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Temporal trend of neonatal mortality and correlation between obstetric and newborns indicators of adolescents and young adults in a decade

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Abstract
Neonatal mortality remains a critical indicator of maternal and child health, particularly in socioeconomically vulnerable populations such as adolescent and young adult mothers. This ecological temporal trend study analyzed neonatal mortality rates in Bahia, Brazil, from 2011 to 2020 among infants born to mothers aged 10–19 and 20–24 years, using publicly available data from Mortality Information System (SIM) and Live Birth Information System (SINASC). Neonatal mortality coefficients (overall, early [0–6 days], and late [7–27 days] per 1,000 live births) were calculated and evaluated via simple linear regression with Newey-West correction to determine annual percentage change and trend significance. Spearman's correlation assessed associations between annual overall neonatal mortality and obstetric (mode of delivery) and newborn variables (gestational age categories, birth weight categories). Of 13,076 deaths under one year in the age groups studied, 10,171 (77.8%) were neonatal, roughly equally distributed between adolescent and young adult mothers. Overall and early neonatal mortality rates declined significantly in both age groups over the decade, while late neonatal mortality remained stable. Most cause-specific preventable neonatal mortality rates decreased, except for an increasing trend in deaths due to maternal conditions affecting the fetus among infants of adolescent mothers. A strong positive correlation was observed between the proportion of borderline preterm births and overall neonatal mortality in the 20–24 age group; no significant correlations emerged for mode of delivery or birth weight. Despite overall declines, neonatal mortality—especially early deaths—remains elevated, underscoring the need for intensified prenatal and perinatal care, targeted interventions for adolescent mothers, and strengthened monitoring of preterm births to further reduce preventable neonatal deaths in vulnerable populations.

Keywords*: Neonatal mortality; Early neonatal mortality; Adolescent mothers; Young adult mothers; Temporal trend analysis; Preventable neonatal deaths; Preterm birth; Bahia, Brazil.*

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I. INTRODUCTION

Infant mortality is one of the key indicators for evaluating the quality of life of a population across different socioeconomic development contexts, as well as the population's access to health services. Globally, a significant reduction in infant deaths has been observed, especially in the post-neonatal component. However, early neonatal death has shown only modest declines, remaining a challenge for developing countries such as Brazil [1].

At the national level, the vulnerability of children—as demonstrated by relatively high neonatal mortality rates and rates of preventable conditions—keeps this population segment prominently on the health agenda, considering the direct relationship between socioeconomic factors and the efficiency of health services in providing prenatal care, delivery assistance, and follow-up of infants [2,3].

According to international parameters, neonatal mortality (NM) assesses the risk of death in children aged 0 to 27 days. Between 1990 and 2019, in developed countries such as Japan, the United Kingdom, Canada, and the United States, these deaths exhibited low mortality coefficients (0.9 deaths per 1,000 live births [LB]; 2.6/1,000 LB; 3.4/1,000 LB; 3.6/1,000 LB, respectively). In contrast, in developing countries such as Brazil, Panama, Guatemala, and Bolivia, the neonatal mortality rates were higher (8.5/1,000 LB; 8.8/1,000 LB; 12.7/1,000 LB; 14.9/1,000 LB, respectively) [4].

In Brazil, studies have indicated a significant reduction in neonatal mortality: from 25.3/1,000 LB in 1990 to 8.5/1,000 LB in 2019. Nonetheless, the neonatal component still accounts for more than 70% of infant deaths. Brazilian regions show discrepancies in neonatal mortality rates depending on regional context: the North and Northeast regions present the highest indices compared to the South and Southeast. Furthermore, there is a considerable difference between early and late neonatal mortality rates. Studies reveal that deaths occurring in the early neonatal period represent approximately 75% of neonatal records, with increases in some Brazilian states [4,5].

According to researchers, this reality results from a combination of numerous factors closely related to maternal and newborn health, such as living conditions, especially access to and adequacy of prenatal care, delivery, postpartum care, and neonatal care. Estimates indicate that 76% of neonatal deaths are classified as preventable, and prevention could lead to a considerable reduction in deaths among children under five years of age [4,6].

In this scenario, the offspring of adolescent mothers present a challenge for healthcare assistance, due to the early onset of the reproductive cycle, which entails psychosocial, economic, and biological problems that impact fetal and neonatal health. Studies indicate that infants born to adolescent mothers are more predisposed to prematurity, low birth weight, neonatal respiratory problems, among others [1,7].

The magnitude and impact of neonatal mortality represent an indicator of socioeconomic development and signal the need for investments in health actions and programs at various levels of care. The present study aims to analyze the trends in early and late neonatal mortality rates among infants of adolescent and young adult mothers and the correlation of neonatal mortality with obstetric and newborn variables in the state of Bahia over the decade 2011 to 2020.

