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Census block based loglinear regression analysis of health and social determinants of maternal mortality in Indonesia 2010–2021

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Despite many health program efforts, the maternal mortality in Indonesia has slowly declined and remains high. A comprehensive understanding of social determinants of maternal mortality is needed to guide improved strategies to accelerate reductions in maternal mortality. This study aimed to assess the health-program and social factors that determine maternal mortality in Indonesia through census block-based log-linear regression analysis of recent large surveys. The following data sets were used: (1) the Indonesia Intercensal Population Survey 2015 merged to the Village Potential Census, 2014; and (2) the Indonesia Population Census 2020-Long Form (conducted in 2022) merged to the Village Potential Census, 2021. Both surveys used the same multistage sampling procedure to select 40,728 and 268,223 census blocks. In each selected census block, a "take all take some" procedure was used to randomly select 16 households. Maternal mortality, its health-program, and social factors were measured at the census block level. Since many census blocks had zero maternal death, a log-linear regression, modelled as $\mathrm{Ln}\,Y'_i = \alpha + \theta_i X_i$, was employed. $\mathrm{Ln}\,Y'_i$ is the natural log transform of maternal mortality ratio; X_i are the factors investigated; θ_i is the regression coefficient of X_i on $\mathrm{Ln}\,Y'_i$. θ_i measures the extent influence of X_i on Y_i. On the study results, the maternal mortality has declined but remains high, and geographic and socioeconomic disparities in maternal mortality have reduced, although they are still striking. There are many factors that have influenced the risk of maternal mortality. Proximity to hospital reduced the risk of maternal mortality. The primary health care system is not yet optimal for reducing the risk of maternal death. Traditional birth attendants hinder the referral for maternal complications. Lack of household transportation increases the risk of maternal mortality. The use of contraception to reduce high-risk births also reduces the risk of maternal mortality. Poverty and low maternal education independently increase the risk of maternal death. Households that are too large; have one or more disabled member; and have experienced child loss are at high risk of maternal mortality. Lack of village electrification and a polluted environment independently increase the risk of maternal mortality. The study results imply the need for multiple strategic interventions to accelerate the reduction of maternal mortality. Optimizing the coverage of quality referral hospitals, particularly in the eastern region, is required. There is a need to facilitate easy transportation from households to the nearest functional EmMONC. There is a need to strengthen the primary health care system to early detect, stabilize, and facilitate timely, safe, and effective referral of cases of maternal complications. Social health insurance should not only cover the cost of health care but also improve the quality of healthcare services. The role of traditional birth attendants should be shifted away from delivery care to improve maternal and neonatal health care. Family planning programs should focus on preventing high-risk births. Women's education needs to be improved. Electrification of all villages and control of environmental pollution to reduce maternal deaths.

Keywords Maternal mortality, Health-program and social determinants, Indonesia

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Background

Maternity should be a time of life, rather than death. Almost all maternal deaths can be prevented. However, across Indonesia women and newborns continue to die because of maternal complications. Despite decades of advancements in maternal health technologies, women in Indonesia still face limited access to quality life-saving solutions. Maternal mortality in developing countries is a major health problem[1,2]. The risk of maternal death, measured through the maternal mortality ratio, is generally 10 to 100 times higher in the lowest income countries compared to the highest income countries[3]. As women in developing countries become pregnant more often, the average lifetime risk of dying a maternal death for women in developing countries is even greater than in developed countries[4].

For one maternal death, many more suffer from chronic, even serious maternal morbidity complications[5,6]. There were 7 to 70 episodes of serious illnesses related to pregnancy and childbirth for every maternal death[7,8]. Maternal death is a tragedy for families, especially among her children[9,10]. In Indonesia, mothers occupy a pivotal position in the family[11], and the survival and the fate of young children often depends on their mothers[12]. A maternal death is often closely followed by the death of the infant[13]. Two studies in Bangladesh[14,15] reported that 90 to 95% of newborns whose mothers died in childbirth, died within one year of birth. One study in Ethiopia showed that newborns with dead mothers have a 46 greater risk of dying within one month after birth as compared to newborns with living mothers[16].

In Indonesia maternal mortality has declined but remains significantly high. BPS-Statistics Indonesia[17] reported a fall in the maternal mortality ratio (MMR) from 305 by 2015 to 189 maternal deaths per 100,000 live births by 2020. On the other hand, the World Health Organization provides lower estimates of Indonesian MMR, 194 in 2015 and 173 per 100,000 live births in 2020[18]. Different data and methods will produce different estimates, but all the estimates consistently show that the maternal mortality is persistently high in Indonesia. By 2020, the estimated MMR in Indonesia is still much higher than the estimated MMR for other ASEAN countries, such as Malaysia, Brunei Darussalam, Philippines, Thailand, Vietnam and Singapore[18]. For example, Malaysia's success in significantly reducing the maternal mortality rate from 540 in 1957 to 28 per 100,000 live births in 2010 is due to several factors, including progress in socio-economic development, strengthening health services[19], and specific initiatives such as the confidential inquiry of maternal deaths to identify areas for improvement[20]. The persistently high level of maternal mortality is a challenge for the Indonesian government to find the right strategy to further accelerate the reduction in maternal mortality. A comprehensive understanding of the health-program and social dimensions of Indonesian maternal mortality will guide health policymakers in finding the right strategy to further accelerate the reduction of maternal mortality rates[21,22]. These dimensions cover, in principle, primary and intermediate factors in the supply and demand for health services which include, among others, poverty, the living environment, access and quality of health services, and women's demographic characteristics, especially education.

