Association of low birthweight with indoor air pollution from biomass fuel in sub-Saharan Africa: A systematic review and meta-analysis

Girum Gebremeskel Kanno and Robel Hussen Kabthyme
School of Public Health, College of Health Sciences and Medicine, Dilla University, Dila, Ethiopia

ABSTRACT
Exposure to indoor air pollution (IAP) from cooking with solid fuels affects 2.8 billion people in developing countries, including children and pregnant women. It also increases the risk of adverse pregnancy outcomes such as low birthweight. This review aims to examine the relationship of IAP with low birthweight.

A systematic literature search was performed using PubMed, CINAHL, global health and Google Scholar electronic databases. Data analysis was done using STATA Version 14. The heterogeneity of the studies was assessed by using I² test. A random-effects model was used to estimate pooled odds ratio. The presence of publication bias was checked using the funnel plot and Egger’s test. A total of 129 studies were reviewed, and 6 studies fulfilled the inclusion criteria. A total of 16,761 mother–child pairs from the selected studies were the study population.

The result of the meta-analysis indicated that indoor air pollution from biomass fuel use was associated with low birthweight with a pooled odds ratio of 1.74 (95% CI: 1.14–2.66). Mothers living in households that utilize biomass fuel have a 74% additional risk of giving a low birthweight child than mothers who live in households without air pollution from biomass fuel.

Indoor air pollution from cooking fuel increases the risk of low birthweight in sub-Saharan Africa. Promoting clean and effective solid fuels at the household level will help to reduce IAP-related adverse health effects, specifically low birthweight.

Introduction
Indoor air pollution is responsible for nearly 2 million deaths in developing countries (Kim et al., 2011). Indoor air pollution has become a serious concern for low-income countries due to a relatively high level of exposure, duration of exposure and a high number of exposed people (Smith, 1993). In 2011, globally one-third of the world population and 90% of the rural household population in developing countries and predominantly 41% of households in Asia and sub-Saharan Africa use biomass fuels as a prime source of energy for cooking, heating and lighting (Amegah et al., 2014; Balakrishnan et al., 2004; Kim et al., 2011).

Burning of these solid fuels in simple household cooking stoves mainly account for household air pollution (HAP) by releasing significant amounts of toxic and health-damaging airborne pollutants including particulate matter (PM), carbon monoxide (CO) nitrogen dioxide (NO₂), formaldehyde and numerous other toxic polycyclic aromatic hydrocarbons (PAHs) (Oliveira et al., 2011; Smith, 2002; JJ Zhang & Smith, 2007).

Biomass fuels are usually burnt on traditional, typically simple, inefficient and unvented household cooking stoves producing large volumes of indoor smoke or air pollutant which often exacerbating the problem and make it far exceed the safe levels (recommended 24-hour mean: PM2.5 < 25 μg/m³ and PM10 < 50 μg/m³) set by the World Health Organization (Balakrishnan et al., 2004; Oliveira et al., 2011; Smith, 1993).

LBW, defined as birthweight less than 2500 g, is a significant risk factor for post-neonatal mortality and morbidity in both developed and developing countries (Behera et al., 1988; WHO, 1997). With More than 90% of all Low birthweight (<2500 g) babies are born in developing countries, it is also a precursor for multiple adulthood health problems including cardiovascular diseases later in life. Low birthweight has been suggested as an important result of exposure to household air pollution resulting from cooking fuels in most developing countries (Boy et al., 2002; Martyn et al., 1995; Pope et al., 2010; Visentin et al., 2014).
Recently, studies have linked exposure to indoor/biomass smoke with adverse health outcomes and with an increased risk of acute respiratory infections (ARI), pneumonia, tuberculosis, chronic lung disease, cataract, cardiovascular diseases and also LBW (Epstein et al., 2013; J Zhang & Smith, 2003). Even if the link between air pollution and respiratory disease is evident in many settings, little is known about its effects on pregnancy outcomes, such as low birthweight (LBW).

