Socioeconomic inequality in neonatal mortality in countries of low and middle income: a multicountry analysis

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Summary

Background Neonatal mortality rates (NMRs) in countries of low and middle income have been only slowly decreasing; coverage of essential maternal and newborn health services needs to increase, particularly for disadvantaged populations. Our aim was to produce comparable estimates of changes in socioeconomic inequalities in NMR in the past two decades across these countries.

Methods We used data from Demographic and Health Surveys (DHS) for countries in which a survey was done in 2008 or later and one about 10 years previously. We measured absolute inequalities with the slope index of inequality and relative inequalities with the relative index of inequality. We used an asset-based wealth index and maternal education as measures of socioeconomic position and summarised inequality estimates for all included countries with random-effects meta-analysis.

Findings 24 low-income and middle-income countries were eligible for inclusion. In most countries, absolute and relative wealth-related and educational inequalities in NMR decreased between survey 1 and survey 2. In five countries (Cameroon, Nigeria, Malawi, Mozambique, and Uganda), the difference in NMR between the top and bottom of the wealth distribution was reduced by more than two neonatal deaths per 1000 livebirths per year. By contrast, wealth-related inequality increased by more than 1·5 neonatal deaths per 1000 livebirths per year in Ethiopia and Cambodia. Patterns of change in absolute and relative educational inequalities in NMR were similar to those of wealth-related NMR inequalities, although the size of educational inequalities tended to be slightly larger.

Interpretation Socioeconomic inequality in NMR seems to have decreased in the past two decades in most countries of low and middle income. However, a substantial survival advantage remains for babies born into wealthier households with a high educational level, which should be considered in global efforts to further reduce NMR.

Funding Canadian Institutes of Health Research.

Lancet Glob Health 2014; 2: e165–173

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Introduction

In 2011, an estimated 3 million children died in the first 4 weeks of life.[1] More than 98% of these neonatal deaths occurred in low-income and middle-income countries (LMICs), and more than three-quarters in sub-Saharan Africa and south Asia.[1] Most neonatal deaths can be avoided with effective low-cost interventions, such as clean delivery practices, exclusive breastfeeding, and access to emergency obstetric and neonatal care.[2] Yet despite broad international consensus about the interventions needed to reduce neonatal mortality rates (NMRs), essential services are clearly not reaching many of the women and newborn babies who need them most.[3] A major challenge is to establish how to expand access to essential interventions, particularly in disadvantaged populations and areas with poor access to health services. Understanding of the social and geographical pattern of NMR is thus crucial for policy makers and planners to expand access to effective interventions that will improve neonatal survival.

Addressing of large and persistent health inequalities has become an important objective of national governments and international organisations.[4,5] Monitoring and description of inequalities across countries and with time can identify patterns and inconsistencies across different populations and serve as a valuable way to examine why inequalities are larger in some populations than in others.[6] A cross-country comparative approach has been used to describe socioeconomic inequalities in mortality of children younger than 5 years[7] and coverage of maternal, neonatal, and child health interventions.[8,9] Although inequalities in NMR favouring higher-income communities have been documented in a few LMIC settings,[10–13] inequalities in many countries have not been described with measures of socioeconomic position and inequality metrics that can be used for comparisons across countries. Furthermore, little is known about how socioeconomic inequalities in NMR have changed with time within LMICs.

A study from India[10] showed that the magnitude of the wealth-related concentration index for neonatal mortality changed little between 1992 and 2005, despite a decrease in NMR and an increase in skilled delivery care resulting from widespread maternal and child health programmes. Other evidence suggests that expansion of health interventions within existing health services could

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differentially benefit advantaged populations—at least initially—leading to increased socioeconomic inequalities in use of health services and health outcomes.[14,15] Such an increase has been reported for child health inequalities in Brazil.[14] Additionally, a study from two regions in Bangladesh[12] showed that an increase in maternal and child health interventions was accompanied by an increase in inequality in NMR between advantaged and disadvantaged populations in a period of 15 years.[12]

Because coverage of essential neonatal survival interventions such as antenatal care, skilled birth attendance, and emergency obstetric care have increased in the past two decades in most LMICs, whether these interventions are exacerbating the socioeconomic gap in neonatal mortality needs to be established.[16] Increasing inequalities might suggest a need for programmes and policies specifically aimed at socioeconomically disadvantaged populations. Our aim was to produce comparable estimates of changes in wealth-related and educational inequalities in NMR in the past two decades across LMICs.

	Survey 1		Survey 2		Time between surveys 1 and 2 (years)
	Year	Sample size	Year	Sample size	
West, north, and central Africa					
Burkina Faso	1998–99	11 805	2010	29 773	11
Cameroon	1998	7956	2011	22 311	13
Egypt	2000	22 915	2008	21 786	8
Gabon	2000	8466	2012	11 227	12
Ghana	1998	6611	2008	5881	10
Nigeria	2003	11 573	2008	55 594	5
Senegal	1997	14 677	2010–11	23 414	13
Southern and east Africa					
Ethiopia	2000	21 755	2011	23 780	11
Kenya	1998	11 283	2008–09	11 645	10
Madagascar	1997	11 476	2008–09	25 344	11
Malawi	2000	22 064	2010	38 945	10
Mozambique	2003	19 785	2011	20 690	8
Rwanda	2000	14 872	2011	17 587	11
Tanzania	1999	6198	2010	15 219	11
Uganda	2000–01	13 272	2011	15 180	10
Zimbabwe	1999	6978	2010–11	10 075	11
South and southeast Asia					
Bangladesh	1999–2000	13 865	2011	18 611	11
Cambodia	2000	20 338	2010	16 198	10
Nepal	2001	14 125	2011	11 292	10
Philippines	1998	16 279	2008	13 389	10
Latin America and Caribbean					
Bolivia	1998	14 747	2008	18 328	10
Colombia	2000	9463	2010	36 945	10
Haiti	2000	13 426	2012	14 001	12
Peru	2000	29 225	2010	19 114	10

