Bayesian Spatial Analysis of Factors Influencing Neonatal Mortality and its Geographic Variation in Ethiopia

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Abstract

**Background:** Ethiopia is a Sub-Saharan country with very high neonatal mortality rates, varying across its regions. The rate of neonatal mortality reduction in Ethiopia is slow, and Ethiopia may not meet the third United Nations sustainable development target by 2030. This study aimed to investigate the spatial variations and contributing factors for neonatal mortality rates in Ethiopia.

**Methods:** We analysed data from the 2016 Ethiopian Demographic and Health Survey, which used a two-stage cluster sampling technique with a census enumeration area as primary and households as secondary sampling units. A hierarchical Bayesian logistic regression model was fitted accounting for socio-economic, health service-related and geographic factors.

**Results:** Higher neonatal mortality rates were observed in eastern, northeastern and southeastern Ethiopia, and the Somali region had higher risks of neonatal mortality. Neonates from dry and drought-affected areas had a higher risk of mortality compared to more humid and less drought-affected areas. Application of traditional substances on the cord increased the risk of neonatal mortality (Adjusted Odds Ratio (AOR) = 2.05, 95% Confidence Interval (CI): 1.10 to 4.26) and health provider counselling on newborn danger signs in the first two days after birth had a lower odds of neonatal mortality (AOR = 0.34, 95% CI: 0.13, 0.75).

**Conclusions:** Applying traditional substances on the umbilical cord, lack of counselling services about neonatal danger signs within the first two days of birth and residing in dry and drought-affected areas were associated with a higher risk of neonatal mortality. Policy-makers and resource administrators at different administrative levels could leverage the findings to prioritise and target areas identified with higher neonatal mortality rates.

Introduction

The neonatal period is critical for newborn survival. The first seven days from birth constitute the early neonatal period, and the time from the seventh to the 28th day is the late neonatal period [1].

In 2018, globally, 2.5 million children died during their first month of life [2]. About 99% of these deaths were in low-and middle-income countries (LMIC) [3, 4], with Sub-Saharan Africa and South Asia accounting for 79% of all neonatal deaths [5]. Children born in Sub-Saharan Africa had ten times the risk of dying in their first month of life than children born in high-income countries [5]. Between 2017 and 2030, over 30 million newborn deaths are predicted globally, with more than half of these occurring in Sub-Saharan Africa [6].

The third Sustainable Development Goal (SDG) target is to reduce the neonatal mortality rate (NMR) below 12 deaths per 1000 live births by the end of 2030 [7]. In order to achieve this target, a significant acceleration of neonatal mortality reduction is required. In the 50 countries with the highest neonatal
mortality rates, the annual rate of neonatal mortality reduction needs to be doubled between 2015 and 2030 to achieve the SDG target [8].

The Sub-Saharan Africa region has made the least progress in reducing neonatal deaths in the last three decades [3, 9]. In almost a third of the region's countries, annual neonatal mortality rates were more than 30 deaths per 1000 live births in 2017, and two-thirds of countries that are at risk of missing the SDG neonatal mortality target are in sub-Saharan Africa [9].

Like most Sub-Saharan countries, Ethiopia has a high neonatal mortality rate [10–13]. In 2012, Ethiopia had the sixth-highest neonatal mortality rate globally, with an estimated death of 87,800 neonates or 31 deaths per 1000 live births [14, 15]. Ethiopia achieved the fourth millennium development target of reducing child mortality by two thirds, three years ahead of the 2015 deadline [16, 17]. The infant mortality rate also showed a promising decline, falling from 119 to 37 per 1000 live births between 1990 and 2019 [18]. However, the decline in neonatal mortality rate has been slow compared to the under-five and infant mortality reduction rates [19]. The United Nations (UN) Inter-agency Group for Child Mortality report indicated that the proportion of neonatal mortality in infant mortality increased from 51% in 1990 to 77% in 2019 in Ethiopia [18, 20]. The current neonatal mortality reduction trends indicated that it would be difficult for Ethiopia to achieve the third SDG target of reducing neonatal mortality rates to below 12 deaths per 1000 live births by 2030 [21, 22].