II. METHODOLOGY

Ecological study with time series analysis of neonatal mortality and its components (early – 0 to 6 days; late – 7 to 27 days) among offspring of adolescent and young adult mothers. Data were obtained from the Mortality Information System (SIM) and Live Birth Information System (SINASC), made available by the Department of Informatics of the Unified Health System (DATASUS), Ministry of Health, for the state of Bahia, covering the decade 2011 to 2020. For direct calculation of the Neonatal Mortality Rates (NMR) and its components, the numerator comprised neonatal deaths and the denominator comprised live births (LB), multiplied by 1,000, stratified by maternal age groups (adolescents and young adults) over the period. Early neonatal mortality was defined using deaths at 0 to 6 days as the numerator, and late neonatal mortality using deaths at 7 to 27 completed days. Maternal age groups followed World Health Organization criteria: adolescents (10–19 years) and young adults (20–24 years). The dependent variables (outcomes) were the overall NMR and its components (early NMR and late NMR). Independent variables, obtained from SIM, were categorized as shown in the table below:

Distribution of maternal and newborn variables obtained from the Mortality Information System (SIM)

MATERNAL VARIABLE	CATEGORIES
Age groups (years)	10–19; 20–24
Education (years of completed schooling)	< 8 years; ≥ 8 years
Mode of delivery	Vaginal; Cesarean
Newborn variable	**Categories / Definitions**
Sex	Male; Female
Race / skin color	White; Black; Brown ("pardo"); Others (Yellow; Indigenous)
Gestational age (weeks)	< 32 (extreme preterm)^a; 32–36 weeks + 6 days (borderline preterm)^b
Birth weight (grams)	≤ 1,499 g (very low birth weight)^c; < 2,500 g (low birth weight)^d

PREVENTABLE CAUSE GROUPS OF NEONATAL DEATH:

Preventable cause category	Description	ICD-10 code
Attention in pregnancy	Maternal conditions affecting fetus or newborn	P00
	Fetus/newborn affected by complications of placenta and membranes	P02
	Disorders related to short gestation and low birth weight, not classified elsewhere	P07
Attention during delivery	Intrauterine hypoxia	P20
	Birth asphyxia	P21
	Neonatal aspiration	P24
Attention to fetus and newborn	Respiratory distress of newborn	P22
	Bacterial sepsis of newborn	P36
	Digestive system disorders of newborn	P77

Source: SIM / DATASUS / Ministry of Health (MS), Brazil.

Footnotes:
a. Frequencies of newborn deaths at gestational ages < 22 weeks; 22–27 weeks; and 28–31 weeks.
b. Frequencies of newborn deaths at gestational ages 32–36 weeks + 6 days.
c. Frequencies of newborn deaths with extreme low birth weight (< 1,000 g) and very low birth weight (1000-1499g).
d. Frequencies of newborn deaths with low birth weight (1,500–2,499 g).

For the analysis of causes of neonatal deaths, we applied the Brazilian classification of preventable deaths—based on adequate care of the woman during pregnancy, delivery, the fetus, and the newborn—whose relevant interventions are carried out within the Health Care System-SUS, in accordance with the categories of the International Classification of Diseases, 10th Revision (ICD-10, Chapter XVI) as recorded in SIM.

Initially, absolute and relative frequencies of the categorized variables were estimated, stratified by maternal and newborn variables in the two studied age groups. Next, direct calculation of the Neonatal Mortality

Rate (NMR) and its components was performed, stratified by maternal age groups and by groups of preventable causes, for each year in the state of Bahia.

In the temporal trend analysis of neonatal mortality and its components (early NMR [0–6 days] and late NMR [7–27 days]), simple linear regression parameters were estimated using the Newey-West method to correct for serial autocorrelation of various orders. The outcome variable in these models was the annual value of the Neonatal Mortality Rate (overall NMR, early and late), presented according to the study covariates (years 2011–2020 and maternal age groups: adolescents and young adults).

Annual percentage changes (APC) and their respective 95% confidence intervals (95% CI) were also estimated. Trends were classified as increasing (positive regression slope) or decreasing (negative regression slope) when $p \leq 0.05$; otherwise, they were considered stable under the adopted model.

The correlation between temporal evolution of the overall NMR and obstetric variables (mode of delivery) and newborn variables (gestational age and birth weight) was assessed using Spearman's rank correlation test, with a significance level of 5%. The proportion (%) of live births was calculated by mode of delivery (vaginal or cesarean), by dividing the number of live births in each category by the total live births for each maternal age group. Likewise, the proportion (%) of live births by gestational-age category was obtained by the ratio of live births in the extreme preterm or borderline preterm categories to the total live births in each maternal age group. The birth-weight proportions were calculated as the ratio of live births with very low birth weight or low birth weight to the total live births in each maternal age group.

All analyses were conducted in R, a public-domain statistical computing language. Because the study used publicly available secondary data from DATASUS, submission to a Research Ethics Committee was not required.

III. RESULTS

In the state of Bahia during the period 2011–2020, a total of 13,076 deaths in children under one year of age were recorded via the Mortality Information System (SIM) among offspring of adolescent and young adult mothers (ages 10–19 and 20–24 years). Of these deaths, 10,171 (77.8%) were neonatal deaths: 8,347 (82.1%) in the early neonatal period (0–6 days) and 1,824 (17.9%) in the late neonatal period (7–27 days). Neonatal deaths were nearly equally distributed between infants of adolescent mothers (5,063; 49.8%) and infants of young adult mothers (5,108; 50.2%).

Table 1 – Distribution of neonatal deaths among children of adolescent and young adult mothers, by maternal and newborn variables. State of Bahia, Brazil, 2011–2020.