Table 1: **Survey characteristics**

Methods

Data sources

We used data from Demographic and Health Surveys (DHS) done between 1997 and 2012. The DHS are comparable household surveys that provide information about sociodemographic characteristics and health indicators such as maternal and child health, nutrition, HIV/AIDS, malaria, and family planning. A household questionnaire is used to obtain data for demographic and socioeconomic characteristics, and information about the environmental conditions of each household. Additionally, a sex-specific questionnaire is given to all women aged 15–49 years who spent the night before the survey in the household in question, which provides information about their characteristics (eg, age and education level) and complete birth histories. For all livebirths, birth histories include the month and year of birth and the child's present vital status. Mothers of children who have died are asked to report the age at death in days if the death occurred in the first 30 days of life, in months if it occurred between 1 and 23 months, and in years when the child was aged 2 years and older. We included livebirths that occurred in the 10 years before the date of interview. For our analysis, we included countries in which data were available from two surveys: one from 2008 or later, and one about 10 years before this most recent survey.

Measures

Neonatal mortality includes children who were born alive but died within the first 30 days of life. We examined changes in NMR inequalities with time for two dimensions of socioeconomic position: maternal education and household wealth. Education was measured as the reported number of years of maternal education. Household wealth was estimated in the DHS with an asset-based index that combines information about ownership of consumer goods, housing quality, and water and sanitation facilities.[17] A wealth index is estimated separately for each survey with principal components analysis, sometimes using slightly different assets that are relevant in each country. As such, each household's wealth score represents its position in the wealth distribution relative to other households within the country. Asset-based measures of household wealth are widely used and show consistent results when compared with household expenditures in the measurement of inequalities in child mortality, education, and health-care use.[18]

Statistical analysis

We examined absolute socioeconomic inequalities in NMR with the slope index of inequality (SII) and relative socioeconomic inequalities with the relative index of inequality (RII).[19] Because absolute and relative measures can lead to different conclusions about the size of and changes in inequalities, examination of both measures is important to present a complete picture of inequalities.[20]

Additionally, by contrast with common measures that compare only extreme groups (eg, the richest and poorest wealth quintiles), such as the rate difference and rate ratio, the SII and RII measure inequality across the entire distribution of socioeconomic position. We calculated the SII by regressing neonatal mortality outcomes against an individual's relative rank in the cumulative distribution of socioeconomic position. The relative socioeconomic ranks range from 0 (poorest) to 1 (richest), so the coefficient for the rank variable (ie, the slope) represents the estimated difference in NMR between the bottom and top of the socioeconomic distribution. Because neonatal mortality is a binary outcome, we used a logistic regression model and estimated average marginal effects on the risk scale with the *margins* command in Stata (version 12.1).[21] We obtained the RII by dividing SII estimates by mean NMR for every survey.[19] The RII represents the proportionate difference in NMR across the distribution of socioeconomic position.

To summarise changes in absolute and relative inequality in NMR with time, we pooled SII and RII estimates across the included countries for the two periods with random-effects meta-analysis. This approach combines survey-specific SII estimates with the DerSimonian and Laird inverse-variance method and does not assume a common homogeneous estimate of socioeconomic differences in NMR across all countries.[22] Finally, we assessed the extent to which educational and wealth-related inequalities in NMR could be statistically explained by other socioeconomic and geographic determinants. We included four variables in the regression models used to estimate the inequality indices: urban versus rural residence; region, state, or province; household wealth (for educational inequality); and education (for wealth-related inequality). We used sampling weights in all analyses and adjusted standard errors for clustering at the level of primary sampling unit.