Economic development that includes the transition from the use of high-polluting (biomass) fuels to clean fuel (e.g. to ethanol, liquid petroleum gas (LPG), electricity), is the ultimate solution to achieve safe indoor air quality levels and consequently to reduce adverse health outcomes such as low birthweight (World Health Organization (WHO), 2010; Woolley et al., 2021). The presence of policies and programs with strong intermin interventions, such as the provision of improved cook-stoves (Thomas et al., 2015), solar stoves (Iessa et al., 2017), improved biomass fuels [18 and behavioral changes that promote the reduction of exposure time during the use of high-polluting fuels such as removal of the vulnerable groups from the cooking area, outdoor cooking, opening windows, can also reduce the impact (Dohoo et al., 2012).

Reports are indicating indoor air pollution with adverse pregnancy outcomes. But results about low birthweight are inconclusive and reviews done at the global level lack to include a sufficient number of studies from sub-Saharan Africa (Amegah et al., 2014; Bruce et al., 2013; Joshua & Sunday, 2016) where indoor air pollution is highly common. Therefore, this study aimed to assess the relationship between exposure to solid biomass fuel and low birthweight in sub-Saharan Africa.

Methods
Registration
This meta-analysis and systematic review was registered on PROSPERO with a protocol number CRD42020160560

Searches
Literature was searched systematically using PubMed, global health, CINAHL and Google Scholar. We applied Boolean operators like “AND”, “NOT” and “OR”. Through consideration of the Boolean operator, we searched as follows: (“Infant, Low Birth Weight [Mesh] OR Infant, Extremely Low Birth Weight OR Low birth weight”) AND (Air pollution, indoor [Mesh] OR Indoor air pollution OR Air quality) AND (Africa South of the Sahara [Mesh] OR Sub Saharan Africa OR Sub-Saharan Africa)

Eligibility criteria
Based on the mentioned inclusion and exclusion criteria, abstracts were reviewed from search results.

Inclusion criteria
Study area: studies conducted in Saharan Africa only.

- Study design: observational studies (cross-sectional, case–control, cohort studies and randomized control trials)
- Language: studies published/written in the English language only were included
- Population: any studies conducted among mothers and their child.
- Publication issue: both published and unpublished articles were searched
- Study period: 2000–2020

Types of studies included
Systematic searching of the studies was undertaken from 10 September 2020 to 22 November 2020 and all results were limited to articles published in the English Language from 2000 till November 2020 G.C. Additionally, all observational studies (case–control, cross-sectional, cohort and randomized control trials) studies were included. Case reports and case series were excluded from this study. Initially, the availability of full-text titles and abstracts of the articles were assessed. Then, the full papers of relevant articles were reviewed. We excluded articles with inaccessible full paper and those published before 2000 from the analysis.

As shown in Figure 1, the primary step of searching, we identified a total number of 129 papers, and 47 papers were excluded due to redundancy. Then, 72 papers were omitted after assessing their titles and abstracts. Ten papers were found to be suitable but the full text of two papers was inaccessible. After assessing the full text of eight papers, two papers were excluded. At last, six studies were included. A total of 16,761 mother-child pairs were involved in the included six studies. The least and largest number of participants included in a study were 387 and 9124, respectively. All the included studies were observational studies that are published between 2000 and 2020.
**Data extraction**

Two authors (GGK and RHK) independently extracted all the necessary data using a standardized data extraction format prepared in Microsoft Excel. Disagreements between the authors during data extractions were discussed and reached on consensus. The data extraction format includes first author, publication year, name of the country and number of samples. Besides, in a format of two by two tables, several events in exposed and unexposed groups were abstracted from each study.

**Outcome measurement**

The main outcome of this study is to examine the relationship between maternal exposure to indoor air pollution and low birthweight. To assess the relationship, the odds ratio was calculated based on binary outcomes from the primary studies.

Fuels used in the households were categorized into low- and high-pollution fuels. Electricity, LPG and biogas were considered as low-pollution fuels, whereas charcoal, wood, crops, straw and animal dung were considered as high-pollution fuels.