Evidence from studies on neonatal survival in Ethiopia report inconsistent neonatal mortality rates. A meta-analysis that pooled prevalence studied showed an overall neonatal mortality rate of 163.5 per 1000 live births [10]. A finding from another systematic review and meta-analysis of 11 studies conducted after 2012 in Ethiopia reported a neonatal mortality rate of 67.8 per 1000 live births [11], but with considerable heterogeneity. The variation in these findings might be due to the small sample size in the individual studies that addressed small areas of the country. In order to make noticeable progress in neonatal survival, policy-makers and resource administrators at all levels need to develop evidence-based strategies prioritising areas identified with high neonatal mortality rates [23].

A range of factors are associated with neonatal mortality, including community-level, socio-economic and proximal factors [23–29] (see Fig. 1). The conceptual framework in Fig. 1 incorporates socio-economic, proximal and geospatial factors that contribute to neonatal mortality. Proximal factors are factors related to health services use and neonatal and maternal characteristics. Findings from this study could inform policy-makers and local administrators to help better service administration identify contributing factors and interventions where the problems are salient.

**Methods**

**Study setting**

Ethiopia is the second-most populous country in Africa, with a population of more than 112 million and a growth rate of 2.6% in 2019 [31]. The majority (80%) of the people reside in rural areas, with agriculture
being the primary income source [32].

**Data Source**

The study is based on secondary data analysis of the 2016 Ethiopian Demographic and Health Survey (EDHS) [33]. The EDHS is a cross-sectional survey with a nationally representative sample. The datasets contain socio-economic, neonatal, maternal, geospatial and health service use related variables. Permission was granted to access the dataset through the Demographic and Health Surveys Program database [34]. The detailed descriptions of the DHS design and sampling procedures can be found elsewhere [35].

**Study Population and Sample Size**

The target population of the study were newborns from birth to the 28th day from birth in Ethiopia. The samples were selected using a two-stage cluster sampling technique using a census enumeration area (EA) as the primary sampling unit and households as the secondary sampling unit. An EA or cluster is a geographic area covering, on average, 181 households. The most recent births of mothers were included in the study to identify the factors associated with neonatal mortality because most of the health services use related variables such as antenatal care, place of delivery, and postnatal care were collected for only the most recent live births.

The sampled total number of live births in the past five years of 2016 EDHS was 10,571, and health service use related data were collected from 7,180 most recent live births, of which 7,071 samples were collected from permanently residing respondents. About 109 participants were visitors and not considered in the analysis (Figure 2).

**Study Variables**

The primary outcome of interest is neonatal mortality, defined as death within 28 days of birth. The explanatory variables at the individual level include living status of the mother, multiple births, size of child at birth, birth order, child sex, umbilical cord care practice, antenatal care use, postnatal care use, duration of pregnancy, tetanus protection at birth, household wealth index, cooking energy commonly used in the household, and educational status of the mother. Factors such as residing in urban or rural areas, the region of residence, mean antenatal care visits per cluster, the proportion of deliveries in health facilities per cluster and the proportion of postnatal care use per cluster were considered at the community level. Geospatial factors such as aridity, episodes of drought and travel times to the nearest town of 50,000 or more dwellers were included at the cluster level (see Appendix 1 for definitions of variables).

**Analysis**

We fitted a multilevel Bayesian logistic regression model using the Stochastic Partial Differential Equation (SPDE) method using the Integrated Laplace approximation (R-INLA) package [36]. The
integrated Laplace approximation methodology is a deterministic approach to approximate Bayesian inference for latent Gaussian models (LGMs), including the Bayesian generalised linear mixed (GLMM) models [37]. It is both faster and more accurate than Markov chain Monte Carlo (MCMC) alternatives for LGMs. The R-INLA package can be used for quick and reliable Bayesian inference in practical applications [36]. The SPDE was implemented in the R-INLA package to fit a spatial model and predict the neonatal mortality rate at unsampled locations [38]. Variables in the final multivariable analysis were selected using bivariable analysis; the best subset variable selection approach was used as a second step. Variables with a p-value of less than 0.15 in the bivariable analysis were further screened using the best subset variable selection method. The best-fitting model from the best subset method was selected using the Watanabe-Akaike Information Criterion (WAIC) and Deviance Information Criterion (DIC). Finally, separate models with and without the spatial correlation were fitted. The model with combined individual and community-level variables accounting for spatial correlation and cluster as a random effect was the best fit model for the data based on the model fitness criteria. We used R version 4.0.3 statistical software for analyses [39].