VARIABLES	**GROUPS**	**MATERNAL AGE**			
		10–19 years		**20–24 years**	
		n	***%***	***n***	***%***
Neonatal deaths (N = 10 171)		5 063	100.0	5 108	100.0
MATERNAL VARIABLES					
Education level *(n = 8 737)*	< 8 years	2 436	56.3	1 659	37.6
	≥ 8 years	1 888	43.7	2 754	62.4
	TOTAL	4 324	100.0	4 413	100.0
Type of delivery *(n = 9 981)*	Vaginal	3 814	76.9	3 381	67.4
	Cesarean	1 147	23.1	1 639	32.6
	TOTAL	4 961	100.0	5 020	100.0
NEWBORN VARIABLES					
Sex *(n = 10 061)*	Male	2 857	57.0	2 787	55.2
	Female	2 153	43.0	2 264	44.8
	Total	5 010	100.0	5 051	100.0
Race/skin color *(N = 8 146)*	White	427	10.6	476	11.6
	Black	133	3.3	157	3.8
	Brown (pardo)	3 460	85.5	3 448	84.1
	Other[1]	25	0.6	20	0.5
	TOTAL	4 045	100.0	4 101	100.0
Gestational age *(n = 6 668)*	< 32 weeks (extreme preterm)[2]	2 681	77.6	2 490	77.5

	32–36 weeks and 6 days (late preterm)[3]	775	22.4	722	22.5
	TOTAL	3 456	100.0	3 212	100.0
Birth weight *(n = 7 330)*	≤ 1 499 g (very low birth weight)[4]	2 762	72.8	2 609	73.8
	< 2 500 g (low birth weight)[5]	1 031	27.2	928	26.2
	Total	3 793	100.0	3 537	100.0
Preventable cause groups *(n = 5 525)*					
ANTENATAL CARE					
Maternal conditions affecting fetus or newborn – P00		166	5.9	232	8.6
Fetus and newborn affected by complications of placenta and membranes – P02		157	5.5	178	6.5
Short gestation and low birth weight, not elsewhere classified – P07		762	27.0	669	25.0
INTRAPARTUM CARE					
Intrauterine hypoxia – P20		177	6.2	192	7.1
Birth asphyxia – P21		245	8.6	221	8.2
Neonatal aspiration – P24		170	6.0	193	7.2
NEWBORN CARE					
Respiratory distress of newborn – P22		588	20.8	460	17.1
Bacterial sepsis of newborn – P36		497	17.5	472	17.5
Digestive system disorders of newborn – P77		71	2.5	75	2.8
	Total	2 833	100.0	2 692	100.0

[1] Other: 10–19 years – Yellow (n = 9); Indigenous (n = 16); 20–24 years – Yellow (n = 8); Indigenous (n = 12)

[a] Includes the frequency of neonatal deaths at < 22, 22–27 and 28–31 weeks of gestation.;

[b] Includes the frequency of neonatal deaths at 32–36 weeks and 6 days of gestation;

[c] Includes the frequency of deaths of extremely low birth weight (< 1 000 g) and very low birth weight (1 000–1 499 g) newborns.

[d] Includes the frequency of deaths of low birth weight (1 500–2 499 g) newborns.

The study findings (Table 1) show that, in both maternal age groups, the majority of neonatal deaths occurred in male infants, of brown ("pardo") skin color, who were extreme preterm with very low birth weight, and born by vaginal delivery. In the adolescent mothers group, more than half (56.3%) had fewer than eight years of schooling.

Among deaths classified as due to preventable causes (Table 1), the highest proportions were related to gestational disorders (ICD-10 P07) and conditions at delivery, notably birth asphyxia (P21), which exceeded 8%. For causes attributed to insufficient attention to the fetus and newborn, respiratory distress (P22) was prominent among infants of adolescent mothers (20.8%), while bacterial sepsis (P36) was notable among infants of young adult mothers (over 17%).

Table 2 – Time-series analysis of the Neonatal Mortality Rate (NMR) and its components, and of the NMR by group of preventable causes, in maternal age groups of adolescent and young adult mothers. Bahia, Brazil, 2011–2020.

TREND ANALYSIS OF THE NMR BY GROUP OF PREVENTABLE CAUSES, 2011–2020

MATERNAL AGE GROUP	CAUSE SUBGROUP (ICD-10)	Median	Mean	SD[a]	APC[b]	95% CI[c]	p-value	Trend
10–19 YEARS	**ANTENATAL CARE**							
	P00 – Maternal conditions affecting fetus or newborn	0.39	0.39	0.09	0.010	0.003; 0.017	0.002 *	Increasing
	P02 – Complications of placenta and membranes	0.36	0.37	0.12	–0.004	–0.011; 0.003	0.225	Stable