**Risk of bias**

Two authors (RH and GG) independently assessed the risk of bias for each article using the tool. For assessing the quality of the studies, Newcastle–Ottawa Scale quality assessment tool was used (Wells et al., 2009). Using an assessment tool as a guideline, two authors independently evaluated the qualities of the original articles. The quality of each study was evaluated using these parameters; those with medium (fulfilling 50% of quality assessment criteria) and high quality (≥6 out of 10 scales) were included for analysis. Disagreements between assessors were solved by taking the mean score of their assessment results.
Data processing and analysis

After extraction, the data were imported to STATA Version 14.0 statistical software for analysis. Heterogeneity among included studies was assessed by using $I^2$ test static and its $p$-value (Ru¨cker et al., 2008). As the test statistic showed, there is significant heterogeneity among the studies ($I^2 = 81.8\%$, $p = 0.000$) as a result a random-effects meta-analysis model was used to estimate the pooled effect. Egger's test at 5% significant level and funnel plot test were used to assess publication bias (Borenstein et al., 2010). Pooled odds ratio with 95% confidence intervals was presented in the forest plot format. For reporting the finding ”Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)” protocol was used.

Table 2. Forest plot showing pooled odds ratio of association of low birthweight with indoor air pollution from biomass fuel in sub-Saharan Africa, 2020.

| Study ID | OR (95% CI) |
|----------|-------------|
| Demelash et al (2015) | 4.60 (1.80, 12.17) |
| Amegah et al (2012) | 2.71 (1.52, 4.84) |
| Milanzi & namacha (2017) | 0.71 (0.40, 1.25) |
| Mish et al (2004) | 1.12 (0.82, 1.55) |
| Foto T (2015) | 2.18 (1.76, 2.70) |
| Admasie et al (2018) | 1.84 (1.08, 3.13) |
| Overall (I-squared = 81.8%, $p = 0.000$) | 1.74 (1.14, 2.66) |

NOTE: Weights are from random effects analysis.

Result

General characteristics of the studies

Out of the six studies included in the review, as indicated in Table 2, five of the studies were cross-sectional studies while the remaining one study was case-control. The studies included were conducted in four countries (Ethiopia, Zimbabwe, and Malawi and Ghana) where a significant proportion of the populations use solid fuel in the indoor environment. Both the case-control study design (Demelash et al., 2015) and the cross-sectional

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The pooled odds ratio of association of low birthweight and indoor air pollution from biomass fuel in sub-Saharan Africa was 1.74 (95% CI: 1.14–2.66). This indicated that children who are born from mothers who used biomass fuel in sub-Saharan Africa were 74% more at risk of having a low birthweight than children who were born from mothers who used clean energy
sources. Random effects model meta-analysis was used to calculate the pooled odds ratio because high heterogeneity was observed across the included studies ($I^2 = 81.8\%, p < 0.000$). See Figure 2.

**Risk of bias**

For all original studies, the risk of bias was checked by using the Newcastle–Ottawa quality assessment tool which encompassed 10 different items (Wells et al., 2009). Of the included six articles, our assessment showed that all (100%) of the included studies had a low risk of bias or has good quality (sup table 1).

The presence of publication bias was evaluated by using the Funnel plot and Egger’s test. The result of funnel plot showed that there was a symmetrical distribution of articles (Figure 3).

The results of Egger’s test for small-study effects showed that there was no statistically significant publication bias in estimating the odds ratio between low birthweight and indoor air pollution from biomass fuel in sub-Saharan Africa ($p = 0.725$).

**Discussion**

In this study, we assessed the effect of maternal exposure to indoor air pollution from biomass fuels on children's birthweight in sub-Saharan Africa. We assessed this association using six eligible studies done in five different sub-Saharan counties. A negative association is observed between maternal exposure to indoor air pollution and the birthweight of her child. Biomass fuels are commonly utilized in the developing world, sub-Saharan African countries are not an exception for this rather they are the face of the problem. Clean energy sources like hydropower are very limited due to poor economic capacity. World Health Organization (WHO), in 2012 estimated that globally nearly 3 billion people, the majority living in low- and middle-income countries (LMICs) are in short of access to clean energy for cooking responsible for close to 4.3 million premature deaths globally (WHO, 2014).

