Environment International 161 (2022) 107089

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

The association between biomass fuel use for cooking and linear growth in young children in Bhaktapur, Nepal

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ARTICLE INFO

Handling Editor: Hanna Boogaard

Keywords:
Indoor air pollution
Child growth
Stunting
Malnutrition
LMIC
Asia

ABSTRACT

Background: There are still many people in the world who prepare their meals on open fires or stoves using solid fuels from biomass, especially in low-and middle-income countries. Although biomass cooking fuels have been associated with adverse health impacts and diseases, the association with child linear growth remains unclear.
Objectives: In a cohort design, we aimed to describe the association between the use of biomass cooking fuels and linear growth in children aged 18–23 months living in the urban and *peri*-urban community of Bhaktapur, situated in the Kathmandu valley in Nepal.
Methods: Caretakers of 600 marginally stunted children aged 6–11 months were interviewed about their source of cooking fuel and other socio-demographic characteristics at enrolment into a randomized controlled trial. Children's body length was measured when children were 18–23 months old. In linear regression models, we estimated the association between the use of biomass fuel and length-for-age Z-scores (LAZ), adjusted for relevant confounders. We repeated these analyses in pre-defined sub-groups and different percentiles of LAZ using quantile regression models.
Results: Among study participants, 101 (18%) used biomass as cooking fuel. The association between biomass fuel and LAZ was not statistically significant in the full sample (adjusted regression coefficient: –0.14, 95% CI: −0.28, 0.00). The association was stronger in some of the sub-groups and in the lower tail of the LAZ distribution (those who are stunted), but neither reached statistical significance.
Discussion: Children from households in poor, urban neighborhoods in Nepal which used biomass fuel for cooking were on average slightly shorter than other children, although the association only approached statistical significance. As this was an observational study, residual confounding cannot be excluded. Further studies are needed to confirm these associations, in particular those seen in certain sub-groups.

1. Introduction

Around 3 billion people globally prepare their meals on open fires or stoves using solid fuels such as wood, waste, dung, and coal, which produce health-damaging pollutants including particulate matter (PM), methane, and carbon monoxide (Ministry of Health Nepal 2017; WHO).

In 2019, air pollution was ranking fourth on the list of risk factors associated with the highest burden of morbidity and mortality globally (Murray et al. 2020). Indoor air pollution (IAP) stemming from burning solid fuels was associated with 59 million disability-adjusted life years (DALY) (2.4% of all DALYs) and 1.6 million deaths (2.9% of all deaths) (Health Effects Institute 2019). Within the Sustainable Development Goal's (SDG) framework, governments have committed to lower the mortality due to household and ambient air pollution and increase the access to clean fuels (SDG target 3.9.1 and 7.1.2, respectively). Still, ambient air pollution as a risk factor for impaired health and premature death has seen one of the largest increases over the past decade (Murray et al. 2020). On the contrary, the proportion of people using solid fuels

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https://doi.org/10.1016/j.envint.2022.107089
Received 19 August 2021; Received in revised form 6 January 2022; Accepted 10 January 2022
Available online 18 January 2022

has decreased globally (IEA 2017). However, trends are not equally distributed; among poor populations, the total number of people using solid fuels in the household has increased due to population growth (IEA 2017). Women and children are especially exposed to IAP, since women commonly spend more time preparing food, accompanied by their young children (Bruce et al. 2000).

Pollutants from fires with solid fuels have been associated with compromised health and diseases, such as pneumonia, lung cancer, stroke, and ischemic heart diseases (WHO). Also, adverse birth outcomes, such as low birthweight, being small for gestational age and preterm birth, have been associated with these pollutants (Amegah and Jaakkola 2016; Khan et al. 2017; Lin et al. 2020; Lu et al. 2020; Malley et al. 2017; Pope et al. 2010; Tielsch et al. 2009; Wylie et al. 2014; Yuan et al. 2020). Studies on the association of IAP and child growth are rare. Despite inconsistent results in the existing individual studies (Corsi et al. 2016; Kim et al. 2017; Kyu et al. 2009; Li et al. 2021; Machisa et al. 2013; Mishra and Retherford 2007; Tielsch et al. 2009), Mishra and Retherford (2007), underlined the potential importance of IAP as a modifiable risk factor for impaired growth in vulnerable children based on their dataset including around 30,000 Indian children, where 37% of the stunting prevalence was attributable to exposure to IAP. Besides different sample and setting characteristics in the individual studies, different assessment methods of air quality could have contributed to inconsistencies in the results. The measurement of specific air pollutant concentrations is possible, both as ambient as well as individual exposure. However, in many epidemiological studies IAP is assessed by the proxy of fuel type use as this is logistically less challenging, less costly, and is not restricted to specific pre-defined pollutants (Clark et al. 2013).