Results

Socio-Economic Characteristics of Study Participants

The majority (87.4%) of the study participants were rural residents. Approximately two-thirds (63.5%) of the mothers did not have formal education, and 6,621 (96.3%) of the households used solid fuel such as wood, dung and charcoal as cooking energy (Table 1).

Table 1: Socio-economic characteristics of study participants, EDHS 2016
| Variable                        | Sample Frequency | Unweighted proportion | Weighted proportion | (95% CI) |
|--------------------------------|------------------|-----------------------|---------------------|---------|
| Educational status of the mother |                  |                       |                     |         |
| No education                   | 4,306            | 60.9                  | 63.5                | (61.8, 65.1) |
| Primary education              | 1,904            | 26.9                  | 28.3                | (26.7, 29.9) |
| Secondary and above            | 861              | 12.2                  | 8.2                 | (7.4, 9.2) |
| Living situation of the mother |                  |                       |                     |         |
| Living with partner            | 6,552            | 92.7                  | 93.7                | (92.8, 94.4) |
| Not living with a partner      | 519              | 7.3                   | 6.3                 | (5.6, 7.2) |
| Cooking energy used            |                  |                       |                     |         |
| Solid fuel                     | 6,621            | 93.6                  | 96.3                | (95.7, 96.8) |
| Clean fuel                     | 450              | 6.4                   | 3.7                 | (3.2, 4.3) |
| Household wealth tertiles      |                  |                       |                     |         |
| Highest                        | 2,500            | 35.4                  | 35.2                | (33.6, 36.9) |
| Middle                         | 1,010            | 14.3                  | 20.9                | (19.6, 22.4) |
| Lowest                         | 3,561            | 50.4                  | 43.8                | (42.1, 45.5) |
| Place of residence             |                  |                       |                     |         |
| Urban                          | 1,477            | 20.9                  | 12.6                | (11.5, 13.7) |
| Rural                          | 5,594            | 79.1                  | 87.4                | (86.3, 88.4) |
| Region                         |                  |                       |                     |         |
| Tigray                         | 761              | 10.8                  | 7.1                 | (6.6, 7.7) |
| Afar                           | 634              | 9.0                   | 0.9                 | (0.8, 1.0) |
| Amhara                         | 729              | 10.3                  | 20.9                | (19.5, 22.3) |
| Oromia                         | 1,020            | 14.4                  | 41.6                | (39.8, 43.4) |
| Somali                         | 801              | 11.3                  | 3.6                 | (3.3, 3.9) |
| Benishangul                    | 575              | 8.1                   | 1.1                 | (0.9, 1.2) |
The median age of mothers who participated in the study was 28.0 years, with an interquartile range of 25 to 34 years. More than half (57.9%) of the study participants did not take iron supplements during their recent pregnancy, and the majority (88.6%) did not receive counselling services on newborn danger signs during their postpartum period. Traditional substances such as dung, oil, and different ointments were applied as cord care for most newborns (80.4%) (Table 2).

**Table 2: Maternal, neonatal and health service-related (proximate) factor characteristics**

| Location         | N  | Median | Interquartile Range |
|------------------|----|--------|---------------------|
| SNNPR            | 881| 12.5   | (19.9, 22.6)        |
| Gambela          | 529| 7.5    | (0.2, 0.3)          |
| Harari           | 408| 5.8    | (0.2, 0.3)          |
| Addis Adaba      | 361| 5.1    | (2.3, 2.9)          |
| Dire Dawa        | 372| 5.3    | (0.4, 0.5)          |

