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Adeladza Kofi Amegah

HOUSEHOLD FUEL AND GARBAGE COMBUSTION, STREET VENDING ACTIVITIES AND ADVERSE PREGNANCY OUTCOMES

EVIDENCE FROM URBAN GHANA

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU, FACULTY OF MEDICINE, INSTITUTE OF HEALTH SCIENCES;
CENTER FOR ENVIRONMENTAL AND RESPIRATORY HEALTH RESEARCH;
MEDICAL RESEARCH CENTER OULU;
UNIVERSITY OF CAPE COAST, DEPARTMENT OF BIOMEDICAL AND FORENSIC SCIENCES

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Evidence from Urban Ghana

Academic dissertation to be presented with the assent of the Doctoral Training Committee of Health and Biosciences of the University of Oulu for public defence in Auditorium A101 of the Department of Anatomy and Cell Biology (Aapistie 7 A), on 14 November 2014, at 12 noon

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Abstract

Air pollution is a major concern in urban areas of developing countries as a result of industrial expansion and increased vehicular ownership, and in most households due to solid fuel use and garbage burning at home. Urban poverty is also widespread in developing countries, and besides perpetuating household air pollution (HAP), it has also meant hazardous occupational choices such as street vending by the urban poor. The epidemiologic evidence linking HAP exposure with adverse pregnancy outcomes is very limited. Research on the health effects of street vending is also scarce with its relationship with fetal growth still unexplored in spite of women dominating this venture.

This project assessed the effects of HAP practices and ambient air pollution exposure on fetal growth and gestational duration, and elaborated the role of environmental exposures in the influence of socioeconomic deprivation on pregnancy endpoints. The project comprised an epidemiologic study, and a qualitative and quantitative synthesis of evidence.

A cross-sectional study of 1,151 mothers-infant pairs accessing postnatal services at the Korle Bu Teaching Hospital in Accra (n = 592), and the four main health facilities in Cape Coast (n = 559) was conducted. Information on socioeconomic characteristics and activity patterns of mothers, and characteristics of the indoor and outdoor environment were collected in a structured questionnaire. Birth weight and gestational age was retrieved from hospital records. PUBMED, Ovid MEDLINE, SCOPUS and CINAHL databases were searched for studies investigating HAP exposure and pregnancy outcomes for the review.

Multivariate modeling adjusting for confounders resulted in a 243g (95% CI: 496, 11) reduction in birth weight and 41% (risk ratio [RR] = 1.41; 95% CI: 0.62, 3.23) increased risk of low birth weight (LBW) for use of charcoal. Garbage burning was associated with a 195% (RR = 2.95; 95% CI: 1.10, 7.92) increased risk of LBW. The meta-analysis indicated an 86.43g (95% CI: 55.49, 117.37) reduction in birth weight and a 35% (summary-effect estimate [EE] = 1.35; 95% CI: 1.23, 1.48) increased risk of LBW for solid fuel use. Increased risk of other pregnancy endpoints with use of solid fuels was also noted in the meta-analysis. Moderate street vending activity and high traffic density in the vending area jointly resulted in 84% (RR = 1.84; 95% CI: 1.05, 3.24) and 29% (RR = 1.29; 95% CI: 0.68, 2.46) increased risk of LBW and preterm birth, respectively. Evidence of the effects of maternal socioeconomic disadvantage on pregnancy outcomes was noted, with HAP especially substantially mediating the observed effects.

Interventions for mitigating the effects of solid fuel use on health call for eliminating barriers to the adoption of cleaner fuels and educating women about behavioral changes required to minimize exposure. Government should also extend their social safety net programs to pregnant women engaged in hazardous occupations to enable them give up or minimize the number of hours in the work.

Keywords: air pollution, birth weight, cooking fuel, garbage burning, gestational length, pregnancy outcome, socioeconomic status, street vending

Amegah, Adeladza Kofi, Polttoaineiden ja jätteiden kotipoltto, katumyynti ja sikiön kehityshäiriöt. Todistusaineistoa Ghanan kaupunkialueilta
Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta, Terveystieteiden laitos; Ympäristöterveyden ja keuhkosairauksien tutkimuskeskus; Medical Research Center Oulu; University of Cape Coast, Department of Biomedical and Forensic Sciences
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Tiivistelmä

Ilmansaasteet ovat merkittävä huolenaihe kehitysmaiden urbaaneilla alueilla teollisuuden ja ajoneuvoliikenteen lisäännyttyä sekä useimmissa kodeissa biomassan, hiilen ja jätteiden polttamisen takia. Urbaani köyhyys on kehitysmaissa laajamittaista, ja sisäilman saasteongelmien pahentamisen lisäksi se johtaa vaarallisiin ammatinvalintoihin, kuten kadulla tapahtuvaan myyntityöhön. sisäilman saasteiden ja sikiön kehityshäiriöiden välisistä yhteyksistä on kuitenkin vain vähän epidemiologisia todisteita. Katumyynnin terveysvaikutuksia on tutkittu hyvin vähän, eikä sen yhteyttä sikiön kasvuun ole tutkittu, vaikka naiset ovat vahvasti edustettuna kyseisellä alalla.

Tässä väitöskirjassa tarkasteltiin sisäilman saasteiden ja ympäristön ilmansaasteiden vaikutuksia sikiön kasvuun ja raskauden kestoon sekä tutkittiin ympäristöaltisteiden roolia sosioekonomisen vähäosaisuuden vaikutuksessa sikiön kehityshäiriöihin. Väitöskirja koostuu epidemiologisesta tutkimuksesta sekä määrällisestä ja laadullisesta aineiston yhdistelemisestä.

Poikittaistutkimukseen osallistui 1151 äiti-vauvaparia, jotka olivat käyneet synnytyksen jälkeen neuvolassa Korle Bu -opetussairaalassa Accrassa (n=592) tai jossain Cape Coastin neljästä pääsairaalasta (n=559). Kyselyllä kerättiin tietoa äitien sosioekonomisesta asemasta ja liikkuvuudesta sekä sisä- ja ulkoympäristön ominaisuuksista. Vauvojen syntymäpainot ja syntymähetken raskausviikot selvitettiin sairaaloiden rekistereistä. Sisäilman saasteille altistumista ja sikiön kehityshäiriöitä tarkastelevia tutkimuksia etsittiin katsausta varten PUBMED-, Ovid MEDLINE-, SCOPUS- ja CINAHL-tietokannoista.

Monimuuttujamallissa, jossa sekoittavat tekijät oli huomioitu, puuhiilen käyttö pienensi syntymäpainoa 243 grammaa (95 % luottamusväli: 496-11) ja lisäsi alhaisen syntymäpainon riskiä 41 % (riskisuhde [RR]=1.41; 95 % luottamusväli: 0.62-3.23). Roskien polttoon liittyi 195 % (RR=2.95; 95 % CI: 1.10-7.92) suurentunut alhaisen syntymäpainon riski. Meta-analyysissä biomassan ja hiilen poltto alensi syntymäpainoa 86.43 grammaa (95 % luottamusväli: 55.49-117.37) ja lisäsi alhaisen syntymäpainon riskiä 35 % (meta-analyysin riskisuhde =1.35; 95 % luottamusväli: 1.23-1.48). Meta-analyysissä havaittiin myös muita biomassan ja hiilen polttoon liittyviä kohonneita kehityshäiriöiden riskejä. Kohtalainen katumyyntiaktiivisuus ja korkea liikennetiheys myyntialueella yhdessä lisäsivät matalan syntymäpainon riskiä 84 % (RR=1.84; 95 % luottamusväli: 1.05-3.24) ja ennenaikaisen syntymän riskiä 29 % (RR=1.29; 95 % luottamusväli 0.68-2.46). Tutkimuksessa todettiin äidin matalan sosioekonomisen aseman vaikutus sikiön terveyteen ja havaittiin, että sisäilman saasteiden rooli havaittujen vaikutusten välittäjänä on merkittävä.

Biomassan ja hiilen polttamisesta aiheutuvien terveysuhkien ehkäisemiseksi puhtaampien polttoaineiden käyttöä tulisi edistää ja naisia tulisi valistaa siitä, kuinka ilmansaasteille altistumista voi vähentää. Hallituksen tulisi sosiaalitukien avulla mahdollistaa vaarallisissa ammateissa työskentelevien, raskaana olevien naisten työajan minimointi.