Objective

Through a census block log-linear regression model applied to the latest national population survey data, SP 2015 and SP 2020-LF, this study aims to examine the health-program and social determinants of maternal mortality in Indonesia. This study complements our previous research[23] on the relationship between contraceptive use and the risk of maternal death based on SP 2015 data. To expand the health and social dimensions of maternal mortality, this study combines population census/survey data with village potential census data. Thus, the focus is not on estimating maternal mortality rates, but rather on identifying the range of health-program and social factors that are associated with maternal mortality.

Conceptual framework

This study refers to McCarthy and Maine's conceptual framework for determinants of Maternal Mortality (1992) in explaining how health-program and social influence the risk of maternal mortality[6]. The framework clarifies that health-program and social efforts to reduce maternal mortality must achieve one or more of the following three intermediate outcomes: (1) reduce the likelihood of a woman of becoming pregnant; (2) reduce the likelihood of serious complications of pregnancy or childbirth; and/ or (3) improve outcomes of women with serious maternal complications.

Reducing pregnancies to reduce maternal mortality will be effective if the focus is on reducing high-risk pregnancies, including unwanted pregnancies[24,25], the "four-too" pregnancies (Too young, Too old, Too close, and Too many)[26,27], and pregnancies among chronically ill or undernourished woman[28,29]. Reducing high-risk pregnancies will also reduce the likelihood of serious complications of pregnancies and childbirths[30,31].

Improving access and quality of comprehensive emergency obstetric and neonatal services will improve the outcomes in the treatment of serious maternal complications[32,33]. A delay in receiving adequate treatment in comprehensive emergency obstetric services increases the risk of maternal death[34]. There are three levels of delay for mothers with life-threatening complications in receiving adequate treatment at a referral hospital (as comprehensive emergency obstetric and neonatal services)[35,36]: (1) delay in deciding on seeking health care; (2) delay in reaching an adequate health care facility, that is, the referral hospital; and (3) delay in receiving adequate treatment at that healthcare facility. Thus, the health-program and social determinants of maternal mortality include factors that influence the health status of mothers and their exposure to disease and their access to quality maternal health services[37].

Methods

Study population

Data were taken from the 2015 Indonesian Intercensal Population Survey (merged at the village level into the 2014 Village Potential Census), hereafter referred to as SP 2015, and the 2020 Long Form Survey as part of the Indonesian Population Census (conducted in 2022) (merged at the village level into the 2021 Village Potential Census), hereafter called SP 2020-LF). Both surveys used the same multistage sampling procedure to collect census blocks and households in 34 provinces[17]. Through Probability Proportional to Size (PPS) sampling, the two surveys sampled 40,728 and 268,223 census blocks respectively.

A census block is a geographic cluster that consists of approximately 150 households. In each selected census block, the survey enumerator created a list of households identified as experiencing or not experiencing death in the last five years. From the list of households, the "take all take some" sampling method was used to draw 16 households. If the list contained eight or fewer households with a death experience in the last five years, a "take all" procedure was applied by including all of these households in the sample. The remaining number of households (sixteen households minus the number of households with the experience of a member dying in the last five years) was randomly drawn from the list to obtain a total of 16 households. If there were more than eight households with deaths in the last five years, these households were stratified according to the education of the head of the household, and then systematically drawn to only eight households. Eight other households with no death experience in the last five years were randomly drawn from the list to complete a total of 16 households.

Study variables and their measurement

The research variables are measured at the census block level. Maternal mortality, measured through a natural logarithm transformation of the Maternal Mortality Ratio (MMR), is treated as a study-dependent variable. Health-program and social factors considered to influence mothers' health status and their exposure to disease and access to maternal health services were treated as independent variables in the analysis[37]. These factors include the living environment (i.e. urban vs. rural), characteristics of women of reproductive age and household[38], high-risk births and contraceptive use[39], traditional health system, women's employment status, and transportation[37], and the health care system[2]. Most factors at the census block level were measured in proportions of a reference category, and these proportions were then categorized as low, medium, and high, or low and high. The health-program factors were measured through the density of health facilities and/ or health providers at district, sub-district, or village levels, as appropriate.

Analysis method

We used census block-level ecological analysis to ensure that mortality risks between different categories of independent variables were comparable. We included in our analysis all 40,728 census blocks in SP 2015 and 268,223 census blocks in SP 2020-LF. Ecological analysis was carried out because analysis at the individual mother level is faced with the problem of limited information regarding the individual factors of mothers who died. Since the distribution of Maternal Mortality Ratio (MMR) in census blocks is very skewed, with many census blocks having no maternal deaths, the MMR is converted to natural log MMR with the addition of a small constant (one) to avoid a zero value. This natural log transformation (MMR + 1) was treated as the dependent variable in the census block-level ecological log-linear regression analysis to assess health-program and social determinants of maternal mortality. The census block-level ecological log-linear regression model[40] applied in this study was as follows:

$$\mathrm{Ln}\ Y_i' = \alpha + \beta_i X_i + e_i$$

Where: Ln $Y'_i = (MMR_i + 1) * 100{,}000$); $MMR_i = (MD_i / LB_i) * 100{,}000$; e_i is the error term, MD_i is the number of maternal deaths during the past five years preceding the survey in census block i, LB_i is the number of live births during the past five years preceding the survey in census block i, X_i is a factor i being investigated; β_i is the log-linear regression coefficient of X_i which measures the net effect of X_i on Y'_i by controlling statistically other X_i.