Nepal is a low-resource country in which, according to the Demographic Health Survey 2016, 66% of all households were using solid fuel for cooking (Ministry of Health Nepal 2017). Although the proportion seems to have reduced from around 75% in 2011, it is still large (Government of Nepal 2012; Ministry of Health and Population Nepal 2011). Due to the use of biomass cooking fuels, no separate rooms for cooking, and poor ventilation, the air quality in Nepalese households was much poorer than acceptable levels stated in the WHO guidelines for air quality (Bartington et al. 2017; Devakumar et al. 2014; WHO 2014). According to the Global Burden of Disease project, IAP was considered as the second most important risk factor for mortality and morbidity in 2019 in Nepal (IHME).

In the current study, our aim was to describe the association between IAP, measured as the use of biomass cooking fuel at age 6–11 months, and linear growth at the age of 18–23 months in an at-risk population of children living in Bhaktapur, Nepal.

2. Methods

2.1. Study setting

The study was conducted in the urban and *peri*-urban municipality of Bhaktapur, which is situated in the East of the densely populated Kathmandu valley at 1300 m above sea level. The municipality had around 82,000 inhabitants in 2011 (Government of Nepal 2014). The climate is characterized by a warm and wet monsoon season (June–September) and a cold and dry winter season (December–February). The main livelihood is agriculture, with small-scale self-owned businesses and daily wage labor also being important sources of income. The diet of people in this municipality tends to be simple with large consumption of rice and pulses (Henjum et al. 2015; Shrestha et al. 2014). In 2015, the ambient air quality in Kathmandu Valley could not fulfill the National Ambient Air Quality Standards with most pollutants having a higher concentration than recommended (Karki et al. 2016). Values, when compared to the WHO guidelines, would also have exceeded those (WHO 2014). A major highway through Bhaktapur, about 10–12 brick kilns on the outskirts of the municipality, and predominantly western winds from Kathmandu city contribute to the bad ambient air quality in Bhaktapur (Joshi 2003; Karki et al. 2016; Pokhrel et al. 2015).

2.2. Data collection and definitions

For these analyses, we used data of children enrolled in a community-based, randomized, double-blind, placebo-controlled trial assessing the effect of daily vitamin B12 supplementation over a period of 12 months (Strand et al. 2017). Between April 2015 and February 2017, 600 children aged 6–11 months and with a length-for-age Z-score of < -1 were enrolled into the study. Exclusion criteria included a lack of consent, having severe systemic illnesses requiring hospitalization, taking B vitamin supplements that include vitamin B12, having severe anemia (Hb < 7 g/dl) or ongoing acute infection such as fever or infection that requires medical treatment, and being severely malnourished (weight-for-length Z-score < -3). The supplementation did not affect the main outcomes, i.e., neurodevelopment, growth, and hemoglobin (Strand et al. 2020).

Children's weight was measured with portable electronic scales to the nearest 100 g, and length was measured with infantometers to the nearest mm (both seca, Germany). Measurements were performed according to standard guidelines at the clinic the end of the supplementation period, i.e., when the child was between 18 and 23 months of age. Two measurements were performed independently by trained field workers. In case of a deviation, a third measurement was done. The average of the 2 measurements was used for analysis. All anthropometric measurements of the children are expressed as Z-scores in reference to the WHO Child Growth Standards (WHO 2006). Stunting is defined as a length-for-age Z-score (LAZ) < -2, wasting as a weight-for-length Z-score (WLZ) < -2, and underweight as a weight-for-age Z-score (WAZ) < -2. Anthropometric measurements of parents were performed at enrolment by trained field workers at the study clinic using an electronic scale for weight (Salter/HoMedics Group, UK and seca, Germany) and a stadiometer for height (Prestige, Hardik Medi Tech, India).