Asiasanat: ilmansaaste, jätteiden poltto, katumyynti, polttoaine, raskauden kesto, sikiön kehityshäiriöt, sosioekonominen asema, syntymäpaino

Behold, I will do a new thing; now it shall spring forth; shall ye not know it? I will even make a way in the wilderness, and rivers in the desert.
Isaiah 43:19

Dedicated to my beloved children Kofi, Kweku and Maafia

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Oulu, September 26, 2014 Adeladza Kofi Amegah

Abbreviations

ARLI	Acute lower respiratory infection
BRT	Bus Rapid Transit
CI	Confidence interval
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary disease
EE	Effect estimate
EPA	Environmental Protection Agency
GDHS	Ghana Demographic and Health Survey
GH₵	Ghana Cedis
HAP	Household air pollution
IUGR	Intrauterine growth retardation
KBTH	Korle Bu Teaching Hospital
LBW	Low birth weight
LPG	Liquefied petroleum gas
MeSH	Medical Subject Heading
NO_2	Nitrogen dioxide
NOS	Newcastle-Ottawa Scale
O_3	Ozone
OR	Odds ratio
PAH	Polycyclic aromatic hydrocarbon
PM	Particulate matter
PM_{10}	Particulate matter with aerodynamic diameter less than 10 micrometers
$PM_{2.5}$	Particulate matter with aerodynamic diameter less than 2.5 micrometers
ppb	parts per billion
ppm	parts per million
PTB	Preterm birth
RCH	Reproductive and Child Health
RCT	Randomized controlled trial
RR	Relative risk
SES	Socioeconomic status
SGA	Small for gestational age
SO_2	Sulfur dioxide
TB	Tuberculosis

ug/m^3	micrograms per cubic meter
VOCs	Volatile organic compounds
β	Regression coefficient from a linear regression model representing effect size

Original publications

This thesis is based on the following publications, which are referred to throughout the text by their Roman numerals:

I Amegah AK, Jaakkola JJK, Quansah R, Norgbe GK & Dzodzomenyo M (2012) Cooking fuel choices and garbage burning practices as determinants of birth weight: a cross-sectional study in Accra, Ghana. Environ Health 11: 78.

II Amegah AK & Jaakkola JJK (2014) Work as a street vendor, associated traffic-related air pollution exposures and risk of adverse pregnancy outcomes in Accra, Ghana. Int J Hyg Environ Health 217: 354–362.

III Amegah AK, Damptey OK, Sarpong GA, Duah E, Vervoorn DJ & Jaakkola JJK (2013) Malaria infection, poor nutrition and indoor air pollution mediate socioeconomic differences in adverse pregnancy outcomes in Cape Coast, Ghana. PLoS One 8(7): e69181.

IV Amegah AK, Quansah R & Jaakkola JJK (2014) Household air pollution from solid fuel use and risk of adverse pregnancy outcomes: a systematic review and meta-analysis of the empirical evidence. Manuscript.

Contents

1 Introduction

Globally, 41% of households, mainly in developing countries in Asia and sub-Saharan Africa, rely on solid fuels (coal and biomass) as their primary cooking fuel (Bonjour *et al.* 2013). In sub-Saharan Africa, the proportion of the population relying on biomass as their primary cooking fuel is as high as 76–81% (UNDP/WHO 2009, OECD/IEA 2006). Solid fuels are mostly used by rural and low-income urban households, burning them in open fires and inefficient traditional cookstoves, often in poorly ventilated cooking spaces. As a result, high levels of combustion pollutants including particulate matter (PM), carbon monoxide (CO) and polycyclic aromatic hydrocarbons (PAHs) are released, to which women who are customarily responsible for household cooking and their young children are most exposed with severe consequences for their health. Low-income households of developing countries also often resort to open burning of garbage at home due to lack of access to waste collection services, a practice that poses similarly severe health consequences for household members.

Over the last decades, ambient air pollution has also emerged as a major public health concern in urban areas of developing countries due to industrial expansion of these areas and rapid population growth with its associated proliferation of slum settlements and increased vehicular ownership. According to Cohen *et al.* (2004), populations of rapidly expanding cities of developing countries are increasingly exposed to high levels of ambient air pollution that rival and often exceed the levels experienced in developed countries in the first half of the 20th century. While developed countries have enforced emissions standards and regulations, this is not always the case in many developing countries for a variety of reasons, including lack of technological and economic resources and lack of political will (Islam & Slusarska 2013). Together with other formal and informal outdoor workers, street vendors who dominate the huge informal economy in developing countries are the group most exposed to urban air pollution in developing countries.

The epidemiologic evidence linking household air pollution (HAP) exposure from solid fuel use and garbage burning at home with adverse pregnancy outcomes is very limited. The majority of the limited studies also have major methodological limitations with obvious implications for the validity of their findings and the quality of evidence reported. The apparent lack of research on the relationship is totally at variance with the widespread projection of HAP as the most important environmental exposure for pregnant women in developing countries. Also, the numerous studies investigating the relationship between urban air pollution and pregnancy outcomes over the last two decades have emanated mostly from developed countries. There is very limited research on ambient air pollution exposure and associated health effects among outdoor workers in developing countries. The relationship between street vending, and fetal growth and pregnancy outcomes remains unexplored in spite of women dominating the venture.

Another worrying problem in urban zones in developing countries is widespread poverty and socioeconomic deprivation due to the rapid population growth and concomitant proliferation of slum settlements. Socioeconomic circumstances determine indoor air quality and urban air pollution exposure in developing countries. The urban poor patronize solid fuels mostly due to their relative cheapness and availability, and frequently burn garbage at home as a mode of managing their solid waste. Street vending has also become the mainstay of the urban poor as a means of livelihood. Investigating the effects of household fuel choices, garbage burning at home, and street vending activities on fetal growth and duration of gestation is thus important for improving birth outcomes in developing countries. Furthermore, socioeconomic status is well documented to have strong effects on health outcomes, and hence elaborating the mediating role of environmental exposures in the influence of socioeconomic deprivation on birth outcomes is important for better tailoring of intervention strategies.

2 Review of the literature

This chapter systematically reviews the body of literature in which the topic is situated whilst highlighting the major gaps in knowledge to provide the background and justification for the work. The review covers the following areas: (1) the health effects of household use of solid fuels; (2) the state of urban air pollution in Ghana, available evidence on exposures among the group most vulnerable (street vendors) and possible adverse health effects; (3) urban poverty, linkages with household air pollution and its perpetuation of street vending activities; (4) the epidemiology and sequelae of selected adverse pregnancy outcomes; and finally (5) the biological pathway through which air pollution exposure impacts on fetal growth.

2.1 Health effects of household use of solid fuels

Over the last decade, epidemiologic studies investigating the relation of solid fuel use with several health outcomes including acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD), lung cancer, ocular disease and pregnancy outcomes have been accumulating worldwide. Several reviews have also attempted to summarize the available evidence during the period. This section synthesizes the findings of the available reviews. Google Scholar and PubMed databases were systematically searched for qualitative and quantitative reviews on the health effects of solid fuel use. Regarding health outcomes for which reviews do not exist, evidence from methodologically sound empirical studies are presented.

2.1.1 Choices and emission characteristics

Biomass – wood, charcoal, crop residue and dung, and coal – lignite, bituminous coal and anthracite, are the primary cooking and heating fuels in many households in developing countries. Masera *et al.* (2000) identified four factors that determine household fuel choices: (a) cost of fuel, stove type and accessibility to fuels, (b) technical characteristics of stoves and cooking practices, (c) cultural preferences, and (d) the potential health impacts. Anenberg *et al.* (2013) also recently asserted that household energy decisions are influenced by income, tradition, social expectations, and fuel availability. According to Balakrishnan *et al.* (2004), of the many factors affecting household energy decisions, family income is the most influential. Wood is the most commonly used biomass fuel in developing countries. In sub-Saharan Africa, almost 70% of people in the region rely on wood (and its by-products) as their primary cooking fuel (UNDP/WHO 2009). In India alone the proportion of the population relying on wood for cooking is 58%, with the percentage in the rest of South Asia estimated at 49% (UNDP/WHO 2009). In many poorer countries of sub-Saharan Africa and South Asia, almost all rural households rely exclusively on wood, dung, or crop residue (Rehfuess *et al.* 2011, Bruce *et al.* 2006). Use of coal as primary cooking fuel is not widespread throughout the developing world, but concentrated in certain countries such as China, where 29% of the population use this fuel (UNDP/WHO 2009), and South Africa, where it is used in low-income households and coal mining areas (Balmer 2007). Charcoal use is widespread in urban areas of sub-Saharan Africa with more than 80% of urban households using this fuel as their main cooking fuel (Zulu & Richardson 2013).

Households often burn solid fuels in open fires consisting of three stones/bricks or U-shaped mud stoves, and in inefficient traditional cookstoves. Solid fuels are difficult to burn in these simple household combustion devices without substantial emissions of pollutants, mainly because of the difficulty of achieving complete premixing of the fuel with air during combustion (Smith *et al.* 2000). Consequently, a substantial fraction of the fuel carbon is converted to products of incomplete combustion (Zhang & Smith 2007). Emissions from combustion of solid fuels are a complex mixture of particulate and gaseous species including PM, CO, nitrogen dioxide (NO_2), sulfur oxides, PAH, other hydrocarbons, and carcinogenic compounds such as benzene, formaldehyde, 1,3-butadiene and styrene (Zhang & Smith 2007). Coal combustion emits other pollutants as they contain intrinsic contaminants such as sulfur, arsenic, silica, fluorine, lead and mercury which are released in their original or oxidized form during combustion (Zhang & Smith 2007). Indoor concentrations of emissions from combustion of solid fuels in the presence of poor ventilation usually exceed air quality guidelines by several folds.