$\beta_i = 0$ is the null statistical hypothesis. $\beta_i > 0$ (positive) means the positive effect of X_i on Y_i; and for $\beta_i < 0$ (negative) means the negative effect of X_i on Y_i. β_i is presented in a confidence interval or significant testing, marked with one star* if significant by $p < 0.05$ and two stars** if significant by $p < 0.01$.

To increase the sensitivity of the analysis of social determinants of maternal mortality, we expanded the definition of "maternal mortality" to include not only pregnancy-related deaths but also deaths of women of childbearing age in households with children under five without a mother.

Results

The results of this research are presented thematically, including levels, trends and geographic disparities in maternal mortality, as health issues, and the health-program and social determinants of maternal mortality. This research analysis focused on health program and social factors that influence maternal mortality risk. Health program factors are immediate or intermediate determinants, while social and environmental factors are distant determinants of maternal mortality. Box 1. below summarizes the research results on the themes of maternal mortality in Indonesia.

Issues

Maternal mortality has declined but remains high

The maternal mortality in Indonesia from 2010 to 2021 has declined but remains high. The data analysis in this study showed a reduction in the maternal mortality ratio from 326 (SP 2015) to 256 maternal deaths per 100,000

Theme
Issues
Maternal mortality has declined but remains high
Still striking geographical and socio-economic disparities in maternal mortality
Immediate or intermediate determinants
Contraceptive use through reduced high risk births reduces maternal mortality
Traditional Birth Attendants hinder referral of maternal complications
The primary health care system is not yet optimal in facilitating safe and timely referral of cases of maternal complications
Proximity to a referral hospital reduces the risk of maternal mortality
Availability of transportation at the household level reduces the risk of maternal mortality
Primary or distant determinants
Reducing poverty reduce the risk of maternal mortality
Increasing education of women reduces the risk of maternal mortality
Not yet clear whether women's employment is related to maternal mortality
Households of too large size, with one or more disabled members, and/or with child loss are at high risk of maternal mortality
Village electrification, the presence of village office, and environmental pollution reduce the risk of maternal mortality

Box 1. The study resulted themes of maternal mortality in Indonesia, 2010–2021.

		SP 2015		SP 2020-LF	
		# Census blocks	MMR [Coeff]	# Census blocks	MMR [Coeff]
Indonesia		40,728	326	268,223	257
		%		%	
Urban/Rural	Urban	47.1	280 [Ref]	59.5	250 [Ref]
	Rural	52.9	386 [0.6*]	40.5	296 [0.04**]
Major Island region	Jawa-Bali	43.1	282 [Ref]	44.3	228 [Ref]
	Sumatera	26.4	355 [0.14*]	24.7	260 [0.06**]
	Kalimantan	8.6	339 [0.15*]	9.1	330 [0.06**]
	Sulawesi	11.1	409 [0.25*]	11.1	284 [0.08*]
	NTB-NTT-Maluku-Papua	10.8	427 [0.44*]	10.8	369 [0.10*]
		100.0		100.0	

Table 1. LLR coefficients of geographical factors on maternal mortality, Indonesia. Maternal deaths included pregnancy related deaths and the deaths of woman reproductive age in the household with the under-five child of no mother. The log linear regression (LLR) analysis controls for other social and health-system factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

live births (SP 2020-LF) (See Table 1). Meanwhile, BPS-Statistics Indonesia (2023:57) reported a decrease in the maternal mortality ratio from 305 in 2010–2014 to 189 per 100,000 live births in 2017-2021[17]. The estimated maternal mortality ratio in our study was higher because our definition of maternal mortality includes not only pregnancy-related deaths but also deaths of women of childbearing age in households with children under five without mothers. Using different data and techniques, the World Health Organization (2023: 84) estimated the maternal mortality ratio in Indonesia to be 193 in 2015 and 173 per 100,000 live births in 2020[18]. In 2020, the maternal mortality ratio per 100,000 live births in Indonesia (173) was higher than that in other neighbouring ASEAN countries: Malaysia (21), Brunei Darussalam (44), the Philippines (78), Thailand (29), and Singapore (7). Studies using different data sources, methods, and definitions have reported different estimates of maternal mortality. Unfortunately the data on which these assessments are based are generally unreliable. However, all the estimates consistently report the still high maternal mortality in Indonesia –above 170 maternal deaths per 100,000 live births.