	Mean number of neonatal deaths per 1000 livebirths				Mean years of maternal education			
	Survey 1	Survey 2	Difference between survey 2 and survey 1	Annual change*	Survey 1	Survey 2	Difference between survey 2 and survey 1	Annual change*
West, north, and central Africa								
Burkina Faso	43·3	34·1	−9·1 (−14·4 to −3·8)	−0·8	0·4	0·8	0·4 (0·2 to 0·6)	0·04
Cameroon	40·5	32·4	−8·2 (−14·2 to −2·1)	−0·6	4·2	4·6	0·4 (0·3 to 1·1)	0·03
Egypt	28·7	17·4	−11·3 (−14·8 to −7·8)	−1·4	5·2	7·2	2·0 (1·6 to 2·4)	0·25
Gabon	31·6	25·0	−6·6 (−14·1 to 0·9)	−0·6	6·5	7·5	1·0 (0·6 to 1·4)	0·08
Ghana	32·2	32·4	0·2 (−7·7 to 8·0)	0·0	4·6	4·9	0·3 (−0·2 to 0·8)	0·03
Nigeria	53·0	45·8	−7·1 (−13·4 to −0·8)	−1·4	3·6	4·4	0·8 (0·1 to 1·5)	0·16
Senegal	37·7	32·1	−5·6 (−10·7 to −0·5)	−0·4	1·4	1·5	0·1 (−0·2 to 0·4)	0·01
Southern and east Africa								
Ethiopia	57·9	42·4	−15·5 (−22·1 to −9·0)	−1·4	0·7	1·2	0·5 (0·3 to 0·7)	0·05
Kenya	26·8	33·2	6·4 (0·0 to 12·7)	0·6	6·4	6·9	0·5 (0·1 to 0·9)	0·05
Madagascar	40·1	24·1	−16·0 (−21·0 to −11·0)	−1·5	3·2	3·3	0·1 (−0·2 to 0·4)	0·01
Malawi	45·4	33·1	−12·3 (−16·8 to −7·8)	−1·2	3·2	4·5	1·3 (1·0 to 1·6)	0·13
Mozambique	47·2	31·9	−15·3 (−21·0 to −9·5)	−1·9	1·9	2·8	0·9 (0·7 to 1·1)	0·11
Rwanda	49·9	29·3	−20·6 (−26·1 to −15·0)	−1·9	3·3	3·8	0·5 (0·3 to 0·7)	0·05
Tanzania	45·2	27·5	−17·7 (−25·1 to −10·4)	−1·6	4·5	4·9	0·4 (0·0 to 0·8)	0·04
Uganda	34·5	30·2	−4·2 (−9·7 to 1·2)	−0·4	3·8	4·8	1·0 (0·7 to 1·3)	0·10
Zimbabwe	26·1	27·8	1·7 (−5·6 to 9·0)	0·2	7·1	8·7	1·6 (1·3 to 1·9)	0·15
South and southeast Asia								
Bangladesh	50·2	36·0	−14·3 (−19·8 to −8·8)	−1·3	2·7	4·7	2·0 (1·7 to 2·3)	0·18
Cambodia	38·9	31·1	−7·8 (−13·0 to −2·7)	−0·8	2·8	4·0	1·2 (1·0 to 1·4)	0·12
Nepal	47·3	34·9	−12·4 (−18·9 to −5·8)	−1·2	1·2	3·0	1·8 (1·4 to 2·2)	0·18
Philippines	19·1	16·6	−2·5 (−5·9 to 1·0)	−0·3	8·3	9·9	1·6 (1·3 to 1·9)	0·16
Latin America and Caribbean								
Bolivia	36·1	30·7	−5·5 (−11·0 to 0·1)	−0·6	5·6	6·8	1·2 (0·9 to 1·5)	0·12
Colombia	16·2	11·7	−4·4 (−7·8 to −1·1)	−0·4	6·8	8·4	1·6 (1·3 to 1·9)	0·16
Haiti	35·8	31·7	−4·0 (−11·1 to 3·0)	−0·3	2·4	4·5	2·0 (1·7 to 2·5)	0·17
Peru	22·4	10·8	−11·6 (−14·7 to −8·4)	−1·2	7·2	8·5	1·2 (1·0 to 1·6)	0·12

Data in parentheses are 95% CIs. *Difference between survey 2 and survey 1 divided by the number of years between the two surveys.

Table 2: **Changes in neonatal mortality rates and mean years of maternal education between surveys 1 and 2, by country**