CI: Confidence Interval
| Variable                                         | Sample Frequency | Unweighted proportion | Weighted proportion | (95% CI)             |
|-------------------------------------------------|------------------|-----------------------|---------------------|----------------------|
| Sex of child                                    |                  |                       |                     |                      |
| Male                                            | 3,660            | 51.8                  | 52.0                | (50.3, 53.7)         |
| Female                                          | 3,411            | 48.2                  | 48.0                | (46.3, 49.7)         |
| Birth type                                      |                  |                       |                     |                      |
| Singleton                                       | 6,962            | 98.5                  | 98.4                | (97.9, 98.8)         |
| Twin                                            | 109              | 1.5                   | 1.6                 | (1.2, 2.0)           |
| Umbilical cord care                             |                  |                       |                     |                      |
| Nothing applied                                 | 1,036            | 14.6                  | 14.2                | (13.0, 15.4)         |
| Substances applied                              | 5,632            | 79.6                  | 80.4                | (79.0, 81.7)         |
| Don't know                                      | 403              | 5.7                   | 5.4                 | (4.7, 6.2)           |
| Mother took iron supplements during pregnancy   |                  |                       |                     |                      |
| No                                              | 3,849            | 54.4                  | 57.9                | (56.2, 59.6)         |
| Yes                                             | 3,201            | 45.3                  | 41.9                | (40.2, 43.6)         |
| Don't know                                      | 21               | 0.3                   | 0.2                 | (0.1, 0.4)           |
| Health provider counselled on newborn dangers   |                  |                       |                     |                      |
| No                                              | 6,151            | 87.0                  | 88.6                | (87.6, 89.6)         |
| Yes                                             | 881              | 12.5                  | 10.8                | (9.9, 11.8)          |
| Don't know                                      | 39               | 0.5                   | 0.5                 | (0.3, 0.8)           |
| Size of the neonate at birth                    |                  |                       |                     |                      |
| Average                                         | 2,937            | 41.4                  | 40.4                | (38.8, 42.1)         |
| Large                                           | 2,136            | 30.2                  | 31.8                | (30.2, 33.4)         |
| Small                                           | 1,915            | 27.1                  | 26.9                | (25.4, 28.5)         |
| Don't know                                      | 83               | 1.2                   | 0.9                 | (0.6, 1.3)           |
Number of antenatal care visits

| Number of Visits | Count | Percent | Category | Percent (CI) |
|------------------|-------|---------|----------|--------------|
| 4 or more        | 2,554 | 36.1    |          | (30.3, 33.4) |
| 1 to 3           | 2,052 | 29.0    |          | (29.1, 32.4) |
| No antenatal     | 2,465 | 34.9    |          | (35.8, 39.2) |

Place of delivery

| Place of Delivery | Count | Percent | Category | Percent (CI) |
|-------------------|-------|---------|----------|--------------|
| Health facility   | 2,643 | 37.4    |          | (29.9, 33.1) |
| Home              | 4,332 | 61.3    |          | (65.4, 68.6) |
| Other             | 96    | 1.4     |          | (1.1, 1.9)   |

Tetanus protection at birth

| Tetanus Protection | Count | Percent | Category | Percent (CI) |
|--------------------|-------|---------|----------|--------------|
| Protected          | 2,229 | 31.5    |          | (29.5, 32.7) |
| 1-2 injections     | 2,312 | 32.7    |          | (32.0, 35.2) |
| No injection       | 2,530 | 35.8    |          | (33.7, 37.0) |

Duration of pregnancy

| Duration of Pregnancy | Count | Percent | Category | Percent (CI) |
|-----------------------|-------|---------|----------|--------------|
| Preterm               | 118   | 1.7     |          | (1.0, 1.8)   |
| Term                  | 6,953 | 98.3    |          | (98.2, 99.0) |

Preceding birth interval

| Preceding Birth Interval | Count | Percent | Category | Percent (CI) |
|--------------------------|-------|---------|----------|--------------|
| More than two years      | 4,333 | 61.3    |          | (63.2, 66.5) |
| Two years or less        | 1,311 | 18.5    |          | (15.4, 18.0) |
| First birth              | 1,427 | 20.2    |          | (17.2, 19.9) |

Neonatal mortality rate

The overall neonatal mortality rate was 29.0 per 1000 live births (95% Confidence Interval (CI): 24.5 to 34.4) using all births and was 22.0 deaths per 1000 live births (95% CI: 17.1 to 27.9) when including only the most recent live births in the past five years before the EDHS. The highest neonatal mortality rate based on all live births was observed in the Somali regional state with 40.9 deaths per 1000 live births, followed by the Amhara regional state with 32.4 deaths per 1000 live births. The lowest neonatal mortality rate was in Addis Ababa, with 21.0 deaths per 1000 live births. The highest mortality rate in the
most recent births was also in the Somali region, with 37.5 deaths per 1000 live births and the lowest mortality rate was in Addis Ababa with 7.8 deaths per 1000 live births (Figure 3).