2.1.2 Health effects

There is strong evidence linking solid fuel use with three important diseases: ARLI, COPD, and lung cancer. Estimates from four meta-analyses reviewed (Smith *et al.* 2004, Dherani *et al.* 2008, Misra *et al.* 2012, Bruce *et al.* 2013) suggest solid fuel use increases the risk of ALRI by a factor of 1.7 to 2.5

(summary effect estimates of 2.3 [95% CI: 1.9, 2.7], 1.78 [95% CI: 1.45, 2.18], 2.51 [95% CI: 1.53, 4.10] and 1.73 [95% CI: 1.47, 2.03] respectively). Household solid fuel use increases the risk of COPD among exposed women by a factor of 2.4 to 3.2 based on a review of three meta-analyses (Smith *et al.* 2004, Po *et al.* 2011, Hu *et al.* 2010). The summary odds ratios (ORs) reported by these studies were 3.2 (95% CI: 2.3, 4.8), 2.40 (95% CI: 1.47, 3.93) and 2.73 (95% CI: 2.28, 3.28) respectively. For all exposed adults, estimates from two meta-analyses (Kurmi *et al.* 2010, Hu *et al.* 2010) indicate an increased risk of about 3 folds (summary ORs of 2.80 [95% CI: 1.85, 4.23] and 2.65 [95% CI: 1.75, 4.03] respectively). Regarding chronic bronchitis, estimates from the reviews of Kurmi *et al.* (2010) and Hu *et al.* (2010) suggest that the use of solid fuels increases the risk of this outcome among exposed adults by a factor of 2.3 to 2.6 (summary ORs of 2.32 [95% CI: 1.92, 2.80] and 2.56 [95% CI: 1.77, 3.70] respectively). Among exposed women, the summary OR estimated was 2.52 (95% CI: 1.88, 3.38) (Po *et al.* 2011).

The evidence linking HAP exposure with lung cancer risk has originated mainly from China and has focused mostly on the usage of coal, a widely used solid fuel in that country. Estimates from the meta-analyses reviewed suggest that household use of coal increases lung cancer risk by a factor of about 2 in exposed women (Zhao *et al.* 2006, Smith *et al.* 2004), and by a factor of about 1.8 to 2.7 among all exposed adults (Zhao *et al.* 2006, Hosgood *et al.* 2011, Kurmi *et al.* 2012, Smith *et al.* 2004). The summary ORs reported for exposed women were 1.83 (95% CI: 0.62, 5.41) and 1.94 (95% CI: 1.09, 3.47) respectively. Kurmi *et al.* (2012) also provided estimates for biomass fuel use (predominantly wood), and they were slightly lower (summary OR = 1.50 [95% CI: 1.17, 1.94]). The International Agency for Research on Cancer (IARC 2010) has classified indoor emissions from household coal combustion as a human carcinogen (group 1) and those from biomass fuel, primarily wood, as a probable human carcinogen (group 2A).

Health outcomes for which there is weak to moderate evidence of its association with solid fuel use include upper respiratory infection and otitis media, asthma, tuberculosis (TB), pharyngeal and laryngeal cancer, neonatal mortality, adverse pregnancy outcomes, nutritional deficit, cardiovascular diseases and endocrine disorders, and ocular morbidities. Desai *et al.* (2004) reviewed three studies and reported exposure to solid fuel smoke to exacerbate asthma by a factor of 1.6 (95% CI: 1.0, 2.5) for children aged 5–14 years and by a factor of 1.2 (95% CI: 1.0, 1.5) for persons >15 years. Po *et al.* (2011), however, found no significant association of biomass fuel use with asthma in children (summary OR = 0.50; 95% CI: 0.12, 1.98) and women (summary OR = 1.34; 95% CI: 0.93, 1.93) in their review. A recent review (Sumpter & Chandramohan 2013) associated TB with HAP exposure, reporting a summary OR of 1.30 (95% CI: 1.04, 1.62). Previous reviews (Desai *et al.* 2004, Slama *et al.* 2010, Lin *et al.* 2007) did, however, highlight the small number of available studies and limited quality of the evidence, and subsequently indicated that the association of HAP with TB is not supported by the available evidence.

Bruce *et al.* (2013) reviewed three studies and reported a summary OR of 1.27 (95% CI: 1.12, 1.43) and 1.55 (95% CI: 1.04, 2.30) for the relation of biomass fuel use with moderate stunting and severe stunting, respectively. A study in India has also associated biomass fuel smoke exposure with increased risk of underweight (Relative risk [RR] = 1.45; 95% CI: 1.20, 1.75) but not wasting (RR = 1.08; 95% CI: 0.86, 1.37) among infants (Tielsch *et al.* 2009). A study in India (Mishra & Retherford 2007) and multiple countries (Kyu *et al.* 2010) found biomass fuel use to increase the risk of moderate-to-severe childhood anemia by a factor of 1.6 to 2.8 (RR = 1.58 [95% CI: 1.28, 1.94] and OR = 2.8 [95% CI: 1.37, 5.72] respectively). A recent study in Swaziland (Machisa *et al.* 2013), however, observed no statistically significant associations between biomass fuel use and childhood anemia (RR = 0.8; 95% CI: 0.6, 1.2). Desai *et al.* (2004) reviewed three studies and reported solid fuel smoke exposure to increase the risk of cataract by a factor of 1.3 (95% CI: 1.0, 1.7). A recent systematic review (West *et al.* 2013) reported that there is evidence indicating an association of household biomass fuel use with cataract.

Two multi-country case control studies in North Africa (Feng *et al.* 2009), and Central and Eastern Europe (Sapkota *et al.* 2013) and a multi-center case control study in India (Sapkota *et al.* 2008) have associated solid fuel use with increased risk of pharyngeal and laryngeal carcinoma, albeit some of the associations were not statistically significant. Feng *et al.* (2009) associated nasopharyngeal carcinoma with wood smoke exposure during childhood (OR = 1.38, 95% CI: 0.95, 2.00) and adulthood (OR = 1.23, 95% CI: 0.82, 1.85). Sapkota *et al.* (2008) and Sapkota *et al.* (2013) found lifetime coal use to increase the risk of laryngeal cancer by a factor of 2.4 to 5.4 (OR of 2.42 [95% CI: 0.94, 6.25] and 5.37 [95% CI: 2.39, 12.04] respectively). These authors also reported lifetime wood use to increase the risk of pharyngeal cancer by a factor of 1.6 to 4.1 (ORs of 1.56 [95% CI: 1.09, 2.25] and 4.05 [95% CI: 1.30, 12.68] respectively).

Regarding the relation of solid fuel use with adverse pregnancy outcomes, estimates from three meta-analyses reviewed (Misra *et al.* 2012, Pope *et al.* 2010, Bruce *et al.* 2013) suggest that solid fuel use increases low birth weight (LBW) risk by a factor of 1.4 to 1.5 (summary ORs of 1.45 [95% CI: 1.13, 1.87], 1.38 [95% CI: 1.25, 1.52] and 1.40 [95% CI: 1.26, 1.54] respectively). Pope *et al.* (2010) also reported a summary effect estimate of −95.6g (95% CI: −68.5, −124.7) and 1.51 (95% CI: 1.23, 1.85) for birth weight and stillbirth, respectively. Pope *et al.* (2010), however, pointed to limitations in the extent and quality of available evidence at the time of their study. The work of Misra *et al.* (2012) consisted of the very same studies previously reviewed by Pope and co-workers and did not include any of the most recent original reports published since 2010. The focus of the work of Bruce *et al.* (2013) was to propose intervention estimates for child survival outcomes linked to HAP and accordingly, attempted to update the estimates of Pope and co-workers. However, the authors reported only one new eligible study on LBW with no new evidence on stillbirth found. A significant number of studies published since the review of Pope *et al.* (2010) was not captured in their revised estimate.