Still striking geographical disparities in maternal mortality

Urban-rural disparities in maternal mortality have slightly reduced during the past decade. The risk of maternal mortality was 6% (SP 2015) and 4% (SP 2020-LF) higher in rural than in urban areas (See Table 1). Geographical disparities in maternal mortality (by island region) have decreased significantly but remain striking. The risk of maternal death outside Java-Bali is much higher than that in the Java-Bali region. Java-Bali has the lowest risk of maternal death, while the eastern region which includes NTB, NTT, Maluku and Papua has the highest risk of maternal death. The risk of maternal death in the eastern region (NTB, NTT, Maluku and Papua) compared to the Java-Bali region was 44% higher in SP 2015, and decreased to only 11% higher in SP 2020-LF (See Table 1). The risk of maternal mortality in the regions of Sumatra, Kalimantan, and Sulawesi as compared to the Java-Bali region was 15–25% in SP 2015, and 6–8% higher in SP 2020-LF (See Table 1).

		SP 2015	SP 2020-LF
Contraceptive use	Low	ref	NA
	Middle	0.004 [-0.04-0.05]	NA
	High	-0.05* [(-0.09) - (-0.002)]	NA
High-risk birth[@]	Low	ref	ref
	Middle	0.11* [0.07–0.16]	0.03** [0.02–0.04]
	High	0.21* [0.17–0.26]	0.047** [0.03–0.06]

Table 2. LLR coefficients of high risk birth and contraceptive use on maternal mortality, Indonesia. [@] The high-risk births included unintended and the "four-too" births for SP 2015, and only the "four-too" births for SP 2020-LF. Log linear regression (LLR) analysis controls for other social and health factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

Year	2002/3	2007	2012	2017
Unintended births	7.6	7.9	7.9	7.6
The "four-too" births	52.8	49.8	43.0	43.5
Too young: 15–19 years old	12.3	10.3	9.4	8.7
Too old: 40–49 years	3.2	3.7	3.9	4.0
Too close: interval < 24 months	11.4	11.3	9.6	9.0
Too many: Parity 3+	37.7	36.7	30.6	34.7
Unintended and the "four-too" births	7.3	7.3	7.1	7.3

Table 3. Prevalence (%) of unintended and the "four-too" births, Indonesia 2000–2017. *Source* Indonesia Demographic Health Surveys 2002/3, 2007, 2012, and 2017.

Socioeconomic disparities in maternal mortality have reduced but remain Stark

The risk of maternal mortality in census blocks with a high proportion of poor households compared to census blocks with a low proportion of poor households was 7–27% higher in the early 2010s (SP 2015) and decreased to 5–7% higher in the 2010s (SP 2020-LF) (See Table 6). The decrease in socioeconomic disparities in maternal mortality from 2010 to 2021 was most likely caused by the provision of social health insurance since the mid-2010s.

Intermediate determinants of maternal mortality

Contraceptive use through reduced high risk births reduces maternal mortality

Contraceptive use and high-risk birth are closely related. Contraceptive use, by reducing births and high-risk births, reduces maternal mortality[41]. Contraceptive use or reduced high-risk births can be cited as outcomes of a family planning program. Our research showed that increasing contraceptive use and decreasing high-risk births reduced the risk of maternal death. Analysis of the SP 2015 data showed that the risk of maternal death was 5% lower in census blocks with a higher proportion of contraceptive use than in census blocks with a low proportion of contraceptive use (See Table 2). It is important to note that the log linear regression coefficient of contraceptive use on maternal mortality appears too small because the analysis controls for high-risk births.

High-risk birth increases the risk of maternal mortality. The risk of maternal death ranges from 11 to 21% (SP 2015) and 3–47% (SP 2020-LF) higher in census blocks with higher proportions of high-risk births than in census blocks with a low proportion of high-risk births (See Table 2). We defined high-risk births as including only unintended births and "four-too" births (too young, too old, too close, and too many). These data indicate that unintended pregnancies and the "four-too" pregnancies increase the risk of maternal death. Consistent with other studies, the unintended[42,43] and the "four-too" pregnancies[44,45] increase the risk of maternal mortality.

Considering that Indonesia is still facing a high prevalence of unwanted births and the "four-too" births" (See Table 3), the family planning program has a great opportunity to further contribute to reducing maternal mortality. Reducing the number of high-risk births will significantly reduce the number of maternal deaths[46].

Traditional birth attendants hinder referral of maternal complications

Our research showed that the presence of TBAs increases the risk of maternal death. Villages with a high density have a risk of maternal mortality that is 1–16% (SP 2015) and 5% (SP 2020-LF) higher than that in villages with a low density of TBAs (See Table 4).

The primary health care system is not yet optimal in facilitating safe and timely referral of cases of maternal complications

This study indicates that the primary health care (PHC) system – measured through subdistrict or village density of PHC facilities, physicians, or midwives – is not yet optimal in facilitating safe and timely referral of cases of maternal complications. Analysis of SP 2015 and SP2020-LF data provides conflicting results regarding the effect of the density of PHC facilities, physicians, and midwives on the risk of maternal mortality. The risk of maternal