Factors Associated with Neonatal Mortality

We found that health provider counselling on newborn dangers signs in the first two days after birth had a lower odds of neonatal mortality (Adjusted Odds Ratio (AOR)=0.34, 95% CI: 0.13, 0.75). Similarly, umbilical cord care during the early days (not further defined) of birth influence neonatal survival. Application of traditional substances on the cord increased the risk of neonatal mortality (AOR=2.05, 95% CI: 1.10 to 4.26) compared to those who did not apply traditional substances.

Neonates from dry areas were at higher risk of mortality than those from humid areas (AOR=2.65, 95% CI: 1.01 to 7.18), and areas with drought episodes of greater than five experienced higher rates of neonatal mortality compared to areas with five or fewer drought episodes in the previous 21 years (AOR=1.92, 95% CI: 1.07 to 3.54). Twin pregnancies had a higher risk of neonatal mortality (AOR =8.65, 95% CI: 4.52, 15.58) compared to singletons, and female neonates were 74% less likely to die compared to their male counterparts (AOR = 0.26, 95% CI: 0.18 to 0.38). Term births had a lower risk of mortality compared to preterm births (AOR =0.09, 95% CI: 0.05 to 0.17) and neonates with unknown birth size, as reported by their mothers, had a higher risk of death compared to average size neonates (AOR=4.25, 95% CI: 1.52 to 10.10). Newborns born to mothers residing in rural areas had a higher risk of neonatal mortality than those who lived in urban areas (AOR=2.65, 95% CI: 1.20 to 6.14) (Table 3).

Table 3: Factors influencing neonatal mortality in Ethiopia, EDHS 2016
| Variable                              | Category         | AOR (95% CI) |
|---------------------------------------|------------------|--------------|
| Sex of child                          | Male             | 1.00         |
|                                       | Female           | 0.26 (0.18, 0.37) |
| Birth type                            | Singleton        | 1.00         |
|                                       | Twin             | 8.69 (4.51, 15.82) |
| Birth order                           |                  | 1.07 (0.99, 1.15) |
| Umbilical cord care                   | Nothing applied  | 1.00         |
|                                       | Substances applied| 2.29 (1.22, 4.79) |
|                                       | Do not know      | 4.00 (1.64, 9.97) |
| Mother took iron supplements during pregnancy | No               | 1.00         |
|                                       | Yes              | 0.81 (0.51, 1.28) |
| Health provider counselled on newborn dangers | No               | 1.00         |
|                                       | Yes              | 0.36 (0.14, 0.80) |
|                                       | Do not know      | 1.85 (0.30, 7.25) |
| Size of the neonate at birth          | Average          | 1.00         |
|                                       | Large            | 1.37 (0.89, 2.15) |
|                                       | Small            | 0.69 (0.43, 1.11) |
|                                       | Do not know      | 4.25 (1.52, 10.10) |
| Number of antenatal care visits       | 4 or more        | 1.00         |
|                                       | 1 to 3           | 0.88 (0.51, 1.48) |
|                                       | No antenatal care| 1.69 (0.91, 3.14) |
| Place of delivery                     | Health facility  | 1.00         |
| Table 3: Factors influencing neonatal mortality in Ethiopia, EDHS 2016 | At home | 0.60 (0.36, 1.04) |
|---------------------------------------------------------------|---------|------------------|
|                                                               | Other   | 0.50 (0.05, 2.55) |
| Tetanus protection at birth                                   | Protected | 1.00 |
|                                                               | 1 to 2 injections | 0.87 (0.53, 1.43) |
|                                                               | No injection   | 1.10 (0.65, 1.90) |
| Duration of pregnancy                                         | Preterm   | 1.00 |
|                                                               | Term      | 0.07 (0.04, 0.13) |
| Educational status of the mother                              | No education | 1.00 |
|                                                               | Primary education | 1.38 (0.85, 2.18) |
|                                                               | Secondary and above | 1.69 (0.75, 3.58) |
| Living situation of the mother                                | Living with a partner | 1.00 |
|                                                               | Not living with a partner | 1.43 (0.74, 2.52) |
| Cooking energy used                                           | Clean fuel | 1.00 |
|                                                               | Solid fuel  | 1.43 (0.47, 5.51) |
|                                                               | 1.00 |
| Household wealth index                                        | Lowest tertile | 1.00 |
|                                                               | Middle tertile | 0.88 (0.50, 1.51) |
|                                                               | Highest tertile | 1.06 (0.62, 1.78) |
| Place of residence | Urban | Rural | 2.65 (1.20, 6.14) |
|--------------------|-------|-------|------------------|
| Region             |       |       |                  |
| Tigray             | 1.00  |       |                  |
| Afar               | 0.54 (0.20, 1.41) |       |                  |
| Amhara             | 0.31 (0.10, 0.92) |       |                  |
| Oromia             | 0.34 (0.11, 0.98) |       |                  |
| Somali             | 1.50 (0.64, 3.60) |       |                  |
| Benishangul        | 0.24 (0.07, 0.82) |       |                  |
| SNNPR              | 0.20 (0.06, 0.66) |       |                  |
| Gambela            | 0.20 (0.06, 0.53) |       |                  |
| Harari             | 0.59 (0.20, 1.69) |       |                  |
| Addis Adaba        | 0.14 (0.02, 0.77) |       |                  |
| Dire Dawa          | 0.79 (0.26, 2.20) |       |                  |
| Mean antenatal care visits per cluster | 1.20 (0.95, 1.51) |
| Proportion of deliveries in health facility per cluster | 0.41 (0.12, 1.38) |
| Proportion of postnatal care use per cluster | 0.28 (0.04, 1.83) |
| Aridity            |       |       |                  |
| Humid              | 1.00  |       |                  |
| Very humid         | 1.65 (0.84, 3.09) |       |                  |
There were also variations in risks of neonatal mortality among the regions. After controlling for the socio-economic, neonatal, maternal, health service use and geographic factors, the spatial distribution showed higher risks of neonatal mortality in the eastern, northeastern and southeastern parts of Ethiopia. The risks of neonatal mortality tail off while moving from Eastern to the Western parts of the country. The Somali region had a higher risk of neonatal mortality (Figure 4).