During enrolment, when the children were 6–11 months old, information on the children and their families were collected by interviewing the caretakers. This information included household characteristics, such as available assets, number of rooms in the house, a kitchen separate from the bedroom, sources of drinking water supply, sanitation facilities, type of cooking fuel, and indoor smoking. Parents were asked about which of the following fuels were primarily used for cooking: firewood, straw, cow dung, kerosene, gas, electricity, or others. We defined biomass fuel as firewood, straw, or cow dung. Information on the family members included parental age, level of educational attainment, and occupation group. For our analysis, we dichotomized educational level into completed at least secondary school, and below. For occupation, we dichotomized the occupation groups into work and no formal work. In addition, at enrolment, the mothers were interviewed about breastfeeding history and hospitalization history of the child. Exclusive breastfeeding (EBF) was defined as not receiving any other solids or liquids other than breastmilk. From hospital records, the following information about the child was retrieved: birthdate, birthweight, and gestational week at birth. Preterm birth was defined as being born ≤ 37 weeks of gestation, and low birthweight was defined as a birthweight of < 2500 g.

As indicator for socio-economic status, we calculated a WAMI index as suggested by (Psaki et al. 2012). WAMI is a composite measure consisting of indicators for safe drinking water and sanitation, mother's education, income, and the availability of household assets. In our study, we did not have information on household income, and thus adapted the calculation to include the three other components. Details on the calculations can be found in the supplementary Table S1. The WAMI index ranges from 0 to 1 with a higher value indicating a better status. We used this index as continuous variable.

2.3. Statistical analysis

All analyses were performed using Stata 16 (StataCorp LLC). The characteristics of the study population are described using count and percentage for categorical variables and mean and standard deviation (SD) for continuous variables.

To estimate the association between biomass fuel use and linear growth, we used linear regression models with LAZ as outcome. We selected the following covariates based on their epidemiologic or clinical importance, and availability in the study: WAMI, age, date of enrolment (calendar month), sex, maternal age, paternal education, and indoor tobacco smoking in the household. All covariates were entered into the final model simultaneously. To confirm variable selection, we used Lasso regression and chose the model with the lowest mean squared error and highest R^2 (Tibshirani 1998).

We repeated the analyses with the final linear regression model in the following pre-defined subgroups: sex (male vs. female), number of rooms in the house (> 2 rooms vs. ≤ 2 rooms), kitchen separate from the bedroom (yes vs.no), exclusively breastfed till 3 months of age (yes vs. no), hospitalized during the first month of life (yes vs. no), and low WAMI (≤ 33rd percentile vs. > 33rd percentile) and report the association separately for each stratum. We formally assessed a statistical interaction of these sub-groups and biomass fuel use; interaction terms were not included in the final multiple regression model. In addition, we used quantile regression, which provides conditional regression coefficients for each defined percentile in the outcome variable (Koenker and Bassett 1978) to assess if there was a difference in the association of biomass cooking fuel use and LAZ in the different parts of the LAZ distribution. We entered the same covariates as in the final linear regression model and used the following percentiles: 95, 90, 80, 70, 60, 50, 40, 30, 20, 10, and 5.

2.4. Ethics

The original trial received ethical clearance in Nepal from the Nepal Health Research Council (NHRC #233/2014), and in Norway from the Regional Committee for Medical and Health Research Ethics (REC # 2014/1528) including the use of data in an observational study design. After informing the caretakers about the study, they gave their informed consent by signature, or, in case of illiteracy, by a thumbprint in the presence of an impartial witness.

3. Results

Anthropometric data was available for 572 children at the end of the study, i.e., when the children were 18–23 months old. At enrolment, children were on average 8 months old (±1.8 months), and about half of the children were male (51.2%) (Table 1). Of all children, 20% had a low birthweight and 10% were born preterm. While < 5% of the parents were underweight, 19% of the children were underweight at enrolment. Both at enrolment and end of the study, 33% of children were stunted. Most children were breastfed at enrolment (97.5%), but only 46% were reported to be exclusively breastfed till 3 months of age.

Most families reported using liquified petroleum gas (LPG) as cooking fuel (79.6%, n = 455) at enrolment; biomass fuel was reported by 17.7% (n = 101) families of the study participants. The remaining 16 families used either kerosene (n = 6) or electricity (n = 10).