	P07 – Short gestation & low birth weight, not elsewhere classified	1.81	1.88	0.45	–0.106	–0.156; –0.056	0.000*	Decreasing
	INTRAPARTUM CARE							
	P20 – Intrauterine hypoxia	0.46	0.43	0.13	–0.035	–0.048; 0.023	0.000*	Decreasing
	P21 – Birth asphyxia	0.61	0.62	0.15	–0.027	–0.039; –0.016	0.000*	Decreasing
	P24 – Neonatal aspiration	0.43	0.42	0.07	0.004	–0.003; 0.013	0.261	Stable
	NEWBORN CARE							
	P22 – Respiratory distress of newborn	0.33	0.35	0.09	0.002	–0.005; 0.009	0.601	Stable
	P36 – Bacterial sepsis of newborn	1.25	1.24	0.21	–0.021	–0.035; –0.006	0.004*	Decreasing
	P77 – Digestive system disorders of newborn	0.15	0.16	0.06	–0.002	–0.005; –0.001	0.027*	Decreasing
20–24 YEARS	**ANTENATAL CARE**							
	P00 – Maternal conditions affecting fetus or newborn	0.47	0.46	0.12	–0.105	–0.124; –0.087	0.000*	Decreasing
	P02 – Complications of placenta and membranes	0.33	0.35	0.09	–0.103	–0.121; –0.086	0.000*	Decreasing
	P07 – Short gestation & low birth weight, not elsewhere classified	1.21	1.31	0.35	–0.090	–0.115; –0.084	0.000*	Decreasing
	INTRAPARTUM CARE							
	P20 – Intrauterine hypoxia	0.37	0.37	0.12	–0.020	–0.036; –0.021	0.000*	Decreasing
	P21 – Birth asphyxia	0.43	0.43	0.12	–0.020	–0.025; –0.014	0.000*	Decreasing
	P24 – Neonatal aspiration	0.37	0.38	0.05	0.004	–0.002; 0.011	0.217	Stable
	NEWBORN CARE							
	P22 – Respiratory distress of newborn	0.92	0.91	0.11	–0.002	–0.016; 0.011	0.729	Stable
	P36 – Bacterial sepsis of newborn	0.89	0.93	0.18	–0.022	–0.046; 0.001	0.070	Stable
	P77 – Digestive system disorders of newborn	0.14	0.15	0.05	–0.002	–0.007; 0.002	0.320	Stable

Sources: SIM/SINASC/DATASUS/SVS/MS.
$p \leq 0.05$;
(a) SD: Standard Deviation ;
(b) APC: Annual Percent Change ;
(c) 95% CI: 95% Confidence Interval

Over the study period, the temporal trends for the overall neonatal mortality rate (NMR) and the early neonatal mortality rate (ENMR) (Table 2) were significantly decreasing ($p < 0.05$) in both maternal age groups; however, the late neonatal mortality rate (LNMR) showed no significant trend and remained stable. When examining the evolution of NMR by groups of preventable causes (Table 2), most cause-specific rates exhibited a significant decreasing trend (negative regression slope) in both age groups, with the exception of an increasing trend for

deaths attributed to "maternal conditions affecting the fetus or newborn" (ICD-10 P00) in the adolescent mothers group.

Table 3 – Spearman's correlation (r) between the Neonatal Mortality Rate (NMR) and obstetric and newborn variables. State of Bahia, Brazil, 2011–2020.

		NMR			
		MATERNAL AGE GROUP			
		10–19 years		**20–24 years**	
OBSTETRIC VARIABLES		***r***	***p*-value**	***r***	***p*-value**
Proportion by delivery type	Vaginal (%)	0.575	0.087	0.145	0.687
	Cesarean (%)	–0.539	0.113	-0.291	0.413
NEWBORN VARIABLES					
Proportion by gestational age	< 32 weeks (extreme preterm) (%)[A]	–0.018	0.972	-0.504	0.136
	32–36 weeks + 6 days (late preterm) (%)[B]	0.309	0.387	0.893	0.000[*]
Proportion by birth weight	≤ 1 499 g (very low birth weight) (%)[c]	0.418	0.232	-0.170	0.638
	< 2 500 g (low birth weight) (%)[D]	–0.224	0.536	-0.279	0.433

Sources: SIM/SINASC/DATASUS/SVS/MS.

$p \leq 0.05$;

[A] Includes births at < 22, 22–27 and 28–31 weeks of gestation.;

[B] Includes births at 32–36 weeks and 6 days of gestation.

[c] Includes births of extremely low (< 1 000 g) and very low (1 000–1 499 g) birth weight.;
[D] Includes births of low birth weight (1 500–2 499 g).

Regarding correlations (Table 3), in the 20–24 age group there was a strong, direct, statistically significant correlation between the annual proportion of borderline preterm births (gestational age 32–36 weeks + 6 days) and the overall NMR (Spearman's r = 0.893; p = 0.000). For the other selected variables—proportion of delivery type (vaginal vs. cesarean) and birth weight categories—no significant correlations with NMR were observed in either maternal age group.

IV. DISCUSSION

The findings of this research indicate that, in the state of Bahia, neonatal mortality indicators among offspring of adolescent and young adult mothers experienced a significant decline over the decade 2011–2020, a pattern similar to studies conducted in other contexts and countries [6]. Data from the World Health Organization (WHO) show that neonatal deaths—the principal component of infant mortality—have decreased over recent decades (2000–2020) [8].

In the period studied, the time-series analysis demonstrated a significant downward trend in both overall neonatal mortality rate (NMR) and early neonatal mortality rate (ENMR) among newborns in both maternal age groups, with modest annual percentage changes in Bahia. At the national level, these findings may relate to the

positive impact of investments made in recent decades aimed at maternal and child health prevention and care, improving access to health services for the mother–child dyad [2,6].