**Discussion**

We found that most parts of the Somali region had higher risks of neonatal mortality, which is in line with the higher incidence of neonatal mortality in that state identified in other reports [13]. This might be related to the limited infrastructure and health service coverage in the state. The 2014 service provision and availability survey report indicated that the Somali regional state was one of the worst-performing, with health facilities infrastructure coverage [41]. Most of the Somali regional areas are also dry [42], which has been identified as a contributing factor to neonatal mortality in this study.

Environmental factors such as aridity and episodes of drought were associated with neonatal mortality. Neonates from the dry and more frequent drought areas have a higher risk of mortality. This may have resulted from shortages of precipitation that led to recurrent and substantial shortfalls in agricultural production and claimed tens of thousands of human and animal lives [43]. This is particularly meaningful as Ethiopia’s economy is predominantly reliant on rain-dependent farming and livestock. Over 15 million agro-pastoralists in Ethiopia are herding livestock in drought-prone arid and semi-arid areas. Most of the drought and food crisis events have been geographically concentrated in two broad zones, the country’s eastern and northern parts [44]. The country’s dependency on agriculture, combined with
repeated drought-hit and ongoing political fragility, negatively impacts its agro-economic and health systems [45].

Health provider counselling on newborn dangers signs within the first two days after birth was found to decrease neonatal mortality risk. Early postnatal care and counselling promote prompt health care seeking behaviour and early intervention [46–48]. Early recognition of danger signs in sick neonates is the fundamental strategic approach for improved neonatal care and survival in low-income countries [49, 50]. The WHO and UNICEF had also issued a strategy to implement a home visit scheme for newborn children to improve survival [51].

The application of traditional substances on the umbilical cord was found to increase neonatal mortality. Some of the traditional substances commonly applied in the study area were dung, oil, ointment, and butter, which can increase bacterial colonisation of the umbilical wound [52, 53]. Neonatal sepsis usually stems from local umbilical cord infections and later becomes systemic, one of the most typical cause of neonatal deaths [54].

The current study showed that neonates born to mothers residing in rural areas were at higher risk of neonatal mortality compared with those living in urban areas. This finding is in line with a meta-analysis finding in Ethiopia [10], a study in Nigeria [29] and another study from Gansu province China [55]. This can be related to the limited access to obstetric and neonatal care services such as low institutional delivery and caesarean delivery rates [56], limited sanitation and water supplies and a lower proportion of education and awareness about neonatal care in the rural areas [57].