Biomass fuel use for cooking was inversely associated with LAZ, if adjusted for WAMI, age, date of enrolment, sex of the child, maternal age, education of the father, and indoor smoking. However, the association only approached statistical significance (adjusted regression coefficient: –0.14, 95% CI: −0.28, 0.00) (Table 2). The model explained about 6% of the variation in LAZ. Using Lasso regression for variable selection, the model with the lowest mean squared error and highest R^2 selected all covariates except indoor smoke, and results were similar (Supplementary Table S2). The association between biomass fuel and linear growth status in the pre-defined subgroups is shown in Fig. 1. An inverse association was seen among boys, but not among girls. For the remaining sub-groups, a pattern could be seen, where in the children in the “worse-off” group (i.e., <2 rooms in the house, no separate kitchen, no EBF at 3 months, previously hospitalized, low WAMI), the use of biomass fuel was not associated with LAZ. In the “better-off groups”, the

Table 1
Characteristics at enrolment for 572 children living in Bhaktapur, Nepal.

	N	*n (%)*	Mean (SD)
Infant characteristics			
Mean age of child (months), mean (SD)	572		8.0 ± 1.8
Male child, % (n)	572	293 (51.2)	
Low birth weight (<2500 g)	552	109 (19.8)	
Pre-term birth (<37 weeks of gestation)	552	59 (10.3)	
Hospitalization within 1st month of age	572	51 (8.9)	
Demographic features			
Mother’s age, mean ± SD	572		27.5 ± 4.6
Father’s age[2], mean ± SD	476		30.3 ± 5.2
Mothers who completed secondary school or above	572	364 (63.6)	
Fathers who completed secondary school or above	571	371 (65.1)	
Mothers who work	571	243 (42.6)	
Fathers who work	570	556 (97.5)	
Socio-economic status			
Family staying in joint family	572	288 (50.4)	
Family residing in rented house	572	268 (46.9)	
Kitchen and bedroom in same room	572	279 (48.8)	
Family having own land	572	282 (47)	
Receiving remittance from abroad	572	54 (9.4)	
Breastfeeding status			
No breastfeeding at enrolment	572	14 (2.5)	
Exclusive breastfeeding for 3 months or more	566	258 (45.6)	
Nutritional status of infants			
Underweight (weight for age z-score ≤ -2)	572	110 (19.2)	
Wasting (weight for length z-score ≤ -2)	572	19 (3.3)	
Stunting (length for age z-score ≤ -2)	572	188 (32.9)	
Nutritional status of mothers			
BMI of mother, mean ± SD	572		23.8 ± 3.5
Maternal underweight (BMI < 18.5 kg/m^2)	572	28 (4.9)	
BMI of father, mean ± SD	435		23.8 ± 3.7
Paternal underweight (BMI < 18.5 kg/m^2)	435	19 (4.4)	

Table 2
Association between length-for-age Z-score at 18–23 months of age and selected characteristics of the study children, their parents, and their households.

Variable	N	Crude coefficient (95% CI)	Adjusted coefficient (95% CI)[a]
Biomass fuel, (ref. no)	572	−0.14 (−0.28, 0.01)	−0.14 (−0.28, 0.00)
WAMI, (0–1)	572	0.55 (0.18, 0.92)	0.32 (−0.10, 0.74)
Age (in months)	572	0.03 (−0.00, 0.06)	0.03 (0.01, 0.06)
Date of enrolment (calendar month)	572	0.01 (−0.01, 0.02)	0.01 (0.00, 0.01)
Sex (ref. male)	572	0.17 (0.06, 0.28)	0.17 (0.06, 0.27)
Maternal age (in years)	572	0.00 (−0.01, 0.01)	0.00 (−0.01, 0.01)
Education father (ref: secondary school or above	571	0.22 (0.10, 0.33)	0.16 (0.03, 0.30)
Indoor smoking in household (ref: no)	572	0.01 (−0.09, 0.12)	−0.03 (−15.6, −3.32)

[a] Adjusted for all covariates simultaneously.