Studies in India (Tielsch *et al.* 2009, Epstein *et al.* 2013) have weakly associated biomass fuel use with neonatal death (RR = 1.17 [95% CI: 0.70, 1.96] and OR = 0.84 [95% CI: 0.39, 1.81] respectively). On the cardiovascular health effects of solid fuel use, a randomized trial in Guatemala (McCracken *et al.* 2007) found systolic and diastolic blood pressure to be lower (reduction of 3.7 mmHg [95% CI: −8.1, 0.6] and 3.0 mmHg [95% CI: −5.7, −0.4] respectively) among women randomly assigned to cook with an improved woodstove (plancha) compared with controls who continued to use traditional open fires. A recent study in China (Lee *et al.* 2012) also associated solid fuel use with increased risk of hypertension (OR = 1.70; 95% CI: 1.40, 2.07) and coronary heart disease (OR = 2.58; 95% CI: 1.53, 4.32). Lee *et al.* (2012) also associated solid fuel use with increased risk of diabetes (OR = 2.48; 95% CI: 1.59, 3.86). A study in Mozambique (da Costa *et al.* 2004) associated biomass smoke exposure with otitis media (ORs of 1.85 [95% CI: 1.57, 2.19] and 1.50 [95% CI: 1.39, 1.62] for wood and charcoal smoke exposure, respectively). A synthesis of the reviews summarizing evidence on the adverse health effects of solid fuel use is provided in Table 1.

Table 1. Synthesis of the strength of evidence on the adverse health effects of solid fuel use

Strength of evidence	Health outcomes	Author, Year	No. of studies reviewed	Results
Strong evidence	ALRI	Smith *et al.* 2004	8 studies of cohort and case control design included.	Summary OR = 2.3 (95% CI: 1.9, 2.7)
		Dherani *et al.* 2008	24 studies of cross-sectional, case control and cohort design included.	Summary OR = 1.78 (95% CI: 1.45, 2.18)
		Misra *et al.* 2012	9 studies of case control and cross-sectional design included	Summary OR = 2.51 (95% CI: 1.53, 4.10)
		Bruce *et al.* 2013	26 studies of cohort, case control, cross-sectional and randomized controlled trial (RCT) design included.	Summary OR = 1.73 (95% CI: 1.47, 2.03)
	COPD and Chronic bronchitis	Smith *et al.* 2004	11 studies of cohort, case control and cross-sectional design included	Summary OR (Women) = 3.2 (95% CI: 2.3, 4.8)
		Kurmi *et al.* 2010	23 studies of cohort, case control and cross-sectional design included (COPD, n = 10; chronic bronchitis, n = 11).	Summary OR: COPD = 2.80 (95% CI: 1.85, 4.23) Chronic bronchitis = 2.32 (95% CI: 1.92, 2.80)
		Hu *et al.* 2010	15 studies of case control and cross-sectional design included (COPD, n = 9; chronic bronchitis, n = 8).	Summary OR: All studies = 2.44 (95% CI, 1.79, 3.33) All studies (Women) = 2.73 (95% CI: 2.28, 3.28) COPD = 2.65 (95% CI: 1.75, 4.03) Chronic bronchitis = 2.56 (95% CI: 1.77, 3.70)
		Po *et al.* 2011	11 studies of case control and cross-sectional design included (COPD, n = 6; chronic bronchitis, n = 6)	Summary OR: COPD (Women) = 2.40 (95% CI: 1.47, 3.93) Chronic bronchitis (Women) = 2.52 (95% CI: 1.88, 3.38)

Strength of evidence	Health outcomes	Author, Year	No. of studies reviewed	Results
	Lung cancer	Smith *et al.* 2004	16 case control studies included with all except two studies conducted in China (Women, n = 9; Both sexes, n = 5).	Summary OR: Women = 1.17 (95% CI: 1.02, 1.35) Both sexes = 1.86 (95% CI: 1.48, 2.35) Studies adjusting for smoking and chronic respiratory disease: Women = 1.94 (95% CI: 1.09, 3.47) Both sexes = 2.55 (95% CI: 1.58, 4.10)
		Zhao *et al.* 2006	7 case control studies included (women, n = 3; both sexes, n = 5).	Summary OR: Women = 1.83 (95% CI: 0.62, 5.41) Both sexes = 2.66 (95% CI: 1.39, 5.07)
		Hosgood *et al.* 2011	25 case control studies included (Mainland China and Taiwan, n = 20)	Summary OR: Global = 2.15 (95% CI: 1.61, 2.89) China & Taiwan = 2.27 (95% CI: 1.65, 3.12)
		Kurmi *et al.* 2012	28 studies of case control, cross sectional and cohort design included	Summary OR: All studies = 1.70 (95% CI: 1.50, 1.94) Coal use = 1.82 (95% CI: 1.60, 2.06) Biomass use = 1.50 (95% CI: 1.17, 1.94)
Weak to moderate evidence	Asthma	Desai *et al.* 2004	3 studies (2 case control and 1 cross-sectional) included.	Summary RR: 5–14 yrs = 1.6 (95% CI: 1.0, 2.5) 15+ yrs = 1.2 (95% CI: 1.0, 1.5)
		Po *et al.* 2011	9 studies of case control and cross-sectional design included (children, n = 4; women, n = 5)	Summary OR: Children = 0.50 (95% CI: 0.12, 1.98) Women = 1.34 (95% CI: 0.93, 1.93)
	TB	Desai *et al.* 2004	4 studies (2 case control and 2 cross-sectional) included.	Summary RR = 1.5 (95% CI: 1.0, 2.4)

Strength of evidence	Health outcomes	Author, Year	No. of studies reviewed	Results
		Sumpter & Chandramohan 2013	13 studies (10 case control and 3 cross-sectional) included.	Summary OR = 1.30 (95% CI: 1.04, 1.62)
		Slama *et al.* 2010	6 studies (3 case control and 3 cross-sectional) included.	Studies reviewed do not provide sufficient evidence of an excess risk of TB due to HAP exposure from coal or biomass combustion
		Lin *et al.* 2007	5 studies (case control, n = 3; cross-sectional, n = 2) included	Summary OR: Case control = 1.06 (95% CI: 0.50, 2.24) Cross-sectional = 2.58 (95% CI: 2.00, 3.32)
	Nutritional deficit	Bruce *et al.* 2013	3 studies (1 cohort and 2 cross-sectional) included.	Moderate stunting: Summary OR = 1.27 (95% CI: 1.12, 1.43) Severe stunting: Summary OR = 1.55 (95% CI: 1.04, 2.30)
	Ocular morbidities	Desai *et al.* 2004	3 studies (2 case control and 1 cross-sectional) included.	Cataract: Summary RR* = 1.3 (95% CI: 1.0, 1.7).
		West *et al.* 2013	11 studies included.	Biomass fuel use associated with risk of cataract based on the studies reviewed with almost all RR estimates > 1.0
	Adverse pregnancy outcomes	Pope *et al.* 2010	10 studies of case control, cohort, cross-sectional and RCT design included (birth weight, n = 6; stillbirth, n = 4).	Birth weight (grams): Summary effect size (ES) = −95.6 (−68.5, −124.7) LBW: Summary OR = 1.38 (95% CI: 1.25, 1.52) Stillbirth: Summary OR = 1.51 (95% CI: 1.23, 1.85)
		Misra *et al.* 2012	6 studies of case control, cohort, cross-sectional and RCT design included	LBW: Summary OR = 1.45 (95% CI: 1.13, 1.87)
		Bruce *et al.* 2013	7 studies of case control, cohort, cross-sectional and RCT design included.	LBW: Summary OR = 1.40 (95% CI: 1.26, 1.54)

ALRI, acute lower respiratory infection; COPD, chronic pulmonary obstructive disease; TB, tuberculosis; CHD, coronary heart disease; BP, blood pressure; ES, effect size; OR, odds ratio; RR, relative risk.
*Informal meta-analysis with lower end of the range of relative risks set at 1.0 (no effect), and the upper end at the geometric mean of the available relative risks from household studies in developing countries. The central estimate was set as the geometric mean between the upper and lower ends of the nominal confidence interval.

2.2 Urban air pollution

Urban air pollution has worsened in most cities of developing countries with the situation driven by population growth, industrialization, and increased vehicle use (Rahman *et al.* 2001). Recent global estimates of long-term average ambient concentrations of fine particles ($PM_{2.5}$) and ozone found cities of Asia, Middle East and Africa to record the highest levels of air pollution in the world, with $PM_{2.5}$ concentrations reaching 100µg/m^3 compared to <20µg/m^3 in most European and North American cities (Brauer *et al.* 2012). Vehicular emissions are a major source of urban air pollution in developing countries. Rapid urban growth in cities of these countries has generated a highly polluting traffic fleet consisting mainly of old, poorly maintained vehicles and two-stroke vehicles (Assamoi & Liousse 2010, Linden *et al.* 2012). Kinney *et al.* (2011) also asserted that in cities of developing countries, lack of effective transport and land use planning has resulted in increased vehicle ownership and traffic congestion, with air pollution hotspots created along roads. Household combustion activities also contribute to urban air pollution in developing countries. According to Barnes *et al.* (2005) sources of air pollution in developing country cities include those that are common in developed nations as well as solid fuel use for domestic and commercial purposes. van Vliet & Kinney (2007) also identified domestic use of charcoal and wood for cooking and uncontrolled burning of garbage as sources of urban air pollution in many sub-Saharan African countries. Data on air pollution levels in developing country cities is lacking due to very few countries possessing the systems and capacity to routinely monitor air quality. A recent review of urban PM monitoring studies in Africa (Petkova *et al.* 2013) found routine air monitoring to be limited across the continent with many countries lacking air quality standards.