When using biomass-based fuel sources like charcoal, wood and cow dung, the emission of CO, NO$_2$ and PM is very high (Wafula et al., 1990). Over the last 20 years, scientific evidences that link exposure to ambient air pollution with adverse pregnancy outcomes have been increasing. However, most of these evidences are epidemiological (Glinianaia et al., 2004; Lacasaña et al., 2005; Maisonet et al., 2004; Sapkota et al., 2012; Stieb et al., 2012). Access to clean air and energy, water, sanitation and hygiene are among the critical objectives of sustainable development goals (UN, 2015). On this basis, low-income countries and their emerging cities are advised to line up their strategies to sustainable development goals (SDG). In this regard, even if there are some efforts, sub-Saharan countries seem lagging. In Africa, up to 93.5% of women use charcoal and nearly 80% of households in the cities of Africa use charcoal as their main fuel source for cooking (Kadir et al., 2010; Zulu & Richardson, 2013).

We found the maternal exposure to air pollution from biomass fuel increases the odds of low birthweight in children by 1.74 (AOR = 1.74, CI: 1.14–2.66). Our finding is supported by the results from different studies done previously. Meta-analysis of five studies done to see this association revealed a 95.6 g decrement in birthweight and 38% increased risk of low birthweight among women who are exposed to indoor air pollution (Pope et al., 2010). A finding from Pakistan also suggests newborns from wood users weigh 82 g less than infants from natural gas users.

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**Table 1. Summary of search results for the PubMed, Google Scholar and other databases**

| Databases     | Searching terms                                                                 | Number of studies |
|---------------|----------------------------------------------------------------------------------|-------------------|
| Google Scholar| “Low birth weight” OR “very low birth weight” AND “indoor air pollution” OR “air quality” | 86                |
| PubMed        | Search (((air pollution, indoor”[MeSH Terms] OR indoor air pollution[Text Word]) AND (“Infant, Low Birth Weight”[Mesh]) OR “Infant, Extremely Low Birth Weight”[Mesh] OR “Infant, Very Low Birth Weight”[Mesh] OR low birth weight[Text Word]) AND “Africa South of the Sahara”[Mesh]) | 31                |
| Total retrieved articles |                                                                                   | 129               |
| Included papers |                                                                                   | 6                 |

*ACINAHL and global health.

**Table 2. Summary of six studies included in the systematic review and meta-analysis of the association of low birthweight and indoor air pollution from biomass fuel in sub-Saharan Africa, 2020**

| No. | Author                          | Year | Country | Sample size | Quality score |
|-----|---------------------------------|------|---------|-------------|---------------|
| 1   | Demelash et al (Demelash et al., 2015) | 2015 | Ethiopia| 387         | 8             |
| 2   | Amegah et al (Amegah et al., 2012) | 2012 | Ghana  | 592         | 9             |
| 3   | Milanzi & Namacha (Milanzi & Namacha, 2017) | 2017 | Malawi | 9124        | 9             |
| 4   | Mishra et al (Mishra et al., 2004) | 2004 | Zimbabwe| 2299        | 9             |
| 5   | Foto T (Foto, 2015)           | 2015 | Zimbabwe| 3317        | 9             |
| 6   | Admasie et al (Admasie et al., 2018) | 2018 | Ethiopia| 1042        | 9             |
(Siddiqui et al., 2008). A randomized control trial done in Guatemala found children born from mothers who used open fires weigh lighter by 89 g in comparison to infants born from mothers who used stove (Thompson et al., 2011). Another study done in India reported children from households using high-pollution fuels (charcoal, wood, straw, crop residues, animal dung and kerosene) are lighter by 73 g than those born in households using clean fuel sources (LPG, natural gas, electricity and biogas) (Sreeramareddy et al., 2011).

The possible explanation for the observed association can be explained by different ways hypothesized by different researchers. The oxygen-carrying capacity of maternal hemoglobin is thought to be reduced by carbon monoxide; this negatively affects the delivery of oxygen to the fetus (Salam et al., 2005). Fetal hemoglobin has more affinity to CO binding than adult hemoglobin and CO can cross the placental barrier; hence, fetal oxygen delivery is reduced (Di Cera et al., 1989; Longo, 1977; Sangalli et al., 2003). So, consequential tissue hypoxia can reduce fetal growth, which may result in low birthweight (Bosley et al., 1981; Salam et al., 2005).