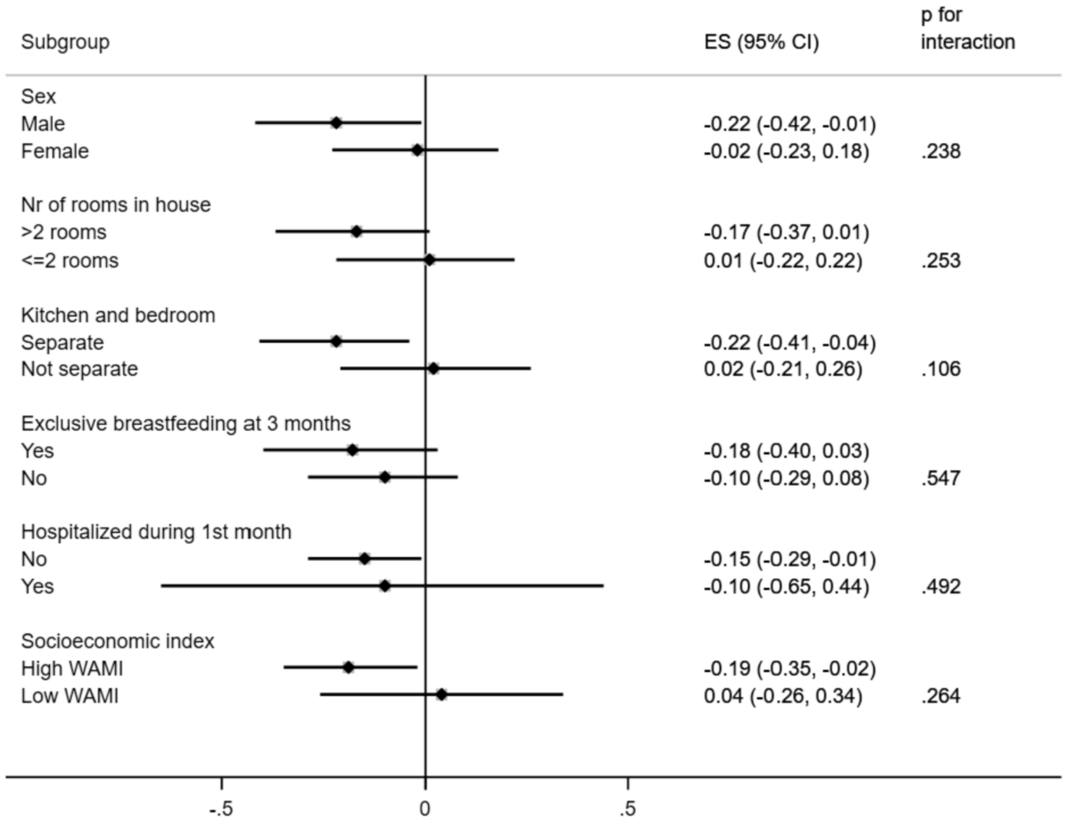

Fig. 1. Association between biomass cooking fuel and length-for-age Z-score according to pre-defined sub-groups. Regression coefficients displayed are from linear regression models, adjusted for WAMI, age, date of enrolment, sex of the child, maternal age, education of the father, and indoor smoking. The p-value is for the interaction term added to the regression models.

use of biomass cooking fuel was associated with a lower mean LAZ (for number of rooms in the house and EBF the association did not reach statistical significance). However, there was no statistically significant interaction between biomass fuel and any of these sub-group variables.

The distribution of the length-for-age Z-score (LAZ) at end study according to cooking fuel use is shown in Fig. 2. In this graphic, there was a larger distance between the fuel use groups at the lower tail of the LAZ distribution. This was also reflected in the results from the quantile regression analyses, where the regression coefficients were larger at the 20th and 10th percentiles; however, the coefficients at these centiles were not statistically different from the coefficient at the 50th percentile ($F = 2.73$, $p = 0.1$) (Fig. 3).

