to birth asphyxia and trauma	Neonatal preterm birth	Neonatal sepsis and neonatal infections	Other neonatal disorders
Nepal	107 (68 to 160)	1480 (1070 to 2001)	955 (694 to 1292)	279 (191 to 396)	527 (321 to 826)
Bangladesh	51 (33 to 73)	1188 (821 to 1647)	1314 (928 to 1796)	472 (308 to 659)	423 (272 to 631)
Pakistan	281 (198 to 390)	2928 (2245 to 3645)	2188 (1695 to 2806)	427 (320 to 551)	789 (567 to 1050)
India	115 (86 to 152)	710 (506 to 1133)	2147 (1744 to 2653)	322 (246 to 413)	440 (310 to 590)
Bhutan	93 (53 to 150)	1094 (733 to 1503)	1425 (1016 to 1893)	206 (139 to 308)	383 (238 to 597)

Fig. 3 The DALYs attributable to neonatal disorders in South Asian countries in 2021, based on the GBD 2021 study

two extremes, showing a relatively similar range. Overall, Pakistan had consistently high DALYs across most conditions, with Bangladesh and Nepal displaying elevated values for specific disorders. Bhutan generally reported the lowest burden, except for neonatal encephalopathy due to birth asphyxia and trauma and neonatal preterm birth.

The ARIMA model predicted a decline in the age-standardized mortality rate for neonatal disorders across Nepal, Bangladesh, Pakistan, India, and Bhutan between 2022 and 2031 (Fig. 4). In Nepal, the age-standardized mortality rate decreases gradually to 24 (15–32) per 100,000 by 2031 (supplementary Table 1). Similarly, India shows a consistent reduction falling to 23 (16–31) by the end of the forecast period. Bhutan follows a comparable trend, with the mortality rate of 19 (9–29) by 2031. These three countries show a steady improvement in neonatal mortality rates over time.

In contrast, Bangladesh exhibits the most significant decline, starting at 31 (30–32) in 2022 and dropping sharply to 11 (−2–24) by 2031. This indicates rapid progress in reducing neonatal mortality, though the wider confidence intervals in later years suggest increased variability. On the other hand, Pakistan's age-standardized mortality rate remains notably higher than the other countries, beginning at 69 (66–71) in 2022 and only marginally decreasing to 64 (50–78) by 2031, highlighting persistent challenges in neonatal health.

Overall, the results reveal significant improvements in neonatal mortality rates across most countries, particularly in Bangladesh, where the reduction is most pronounced. However, persistently high age-standardized mortality