The mechanism on which particulate matter can affect fetal growth is not clearly known. However, previous studies suggested that exposure to PM could cause induce pulmonary and placental inflammation, affect endothelial functions, may cause oxidative stress and may stimulate hemodynamic reactions that restrict the growth of the fetus by reduced transplacental nutrient and oxygen exchange (Kannan et al., 2006; Wylie et al., 2017). High cell proliferation and dynamic metabolic mechanisms during intrauterine fetal development have been recognized as the physiological course that makes the developing fetus extremely vulnerable to environmental toxicants (Calabrese, 1986).

Household air pollution is the single most important environmental health risk factor worldwide. As a result, to achieve the SDG 7 target of universal access by 2030, the promotion and implementation of ongoing projects that can increase access to clean energy sources at the point of use must be enhanced and making efficient stoves available that can cleanly burn biomass fuels should be given due attention. Priority should also be given to enhancing and supporting research and development of innovative, low-emissions technologies (World Health Organization, 2016).

**Conclusion and recommendation**

Indoor air pollution from cooking fuel increases the risk of low birthweight in sub-Saharan Africa. In sub-Saharan Africa, mothers living in households that utilize biomass fuel were 74% more at risk of giving a low birthweight child than mothers who live in households that utilizes clean energy sources. Promoting clean and effective solid fuels at the household level will help to reduce IAP-related adverse health effects, specifically low birthweight.

**List of abbreviations**

- **AOR**: Adjusted odds ratio
- **CI**: Confidence interval
- **CO**: Carbon monoxide
- **GC**: Gregorian calendar
- **HAP**: Household air pollution
- **IAP**: Indoor air pollution
- **LBW**: Low birthweight

![Figure 3. Funnel plot with 95% confidence limits of association of low birthweight with indoor air pollution from biomass fuel in sub-Saharan Africa, 2020.](image-url)
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Disclosure statement

The authors declare that they have no competing interests.

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Notes on contributors

Girum Gebremeskel Kanno is a lecturer and a researcher at Dilla University, college of health science and medicine, school of public health Dilla Ethiopia. He is an Environmental health professional specialized in Water supply and Sanitation Management (MSc) from Haramaya University. His research interests are focusing mainly on the assessment of the water hygiene sanitation services and their public health significance as well as assessing the link between indoor air pollution from biomass fuel use and pregnancy outcomes.

Robel Hussen Kabthymer is also a lecturer and researcher at Dilla University, Department of Human Nutrition. He specialized in Human Nutrition (MSc) from Jimma University. His research interests are but are not limited to the link between environmental health and maternal and child nutritional outcomes, malnutrition, and nutritional epidemiology. In the future, the researchers are interested to conduct multi-center intervention-based research projects with different partners and are willing for collaboration from any researchers all over the world.

ORCID

Girum Gebremeskel Kanno http://orcid.org/0000-0001-6689-1983

Robel Hussen Kabthymer http://orcid.org/0000-0002-6734-0312

PUBLIC INTEREST STATEMENT

Low birthweight which is defined as weight at birth less than 2500 g is a significant public health problem in sub-Saharan Africa. Because of the use of biomass fuel by large proportion in the region, indoor air pollution from biomass fuel use leads pregnant women to inhale thick smoke for hours on end as they prepare meals for their families and tend fires to keep the home warm, which consequently lead to adverse pregnancy outcomes such as low birthweight and premature death. Despite the progress made to reduce the burden of maternal and infant mortality and morbidity in the pre SDG (Sustainable Development Goals) era, low birthweight is still one of the challenges that need to be addressed in the region. Identifying the link between biomass fuel use with low birth-weight can help the efforts to revise, amend or implement programs that help achieve the SDG goal seven, by engaging the energy and health sectors together.

Data availability statement:

Data will be available upon reasonable request of the corresponding author.

Competing Interests: The authors declare no competing interests.

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LPG: Liquid petroleum gas
PM: Particulate matter
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
UN: United Nations
WHO: World Health Organization
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