	Absolute inequality			Relative inequality		
	SII for survey 1*	SII for survey 2*	Annual change†	RII for survey 1	RII for survey 2	Annual change†
West, north, and central Africa						
Burkina Faso	−7·0 (−20·6 to 6·6)	−12·4 (−21·0 to −3·9)	−0·5 (−1·8 to 0·9)	−0·16 (−0·48 to 0·15)	−0·36 (−0·62 to −0·11)	−0·02 (−0·05 to 0·02)
Cameroon	−37·6 (−59·6 to −15·5)	−10·5 (−21·3 to 0·3)	2·1 (0·2 to 4·0)	−0·93 (−1·47 to −0·38)	−0·32 (−0·66 to 0·01)	0·05 (0·00 to 0·10)
Egypt	−13·9 (−23·1 to −4·8)	−9·4 (−16·7 to −2·1)	0·6 (−0·9 to 2·0)	−0·48 (−0·80 to −0·17)	−0·54 (−0·96 to −0·12)	−0·01 (−0·07 to 0·06)
Gabon	4·7 (−11·8 to 21·3)	1·9 (−14·4 to 18·1)	−0·2 (−2·2 to 1·7)	0·15 (−0·37 to 0·67)	0·07 (−0·57 to 0·72)	−0·01 (−0·08 to 0·06)
Ghana	−13·5 (−28·7 to 1·6)	1·8 (−16·2 to 19·9)	1·5 (−0·8 to 3·9)	−0·42 (−0·89 to 0·05)	0·06 (−0·50 to 0·61)	0·05 (−0·03 to 0·12)
Nigeria	−38·5 (−58·4 to −18·5)	−18·2 (−26·5 to −10·0)	4·0 (−0·3 to 8·4)	−0·73 (−1·10 to −0·35)	−0·40 (−0·58 to −0·22)	0·07 (−0·02 to 0·15)
Senegal	−28·9 (−43·6 to −14·3)	−13·7 (−24·4 to −3·0)	1·2 (−0·2 to 2·6)	−0·77 (−1·16 to −0·38)	−0·43 (−0·76 to −0·09)	0·03 (−0·01 to 0·07)
Southern and east Africa						
Ethiopia	4·5 (−10·6 to 19·6)	−19·4 (−33·5 to −5·4)	−2·2 (−4·0 to −0·3)	0·08 (−0·18 to 0·34)	−0·46 (−0·79 to −0·13)	−0·05 (−0·09 to −0·01)
Kenya	−15·1 (−28·8 to −1·5)	−11·0 (−28·7 to 6·7)	0·4 (−1·8 to 2·6)	−0·56 (−1·07 to −0·06)	−0·33 (−0·86 to 0·20)	0·02 (−0·05 to 0·10)
Madagascar	−7·7 (−22·3 to 6·9)	−1·6 (−10·1 to 7·0)	0·6 (−1·0 to 2·1)	−0·19 (−0·55 to 0·17)	−0·06 (−0·42 to 0·29)	0·01 (−0·03 to 0·06)
Malawi	−20·5 (−33·0 to −8·0)	1·0 (−7·6 to 9·6)	2·2 (0·6 to 3·7)	−0·45 (−0·73 to −0·18)	0·03 (−0·23 to 0·29)	0·05 (0·01 to 0·09)
Mozambique	−35·7 (−53·6 to −17·8)	0·3 (−10·5 to 11·1)	4·5 (1·9 to 7·1)	−0·76 (−1·13 to −0·38)	0·01 (−0·33 to 0·35)	0·10 (0·03 to 0·16)
Rwanda	−20·4 (−34·0 to −6·8)	−8·4 (−18·8 to 1·9)	1·1 (−0·5 to 2·6)	−0·41 (−0·68 to −0·14)	−0·29 (−0·64 to 0·07)	0·01 (−0·03 to 0·05)
Tanzania	7·4 (−13·9 to 28·8)	14·6 (3·4 to 25·8)	0·7 (−0·8 to 2·1)	0·16 (−0·31 to 0·64)	0·53 (0·12 to 0·94)	0·03 (−0·02 to 0·09)
Uganda	−12·9 (−25·6 to −0·2)	9·9 (−2·1 to 22·0)	2·1 (0·5 to 3·7)	−0·37 (−0·74 to −0·01)	0·33 (−0·07 to 0·73)	0·06 (0·01 to 0·11)
Zimbabwe	0·6 (−11·7 to 13·0)	−6·3 (−22·1 to 9·4)	−0·6 (−2·3 to 1·1)	0·02 (−0·45 to 0·50)	−0·23 (−0·80 to 0·34)	−0·02 (−0·08 to 0·04)
South and southeast Asia						
Bangladesh	−25·8 (−39·7 to −11·9)	−17·7 (−28·3 to −7·0)	0·7 (−0·8 to 2·1)	−0·51 (−0·79 to −0·24)	−0·49 (−0·79 to −0·20)	0·00 (−0·03 to 0·04)
Cambodia	−10·8 (−22·7 to 1·2)	−26·4 (−38·0 to −14·8)	−1·6 (−3·2 to 0·1)	−0·28 (−0·58 to 0·03)	−0·85 (−1·22 to −0·48)	−0·06 (−0·11 to −0·01)
Nepal	−15·2 (−29·3 to −1·1)	−14·4 (−28·5 to −0·3)	0·1 (−1·9 to 2·1)	−0·32 (−0·62 to −0·02)	−0·41 (−0·82 to −0·01)	−0·01 (−0·06 to 0·04)
Philippines	−9·0 (−17·4 to −0·6)	−10·7 (−19·5 to −1·9)	−0·2 (−1·4 to 1·0)	−0·47 (−0·91 to −0·03)	−0·64 (−1·17 to −0·12)	−0·02 (−0·09 to 0·05)
Latin America and Caribbean						
Bolivia	−53·5 (−69·0 to −38·1)	−41·3 (−54·4 to −28·3)	1·2 (−0·8 to 3·2)	−1·48 (−1·91 to −1·05)	−1·35 (−1·78 to −0·92)	0·01 (−0·05 to 0·07)
Colombia	−9·1 (−18·3 to 0·2)	−2·0 (−7·4 to 3·3)	0·7 (−0·4 to 1·8)	−0·56 (−1·13 to 0·01)	−0·17 (−0·63 to 0·29)	0·04 (−0·03 to 0·11)
Haiti	−7·4 (−25·4 to 10·7)	−0·1 (−13·0 to 12·8)	0·6 (−1·2 to 2·5)	−0·21 (−0·71 to 0·30)	−0·00 (−0·41 to 0·40)	0·02 (−0·04 to 0·07)
Peru	−28·2 (−36·1 to −20·3)	−10·0 (−17·4 to −2·7)	1·8 (0·7 to 2·9)	−1·26 (−1·61 to −0·91)	−0·93 (−1·61 to −0·25)	0·03 (−0·04 to 0·11)
All countries‡	−16·1 (−21·3 to −10·8)	−8·5 (−12·7 to −4·3)	0·7 (0·2 to 1·2)	−0·45 (−0·61 to −0·30)	−0·30 (−0·44 to −0·15)	0·01 (0·00 to 0·03)

Data in parentheses are 95% CIs. SII=slope index of inequality. RII=relative index of inequality. *Change in mean number of neonatal deaths per 1000 livebirths. †Difference between survey 2 and survey 1 divided by the number of years between the two surveys; positive values indicate a reduction in wealth-related inequality. ‡Pooled estimates from random effects meta-analysis, for which the inverse-variance DerSimonian and Laird method was used.

Table 3: **Changes in absolute and relative wealth-related inequality in neonatal mortality, by country**

Role of the funding source

The sponsor of the study had no role in study design, data analysis data collection, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study; all authors had final responsibility for the decision to submit for publication.

Results

24 countries were eligible for inclusion (table 1). We included Nigeria although the two surveys were done only 5 years apart, because the country accounts for about 15% of all neonatal deaths in Africa.[23] The survey sample sizes varied greatly between countries (table 1). Generally, sample sizes tended to be larger in survey 2 than in survey 1 (table 1). Median time between surveys 1 and 2 was 11 years (IQR 10–12).

Mean NMR varied across countries and with time (table 2). In nearly all countries, NMR decreased between the first and second survey (table 2). In 11 of the 24 countries, the estimated decrease in mean NMR was greater than one neonatal death per 1000 livebirths per year (table 2). Only in Kenya was there robust evidence that NMR increased (table 2). Years of maternal education varied greatly across countries (table 2). The point estimates for educational attainment increased with time in all countries, although several of the CIs crossed the null value (table 2).