Regarding the late neonatal mortality component (LNMR), the present study's finding diverges from other investigations using data from Brazilian states over 2000–2018, which showed reductions in LNMR. The stability of late neonatal mortality (LNMR; $p > 0.05$) observed here for 2011–2020 may serve as a warning for regional health managers and professionals in Bahia, since a reduction would be expected in response to implementation of maternal–child health policies and programs in Bahia, in line with WHO recommendations [6,8]. From this perspective, it is necessary to re-evaluate the indicators that influence maternal and neonatal mortality rates—for example, women's access to prenatal, delivery, and postpartum care, which affect the quality of neonatal assistance and newborn care during and after birth.

When indicators are delineated annually for trend and significance analysis, they become highly useful tools to assess the impact of interventions directed at pregnancy, delivery, and birth. Observing trends in overall neonatal mortality rate and its early and late components guides political decisions and targeted interventions in health services and practices [1].

Moreover, time-series studies are important and necessary because they make it possible to profile indicators, identifying atypical patterns (increasing, decreasing, or stationary) in mortality trends over time, as well as the possible factors capable of modifying these distributions positively, negatively, or stably [9].

According to researchers, intersectoral policies can help address problems such as low education, inadequate sanitation, barriers to healthcare access, and insufficient capacity to meet populations' real needs in different social contexts, aligned with structural and socioeconomic development indices.

In this view, at the national level in Brazil, implementation of programs such as Health Care System-SUS egy may have positively influenced educational access, expansion of higher-complexity health services, and, consequently, family income management [10].

In the present study, with respect to the evolution of overall NMR by preventable causes—"amenable to effective and accessible health interventions"—the findings revealed a significant downward trend in this rate among newborns in both maternal age groups, suggesting advances in population access to health services and investments in care pathways. These results corroborate Brazilian studies analyzing trends in avoidable mortality under the Unified Health System (SUS), which have shown declines in neonatal mortality from preventable causes across all Brazilian regions, with reductions twice as large for avoidable causes compared to non-avoidable causes [10,11].

Concerning overall NMR due to preventable causes in pregnancy—specifically "maternal conditions affecting the fetus or newborn" (ICD-10 P00)—a significantly increasing trend was observed among offspring of adolescent mothers. This indicates that, despite overall improvements in maternal and child health nationwide, regional challenges remain for specific vulnerable groups. The literature consistently recognizes greater vulnerability of adolescent mothers and their infants, exacerbated by socioeconomic inequalities in Brazil's poorer regions, such as the Northeast, where Bahia is located. This reality can influence national health indicators, given Brazil's continental dimensions and socioeconomic and cultural disparities across regions [11].

It is also important to emphasize investments in professional training for care during the pregnancy–puerperal period. Such care directly affects health status and, consequently, reduces neonatal deaths, especially in the early neonatal period [12].

Regarding the correlation of overall NMR with obstetric and newborn variables, the present study found a positive, statistically significant correlation between overall NMR and gestational age in borderline preterm newborns of young adult mothers, corroborating a national study on neonatal mortality trends conducted for 2007–2017 [13].

A systematic review of studies in Brazil from 2000 to 2018 reported a significantly higher likelihood of neonatal death among preterm newborns with gestational age under 37 weeks [14].

Researchers point to a significant direct correlation between overall NMR and live births to adolescent mothers, as well as an inverse correlation between this indicator and prematurity (lower gestational age). A reduction in births to adolescent mothers may be interpreted as socially favorable, since pregnancy in adolescence often results in adverse maternal and child outcomes. Other risk factors for neonatal death include absence or low quality of prenatal care, maternal health problems, birth asphyxia, and prematurity. These conditions are largely preventable through health service interventions, underscoring the importance of preventive actions to improve neonatal mortality indicators [3,14,15], which can contribute to eradicating avoidable neonatal mortality in line with the United Nations Sustainable Development Goals.

For neonatal mortality prevention, it is worth highlighting the importance of infant and fetal mortality prevention committees in each Brazilian state as tools to inform policies, actions, and investments aimed at reducing deaths. These strategies demonstrate the need for professional training of health teams, focusing on consolidating policies and actions to improve the quality of mother–child health care [16].

The findings of this and other investigations reveal that the neonatal component of infant mortality can be influenced directly or indirectly by maternal health conditions and prenatal and delivery care. Therefore, understanding these indicators helps identify regions and population groups at higher risk of adverse pregnancy and birth outcomes, guiding expansion and intensification of policies and intervention strategies in health.

Finally, study limitations include use of secondary records: inadequate completion of death certificates may lead to misclassification of deaths occurring shortly after birth as stillbirths; as well as data capture failures due to incomplete variables related to prenatal care, delivery, and birth outcomes. Such gaps in SIM and SINASC records can pose difficulties in analyzing certain variables related to maternal and fetal health conditions, including deaths in children under one year, especially in less-developed regions [17,18].

V. CONCLUSION

This study examined temporal trends in neonatal mortality among infants born to adolescent (10–19 years) and young adult (20–24 years) mothers in the state of Bahia, Brazil, over the decade 2011–2020, and explored correlations between overall neonatal mortality rates and key obstetric and newborn variables. The findings reveal both encouraging progress and persistent challenges. Overall neonatal mortality rate (NMR) and early neonatal mortality rate (ENMR) exhibited significant and sustained declines in both maternal age groups over the ten-year period, reflecting positive impacts of broader investments in maternal-child health and health system strengthening. However, late neonatal mortality rate (LNMR) remained stable, and specific cause-related patterns diverged: most preventable cause-specific neonatal mortality rates decreased significantly, yet neonatal deaths due to maternal conditions affecting the fetus (ICD-10 P00) increased among infants of adolescent mothers. Additionally, in the young adult mothers group, a strong positive correlation between the proportion of borderline preterm births (32–36 weeks + 6 days) and overall NMR was identified, underscoring prematurity as a key determinant of neonatal outcomes. No significant correlations emerged between NMR and mode of delivery or birth weight categories within the studied age groups. These results carry important implications for public health policy, clinical practice, and future research, pointing to areas requiring intensified attention and targeted strategies.