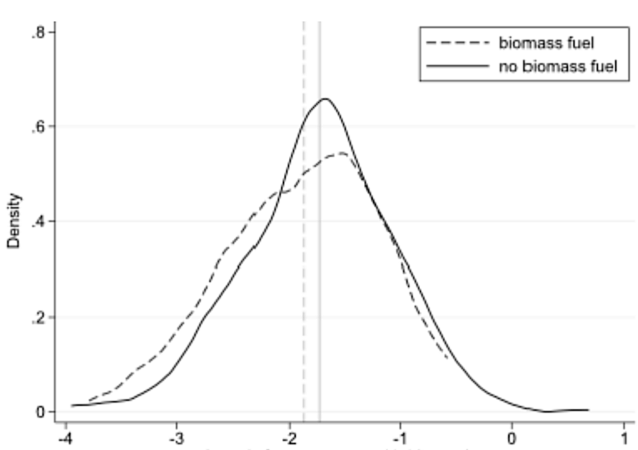

Fig. 2. Distributions (black lines) and means (grey lines) of length-for-age Z-scores according to use of biomass fuel for cooking in children aged 18–23 months living in Bhaktapur, Nepal.

4. Discussion

In our study, 18 % of the families reported to use biomass fuel for cooking. The use of biomass fuel was associated with a lower length-for-age Z-score (LAZ) at ages 18–23 months, although only approaching statistical significance. In sub-group analyses, there was a significant association between biomass fuel and LAZ in boys, but not in girls. There was also an association in the "better-off groups", namely in children living in houses with >2 rooms and in which the kitchen was separate

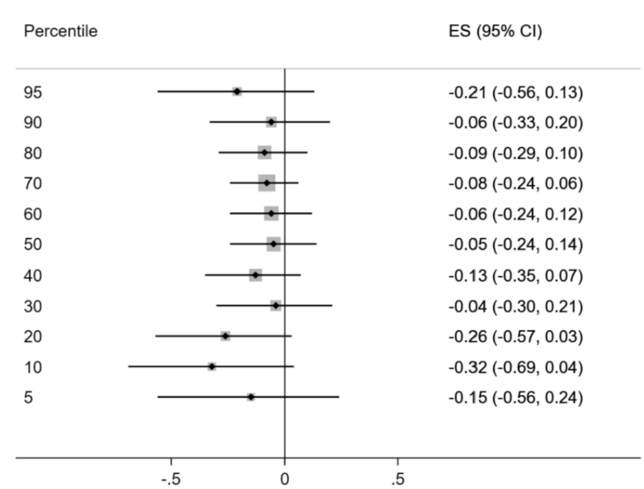

Fig. 3. Association between biomass cooking fuel and length-for-age Z-score according to pre-defined percentiles on the outcome variable. Regression coefficients (ES) and 95% confidence intervals (95 %CI) are from linear regression models, adjusted for WAMI, age, date of enrolment, and sex of the child, maternal age, education of the father, and indoor smoking.

from the bedrooms, in those children exclusively breastfed till 3 months of age, those not previously hospitalized, and those with a higher WAMI index. These associations were not seen in the "worse-off groups". The tendency of a stronger association of biomass fuel in the lower tail of the LAZ distribution (those who are stunted) did not reach statistical significance.

While there has been a general decline in the use of biomass fuel for heating and cooking globally (IEA 2017), among the most disadvantaged populations, biomass use is still common (IEA 2017). In our population enrolled from the Bhaktapur community in 2015–2017, 18% of the families used biomass fuel, while 80% used LPG. Although this is comparable to the census conducted in Bhaktapur in 2011 (Government of Nepal 2014), it might be an overestimation of the habitual use of biomass fuel due to the devastating earthquake that hit Nepal in 2015. During the earthquake, many houses were destroyed, and the availability of LPG gas was restricted due to an interruption of supply from India. Thus, many people had to resort to using biomass fuel for some time (Acharya and Adhikari 2021; Lamichhane 2015). Our findings are not representative of the whole of Nepal, where around 66% used biomass fuel according to the Demographic Health Survey in 2016 (Ministry of Health Nepal 2017). In Nepal, around 80% live in rural households with restricted access to reliable electricity and clean energy. Measures of IAP were found to be closely associated with socioeconomic status, explaining the differences in biomass fuel use to a large extent (Ghimire et al. 2019).