In most countries, the SII and RII estimates for both surveys suggest inequality favouring higher-income communities in NMR (table 3). For example, the SII for Nigeria in survey 2 is –18·2 (95% CI –26·5 to –10·0), signifying that moving from the bottom to the top of the wealth distribution is associated with an estimated 18·2 fewer neonatal deaths per 1000 livebirths. The corresponding RII is –0·40 (–0·58 to –0·22), indicating that the NMR is 40% lower for babies born into

	Absolute inequality			Relative inequality		
	SII for survey 1*	SII for survey 2*	Annual change†	RII for survey 1	RII for survey 2	Annual change†
West, north, and central Africa						
Burkina Faso	−1·3 (−28·9 to 26·2)	−23·5 (−41·6 to −5·4)	−1·8 (−4·6 to 0·9)	−0·03 (−0·67 to 0·60)	−0·69 (−1·22 to −0·16)	−0·05 (−0·12 to 0·01)
Cameroon	−48·2 (−70·9 to −25·5)	−11·6 (−22·2 to −0·9)	2·8 (0·9 to 4·8)	−1·19 (−1·75 to −0·63)	−0·36 (−0·69 to −0·03)	0·06 (0·01 to 0·11)
Egypt	−19·0 (−28·7 to −9·2)	−9·4 (−16·3 to −2·5)	1·2 (−0·3 to 2·7)	−0·66 (−1·00 to −0·32)	−0·54 (−0·94 to −0·15)	0·02 (−0·05 to 0·08)
Gabon	−2·4 (−18·2 to 13·4)	−5·9 (−21·6 to 9·7)	−0·3 (−2·1 to 1·6)	−0·08 (−0·57 to 0·42)	−0·24 (−0·86 to 0·39)	−0·01 (−0·08 to 0·05)
Ghana	−13·5 (−31·0 to 3·9)	−18·9 (−39·9 to 2·2)	−0·5 (−3·3 to 2·2)	−0·42 (−0·96 to 0·12)	−0·58 (−1·23 to 0·07)	0·02 (−0·10 to 0·07)
Nigeria	−34·3 (−59·2 to −9·4)	−15·4 (−24·1 to −6·7)	3·8 (−1·5 to 9·0)	−0·65 (−1·12 to −0·18)	−0·34 (−0·52 to −0·15)	0·06 (−0·04 to 0·16)
Senegal	−45·5 (−69·8 to −21·3)	−5·3 (−19·2 to 8·6)	3·1 (1·0 to 5·3)	−1·21 (−1·85 to −0·57)	−0·16 (−0·60 to 0·27)	0·08 (0·02 to 0·14)
Southern and east Africa						
Ethiopia	−54·3 (−86·6 to −22·0)	−28·4 (−47·9 to −9·0)	2·3 (−1·1 to 5·7)	−0·94 (−1·50 to −0·38)	−0·67 (−1·13 to −0·21)	0·02 (−0·04 to 0·09)
Kenya	−15·2 (−26·9 to −3·4)	−18·2 (−35·3 to −1·0)	−0·3 (−2·4 to 1·8)	−0·57 (−1·00 to −0·13)	−0·55 (−1·07 to −0·03)	0·00 (−0·07 to 0·07)
Madagascar	−21·6 (−35·7 to −7·5)	−3·1 (−11·5 to 5·3)	1·7 (0·2 to 2·3)	−0·54 (−0·89 to −0·19)	−0·13 (−0·47 to 0·22)	0·04 (−0·01 to 0·08)
Malawi	−17·5 (−30·3 to −4·7)	−0·6 (−8·9 to 7·7)	1·7 (0·2 to 3·2)	−0·39 (−0·67 to −0·10)	−0·02 (−0·27 to 0·23)	0·04 (−0·00 to 0·07)
Mozambique	−28·5 (−46·1 to −10·9)	−2·2 (−13·4 to 8·9)	3·3 (0·7 to 5·9)	−0·60 (−0·98 to −0·23)	−0·07 (−0·42 to 0·28)	0·07 (0·00 to 0·13)
Rwanda	−40·0 (−56·9 to −23·1)	−7·3 (−17·5 to 2·8)	3·0 (1·2 to 4·8)	−0·80 (−1·13 to −0·46)	−0·25 (−0·60 to 0·10)	0·05 (0·01 to 0·09)
Tanzania	−20·6 (−51·7 to 10·4)	6·5 (−5·5 to 18·5)	2·5 (−0·6 to 5·5)	−0·46 (−1·14 to 0·23)	0·24 (−0·20 to 0·67)	0·06 (−0·01 to 0·14)
Uganda	−12·9 (−25·2 to −0·5)	2·7 (−9·7 to 15·2)	1·4 (−0·2 to 3·0)	−0·37 (−0·73 to −0·02)	0·09 (−0·32 to 0·50)	0·04 (−0·01 to 0·09)
Zimbabwe	−24·3 (−40·6 to −8·0)	−15·5 (−31·8 to 0·8)	0·7 (−1·2 to 2·7)	−0·93 (−1·55 to −0·31)	−0·56 (−1·14 to 0·03)	0·03 (−0·04 to 0·10)
South and southeast Asia						
Bangladesh	−22·8 (−38·1 to −7·4)	−18·6 (−31·4 to −5·9)	0·4 (−1·3 to 2·0)	−0·45 (−0·76 to −0·15)	−0·52 (−0·87 to −0·16)	−0·01 (−0·04 to 0·03)
Cambodia	−16·7 (−28·6 to −4·7)	−23·8 (−36·9 to −10·6)	−0·7 (−2·5 to 1·1)	−0·43 (−0·74 to −0·12)	−0·76 (−1·19 to −0·34)	−0·03 (−0·09 to 0·02)
Nepal	−45·4 (−69·9 to −20·9)	−24·5 (−42·0 to −7·0)	2·1 (−0·9 to 5·1)	−0·96 (−1·48 to −0·44)	−0·70 (−1·20 to −0·20)	0·03 (−0·05 to 0·10)
Philippines	−13·1 (−21·8 to −4·5)	−9·2 (−17·6 to −0·7)	0·4 (−0·8 to 1·6)	−0·69 (−1·14 to −0·24)	−0·55 (−1·06 to −0·05)	0·01 (−0·05 to 0·08)
Latin America and Caribbean						
Bolivia	−50·6 (−66·4 to −34·7)	−39·2 (−53·4 to −25·1)	1·1 (−1·0 to 3·3)	−1·40 (−1·84 to −0·96)	−1·28 (−1·74 to −0·82)	0·01 (−0·05 to 0·08)
Colombia	−12·4 (−22·1 to −2·7)	−5·5 (−10·8 to −0·1)	0·7 (−0·4 to 1·8)	−0·77 (−1·37 to −0·17)	−0·47 (−0·92 to −0·01)	0·03 (−0·04 to 0·11)
Haiti	−14·3 (−32·7 to 4·1)	−7·5 (−21·5 to 6·5)	0·6 (−1·4 to 2·5)	−0·40 (−0·91 to 0·12)	−0·24 (−0·68 to 0·20)	0·01 (−0·04 to 0·07)
Peru	−25·7 (−33·8 to −17·7)	−13·4 (−20·3 to −6·6)	1·2 (0·2 to 2·3)	−1·15 (−1·51 to −0·79)	−1·25 (−1·88 to −0·61)	−0·01 (−0·08 to 0·06)
All countries‡	−22·8 (−27·7 to −18·0)	−10·9 (−14·5 to −7·3)	1·1 (0·7 to 1·6)	−0·66 (−0·79 to −0·53)	−0·41 (−0·54 to −0·27)	0·02 (0·01 to 0·04)