First, the observed downward trends in overall NMR and ENMR across both adolescent and young adult maternal age groups represent a notable achievement. Such declines likely reflect the cumulative effects of multiple policy and programmatic interventions over preceding decades, including expanded prenatal care coverage, improved obstetric practices, enhanced neonatal resuscitation capacity, and implementation of evidence-based maternal-child health initiatives at national and regional levels. In Brazil, initiatives such as the Family Health Strategy (Estratégia Saúde da Família), “Rede Cegonha” (Stork Network), and targeted programs promoting maternal and child health have likely contributed substantially to improved access to prenatal consultations, skilled birth attendance, immediate newborn care, and timely referral for complications. In Bahia, regional adaptation and implementation of these initiatives appear to have produced measurable benefits, as evidenced by consistent declines in NMR and ENMR from 2011 to 2020. The modest but statistically significant annual percentage changes indicate steady progress rather than abrupt shifts, consistent with gradual health system maturation. This positive trajectory aligns with global patterns documented by WHO, which report reductions in neonatal mortality over recent decades, albeit at varying rates across regions and countries.

Nevertheless, the persistence of stable LNMR highlights an area of concern. Late neonatal deaths (7–27 days) remained essentially unchanged in Bahia during the study period, diverging from expectations that improvements in neonatal care and health services would extend beyond the first week of life into the late neonatal period. Late neonatal mortality often reflects factors such as postnatal infections, care-seeking behavior, quality of home-based newborn care, and health system responsiveness for complications emerging after hospital discharge. The stability of LNMR suggests that while early interventions—such as intrapartum monitoring, immediate neonatal resuscitation, and early postnatal care—have improved, post-discharge continuity of care and community-based support may be insufficiently robust. This pattern warrants deeper examination of health service delivery models, including follow-up schedules for newborns, community health worker engagement, mechanisms for early detection and management of neonatal sepsis and other late-onset complications, and health education for caregivers. Strengthening the continuum of care from facility to home, including standardized postnatal home visits, telehealth support, and community-level surveillance, is likely essential to reduce late neonatal deaths.

Another critical finding is the differential trend in cause-specific neonatal mortality related to maternal conditions affecting the fetus (ICD-10 P00) among adolescent mothers. The statistically significant increase in neonatal deaths due to such conditions in this group indicates that, despite overall improvements, adolescent pregnancies continue to confer specific vulnerabilities. Maternal conditions that affect the fetus—such as hypertensive disorders, maternal infections, nutritional deficiencies, and other health issues—may be more prevalent or less effectively managed in adolescent pregnancies. Adolescents often face barriers in accessing high-

quality prenatal care, may have lower health literacy, and are more likely to experience socioeconomic disadvantages that exacerbate risks. The upward trend in P00-related neonatal mortality among adolescent mothers suggests that general improvements in maternal-child health services have not translated into uniformly equitable outcomes across all subpopulations. It underscores the need for targeted interventions tailored to the unique needs of pregnant adolescents: early identification of pregnancy, age-appropriate prenatal counseling, enhanced screening for risk conditions, intensified monitoring and management of maternal health issues, nutritional support, psychosocial care, and community-based outreach programs to engage adolescents. Moreover, intersectoral measures addressing underlying determinants—education, social support, poverty alleviation, adolescent-friendly health services—are essential to mitigate the elevated risk of adverse fetal outcomes in this group.

The strong positive correlation between the proportion of borderline preterm births (gestational age 32–36 weeks + 6 days) and overall NMR in the 20–24 years group further highlights prematurity as a central driver of neonatal mortality. Borderline preterm infants, while often surviving the immediate postnatal period, remain at higher risk for complications such as respiratory distress, sepsis, feeding difficulties, and thermoregulatory challenges. The significant association implies that fluctuations in the rate of borderline preterm births have a measurable impact on neonatal mortality trends. This finding indicates that, in addition to general neonatal care improvements, focused efforts to prevent preterm birth and optimize management of preterm infants are warranted. Preventive strategies include identifying and managing risk factors for preterm labor—e.g., infections, maternal chronic conditions, multiple pregnancies—and interventions such as antenatal corticosteroids, tocolysis, and referral to specialized care when indicated. For infants born preterm, ensuring access to appropriate neonatal intensive care resources, kangaroo mother care, feeding support, infection prevention protocols, and structured follow-up are critical to improve survival. Furthermore, exploring social determinants and obstetric practices contributing to preterm birth rates in the young adult population could inform preventive policies: for instance, assessing the role of maternal stress, occupational exposures, interpregnancy intervals, and health behaviors in influencing preterm birth incidence.