		SP 2015	SP 2020-LF
TBA density at the village	Low	ref	ref
	Middle	0.01 [(-0.03)-0.06]	-0.002 [(-0.02)-0.01]
	High	0.16* [0.12–0.20]	0.05 [0.04–0.06]
PHC facility density at subdistrict	Low	ref	ref
	Middle	-0.01 [(-0.05)-0.04]	0.02* [0.01–0.03]
	High	0.15* [0.10–0.19]	0.01 [0.00-0.02]
Physician density at subdistrict	Low	ref	ref
	Middle	-0.12* [(-0.17)-(-0.07)]	0.02* [0.01–0.03]
	High	-0.11* [(-0.15)-(-0.63)]	0.03* [0.02–0.05]
Midwife density at village	Low	ref	ref
	Middle	-0.02 [(-0.07)-0.03]	0.01 [(-0.003)-0.02]
	High	0.04 [(-0.01)-0.08]	0.02* [0.01–0.03]
Hospital density at district	Low	ref	ref
	Middle	-0.09* [(-0.14)-(-0.05)	0.01 [0.002–0.03]
	High	-0.15* [(-0.19)-(-0.10)]	-0.02* [(-0.04)- (-0.01)]

Table 4. LLR coefficients of health program factors on maternal mortality, Indonesia. Density of health facilities/workers is calculated by dividing the number of facilities/health workers by the population of the village, sub-district or district census block. Log linear regression (LLR) analysis controls for other social and health factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

		SP 2015	SP 2020-LF
Household owned vehicle	Low	ref	NA
	Middle	-0.13* [(-0.18)-(-0.09)]	NA
	High	-0.17* [(-0.22)-(-0.13)]	NA
Village public transport	Yes	ref	ref
	No	0.02 [(-0.03)-0.06]	0.002 [(-0.01)-0 0.01]
Village people in hill	Yes	ref	ref
	No	-0.10* [(-0.14)-(-0.05)]	-0.02* [(-0.03)-(-0.003)]

Table 5. LLR coefficients of transportation availability on maternal mortality, Indonesia. Log linear regression (LLR) analysis controls for other social and health factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

mortality is not lower, and even tends to be higher (SP 2015 and SP 2020-LF), in sub-districts with a high density compared to sub-districts with a low density of primary health care facilities (See Table 4).

Regarding physician density, the risk of maternal mortality was 12% lower (SP 2015), but 3% higher (SP 2020-LF) in subdistricts with a high density compared to subdistricts with a low density of physicians (See Table 4). Analysis of SP 2015 data shows that midwife density has no effect on the risk of maternal death, while analysis of SP 2020-LF data provides an unexpected result, where midwife density is negatively related to the risk of maternal death (See Table 4). The results of this conflicting and inconsistent statistical analysis indicate that the existence of the PHC system does not reduce the risk of maternal mortality.

Proximity to a referral hospital reduces the risk of maternal mortality

As expected, this study showed that the closer the distance to the hospital, the lower the risk of maternal death. The risk of maternal death ranges from 9 to 15% (SP 2015) and is 2% (SP 2020-LF) lower in districts with high hospital density than in districts with low hospital density (See Table 4).

Availability of transportation at the household level reduces the risk of maternal mortality

Ease of transportation reduces the risk of maternal mortality. The UN recommends that every household can access Emergency Obstetric Neonatal Care (EmONC) within a maximum travel time of 2 h[47]. Our study showed that the availability of transportation at the household level, which makes women less dependent on village public transportation, reduces the risk of maternal death. The risk of maternal mortality ranges from 13 to 17% (SP 2015), lower in villages with a lower proportion than in villages with a high proportion of households owning a vehicle (See Table 5). Further, 10% (SP 2015) and 2% (SP 2020-LF) of women living in the hill environment had a higher risk of maternal mortality than those living in a non-hill environment (See Table 5). Neither SP 2015 nor SP 2020-LF showed a significant effect of public transportation availability on the risk of maternal mortality. Differences in the risk of maternal death according to vehicle ownership in the household and the hilly location of residence suggest the importance of limiting the travel time required for women to access emergency obstetric services.

Primary and distant determinants of maternal mortality

The primary and distant determinants of maternal mortality are mainly factors related to household empowerment and living social and physical environments[48]. In this study, factors related to household empowerment include poverty, women's education, women's employment status, household size, household disability status, and child loss status in the household. Meanwhile, factors related to the environment include village electricity, the existence of a village office, and the status of environmental pollution.

Reducing poverty reduces the risk of maternal mortality

Poverty increases the risk of maternal mortality. As cited in the previous section of socio-economic disparities, the SP 2015 and SP 2020-LF data show that the risk of maternal mortality is higher in census blocks with a high proportion of poor households than in those with a low proportion (see Table 6).

Increasing education of women reduces the risk of maternal mortality

Our study showed a dose-response effect of improving women's education on reducing the risk of maternal mortality. The higher the education level of women the lower the risk of maternal mortality. The risk of maternal mortality ranges from 9 to 14% (SP 2015) and 3–4% (SP 2020-LF) higher in census blocks with a high proportion of low-educated women than those in a low proportion (See Table 6).

Not yet clear whether women's employment is related to maternal mortality

Women who work for money contribute to household income[49,50], thereby empowering them to be healthy, but in turn such work reduces mothers' time for household activities[49,51]. However, our study showed an unclear relationship between women's employment status and maternal mortality. Log linear regression analysis applied to SP 2015 and SP 2020-LF data showed that there was no significant effect of women's employment status on the risk of maternal mortality (See Table 6).