Data in parentheses are 95% CIs. SII=slope index of inequality. RII=relative index of inequality. *Change in mean number of neonatal deaths per 1000 livebirths. †Difference between survey 2 and survey 1 divided by the number of years between the two surveys; positive values indicate a reduction in educational inequality. ‡Pooled estimates from random effects meta-analysis, for which the inverse-variance DerSimonian and Laird method was used.

Table 4: **Changes in absolute and relative educational inequality in neonatal mortality, by country**

households at the top of the wealth distribution than for those at the bottom. Generally, the differences in the SIIs and RIIs between the two surveys suggest a reduction in wealth-related NMR inequality in most countries between the first and second surveys (table 3). In five countries (Cameroon, Nigeria, Malawi, Mozambique, and Uganda), the difference in mean NMR between the top and bottom of the wealth distribution was reduced by more than two neonatal deaths per 1000 livebirths per year between the two surveys. By contrast, wealth-related inequality increased by more than 1·5 neonatal deaths per 1000 livebirths per year in Ethiopia and Cambodia.

The meta-analysis for all countries showed that the absolute gap between the top and bottom of the wealth distribution decreased between the two surveys (table 3). The relative inequality across all countries decreased between the two surveys, although the confidence interval for the annual change between the two periods crossed zero (table 3). Although these pooled estimates are useful because they provide an idea of mean changes in NMR inequalities in LMICs, they do mask substantial heterogeneity between countries.

Generally, patterns of change in absolute and relative educational inequalities in NMR (table 4) are similar to those of wealth-related NMR inequalities, although the size of educational inequalities tended to be slightly larger. Education-related inequality in NMR decreased in 19 of the 24 countries (table 4). In Mozambique, Nigeria, Senegal, and Rwanda, the gap in NMR between the least and most educated narrowed by at least three neonatal deaths per 1000 livebirths per year (table 4). According to the pooled estimate across countries, both absolute and relative differences in NMR between the least and most educated reduced between the two surveys (table 4).

Most countries had a reduction in both relative and absolute wealth-related and educational inequality between

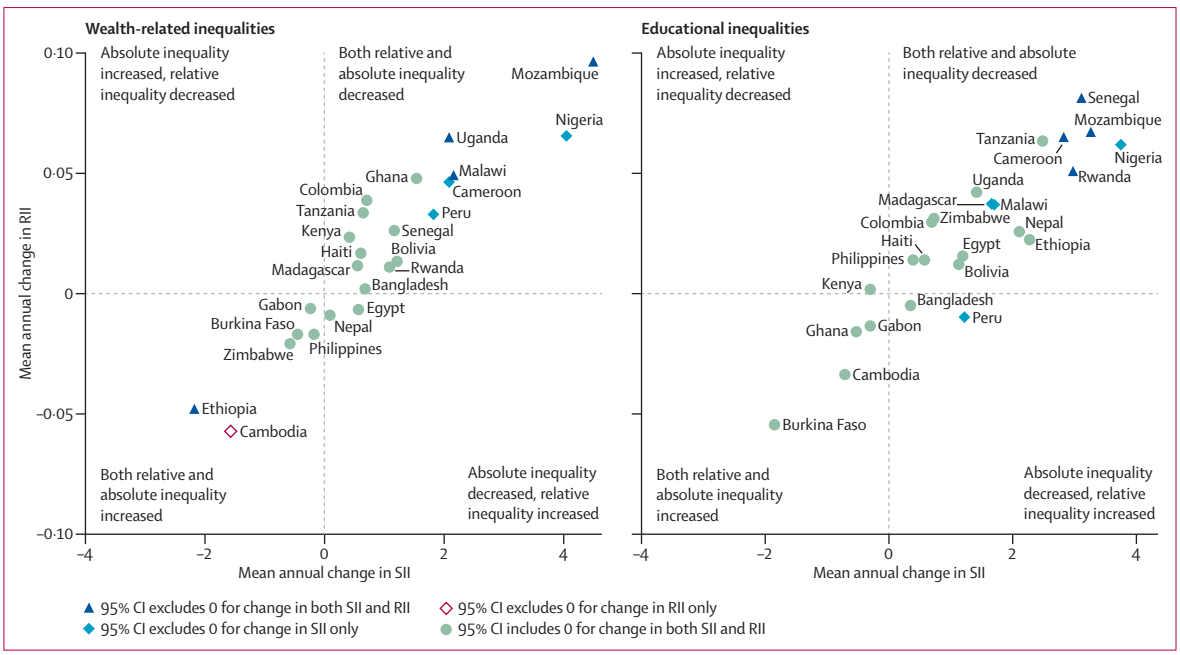

Figure: **The association between mean annual changes in relative and absolute socioeconomic inequalities in neonatal mortality in low-income and middle-income countries[24]**
SII=slope index of inequality. RII=relative index of inequality.