The absence of significant correlations between NMR and mode of delivery or birth weight categories within the maternal age groups suggests that these factors, at least as measured by annual proportions, may play a less pronounced or more complex role in influencing overall neonatal mortality trends in this context. While cesarean versus vaginal delivery practices and low birth weight are known contributors to neonatal outcomes at the individual level, their aggregate annual proportions may not linearly track with NMR across years in this population. It is possible that improvements in intrapartum management and neonatal care have mitigated some risks associated with mode of delivery, and that very low birth weight infants receive specialized care reducing mortality independent of broader trend fluctuations. Alternatively, variations in birth weight distributions or cesarean rates may be insufficiently large or may interact with other unmeasured factors, such as socioeconomic changes or health service access improvements, attenuating detectable correlations at the population level. Nonetheless, continued surveillance of these variables remains important, and more granular analyses—e.g., stratified by risk categories or regional subgroups—could reveal context-specific associations.

Taken together, these findings point to several priority areas for policy and practice:

1. **Strengthening Continuum of Care for Neonates**: The stable LNMR indicates a need to bolster postnatal follow-up systems. Health authorities should optimize protocols for timely home visits by trained community health workers within the first week after discharge and throughout the neonatal period, with standardized checklists for danger signs, referral pathways for prompt management, and integration of telehealth modalities where feasible. Educational interventions for caregivers regarding hygiene, breastfeeding, recognition of infection signs, and when to seek care must be intensified, with culturally appropriate materials and community engagement strategies.

2. **Targeted Interventions for Adolescent Mothers**: The rise in P00-related neonatal mortality among infants of adolescent mothers calls for dedicated adolescent-friendly maternal health services. Health systems should implement early pregnancy identification programs in schools and communities, provide confidential and respectful prenatal care tailored to adolescents' needs, screen and manage maternal health conditions proactively, and offer psychosocial support. Collaborations between health, education, and social services can address underlying determinants—promoting sexual and reproductive health education, delaying adolescent pregnancy, and supporting pregnant adolescents through integrated care packages that include nutritional supplementation, mental health services, and assistance navigating health and social systems.

3. **Prematurity Prevention and Care**: Given the link between borderline prematurity and NMR, interventions to reduce preterm birth incidence and improve care of preterm infants must remain central. This includes promoting early and regular prenatal care visits, screening for and treating infections, optimizing management of

maternal chronic diseases, educating about signs of preterm labor, and ensuring referral networks to higher-level facilities for at-risk pregnancies. For preterm infants, ensuring adequate resources for neonatal intensive care, standardized protocols for respiratory and nutritional support, and follow-up clinics for developmental surveillance are critical to reduce mortality and morbidity.

4. **Equity-Focused Health System Strengthening**: While overall mortality declines demonstrate system progress, disparities persist. Health policies should incorporate equity analyses, identifying underserved municipalities or populations within Bahia where neonatal mortality remains disproportionately high. Strategies may involve allocating additional resources to rural or remote areas, enhancing transportation support for pregnant women, strengthening primary care capacities, and training healthcare providers in culturally sensitive care for diverse communities. Data disaggregation by geographic subregion, socioeconomic status, and ethnicity can guide targeted resource allocation.

5. **Data Quality Improvement and Monitoring**: Reliable, timely data underpins effective decision-making. Persistent gaps in SIM and SINASC data completeness and accuracy—particularly in less developed regions—must be addressed. Efforts should include training for proper completion of death certificates to distinguish neonatal deaths from stillbirths, enhancing data capture processes, and implementing routine audits of mortality data. Strengthening health information systems to allow near real-time monitoring of neonatal outcomes can facilitate rapid response to emerging trends.

6. **Intersectoral and Multisectoral Actions**: Neonatal outcomes are shaped by social determinants: maternal education, poverty, sanitation, nutrition, and social support. Collaborative policies across health, education, social protection, and infrastructure sectors are necessary. Programs like "Family Allowance", which provide conditional cash transfers linked to health and education benchmarks, have shown beneficial effects on maternal-child health. Continued expansion and evaluation of such intersectoral interventions can help address upstream determinants of neonatal mortality.

7. **Professional Training and Capacity Building**: Improving neonatal survival requires ongoing training of healthcare workers at all levels. This includes obstetricians, midwives, nurses, community health workers, and pediatricians. Emphasis should be placed on evidence-based neonatal resuscitation, infection control, management of preterm infants, and effective communication skills to educate families. Simulation-based training, supportive supervision, and continuous quality improvement cycles in health facilities can enhance care standards.

8. **Community Engagement and Behavior Change**: Sustained reductions in neonatal mortality depend on informed and empowered communities. Health promotion campaigns targeting maternal behaviors—early and exclusive breastfeeding, cord care practices, care-seeking for neonatal illness—should be culturally tailored and delivered through trusted community channels. Engaging community leaders, women's groups, and family networks can facilitate acceptance and uptake of recommended practices.

9. **Research and Evaluation**: Although this study provides a comprehensive temporal analysis, further research is needed. Qualitative studies exploring barriers and facilitators to neonatal care among adolescents and young adult mothers can uncover context-specific insights. Intervention studies testing novel models—such as mobile health reminders, peer support networks, or integrated psychosocial interventions for pregnant adolescents—should be conducted with rigorous designs. Cost-effectiveness analyses of enhanced postnatal follow-up strategies and adolescent-targeted programs can inform resource prioritization. Additionally, subpopulation analyses (e.g., rural vs. urban, indigenous communities) can reveal nuanced patterns requiring tailored interventions.