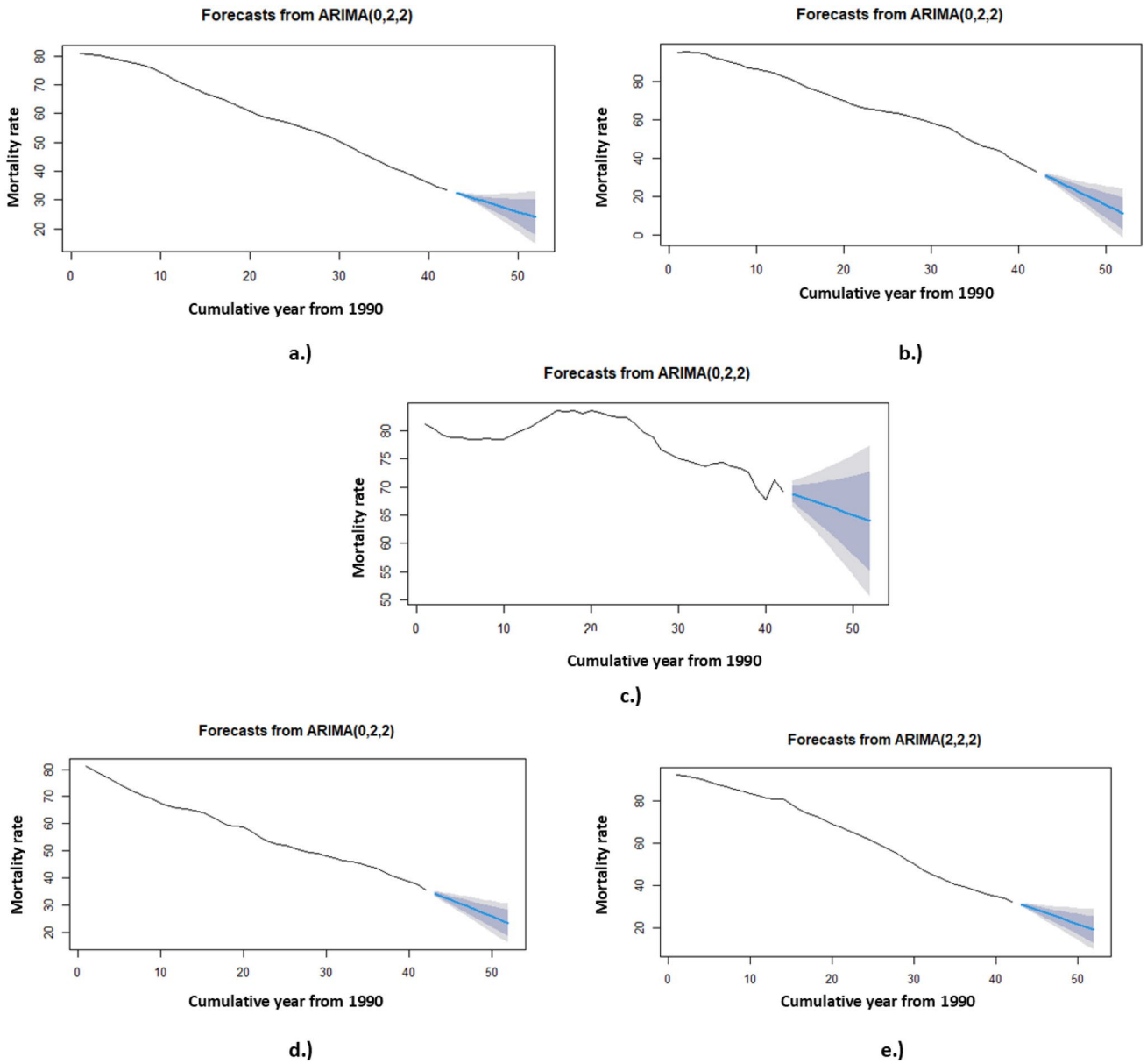

Fig. 4 Future trends of mortality associated with neonatal disorders in South Asia from 2022 to 2031 estimated through GBD study data from 1990 to 2021: **a** Nepal; **b** Bangladesh; **c** Pakistan; **d** India; **e** Bhutan

rate is seen in Pakistan suggesting health disparities in the region.

4 Discussion

The overall results of the study indicate that there has been a consistent decline in neonatal disorders related mortality and DALYs across South Asian region between 1980 and 2021, reflecting significant improvements in neonatal survival and overall health outcomes. While the prevalence of neonatal disorders has increased, this may indicate enhanced case detection and reporting rather than a worsening disease burden, as better health systems are identifying and managing cases earlier and more effectively. The varying progress among countries underscores the need for targeted strategies—India and Bangladesh have made substantial strides, while Pakistan, with persistently high mortality and DALYs, requires urgent attention to improve neonatal care and address systemic health challenges.

Among all countries Pakistan has faced significant challenges in reducing neonatal mortality compared to other countries. Key factors include inadequate healthcare interventions, limited female education, rapid population growth, and poor integration of healthcare programs [17]. Lifesaving measures are not widely implemented, especially in underserved areas, while high rates of low birth weight and poverty further complicate the issue [18, 19]. Poor coverage of community health workers and distance from health facilities were also some factors associated with high mortality [20]. On other hand Bangladesh greatly reduced neonatal mortality through early population policies, community-based family planning, and improved access to healthcare facilities, supported by decentralised health systems and private sector growth [21].

The prevalence of neonatal disorders saw an increased trend in 2021. This can be attributed largely to advances in medical technology and healthcare systems that have significantly improved survival rates, even for infants with severe conditions [12, 16]. However, mortality rates and DALYs have decreased due to improved management and treatment of neonatal disorders, such as neonatal sepsis, where enhanced healthcare interventions have reduced deaths despite a rise in incidence [22, 23]. There was a drastic increase in prevalence of neonatal encephalopathy due to birth asphyxia and trauma between 1990 and 2021 which can be related to the fact that neonatal encephalopathy due to birth asphyxia and trauma is a complex condition with multiple potential causes, including hypoxic ischemic encephalopathy, infections, placental abnormalities, metabolic disorders, and more [24]. This complexity makes it challenging to pinpoint a single cause, contributing to its high prevalence. Despite this significant rise, there is currently no conclusive evidence that fully explains the magnitude of this increase, indicating a need for further research into the underlying causes of this trend.