	Absolute inequality		Relative inequality	
	SII at survey 1	SII at survey 2	RII at survey 1	RII at survey 2
Wealth-related inequality				
Crude	−16·1 (−21·3 to −10·8)	−8·5 (−12·7 to −4·3)	−0·45 (−0·61 to −0·30)	−0·30 (−0·44 to −0·15)
Adjusted for urban *vs* rural location	−10·9 (−15·6 to −6·1)	−8·1 (−12·3 to −3·9)	−0·30 (−0·44 to −0·17)	−0·29 (−0·44 to −0·14)
Adjusted for education level	−8·7 (−13·6 to −3·7)	−5·0 (−9·0 to −0·9)	−0·24 (−0·38 to −0·11)	−0·17 (−0·31 to −0·03)
Adjusted for region, state, or province	−13·6 (−18·8 to −8·5)	−8·3 (−12·3 to −4·3)	−0·38 (−0·52 to −0·24)	−0·30 (−0·43 to −0·16)
Adjusted for all three determinants	−4·5 (−9·0 to 0·9)	−4·7 (−8·3 to −1·1)	−0·13 (−0·25 to 0·00)	−0·17 (−0·30 to −0·04)
Educational inequality				
Crude	−22·8 (−27·7 to −18·0)	−10·9 (−14·5 to −7·3)	−0·66 (−0·79 to −0·53)	−0·41 (−0·54 to −0·27)
Adjusted for urban *vs* rural location	−18·6 (−22·8 to −14·3)	−9·8 (−13·2 to −6·5)	−0·54 (−0·65 to −0·43)	−0·37 (−0·49 to −0·24)
Adjusted for wealth	−15·9 (−20·2 to −11·7)	−7·3 (−9·9 to −4·8)	−0·46 (−0·58 to −0·34)	−0·27 (−0·37 to −0·17)
Adjusted for region, state, or province	−19·1 (−23·3 to −14·8)	−10·1 (−13·6 to −6·6)	−0·56 (−0·67 to −0·45)	−0·37 (−0·50 to −0·24)
Adjusted for all three determinants	−16·1 (−26·4 to −5·8)	−13·0 (−19·6 to −6·4)	−0·50 (−0·78 to −0·22)	−0·53 (−0·79 to −0·27)

Data in parentheses are 95% CIs. Country-specific SII and RII estimates (adjusted for socioeconomic and regional determinants) were pooled with random effects meta-analysis, in which the inverse-variance DerSimonian and Laird method was used. SII=slope index of inequality. RII=relative index of inequality.

Table 5: **Pooled estimates of wealth-related and educational inequality in neonatal mortality, adjusted for socioeconomic and regional determinants**

See Online for appendix

the two surveys (figure). We recorded a strong linear association between the change in SII and the change in RII for wealth-related inequality (r=0·93, p<0·0001) and educational inequality (r=0·91, p<0·0001). Estimates for several countries—eg, Mozambique, Uganda, Cameroon, Malawi, Nigeria, Peru, and Senegal—show large decreases in wealth-related NMR inequality (figure). Substantial progress was also made in many of these countries to reduce the educational gradient in NMR (figure).

We recorded little evidence of an association between the mean change in NMR and changes in absolute (r=0·26, p=0·21) and relative (r=0·11, p=0·59) wealth-related inequality (appendix). However, countries in which the decrease in overall NMR was large tended to have increased reductions in absolute education-related inequality in NMR (r=–0·58, p=0·003; appendix). The association between the mean decrease in NMR and relative education-related inequality was somewhat weaker (r=–0·32, p=0·12; appendix).

A substantial proportion of wealth-related inequality in NMR across the 24 countries was explained by education and to a lesser extent urban versus rural residence (at least

in the first time period; table 5). Adjustment for wealth had the largest effect on educational inequality in NMR (table 5). However, substantial educational inequality remained after adjustment for all factors (table 5).

Discussion

We have shown that absolute and relative socioeconomic inequality in NMR decreased in most of the 24 LMICs included in our analysis in the course of about 10 years. This finding was true for both wealth-related and educational inequality in NMR, which showed similar patterns of change. However, despite overall trends indicating a reduction in NMR inequality, we recorded substantial heterogeneity in both the size and direction of NMR inequalities between countries. In a few countries, inequalities seem to have increased with time.

As far as we are aware, ours is the first study in which inequalities in NMR have been systematically examined across many LMICs (panel). Therefore, comparison with previous research is restricted. However, our results are largely consistent with research from a few low-income settings that has shown that NMR is increased in babies born to mothers of low socioeconomic position,[10,11] although different measures of socioeconomic position and inequality indices hinder direct comparison of the size of inequalities.

We identified large socioeconomic inequalities in NMR for a few countries. In Bolivia, SII estimates for 2008 indicated a difference in mean NMR of more 40 neonatal deaths per 1000 livebirths between the top and bottom of the wealth distribution, and a difference of about 39 neonatal deaths per 1000 livebirths for the education distribution. Although absolute socioeconomic inequality in Bolivia seemed to decrease between the 1998 and 2008 DHS surveys, our result seems to be consistent with other research that has suggested that essential maternal and child health services in Bolivia are not adequately reaching disadvantaged populations, particularly indigenous communities and those in rural areas.[29]

Previous research has suggested possible increasing trends in socioeconomic inequality in NMR,[12] so our findings that NMR inequalities did not seem to have widened in most of the 24 countries we examined is encouraging. Indeed, we have reported evidence of substantial reductions in wealth-related and education inequalities in NMR in several countries, such as Senegal and Rwanda. In both these countries, successful programmes have been implemented in the past decade that remove financial barriers for maternal and newborn health services,[30,31] which could have contributed to the decreases in NMR inequalities.