10. **Sustaining and Scaling Successful Practices**: Where interventions have demonstrated positive impacts—such as structured home visit programs or adolescent-friendly prenatal services—efforts should focus on scaling these approaches sustainably. Pilot projects should include plans for integration into routine health services, budgeting for long-term funding, and mechanisms for monitoring fidelity and outcomes at scale. Documenting and disseminating best practices across municipalities and states can accelerate broader improvements.

11. **Policy Advocacy and Stakeholder Engagement**: Translating evidence into action demands engagement with policymakers, health administrators, and other stakeholders. Clear communication of study findings, emphasizing both achievements and areas needing attention, can support advocacy for continued investments in maternal-child health. Multi-stakeholder forums—including government, civil society, academic institutions, and international partners—can foster shared ownership of strategies to reduce neonatal mortality.

12. **Alignment with Global and National Goals**: The observed trends and challenges should be considered within the context of national commitments to Sustainable Development Goals (SDG), particularly SDG target 3.2, which aims to end preventable deaths of newborns and children under 5 by 2030. Bahia's progress contributes toward national objectives, yet the remaining burdens underscore the need for accelerated efforts. Continuous monitoring against SDG indicators, with periodic reporting at state and municipal levels, can maintain momentum and accountability.

13. **Holistic Approach to Adolescent Health**: Given the heightened vulnerabilities associated with adolescent pregnancy, a holistic approach to adolescent health is crucial. This includes comprehensive sexual and reproductive health education, accessible contraceptive services, youth-friendly health system environments, and social support structures. Reducing adolescent pregnancy rates not only improves neonatal outcomes but also yields broader benefits in education attainment and socioeconomic prospects for young women.

14. **Enhanced Focus on Mental Health and Social Support**: The interplay between maternal mental health, stress, and neonatal outcomes deserves attention. Adolescents and young adult mothers may experience heightened anxiety, depression, or lack of social support, which can influence prenatal behaviors and birth outcomes. Integrating mental health screening and supportive counseling into prenatal and postnatal care can contribute to healthier pregnancies and better neonatal survival.

15. **Addressing Late Neonatal Mortality Through Innovation**: To specifically target late neonatal mortality, innovative interventions may include remote monitoring technologies for early detection of neonatal illness (e.g., mobile phone-based symptom checkers), community-based neonatal care groups, and partnerships with non-governmental organizations to extend outreach to marginalized areas. Piloting such innovations, while rigorously evaluating their effectiveness and feasibility in low-resource settings, can identify scalable solutions.

16. **Equitable Resource Allocation**: Resource allocation should be informed by local data identifying high-burden areas within the state. Municipalities with persistently high NMR should be prioritized for additional support—such as training, equipment, and health workforce reinforcement. Financial and logistic support for transportation of high-risk pregnant women to referral centers can mitigate delays in care.

17. **Strengthening Referral and Transport Systems**: Efficient referral networks for high-risk pregnancies and sick neonates are vital. Ensuring availability of transport, clear communication protocols between primary care and higher-level facilities, and readiness of referral centers to receive and manage high-risk cases can reduce delays that contribute to neonatal deaths.

18. **Monitoring and Addressing Social Determinants**: Regular assessment of social determinants—poverty levels, education metrics, housing conditions, environmental sanitation—should accompany health surveillance. Programs that simultaneously address multiple determinants (e.g., improving water and sanitation in conjunction with maternal health outreach) may yield synergistic benefits for neonatal survival.

19. **Longitudinal Cohort Studies and Data Linkage**: To deepen understanding of risk trajectories, longitudinal cohort studies following pregnant adolescents and young adult mothers through pregnancy and into the neonatal period could provide insights into factors influencing adverse outcomes. Enhanced data linkage between maternal health records, neonatal care data, and social service databases can enable more comprehensive analyses of risk and protective factors.

20. **Capacity Building for Data Analysis and Utilization**: Strengthening local capacity for data analysis and interpretation can empower health managers to use surveillance data proactively. Training in epidemiological methods, time-series analysis, and data visualization can support timely identification of concerning trends and prompt corrective actions.

In summary, the significant reductions in overall neonatal and early neonatal mortality rates among infants of adolescent and young adult mothers in Bahia from 2011 to 2020 reflect commendable advances in maternal-child health services. These achievements underscore the effectiveness of broad health system investments, enhanced prenatal and obstetric care, and evidence-based neonatal interventions. However, the persistence of stable late neonatal mortality and the increase in neonatal deaths due to maternal conditions among adolescent mothers reveal continuing gaps. Addressing these issues demands a multifaceted approach: strengthening the continuum of care across the early and late neonatal periods; tailoring interventions to the specific vulnerabilities of adolescent pregnancies; prioritizing prematurity prevention and optimal care; and

systematically addressing socioeconomic and structural determinants through intersectoral collaboration. Enhanced data quality, equity-focused resource allocation, innovative community-based strategies, and rigorous research into context-specific

barriers and facilitators will be vital. Policymakers, health professionals, and communities must sustain and scale effective practices, embed continuous monitoring and evaluation, and commit to targeting the most vulnerable populations to accelerate progress toward eliminating preventable neonatal deaths. By integrating clinical excellence with social support and policy measures, Bahia can further reduce neonatal mortality and contribute to national and global goals of ensuring healthy starts for all newborns, particularly those born to adolescent and young adult mothers in socioeconomically disadvantaged contexts.

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