Households of too large size, with one or more disabled members, and/or with child loss are at high risk of maternal mortality

Households of too large size increase the risk of maternal mortality. The risk of maternal mortality ranges from 3 to 20% (SP 2015) and 5–8% (SP 2020-LF) higher in census blocks with a low proportion of oversized households (more than 6 members) than in those with a high proportion. Households with one or more disabled members increase the risk of maternal mortality. The risk of maternal mortality *r*anges from 4 to 14% (SP 2015) and 5–8% (SP 2020-LF) higher in census blocks with a high proportion of households with one or more disabled members than in those with a low proportion. Households with experiences of child loss increase the risk of maternal mortality. The risk of maternal mortality ranges from 19 to 25% (SP 2015) and 10–12% (SP 2020-LF) higher in census blocks with a high proportion of households experiencing child loss than in those with a low proportion (See Table 7).

Village electrification, the presence of a village office, and environmental pollution reduce the risk of maternal death

Village electrification and the presence of a village office reduced the risk of maternal mortality. The risk of maternal mortality was 26% (SP 2015), and 6% (SP2020-LF), was lower in villages that had electricity than in villages that did not have electrification (See Table 8). The risk of mortality was 14% (SP 2015) and 2% (though not significant) (SP 2020-LF) higher in villages with no office than in villages with an office (See Table 8).

Living environmental pollution increases the risk of maternal mortality. The risk of maternal mortality was 5% (SP 2015) and 1% (although not significant) (SP 2020-LF) lower in unpolluted villages than in environmentally polluted villages (See Table 8).

		SP 2015	SP 2020-LF
Poor household[@]	Low	ref	ref
	Middle	0.07* [0.02–0.11]	0.05** [0.04–0.06]
	High	0.27* [0.22–0.32]	0.07** [0.06–0.08]
Low educated woman	Low	ref	ref
	Middle	0.09* [0.05–0.13]	0.03** [0.02–0.04]
	High	0.14* [0.10–0.18]	0.04** [0.03–0.06]
Women employment	Low	ref	ref
	Middle	-0.16 [(-0.06)-0.03]	-0.01 [(-0.02) – 0.01]
	High	0.03 [(-0.02)-0.08]]	-0.001 [(-0.01) – 0.01]

Table 6. LLR coefficients of household socio-economic, woman education, and women employment on maternal mortality, Indonesia. [@]Poor household is defined as a household in the lowest 40% of socio-economic quintiles. The log linear regression (LLR) analysis controls for other social and health-system factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

		SP 2015	SP 2020-LF
Too large size household@	Low	ref	ref
	Middle	0.03 [(-0.02)-0.08]	0.05** [0.040–0.063]
	High	0.20* [0.15–0.25]	0.08** [0.07–0.10]
Household with disabled	Low	ref	ref
	Middle	0.04 [(-0.01)-0.08]	0.07** [0.05–0.08]
	High	0.14* [0.09–0.18]	0.02** [0.01–0.03]
Household ever had child loss	Low	ref	ref
	Middle	0.19* [0.14–0.25]	0.10** [0.09–0.12]
	High	0.25* [0.21–0.29]	0.12** [0.11–0.14]

Table 7. LLR coefficients of household empowerment on maternal mortality, Indonesia. Log linear regression (LLR) analysis controls for other social and health factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

		SP 2015	SP 2020-LF
Village electricity	Yes	-0.26* [(-0.31)-(-0.21)]	-0.06** [(-0.07)-(-0.04)]
	No	ref	ref
Village office	Yes	ref	ref
	No	0.14* [0.06–0.23]	0.02 [(-0.02)-0.05]
Village environmental pollution	Yes	ref	ref
	No	-0.05* [(-0.09)-(-0.01)]	-0.01 [(-0.02)-0.01]

Table 8. LLR coefficient of village environmental characteristics on maternal mortality, Indonesia. Log linear regression (LLR) analysis controls for other social and health factors; *significant at $p < 0.05$, and **significant at $p < 0.01$.

Discussion and recommendations

The discussion and recommendations in this article convey the strengths and limitations of the research, generalize the research results, and then draw policy implications that are relevant to efforts to accelerate the reduction of maternal mortality.

Strengths and limitations

Strengths of the study include the use of "census block-based log-linear regression model" in assessing what health and social program factors are associated with maternal mortality risk" applied to large survey data. This statistical model with the census block level analysis is the most suitable analytical approach for analysing the social determinants of rare events, for example maternal death. The use of a conventional regression with individual women as the unit of analysis cannot be carried out because census or survey data contain insufficient information about the characteristics of mothers who died. The use of the census block level analysis approach applied to the survey data in our analysis is also practically manageable since the survey census blocks in both surveys have been standardized with each composes of 16 households. The use of a census block level analysis approach in this study is practical because the size of the census blocks has been equalized, each consisting of 16 households. In this case we don't need to worry about the within census block statistical variance. Another strength of our study is the innovation of including more health and social program factors in the log-linear regression analysis by combining at the village level the survey database with the village potential census database. Further, the use of the log-linear regression model can examine the net effect of each factor being investigated by statistically control the effect of other independent factors.