In a few countries—notably Ethiopia, Cambodia, and Burkina Faso—we identified substantial increases in wealth or educational inequalities in NMR, or both. Ethiopia and Burkina Faso are two of the poorest countries in the world, and both have high NMR and large socioeconomic disparities in coverage of maternal and child health services.[9] Cambodia also has a fairly high NMR, and evidence suggests that differences in facility-based deliveries and postnatal care between advantaged and disadvantaged populations increased between 2000 and 2010.[32] In all three countries, mean NMR fell substantially in the course of about 10 years. Increasing inequality but decreasing mean NMR is consistent with a situation in which affluent women with high educational attainment (most often living in urban areas) selectively benefit from improved access to delivery and emergency obstetric services. As countries scale up use of health services from initially low levels, early increases in inequality could be expected.[33] This so-called inverse equity hypothesis could explain increasing NMR inequalities in Ethiopia, Cambodia, and Burkina Faso.[14] If the hypothesis holds true, after the initial widening, NMR inequalities in these countries should begin to narrow.

We expect the predominant causes of neonatal mortality to differ greatly across the countries included our analysis, with infections and asphyxia predominating in high-mortality settings (eg, Ethiopia and Nigeria) and complications of preterm birth and malformations more common in settings with lower mortality (eg, Colombia and Peru).[34] Nevertheless, we recorded evidence that NMR inequalities generally persisted across countries with different mean NMRs, suggesting that intervention strategies in different mortality settings need to account for effects on inequalities. For example, in countries with low levels of antenatal care and skilled birth attendance, scaling up of these services to rural and underserved areas might be the most effective strategy to reduce NMR

Panel: Research in context

Systematic review

We systematically searched PubMed for reports published before Aug 30, 2013, using several keyword combinations of socioeconomic factors ("socioeconomic", "income", "wealth", or "education") in addition to "'neonatal' or 'newborn' and 'mortality' or 'death'". We also searched WHO and World Bank databases for relevant reports. We included reports published in English, French, or Spanish, and focused on those about low-income and middle-income countries or global analyses. We identified six national or subnational studies[10–12,25–28] in which socioeconomic differences in neonatal mortality rate (NMR) in a country of low or middle income was assessed, and just one multicountry study[11] in which inequalities in NMR were assessed across eight countries with Demographic and Health Survey data from surveys done before 2005. Additionally, we identified four studies—from Bangladesh,[12] Brazil,[27] Chile,[26] and India[10]—in which changes or trends in NMR inequalities were assessed. Previous research has had poor geographical scope and comparable measures of socioeconomic position or inequality have not been used, meaning that comparisons between countries have not been possible.

Interpretation

To our knowledge, ours is the first study to provide a systematic multicountry assessment of the size of socioeconomic inequalities and trends in NMR inequalities across many countries of low and middle income. Socioeconomic inequality in NMR has decreased in the past two decades in most low-income and middle-income countries. However, babies born into wealthier and more educated households have substantial survival advantage, which should be considered in global efforts to further reduce NMR.

inequalities. In countries with low mortality where most women already deliver in health-care facilities, efforts to improve access to hospital-based obstetric and newborn-care services might be needed.

Our study has provided the first systematic data for socioeconomic inequalities in NMR across many LMICs and can serve as a reference point for further research. However, several limitations need to be considered during interpretation of our results. Although retrospective birth histories obtained through household surveys are the only nationally representative sources of information about neonatal mortality for most births that occur in low-income countries, under-reporting of neonatal deaths that occur in the hours or days after birth, or misclassification of neonatal deaths as stillbirths are of particular concern for the validity of NMR estimates.[34] However, our aim was not to generate definitive estimates of NMR, but rather to estimate the magnitude of, and trends in, socioeconomic inequality in NMR. In this case, the validity of our inequality estimates will be most affected if neonatal deaths are under-reported in a systematic way that differs by socioeconomic factors. Although evidence of under-reporting of neonatal deaths by socioeconomic position is scarce, some evidence is available that misreporting of dates of birth and ages from DHS birth histories is increased for households with low education levels.[35] If mothers of low socioeconomic position are also less likely to report neonatal deaths or to misreport these deaths as stillbirths, this pattern will mean that the size of inequality estimates is underestimated. Finally, neonatal mortality is an infrequent outcome and, with small survey sample sizes, substantial uncertainty affected some of our estimates.

In conclusion, our results suggest that socioeconomic inequality in neonatal mortality has decreased in the past decade in most LMICs examined. However, a substantial survival advantage remains for babies born into wealthier households with a high educational level in most countries. The next step to extend our descriptive work is to understand why some countries have increased NMR inequalities or have experienced increases or reductions in inequalities. Research examining determinants of inequalities with a decomposition approach and assessments of maternal and child health policies in specific countries could be particularly valuable.

Contributors

BM and SH conceptualised the analysis and developed the analysis plan. BM did the analysis and wrote the first draft of the report. All authors interpreted findings, critically reviewed the report for important intellectual content, and approved the final version.

Declaration of interests

We declare that we have no competing interests.

Acknowledgments

BM was supported by a studentship from the Canadian Institutes of Health Research Interdisciplinary Capacity Enhanced Team Grant (#HOA-80072). SH was supported by a Chercheur-boursier Junior 1 from the Fonds de la Recherche en Sante du Quebec. JSK was supported by the Canada Research Chairs programme.

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