2.2.1 Situation in Ghana

Very limited studies have attempted to characterize air pollution levels and variability in Accra and other metropolitan areas of Ghana. A systematic literature search of PubMed and Scopus databases identified four studies that have characterized air pollution levels in Accra (Arku *et al.* 2008, Dionisio *et al.* 2010a, 2010b, Rooney *et al.* 2012). Arku *et al.* (2008) assessed the levels and spatial/temporal patterns of multiple ambient air pollutants in two low-income neighborhoods in Accra over a three-week period and reported 24-hour PM_{10}

mass at four roof-top sites in these two neighborhoods to range from 57.9 to 93.6 μg/m^3 with a weighted average of 71.8μg/m^3. The authors also reported 24-hour $PM_{2.5}$ mass to range from 22.3 to 40.2 μg/m^3 with an average of 27.4μg/m^3. Elemental carbon was found to be 10–11% of $PM_{2.5}$ mass at all the measurement sites with organic matter forming slightly less than 50% of $PM_{2.5}$ mass. Sulfur dioxide (SO_2) and NO_2 concentrations were reported to be lower than the US Environmental Protection Agency (EPA) National Ambient Air Quality Standards.

Dionisio *et al.* (2010a) monitored PM levels in four Accra neighborhoods of varying socioeconomic status (SES) and biomass fuel use for over 22 months, and reported annual $PM_{2.5}$ range of 39–53μg/m^3 at roadside sites and 30–70μg/m^3 at residential sites. Mean annual PM_{10} ranged from 80 to 108 μg/m^3 at roadside sites and 57 to 106 μg/m^3 at residential sites. The authors also reported average CO concentrations at the various monitoring sites to range from 7 to 55ppm, with higher levels recorded at traffic sites. Dionisio *et al.* (2010b) carried out mobile and stationary monitoring of air pollution consecutively for seven days in each of the four Accra neighborhoods traversing a predetermined path including main highways/roads and local roads, and found daily average $PM_{2.5}$ and PM_{10} levels reaching as high as 200 and 400 μg/m^3, respectively, in some segments of the paths' traverse. Rooney *et al.* (2012) analyzed associations of spatial patterns of PM levels with source variables in the same four neighborhoods to help predict PM pollution in other parts of the city and found PM concentrations to increase with road capacity, with the highest levels recorded along the divided multi-lane highway. Median $PM_{2.5}$ and PM_{10} of 53.4 and 144.5 μg/m^3, respectively, were recorded along this highway. In this study, PM levels were also found to decrease with increasing distance from a main road, with $PM_{2.5}$ dropping by 13–15% and PM_{10} by 14–16% for a distance of 50m from a main road.

With regards to other metropolitan areas of Ghana, the systematic search found no studies that have directly monitored air pollution levels in these areas. The search strategy did, however, identify three studies that measured PAH levels in street dust samples in Kumasi (Essumang *et al.* 2006) and Tamale (Obiri *et al.* 2011, 2013). In the Kumasi study, the authors identified 15 different types of PAHs in vehicular fallouts with concentrations ranging from 3,500 μg/kg for carbazole to 111,200 μg/kg for acenaphthene. Concentration of benzo[a]pyrene, a common constituent of PAH, was found to be 27,900 μg/kg. The earlier Tamale study (Obiri *et al.* 2011) identified 13 different PAH types in street dust samples with concentrations ranging from 10,600 μg/kg for chrysene to 119,000 μg/kg for pyrene in high vehicular traffic areas (500 vehicles per hour). In low vehicular traffic areas (20 vehicles per hour) of the city, PAH concentrations ranged from 2,700 µg/kg for benzo[a]pyrene to 32,000 µg/kg for pyrene. The recent Tamale study (Obiri *et al.* 2013) was aimed at quantifying the human health risk associated with vehicular PAH exposure and also identified 11 different types of PAHs in vehicular fallouts with concentrations in low and high vehicular traffic zones ranging from 20.21–52.35 mg/m^3 for naphthalene to 264.38–983.15 mg/m^3 for pyrene. The concentration of benzo[a]pyrene in low and high vehicular traffic zones was 27.83 mg/m^3 and 112.34 mg/m^3, respectively. The studies reviewed provide evidence of substantial contribution of vehicular traffic sources to air pollution levels in Accra and other urban settlements of Ghana.

2.2.2 Street vending, potential air pollution exposures and health effects

Outdoor workers, particularly street vendors, are the group most vulnerable to urban air pollution in developing countries. Street vending is a highly visible activity in urban areas of developing countries due to growing limitations to formal sector employment as a result of national and global policy shifts, and the massive influx of rural dwellers into urban environment in search of better livelihoods (Asiedu & Agyei-Mensah 2008). A systematic search of the PubMed and Scopus databases identified 13 studies that have investigated ambient air pollution exposures among street vendors (Table 2). These studies applied ambient and personal air sampling techniques as well as evaluating biomarkers to assess street vendors' exposure to ambient (mostly traffic-related) air pollutants including PAHs, benzene and other volatile organic compounds (VOCs), PM, ozone (O_3), CO, NO_2, SO_2 and lead.

Average benzene exposure levels among street vendors were exceedingly high, ranging from 32 µg/m^3 in the Vietnamese study (Lan *et al.* 2013) to 83.7 µg/m^3 in a Mexican study (Meneses *et al.* 1999). Studies assessing exposure to other VOCs (Tovalin-Ahumada & Whitehead 2007, Tovalin *et al.* 2006, Romieu *et al.* 1999) including toluene, MTBE, n-pentane, m-/p-xylene ethylbenzene and o-xylene also found exposure levels among street vendors to be significantly high. Kongtip *et al.* (2006), however, reported very low concentrations of total VOCs (1-hour mean of 3.57 ppm) in their study conducted in heavy congested traffic areas of Bangkok, Thailand, where street vendors operate. The authors nevertheless associated a 1-ppm increase in VOC concentration with increased risk of phlegm production, chest tightness and upper respiratory symptoms among street vendors.

PAH exposure levels among street vendors were noted to range from 7.10 to 83.04 ng/m^3 in another study conducted in Bangkok, Thailand (Ruchirawat *et al.* 2005), and to reach 103 μg/m^3 in a study conducted in Cotonou, Benin (Ayi-Fanou *et al.* 2011). The PAH exposure levels reported by these studies were also exceedingly high. These studies also measured urinary PAH metabolites among the street vendors and reported significantly high levels of 1-hydroxypyrene (1-OHP). Two studies (Ayi-Fanou *et al.* 2011, Tovalin *et al.* 2006) evaluated biomarkers of early biologic effects and reported significantly high levels of DNA adducts and highly DNA-damaged cells among the street vendors studied. The findings are suggestive of possible development of diseases such as cancer later in life among these workers.

Three studies (Han *et al.* 2005, Fernandez-Bremauntz *et al.* 1993; Kongtip *et al.* 2006) investigated CO exposure among street vendors, with all except the study by Kongtip and coworkers reporting high levels of exposure among the respondents studied. Kongtip *et al.* (2006) nonetheless associated a 1-ppm increase in CO concentration with increased risk of sore throat, cold and cough among street vendors. CO binds with hemoglobin to form carboxyhemoglobin (COHb), which reduces oxygen-carrying capacity of the blood and causes tissue hypoxia as a result. Fernandez-Bremauntz *et al.* (1993) estimated COHb levels among the street vendors using a computational modeling technique and reported levels of between 2.4 and 4.9%. Regarding exposure to O_3 and $PM_{2.5}$, Tovalin *et al.* (2006) found personal exposure to these pollutants also to be high among street vendors operating in two Mexican cities. Kongtip *et al.* (2006) also reported high $PM_{2.5}$ concentrations (70.94 μg/m^3) in their study area but found levels of O_3 to be very low (1-hour mean of 4.65 ppb). Kongtip *et al.* (2006) associated a 1-μg/m^3 increase in $PM_{2.5}$ concentration with increased risk of eye irritation (OR = 1.02; 95% CI: 1.01, 1.03) and dizziness (OR = 1.03; 95% CI: 1.01, 1.04) among street vendors. Kongtip *et al.* (2006) also monitored NO_2 and SO_2 but reported low concentrations; 1-hour mean of 52.58 ppb and 6.34 ppb, respectively.