In our study, we found an association between parental reported biomass fuel use and child growth at 18–23 months that approached statistical significance. Studies on the effects of IAP and postnatal child growth are rare. A *meta*-analysis reported an association of IAP with both moderate and severe stunting among children younger than 5 years (ORs (95% CIs) of 1.27 (1.12–1.43) and 1.55 (1.04–2.30), respectively) (Bruce et al. 2013). In this *meta*-analysis, the authors only included 2 studies reporting on moderate stunting, and 2 on severe stunting. Reports from single studies are inconsistent (Corsi et al. 2016; Kim et al. 2017; Kyu et al. 2009; Li et al. 2021; Machisa et al. 2013; Mishra and Retherford 2007; Tielsch et al. 2009). An association of biomass fuel and stunting among under 5 children was found in 3 Indian studies (Corsi et al. 2016; Mishra and Retherford 2007; Tielsch et al. 2009), in a multicenter study in 7 countries (Kyu et al. 2009), and a pooled analysis using data from Demographic Health Surveys in 14 low- and middle-income countries. Other studies fail to show an association (Kim et al. 2017; Machisa et al. 2013). Kim et al. (2017) demonstrated that among Asian children aged 6–23 months other factors than biomass fuel smoke were more important to explain impaired growth at their Nepal site, namely maternal height and wealth.

The results from studies measuring the association between IAP and growth may vary due to how IAP was measured. In a study using the Demographic Health Survey data from Swaziland, the use of biomass fuel for cooking was not associated with stunting (Machisa et al. 2013). However, in this study, type of fuel used for heating was not assessed. The authors argue that more people would use biomass for heating, which is usually used over a longer time during the day than cooking, and thus would be another important source of IAP. This was also emphasized in a study in China, where both solid fuels used for cooking and for heating were independently associated with height-for-age in children 6–17 years of age (Liang et al. 2020). The associations were even stronger if both exposures were present. In our study, type of fuel for heating was not ascertained. In Bhaktapur, it is more likely that people would use clean fuels for cooking but biomass for heating during the cold season, than the other way around. Therefore, our estimate is likely to be an underestimation of the association between IAP and growth.

The timing of exposure cannot be established in our study; in other words, we cannot disentangle if we measure associations with maternal IAP exposure or child IAP exposure. An association of air pollution exposure during pregnancy with birthweight has been repeatedly shown (Steinle et al., 2020). However, most studies are observational studies and evidence from randomized controlled trials are ambiguous. While trials in Guatemala (Thompson et al. 2011) and Nigeria (Alexander et al. 2018) showed improvements in birthweight, two trials in Nepal on improved biomass and LPG stoves could not show any impact on adverse birth outcomes (Katz et al. 2020). However, pollutant levels in Nepal were still far above the WHO standard, possibly limiting the protective effect of clean fuel use. The evidence of exposure during pregnancy and prenatal childhood growth is less clear (Clemente et al. 2017; Fossati et al. 2020; Tan et al. 2021). As for the current study, most studies are not able to differentiate between exposure in delimited periods. Notably, a study conducted in South Korea assessed different time windows of exposure to PM10, a measure of air pollution (Kim et al. 2016). While an exposure before conception was not associated with later child weight, exposure both during pregnancy and after birth showed an association with weight up to 5 years of age. In addition, children continuously exposed to high levels of PM10 at ages 0–24 months had a lower weight for age compared to those with continuously low exposure levels. In China, Liang et al. (2020) found that the association of IAP with low height for age was stronger in older children i.e., 15–17 years. They hypothesized that the effect of the exposure would have been accumulated with increasing age. Mechanistic pathways both during pregnancy and after birth are plausible and could have contributed to a lower LAZ at ages 18–23 months in our study. Suggested pathways include systemic inflammation, oxidative stress, interference with thyroid hormone and insulin-like growth factors 1 and 2, DNA methylome alterations, telomere shortening, and an indirect pathway via respiratory disease (Alink et al. 1994; Bates et al. 2013; Isaevska et al. 2021; Kannan et al. 2006). In a Spanish study, exposure to outdoor air pollution was associated with weight and BMI at age 4 years, but this association was partially mediated by birthweight (Fossati et al. 2020). This supports the argument that both pathways can play a role, but also that long-term follow-ups and the assessment of other outcomes in addition to birthweight are important.