Limitations of this study relate to the nature of maternal mortality data obtained from large-scale surveys. Data was obtained from a sample of respondents regarding memories of maternal death in the last five years. These data, especially regarding births and deaths, are generally not free from recall and sampling bias[52]. The risk of errors in remembering the time of maternal death tends to be higher with the larger the sample of respondents[53]. These data limitations can cause over- or under-estimation problems when used to estimate maternal mortality levels, but this is not a problem for analysing differences in maternal mortality according to social groupings. Another limitation includes the comparison between the two large surveys (SP 2015 vs. SP 2020-LF) as they may have different biases in their samples and measurements. Differences in bias between these two surveys may create problems in assessing increases or decreases in the risk of maternal death overtime based on social factors.

Despite data limitations, SP 2025 and SP 2020-LF complement each other and provide consistent and reasonable results regarding health programs and social factors that influence maternal mortality in Indonesia. Regarding data quality and analysis, SP 2015 appeared to be more sensitive than SP 2020-LF in explaining the extent to which health and social program factors determine maternal mortality. In this case, the factor coefficients of the log-linear regression statistical model tended to be much higher in the SP 2015 data than in the SP 2020-LF.

Multiple strategic interventions to accelerate reduction of maternal mortality

Considering the persistent high level of maternal mortality and the striking geographic and socioeconomic disparities, as well as the many factors influencing the risk of maternal mortality, the government needs to carry out multiple strategic interventions to accelerate the reduction in maternal mortality. A single intervention alone is not enough[54]. The health sector itself has limitations for effective interventions on health programs and social related factors causing maternal mortality, but it needs to collaborate closely with various related sectors (family planning, domestic affairs, education, social affairs, workforce, housing and environment, as well as transportation and rural development)[55]. Such intervention strategies may differ by district or province, tailored to regional capacity and the geographical and social situation of the area. To be effective, the multiple strategic interventions need to focus on reducing high-risk pregnancies, reducing serious pregnancy and childbirth complications, and improving the outcomes of women with serious maternal complications[6]. Given the high prevalence of unsafe abortion[56] and its significant contribution to the cause of maternal deaths[57], the strategic interventions need to include improving access and quality of post-abortion care services[58].

Strategic interventions are those that have the potential or are proven to be effective in reducing maternal mortality and they can be carried out in conditions of locally limited resources[59]. The findings of this study (See Box 1) suggest that multiple strategies to reduce maternal mortality should achieve the following 'intermediate' outcomes: (1) Reducing geographic and socio-economic disparities in maternal mortality; (2) Reducing high risk and pregnancies and births; (3) Improving access and quality of EmONC (Emergency Obstetric and Neonatal Care); (4) Strengthened primary health care system in early detection, stabilizing, and facilitating safe and timely referral of cases of maternal complications; (5) Changing role of TBAs from birth attendant to assisting the village midwife; (6) Ease transport from the household to EmONC – maximal 2 h travel time; (7) Empowered households and women to maintain health; (8) All villages are electrified and have offices; and (9) Controlled environmental pollution and improved environmental sanitation.

Reducing Spatial and socio-economic disparities in maternal mortality

Our study shows significant spatial and socio-economic disparities in maternal mortality ratios. Urban-rural, geographic and socio-economic disparities in maternal mortality can be explained by unequal access to family planning and maternal health services[60–63]. Reducing spatial and socioeconomic disparities in maternal mortality is a necessity in the context of efforts to improve women's health.

Strategies to reduce the spatial disparities in maternal mortality should be developed, implemented, monitored, and evaluated, and continuously adapted. These strategies need to be linked to increasing the access, quality, and distribution of maternal health service facilities, especially EmONC[64]. Geographical areas with a high risk of maternal death should be prioritized for EmONC investments. To reduce socioeconomic disparities in maternal mortality, the government needs to improve the coverage and quality of social insurance programs. To be effective, social health insurance programs need to be able to significantly reduce out-of-pocket payments[65], and prioritise poor households and communities at high risk of maternal mortality. Social health insurance programs should be capable of improving the access and quality of maternal health care services[66]. Two studies in Indonesia[67,68] and others in Ghana[69] and Turkey[70] showed that the provision of national or community health insurance has contributed to reducing socioeconomic inequality of maternal health care access. In Nigeria, social health insurance has reduced socioeconomic inequality of maternal mortality[71].

Reducing high risk pregnancies

Our research shows that high-risk pregnancies, included unplanned pregnancies and the "four-too" pregnancies, carry a high risk of maternal death. Other studies show similar results that high-risk births increase the risk of maternal and child morbidity and death[72,73]. A rights-based family planning program is the best approach for reducing high-risk pregnancies[74]. The still high prevalence of unwanted births and "four-too" births in Indonesia (See Table 3) indicates that the family planning program has a great opportunity to contribute further to reducing maternal mortality[75]. In this regard, the family planning program should be strengthened with a focus on increasing demand and sustainable use of contraception, as well as reducing unmet need and discontinuation of contraception, targeted especially at high-risk groups of women of childbearing age[75,76].

Diversion of the role of TBAs to support reducing the risk of maternal mortality

In line with previous research in Indonesia[77–79], our study shows that the presence of traditional birth attendants (TBAs or *dukun*) hinders timely referral of maternal complications, and thus increases the risk of maternal mortality. Management of birth by traditional birth attendants (TBAs) if complications occur in the mother will delay timely referral to emergency obstetric services[79]. In many villages, TBAs are still active, and they are the first point of contact for mothers for consultation regarding pregnancy and childbirth[77,79]. Our previous research[57], although dated, shows that TBA plays an important role in traditional maternal care practices in West Java, a province with a large population currently of more than 50 million. Traditional practices in maternal care are especially prominent in the Java southern districts. Most of these traditional practices increase the risk of maternal death. Considering that TBAs are still actively providing pregnancy and birth services[80] in most villages in Indonesia the government needs to implement practical policies to shift the role of TBAs from direct

assistance with delivery to assistant health service providers in the early detection and safe and timely referral of cases of maternal complications[81]. With this role transfer, the presence of TBAs is expected to reduce rather than increase the risk of maternal mortality.