The risk of neonatal mortality was higher among twin pregnancies compared to singletons. Multiple pregnancies carry an extra risk for both the mother and babies and increase the risk of pregnancy-induced hypertension [58, 59], bleeding during pregnancy [58], congenital abnormalities, and fetal growth retardation, especially in the third trimester due to the increased fetal demands [59]. Multiple pregnancies can also lead to preterm labour, thereby low birth weight, which is the main contributing factor for neonatal mortality [60, 61]. Generally, multiple pregnancies are long known for owing a higher risk of pregnancy and delivery complications and a higher probability of birth defects and infections [62]. Moreover, neonatal survival decreases further when multiple pregnancies are combined with a lack of access to basic and advanced health care services, which is the case in low-income countries like Ethiopia [63].

The study showed that male neonates had a higher risk of mortality during the first 28 days of life than female neonates. This finding agrees with the current body of literature that reports male neonates to have a higher risk of death than female neonates. Evidence showed that male sex neonates are disadvantageous to survive in cases of low birth weight, premature birth, and multiple births than their equivalent female neonates [64–71].

The study found that preterm births were highly associated with neonatal mortality. Evidence showed that preterm birth occurs in 5 to 10% of all pregnancies and accounts for 75% of neonatal morbidity and
70% of neonatal deaths [72, 73], as premature newborns are highly vulnerable to infections [74]. Furthermore, infants born preterm are more likely to have increased cerebral palsy, neurological impairment, and pulmonary disorders [73]. On the other hand, the provision of intensive care for preterm newborns is an enormous burden [72] on the healthcare system.

Limitations Of The Study

As the current study was based on secondary data analysis, there is the possibility of reporting and recall bias for retrospective data relying on memory of a past event. Health service use related factors were collected only for the most recent births, limiting the scope of analysis. Moreover, there were omissions of values for some variables limiting the exhaustive consideration of the determinants. Further, the place of residence at the time of giving birth may have been different to when the participants were surveyed.

Conclusions

Neonates from dry and drought-affected areas were found to have a higher risk of mortality. Areas in the eastern, northeastern and southeastern parts of Ethiopia were identified with higher neonatal mortality rates. The Somali region and neighbouring areas had higher mortality rates. Lack of counselling services about neonatal danger signs within the first two days of birth and applying traditional substances on the umbilical cord are associated with higher neonatal mortality rates.

Policy-makers and resource administrators at different levels could leverage the findings to prioritise and target areas identified with higher neonatal mortality rates. Health professionals should strengthen postnatal counselling and umbilical cord care in the early days of birth. Policy intervention should be in place to integrate postnatal counselling and umbilical cord care into the health extension program packages. Improving access to effective obstetric and neonatal care and strengthening health services for neonates with preterm and twin births can improve neonatal survival.

Abbreviations

AOR: Adjusted Odds Ratio

CI: Confidence Interval/ Credible Interval

DIC: Deviance Information Criterion

EA: Enumeration Areas

EDHS: Ethiopian Demographic and Health Survey

GLMMs: Generalised Linear Mixed Models

INLA: Integrated Laplace Approximation
Declarations

Ethics approval and consent to participate

Ethical approval was granted from the University of Technology Sydney, and an Approval letter to access and use the DHS dataset was obtained from the Demographic and Health Surveys Program. Consent to participate was not required because the study used secondary data and did not involve recruitment of the participants. The University of Technology Sydney Human Research Ethics Committee also approved the research as negligible risk.

Consent for publication

Not applicable

Availability of data and materials

DHS data are publicly available at https://dhsprogram.com/data/available-datasets.cfm

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Not applicable

Authors’ contributions

GDK, AH and DD conceptualised the study approach and analyses. GD analysed the data and wrote the manuscript. AH and DD critically reviewed the manuscript for its intellectual content. All authors read and
approved the manuscript for submission.

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**Figures**
Figure 1

Conceptual framework of factors contributing to neonatal mortality, adapted from the Mosley and Chen framework for child survival [30].
Figure 2

Flow chart of sample size determination for neonatal mortality in Ethiopia, 2016 EDHS.
Figure 3

Regional neonatal mortality rates per 1000 live births among all live births and most recent births in the past five years before the survey, EDHS 2016
Figure 4

Posterior distributions of neonatal mortality risks in Ethiopia after controlling for socio-economic, neonatal, maternal, health service use and geographic covariates, EDHS 2016, (source for boundary shapefile: OCHA Ethiopia [40])

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