Subgroup analyses showed that in male children, there was an inverse association between biomass fuel use and LAZ; this association was not seen in the female children. The reasons for this gender difference are unclear but could relate to underlying biological differences in the metabolism, immune responses, and a general higher vulnerability to environmental insults of boys during pregnancy and at young ages (Becklake and Kauffmann 1999; Kaali et al. 2018; Klein and Flanagan 2016). In the other subgroup contrasts, the association between biomass fuel and LAZ was only seen in the "better-of-groups". In the absence of other studies with similar results, we hypothesize that for children with suboptimal living conditions, in our case characterized by smaller houses, lower socioeconomic status, hospitalization or non-exclusive breastfeeding at 3 months of age, the addition of poor air quality contributes less in relative terms to the multifaceted etiology of impaired linear growth. Other risk factors might be more important for these children. In contrast, in the case of limited occurrence of other risk factors, household air quality does seem to play a role. However, this is a hypothesis only and should be confirmed by future analyses.

Despite high quality anthropometric data and a fairly large sample size, the association between the use of biomass fuel and stunting among young Nepalese children only approached statistical significance. In line with the arguments by (Perumal et al. 2018) we aimed to describe the association of using biomass fuel on different sections of the distribution of LAZ instead of the more commonly approach that models only the outcome mean. There was a tendency of a larger association in the lower tail of the LAZ distribution, which did not reach statistical significance.

The current study is a secondary analysis of data from a RCT which limits the external validity of the study results. The strict inclusion criteria also limit the internal validity of the study as we restricted the inclusions to infants who had a LAZ < -1. Conditioning the analysis on LAZ at enrolment, which could be in the causal pathway, might have introduced bias, most likely leading to an underestimation of the association. Of all 600 enrolled children, 28 (4.7%) were not measured at the end of the study. Of those, 22 children (79%) were living in families using biomass fuel. However, the mean LAZ of those remaining in the study and those not included in analysis was not different at enrolment (Z-score of −1.84 and −1.76, respectively). We expect minimal bias introduced by loss to follow-up. We used the participant reported use of fuel type at the time of enrolment into the study, i.e., when the children were 6–11 months old, as proxy for household air pollution. This proxy has been commonly used in epidemiological studies (Clark et al. 2013) due to advantages including easier logistics and application (especially in children), low costs, and the capture of the entire pollutant mix. But it has also some clear limitations mainly in terms of the quantification of exposure, specification of pollutants, and misclassification. However, we think that misclassification is most likely non-differential in our study and would thus lead to an underestimation of the association. We did not validate the question on fuel use for this particular study, but have used the same question in previous studies, where it predicted the outcomes (pneumonia) well (Bates et al. 2013; Bates et al. 2018). The short-term use of biomass fuel due to the earthquakes as well as a generally high ambient air pollution in Bhaktapur might also have led to an underestimation of the association. We did not have data on dietary intake other than breastfeeding nor were we able to include other potential confounders such as nutritional deficiencies, parental height or other sources of pollution; although this is a limitation to our study, we think that the anthropometric and socio-economic status indicators included as covariates in our models might have captured some of these aspects. Potential residual confounding cannot be excluded.

5. Conclusion

Children from households where biomass fuel was used for cooking were on average slightly shorter than other children. The mean difference in LAZ between these children from poor, urban neighborhoods in Nepal did not reach statistical significance. Features of the study design might have led to an underestimation of the association. As this was an observational study, residual confounding cannot be excluded. Further studies are needed to explain the association seen in certain sub-groups, and to address if specific time periods are more important than others in the etiology of impaired linear growth.

CRediT authorship contribution statement

Catherine Schwinger: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft. **Ingrid Kvestad:** Conceptualization, Methodology, Investigation, Project administration, Funding acquisition, Writing – review & editing. **Ram K. Chandyo:** Conceptualization, Methodology, Investigation, Project administration, Funding acquisition, Writing – review & editing. **Manjeswori Ulak:** Investigation, Project administration, Funding acquisition, Writing – review & editing. **Merina Shrestha:** Investigation, Funding acquisition, Writing – review & editing. **Suman Ranjitkar:** Investigation, Project administration, Funding acquisition, Writing – review & editing. **Tor A. Strand:** Conceptualization, Methodology, Investigation, Project administration, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Thrasher Research Fund (award #11512) was the main funder of the trial this study is based on. Other funding: South-Eastern Norway Regional Health Authority (grant #2012090), and the Research Council of Norway (grant #234495). The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Data will be made available upon request to the last author (Tor A. Strand: tor.strand@uib.no).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2022.107089.

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