Strengthening the primary health care system

Our study shows that the presence of a primary healthcare system, as measured by the density of primary healthcare facilities and/or healthcare providers, does not affect the risk of maternal mortality (See Table 4). The findings of this study imply the need for strengthening the Primary Health Care System in the early detection of maternal complications, stabilization, and safe and timely referral of these complications to EmMONC[82]. Systematic efforts to strengthen the primary healthcare system need to be made so that the system can support the reduction in the risk of maternal and early child mortality. Such systematic efforts could include practical training programs improving the technical and managerial capacity of primary health care providers for early detection of maternal complications, stabilization of patient conditions, and timely safe referral to the nearest EMONC facility; and improving the organization of service systems and infrastructure to facilitate safe, timely referrals[83]. A strong primary healthcare system must be able to detect early and stabilize cases of maternal complications, and facilitate safe and timely referral of cases of complications to the nearest quality hospital, thereby reducing the risk of maternal death[84,85].

Improving access and quality of emergency obstetric and neonatal care

Our research shows that a pregnant woman's proximity to a hospital, as measured by hospital density, reduces the risk of maternal death. This finding is consistent with other studies[46,86,87], which shows that hospitals, defined as EmMONC (Comprehensive Emergency Obstetric and Neonatal Care), particularly in developing countries, play an important role in rescuing cases of life-threatening maternal complications. The timeliness of access and quality services, and the severity of complications determine the success of saving lives[88].

Improving the distribution of EmMONC and facilitating safe transportation from households/villages to EmMONC can increase access for pregnant women with complications to EmMONC. Our research shows that the availability of transport vehicles in households reduces the risk of maternal mortality (See Table 5). These improvements should be prioritized in areas with a high risk of maternal mortality. Furthermore, improving quality throughout the care continuum (from preconception to postpartum and inter-pregnancy care) is required to reduce maternal and early life of morbidity and mortality[89]. Other studies emphasize the importance of ease of transportation and overcoming environmental barriers in accessing emergency obstetric services[90–92].

Improving education of women

The positive dose-response effect of women's education on maternal mortality risk, as shown in this study, implies the need to increase women's education to achieve a long-lasting effect of reducing maternal mortality[93,94]. Increasing the education of women in developing countries reduces the risk of maternal mortality[95,96]. Global surveys have indicated that the high school level (12 years of schooling) is the optimal minimum level women's education to improve maternal health status[95]. The government needs to make systematic efforts to improve women's education and waive school fees for them at least to complete up to senior high school level[95]. Improving women's education means empowering them to access quality health services[97,98].

Empowering households and communities to improve their health status

Consistent with other study findings, our study shows that underpowered households, including households that are too large a size[99], having one or more disabled members[100], or having previously lost a child[101], each have an increased risk of maternal mortality (See Table 7). The greater the number of household members (over size), the greater the possibility of food insecurity[102] and the higher the risk of morbidity and mortality for household members[103,104]. Households with disability tend to be less empowered in enhancing their socio-economic capacity[105] and in accessing health care[106]. Households that have lost children indicate a lack of capacity to improve the health of their members[107], including maternal health[108]. These findings indicate the need for the government to design and implement community empowerment programs to improve the health of households and communities being able to improve their health[109]. Empowering households and communities, economically, socially and politically, leads to a reduction in maternal mortality. The fact that reducing poverty reduces the risk of maternal mortality implies the need of health program interventions to be prioritized for poor communities[4].

Electrifying villages and controlling environmental pollution reduces the risk of maternal mortality

Consistent with other studies[110,111],our study shows that village electrification clearly reduces the risk of maternal mortality (See Table 8). Village electrification will facilitate women in doing social and economic activities, including improved access to quality health care services[110,112]. Findings of these studies imply a need for the government to electrify all villages to empower households and communities to improve their health. The related literature shows that village electrification and the presence of a village office support household health, increase access to health services, and reduce the risk of maternal mortality[113].

In line with a rapidly expanding body of information[114,115], our study shows that environmental pollution increases the risk of maternal mortality (See Table 8). Research shows that environmental water, land and air pollution through increased risk of morbidity increases the risk of maternal death[116–119]. Thus, the government needs to control environmental pollution, including air, water and land pollution, to help reduce the risk of maternal morbidity and mortality.

Data availability

The data that support the findings of this study are available from BPS-Statistics Indonesia but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the corresponding authors upon reasonable request and with permission of BPS-Statistics Indonesia.

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Author contributions

BU developed the research concept, performed the analyses, and wrote the manuscript. NAR, UR, and RJB carried out data processing and created statistical analysis tables from the SP 2015 and SP 2020-LF databases. RM, EL, SN, MD, and TH provided substantial comments and inputs on the research concept and analysis.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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