Two studies conducted in Trujillo, Peru (Naeher *et al.* 2004) and Colombo, Sri Lanka (Arewgoda & Perera 1996) investigated ambient lead exposure among street vendors. Naeher *et al.* (2004) observed very low blood lead levels among the street vendors studied. In contrast, Arewgoda & Perera (1996) reported levels of 130 μg/L among their study participants, which is higher than the critical blood lead level of 100 μg/L proposed by WHO (2000). It must, however, be emphasized that with the phasing out of leaded gasoline in all developing countries under the United Nations Environment Program (UNEP) Partnership for Clean Fuels and Vehicles, ambient lead levels have been significantly reduced in cities of most developing countries, and no longer represent a major health threat to outdoor workers. The three Ghanaian studies characterizing PAH levels in street dust samples (Essumang *et al.* 2006, Obiri *et al.* 2011, 2013) identified street vendors as the group most susceptible to the high levels of PAH reported.

Besides the study of Kongtip *et al.* (2006), two other studies conducted in Johannesburg, South Africa (Pick *et al.* 2002) and Bangkok, Thailand (Leong & Laortanakul 2003) were the only studies to have investigated adverse health outcomes among street vendors. Pick *et al.* (2002) found 54% of women street vendors operating in Johannesburg complaining of work-related illnesses/injuries including burns, cuts, headaches, musculoskeletal problems and visual disturbances. A proportion of these women also reported infertility problems and miscarriages. Leong & Laortanakul (2003) monitored traffic noise along some busy roads in Bangkok and performed audiometric measurements on 3,200 traffic-exposed workers and 800 control subjects who work and live primarily in air-conditioned spaces indoors in an attempt to investigate the relationship between traffic noise and hearing loss. At sites recording high noise levels the authors estimated traffic noise-induced hearing loss to be generally larger among street vendors than the other exposed groups. The authors further reported that street vendors with higher exposure time (10–14 hours) and dose (74–94%) were at greater risk of hearing impairment.

The limited research on the health effects of street vending is totally at variance with the common knowledge that individuals engaged in this trade are exposed to high levels of traffic-related air pollutants per their mode of operation, as revealed by the literature reviewed. The relationship between street vending, and fetal growth and pregnancy outcomes remains unexplored. A systematic search of literature did not identify any study that has examined the relationship. Several epidemiological studies, mostly from developed countries, have however linked urban air pollution exposure with a wide range of adverse pregnancy outcomes over the last two decades, with a number of systematic reviews and meta-analysis (Maisonet *et al.* 2004, Glinianaia *et al.* 2004, Sapkota *et al.* 2012, Shah *et al.* 2011, Stieb *et al.* 2012, Vrijheid *et al.* 2011) also attempting to summarize the available evidence during this period.

Maisonet *et al.* (2004) systematically reviewed 12 studies on ambient air pollutants (CO, SO_2, nitrogen oxides [NO_X], PM and O_3) and LBW, very low birth weight (VLBW), preterm birth (PTB) and intrauterine growth retardation (IUGR) and reported that the effects of air pollution on these outcomes are generally smaller compared to the effects of other known risk factors. Glinianaia *et al.* (2004) also conducted a systematic review of 12 studies investigating the associations between PM exposure and IUGR, PTB and stillbirth, and concluded that the current evidence is compatible with either a small true association or with no association. Stieb *et al.* (2012) conducted a systematic review and meta-analysis of 62 studies investigating the association between ambient air pollution, and birth weight and PTB, and found majority of the studies reporting reduced birth weight and increased odds of LBW with CO, NO_2, $PM_{2.5}$ and PM_{10} exposure. For entire pregnancy exposure, pooled effect size reported by the authors for reduced birth weight ranged from 11.4 g (95% CI: −6.9, −29.7) per 1 ppm CO exposure to 28.1g (95% CI: 11.5, −44.8) per 20 ppb NO_2 exposure. Pooled odds ratios for LBW ranged from 1.05 (95% CI: 0.99, 1.12) per 10 μg/m^3 $PM_{2.5}$ exposure to 1.10 (95% CI: 1.05, 1.15) per 20 μg/m^3 PM_{10} exposure. The authors found fewer effect estimates for PTB and reported that the results were mixed. Stieb *et al.* (2012) also stated that results for O_3 and SO_2 were less consistent for all outcomes.

Sapkota *et al.* (2012) attempted to quantify the association between maternal exposure to $PM_{2.5}$ and PM_{10} during pregnancy, and risk of LBW and PTB. Sapkota *et al.* (2012) reviewed 20 studies and reported a 9% increased risk of LBW (summary OR = 1.09; 95% CI: 0.90, 1.32) and a 15% increased risk of PTB (summary OR = 1.15; 95% CI: 1.14, 1.16) for each 10 μg/m^3 increase in $PM_{2.5}$. The authors found the LBW and PTB risk associated with PM_{10} exposure to be smaller and not statistically significant. Shah *et al.* (2011) systematically reviewed 41 studies investigating the association between ambient air pollutants and LBW, PTB and small for gestational age (SGA) births, and reported the following: (1) exposure to SO_2 was associated with PTB, (2) exposure to $PM_{2.5}$ was associated with LBW, PTB and SGA, (3) exposure to PM_{10} was associated with SGA and (4) the evidence for any association between NO, NO_2, O_3 and CO, and birth outcomes is inconclusive. Vrijheid *et al.* (2011) conducted a systematic review and meta-analysis of 10 studies that examined the association between ambient air pollution and congenital anomalies and found a 10-ppb NO_2 and a 1-ppb SO_2 exposure to be associated with increased risk of coarctation of the aorta (summary ORs of 1.17 [95% CI: 1.00, 1.36] and 1.07 [95% CI: 1.01, 1.13] respectively) and tetralogy of Fallot (summary ORs of 1.20 [95% CI: 1.02, 1.42] and 1.03 [95% CI: 1.01, 1.05] respectively). Vrijheid *et al.* (2011) also found a 10 $\mu g/m^3$ PM_{10} exposure to be associated with increased risk of atrial septal defects (summary OR = 1.14; 95% CI: 1.01, 1.28). The authors found no statistically significant increased risk of other cardiac anomalies and oral clefts with ambient air pollution exposure.

Table 2. Ambient air pollution exposure experiences of street vendors.

Author, Year	Location	Study design	No. of subjects	Exposures	Main results
Han *et al.* 2005	Trujillo, Peru	Environmental monitoring	8	$PM_{2.5}$, CO, VOCs	Highest CO exposure (11.4ppm) recorded among newspaper vendors
Tovalin-Ahumada & Whitehead 2007	Mexico City and Puebla, Mexico	Environmental monitoring	4	VOCs	Median toluene, MTBE, *n*-pentane, and *m* and *p*-xylene exposure levels of 112, 41, 48 and 34 $\mu g/m^3$, respectively.
Tovalin *et al.* 2006	Mexico City and Puebla, Mexico	Environmental and bio-monitoring	4	VOCs, $PM_{2.5}$ and O_3	Median VOCs (about 30), $PM_{2.5}$ and O_3 exposure among outdoor workers including street vendors was higher (at least 2.5-fold) than among office workers In Mexico city, street vendors had higher percentage of highly DNA-damaged cells compared to office workers (77% vs. 21%).
Naeher *et al.* 2004	Trujillo, Peru	Biomonitoring	3	Lead	Office workers had significantly ($p < 0.022$) lower mean blood Pb levels (2.1±0.7 µg/dL) than all traffic-exposed workers including street vendors (3.2±1.8 µg/dL)
Meneses *et al.* 1999	Mexico City, Mexico	Environmental monitoring	8	Benzene	Mean exposure levels among street vendors were high (83.7±45.0 $\mu g/m^3$) compared to office workers (45.2±13.3 $\mu g/m^3$)

Author, Year	Location	Study design	No. of subjects	Exposures	Main results
Ruchirawat *et al.* 2005	Bangkok, Thailand	Environmental and bio-monitoring	72	PAHs, Benzene	Roadside PAH levels ranged from 7.10 to 83.04 ng/m^3 and were about 4–13 times higher than levels in temples (500m from the roads) and schools Roadside benzene levels ranged from 16.35–49.25 ppb with levels in temples ranging from 10.16–16.25 ppb. Mean PAH and benzene exposure levels were significantly higher ($p < 0.001$) in street vendors compared to controls (monks/nuns, primary school children). Urinary 1-OHP levels were significantly higher in street vendors than in controls ($p < 0.01$)
Romieu *et al.* 1999	Mexico City, Mexico	Environmental and bio-monitoring	8	Benzene and other VOCs	Mean benzene exposure levels among street vendors (77µg/m^3) were higher than among office workers (44µg/m^3). A similar trend was observed for ethylbenzene, *m-lp*-xylene and *o*-xylene. Blood benzene levels (beginning and post-shift) for street vendors were significantly higher than levels of office workers
Navasumrit *et al.* 2005	Bangkok, Thailand	Environmental and bio-monitoring	43	Benzene	Roadside levels ranged from 15.49–65.70 ppb with mean of 33.71 ppb and were significantly higher ($p < 0.05$) than mean ambient levels in temple areas (12.39 ppb). Exposure levels in street vendors (cloth, 22.61 ppb; grilled-meat, 28.19 ppb) were significantly higher ($p < 0.05$) than in monks/nuns (12.95 ppb) Urinary t,t-MA levels were significantly higher in street vendors than in monks/nuns ($p < 0.05$).