The prevalence of neonatal disorders was high in India compared to other countries but mortality associated with neonatal disorders remains alarmingly high in Pakistan. Poor delivery systems, outdated hospital facilities, and insufficient healthcare funding all these factors contribute to the country's low newborn survival rate [19]. The high number DALYs associated with neonatal disorders in Pakistan further underscores the inadequate infrastructure for newborn care. Unlike under-five mortality, which is more dependent on public health interventions, neonatal mortality is closely linked to the quality of care provided around the time of birth. Pakistan's Healthcare Access and Quality Index score, ranked 154th out of 195 countries, highlights these critical gaps in the health system [25]. In 2021, preterm birth, recognized as the leading cause of neonatal mortality [26], resulted in the highest mortality rates in India compared to all other countries. Previous studies suggest that contributing factors may include intrauterine hypoxia, congenital infections, maternal hypertensive disorders, and placental complications, particularly maternal and fetal vascular malperfusion and placental abruption [27]. Addressing these issues is crucial for improving neonatal outcomes and reducing mortality rates among preterm infants.

Among all the countries in South Asia, only Bangladesh is on track to achieve the SDG 3.2 target for neonatal mortality by 2030. While Nepal, India, and Bhutan have made substantial progress in reducing neonatal mortality rates, they are not yet projected to meet the SDG target without accelerating their efforts. In contrast, Pakistan remains significantly behind, facing persistent challenges that hinder its progress towards improving neonatal health outcomes. The projected mortality rates for Pakistan indicate that the country will achieve only a five-point reduction in neonatal mortality by 2031 from the 2022. With the current annual rate of reduction in neonatal mortality standing at 2.1%, it is evident that Pakistan is unlikely to meet the SDG target for neonatal mortality by 2030 [28]. To reach this goal, Pakistan would require an annual rate of reduction of 11.6%, which presents a significant challenge. A previous study had already predicted that Pakistan would not meet the SDG target for neonatal mortality by 2030, with estimates suggesting that the goal may only be achieved after 2050 [29].

Since 1990, global under-5 mortality has decreased significantly by 56%, from 5.8 million in 2000 to 2.6 million in 2022 [30]. However, the proportion of deaths occurring within the neonatal period has increased, from 41% of under-5 deaths in 2000 to 47% in 2022. This rise in neonatal mortality is closely linked to complications around the time of birth, which often result from poor maternal health or inadequate quality of care [31]. Although neonatal

mortalities are preventable and effective interventions do exist but the coverage is still very low [32]. Reducing neonatal mortality requires a multifaceted approach that addresses both healthcare access and quality. First and foremost, improving maternal health through proper prenatal care and education is crucial [31]. Ensuring that expectant mothers receive regular checkups, nutritional support, and education on safe delivery practices can significantly reduce complications. Additionally, strengthening healthcare infrastructure by equipping hospitals and clinics with essential medical supplies and trained healthcare professionals ensures better care during birth. Expanding access to skilled birth attendants, promoting early and exclusive breastfeeding, and implementing effective infection control measures also play pivotal roles [33]. Investment in neonatal intensive care units and early detection of high-risk pregnancies through advanced diagnostic tools can further help in preventing neonatal deaths [34].

The GBD study, while comprehensive in quantifying global health loss, faces several limitations [35–40], especially when applied to smaller countries like Nepal and Bhutan. One major limitation is the lack of primary data, as the study may struggle to obtain sufficient observed data to inform its estimates [41]. The use of uniform severity distributions across time and location can also hinder its ability to capture changes in disease severity over time or across regions [41]. GBD estimates may be based on incomplete information from samples, potentially leading to gaps in understanding [42]. There is also a risk of biases if the estimates rely on data from subgroups not representative of the entire population [43].

Despite significant reductions in neonatal mortality, South Asia continues to face substantial challenges related to the growing burden of neonatal disorders, reflected in the increased prevalence and DALYs. Countries such as Bangladesh and India have made notable progress in reducing neonatal mortality, while Pakistan is projected to maintain high mortality rates until at least 2031. To meet the SDG target for neonatal mortality by 2030, intensified efforts are required. These efforts should focus on identifying high-risk pregnancies and improving the quality of care during childbirth to address the root causes and reduce preventable neonatal deaths.

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Declarations

Conflict of Interest The authors declare no competing interests.

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