Author, Year	Location	Study design	No. of subjects	Exposures	Main results
Arewgoda & Perera 1996	Colombo, Sri Lanka	Biomonitoring	26	Lead	Exposure levels among street vendors were 130 µg/L and were higher than controls
Kongtip *et al.* 2006	Bangkok, Thailand	Panel study, Environmental monitoring	77	$PM_{2.5}$, CO, VOCs, NO_2, O_3, SO_2	24-hour mean $PM_{2.5}$ level was high (70.94 µg/m^3). Concentrations of the other pollutants were very low
Fernandez-Bremauntz *et al.* 1993	Mexico City, Mexico	Environmental monitoring	173	CO	8-hour mean CO concentration from fixed sites was 26.2 ppm (range: 13–44 ppm) 3-min mean CO levels: street center (20.1–45.3 ppm), pavement (East/North, 19.5–30.7 ppm; West/South, 15.2–31.8 ppm) Personal CO exposure among street sellers was estimated at 12.0–23.5 ppm with a corresponding 1-h maximum COHb level of 2.4 to 4.9%.
Lan *et al.* 2013	Ho Chi Minh, Vietnam	Environmental monitoring	1	Benzene	Exposure levels were 32 µg/m^3
Ayi-Fanou *et al.* 2011	Cotonou, Benin	Environmental and bio-monitoring	16	PAH, Benzene	Mean ambient benzene and PAH concentrations were 76.0µg/m^3 and 103µg/m^3, respectively. Urinary 1-OHP and phenol were significantly higher ($p < 0.001$) in all the exposed groups including street vendors (> 200 µg/g and 155.5 µg/g, respectively) compared to controls (< 5 µg/g and > 14 µg/g, respectively) Mean DNA adduct levels were also significant higher ($p < 0.001$) in all the exposed groups (> 23) compared to controls (< 3)

2.3 Urban poverty: linkages with household air pollution and perpetuation of street vending activities

Inextricably linked with rapid population growth and the concomitant proliferation of unplanned neighborhoods, slums and squatter settlements in urban areas of developing countries is widespread poverty. As cities have expanded in population size and geographic scale, so has the total spread of urban poverty and inequality (Baker 2008, Baker & Schuler 2004). Poverty in developing countries has for long been a rural phenomenon, but in recent times it has become increasingly urbanized (UN-HABITAT 2003). Sub-Saharan Africa is the most rapidly urbanizing region in the world, with increasing levels of poverty in urban areas. In this region, about 40% of urban residents are poor using the $1/day poverty line, and with the $2/day line, the proportion of urban poor is close to 70% (Ravallion *et al.* 2007, Baker 2008), with two out of five of these residents living in circumstances deemed to be life- and health-threatening (UN-HABITAT 2003). Income inequalities are higher in the developing world than in developed nations, with African cities reported to be the most unequal in the world with an average Gini coefficient of 0.58 (UN-HABITAT 2010).

In Ghana, urban poverty declined during the 1990s from 28% in 1991/92 to 19% in 1998/99, but with substantial geographical variations (Ghana Statistical Service 2000). The poverty reductions observed were concentrated in Accra, where the levels fell from 23.1% in 1991/92 to 3.8% in 1998/99, and in forest settlements. A very marginal decline was observed in other urban settlements during this period except for the savannah settlements where the levels increased. Recent estimates, however, suggest that poverty levels in Accra have increased significantly to 11% in 2005/06 with the large increase in net numbers of migrants from the poorer regions to Accra attributed to this observation (Ghana Statistical Service 2007).

Urban poverty is not just a collection of characteristics but also a dynamic condition of susceptibility to risks (Chazovachii *et al.* 2013). A major feature of urban poverty in developing countries is increased susceptibility to environmental health hazards including household and outdoor air pollution, noise pollution, natural disasters, pathogens and disease vectors. The urban poor often live in poorly ventilated and overcrowded houses which are commonly located in polluted areas close to waste dumps, open drains and sewers, industrial sites and highways, and also lack access to water, sanitation and garbage collection services (Baker 2008, Saksena *et al.* 2003). Heavy reliance on solid fuels for cooking and frequent burning of garbage as a mode of managing household waste, the main sources of HAP, are also very common in urban slums. Even though it is common knowledge that poverty is the main driver of HAP in developing countries, there is very limited empirical evidence emanating from urban settings. A systematic search of the PubMed and Scopus databases identified 5 studies conducted in Accra, Ghana (Boadi & Kuitunen 2005, Zhou *et al.* 2011, 2014), Dhaka, Bangladesh (Gurley *et al.* 2013), Ado-Ekiti, Nigeria (Desalu *et al.* 2012), and Banjul, Gambia (Zhou *et al.* 2014) that provide some evidence of the scale of HAP in poor urban areas and households, and the relative contribution of the two main sources.

Boadi & Kuitunen (2005) surveyed 960 Accra households to ascertain their environmental problems and associated adverse health effects, classifying 77.4% of these households as low-income, 16.6% as medium-income and 6.0% as high-income. The authors found low-income households to be the least served with solid waste collection services, with only 2.2% of these households having access to these services compared to 86.2% of the high-income households ($\chi^2 = 273.52$, 2 df, $p < 0.0001$). The authors further found solid waste burning to be high in households without adequate access to proper disposal facilities ($\chi^2 = 279.12$, 4 df, $p < 0.0001$) with poor households more likely to burn their solid waste ($\chi^2 = 18.02$, 2 df, $p < 0.0001$). Boadi & Kuitunen (2005) also found household cooking fuel choices to be dependent on wealth ($\chi^2 = 136.82$, 2 df, $p < 0.0001$), with 74.8% of poor households using charcoal for cooking compared with 10.3% of high-income households.

Zhou *et al.* (2011) examined household PM pollution in four Accra neighborhoods of varying SES and population densities; poor class and densely populated (Jamestown/Ushertown and Nima), middle class (Asylum Down), and upper class and sparsely populated (East Legon). The authors found biomass fuel use to be highest in Jamestown/Ushertown where 95% (95% CI: 85, 100) of households used this fuel for domestic cooking compared to 22% (95% CI: 3, 41) of surveyed households in East Legon. Cooking area PM was lowest in East Legon (Geometric Means of 25 $\mu g/m^3$ [95% CI: 21, 29] for $PM_{2.5}$ and 28 $\mu g/m^3$ [95% CI: 23, 33] for $PM_{2.5–10}$), and highest in Jamestown/Ushertown (Geometric Means of 71 $\mu g/m^3$ [95% CI: 62, 80] for $PM_{2.5}$ and 118 $\mu g/m^3$ [95% CI: 101, 138] for $PM_{2.5–10}$) and Nima (Geometric Means of 52 $\mu g/m^3$ [95% CI: 44, 63] for $PM_{2.5}$ and 131 $\mu g/m^3$ [95% CI: 114, 150] for $PM_{2.5–10}$). Gurley *et al.* (2013) attempted to describe the seasonal variation and determinants of indoor $PM_{2.5}$ concentrations in Mirpur, a low-income community in urban Dhaka, surveying 258 households as part of an epidemiologic study estimating the incidence and timing of ALRI in 2-year-old children, but contrastingly, found only 16% of households to be using biomass fuels exclusively for cooking. Forty-two percent of the households surveyed used clean fuels (natural gas and electricity) exclusively, with 52% using a combination of clean and biomass fuels.

Desalu *et al.* (2012) surveyed 670 urban (Ado-Ekiti, n = 332) and rural (Ido-Ekiti, n = 338) households to establish the pattern and determinants of household cooking fuel choices and found that 21.7% of the urban households used solid fuels for cooking. The authors found use of solid fuels in urban areas to be significantly associated with low education (Spearman correlation coefficient $r = -0.29$, $p < 0.05$), lack of ownership of dwelling ($r = 0.34$, $p < 0.05$), large household size ($r = 0.31$, $p < 0.05$) and residing in traditional houses ($r = -0.26$, $p > 0.05$). In their recent study, Zhou *et al.* (2014) analyzed the chemical composition and sources of fine particles ($PM_{2.5}$) in cooking areas of the same Accra neighborhoods, a peri-urban area of Banjul, and Basse, a rural area in the Upper River region of Gambia. In peri-urban Banjul most households use firewood or charcoal for cooking, with the authors reporting cooking area $PM_{2.5}$ concentrations of 258 ± 208 $\mu g/m^3$ for households using firewood and 134 ± 152 $\mu g/m^3$ for households using charcoal. Solid waste burning was identified as a significant source of HAP in the low-income Jamestown/Ushertown neighborhood of Accra, contributing 12% of the total cooking area $PM_{2.5}$ mass.

The urban poor are faced with multiple deprivations, with Chazovachii *et al.* (2013) mentioning limited access to employment opportunities and income as one of their daily challenges. For many people, informal employment represents an important livelihood strategy playing a critical role in alleviating poverty and social hardship (OECD 2009). Sethuraman (1997) stated that incomes of the poor consist of returns to their own labor as it is the main and often the only income-generating asset at their disposal. The informal workforce thus looms large in developing countries (Rosenstock *et al.* 2006) with employment in the informal sector of developing countries likely to reach 70% (ILO 2002). In sub-Saharan Africa and South Asia, over 80% of non-agricultural jobs are informal (OECD 2009).

Street vending dominates the informal economy in many developing countries as documented by Rosenstock *et al.* (2006). A study synthesizing the findings of case studies on street vending conducted in six African cities including Kumasi, Ghana, noted that street vending is widespread and the source of employment and income for many urban dwellers (Mitullah 2003). Women have been noted to dominate the informal economy as a whole (OECD 2009) and street vending in particular (Mitullah 2003). Mitullah (2003) cited limited economic opportunities, gender bias in education, and the need to augment the family income as the reasons for women's dominance of street vending. Two (Lan *et al.* 2013, Kongtip *et al.* 2006) of the studies that investigated ambient air pollution exposures among street vendors provide some evidence of the socioeconomic circumstances of these people. According to Lan *et al.* (2013), street vendors are commonly low-income people and live in houses located in narrow lanes in dense residential areas of the city. Kongtip *et al.* (2006) also found street vendors to have low education, with about 40% of the participants educated only up to primary level. Mitullah (2003) also found the majority of street vendors to have primary or less level of education, and indicated low levels of education as one of the factors influencing women's participation in the trade.

2.4 Measures, epidemiology and sequelae of selected adverse pregnancy outcomes

Preterm birth (PTB) is defined as any birth before 37 completed weeks of gestation, or fewer than 259 days since the first day of the woman's last menstrual period (WHO 1977) and can be further subdivided into extremely preterm (< 28 weeks), very preterm (28–< 32 weeks), and moderate or late preterm birth (32–< 37 completed weeks of gestation). Measuring PTB requires a valid estimate of gestational age, which is often difficult in developing countries because of late and infrequent access to prenatal care, inadequate documentation of the date of the last menstrual period and unavailability of early ultrasound examination (Kramer 2003). In 2010, an estimated 14.9 million babies (11.1% of livebirths) were born preterm worldwide with the burden concentrated in south Asia and sub-Saharan Africa where 61% of the PTBs occured (Blencowe *et al.* 2012). PTB is the leading cause of perinatal mortality and morbidity accounting for as much as 75% of perinatal deaths (Ananth & Vintzileos 2006). PTB complications are estimated to be responsible for 35% of the world's 3.1 million annual neonatal deaths, and are now the second most common cause of death after pneumonia in children under 5 years old (Liu *et al.* 2012). PTB also increases the risk of death due to other causes, especially from neonatal infections (Lawn *et al.* 2010). Preterm babies that survive are at increased risk of neurodevelopmental impairments including cerebral palsy, mental retardation and sensory deficits, behavioral problems, and respiratory and gastrointestinal complications (Goldenberg *et al.* 2008, Saigal & Doyle 2008, Mwaniki *et al.* 2012).

Birth weight is the first weight of the infant obtained after birth and should be measured during the first hour after birth before appreciable postnatal loss of weight occurs. Birth weight is determined by two processes: duration of gestation and rate of fetal growth (Kramer 1987). Low birth weight (LBW) is defined by the WHO as birth weight less than 2,500 grams. Infants can be born LBW either because they are born early (preterm birth) or are born small for gestational age, a proxy for intrauterine growth retardation (Kramer 2003). More than 20 million infants worldwide, representing 15.5% of all births, are born LBW, 95.6% of them in developing countries (UNICEF/WHO 2004). Half of all LBW babies globally are born in South-Central Asia where more than a quarter (27%) of all infants are LBW at birth. Levels of LBW in sub-Saharan Africa are estimated at around 15% (UNICEF/WHO 2004). LBW is closely associated with fetal and neonatal mortality and morbidity, inhibited growth and cognitive development, and chronic diseases later in life (Barker 1992) including asthma, type 2 diabetes, hypertension, stroke and heart disease (Svanes *et al.* 1998, Rich-Edwards *et al.* 1997, Barker 1998, Leon *et al.* 1998, Huxley *et al.* 2007).

Small for gestational age (SGA) is defined as infants below the 10th centile of a birth weight for gestational age based on a gender-specific reference population (WHO 1995, de Onis & Habicht 1996). A major challenge in estimating the global burden of SGA babies is the selection of a common reference population (Lee *et al.* 2013). Williams *et al.*'s (1982) reference of Californian live births has been recommended by WHO in view of the multi-racial population, representation at lower gestational ages, and association with survival. SGA infants include babies who are constitutionally small and in the lower tail of the growth curve, in addition to infants who were growth-restricted *in utero* (Smith & Lees 2012). In settings with high rates of SGA births, growth restriction accounts for a high proportion of these births (de Onis *et al.* 1998), justifying its use as a proxy for intrauterine growth retardation (Lee *et al.* 2013). Kramer (2003) stated that some SGA infants are merely constitutionally small rather than nutritionally growth restricted; conversely, some intrauterine growth retardation (IUGR) infants who would otherwise be constitutionally large do not meet the standard criteria for SGA. In 2010, an estimated 32.4 million infants (27% of live births) were born SGA in low income and middle income countries, of which 29.7 million infants were born at full term ($\geq$37 weeks), 10.6 million were born at term and with LBW, and 2.8 million were born preterm and SGA

(Lee *et al.* 2013). The highest proportion of SGA babies is found in South Asia, where more than half (53.5%) of SGA babies are born and nearly one in two infants is born too small, followed by sub-Saharan Africa with a reported 8.2 million (25.1%) SGA babies (Lee *et al.* 2013).

IUGR has other commonly used definitions: birth weight less than 2,500 grams and gestational age ≥37 weeks; and birth weight less than 2 standard deviations below the mean value for gestational age (Kramer 1987). Two subtypes of IUGR can be distinguished: disproportional (also called asymmetric or wasted) IUGR infants with relatively normal length and head circumference for their gestational age, but who are thin, with low weight for length and skinfold measurements; and proportional (symmetric or stunted) IUGR infants with proportional reductions in weight, length, and head circumference (Miller & Merritt 1979, Villar & Belizan 1982). Measuring IUGR also requires a valid estimate of gestational age. de Onis *et al.* (1998) attempted to quantify the magnitude of IUGR in developing countries using babies born full term and with LBW as a proxy measure. The authors estimated that at least 13.7 million infants are born at term with LBW every year, representing 11% of all newborns in developing countries, with nearly 75% of all affected newborns born in Asia (mainly in South-Central Asia), 20% in Africa, and 5% in Latin America.

Stillbirth is the birth of a baby with birth weight of 500g or more, 22 or more completed weeks of gestation, or a body length of 25cm or more, who died before or during labor and birth (WHO 2004). For international comparisons, WHO recommends reporting of stillbirths with birth weight of 1,000g or more, 28 weeks gestation or more, or a body length of 35cm or more. Many developed countries, however, register stillbirths at earlier weeks of gestation, some as early as 16 weeks (Kowaleski 1997). Stillbirths can be classified according to the gestational age at birth, typically into early stillbirths (20–28 weeks gestation) and late stillbirths (after 28 weeks). Stillbirths can also be classified by whether death occurred before or after the onset of labor, termed antepartum and intrapartum stillbirth, respectively. The total predicted number of stillbirths in 2009 was 2.64 million, with 76.2% of these stillbirths occurring in South Asia and sub-Saharan Africa (Cousens *et al.* 2011).

Miscarriage or spontaneous abortion, which is defined as the spontaneous loss of the fetus before 20 weeks of gestation, is the most common adverse pregnancy outcome. Regan & Rai (2000) have suggested that the vast majority of miscarriages occur early, well before 12 weeks of gestation. Regan & Rai (2000) further stated that miscarriage is the most common complication of pregnancy, and that one in four of all women who become pregnant will experience this adverse event. Varying miscarriage rates have been suggested in the medical literature, possibly due to the difficulty in accurately detecting the early stages of gestation. The incidence of clinically recognizable miscarriage in general population studies has consistently been reported as 12–15% (Wilcox *et al.* 1988, Regan *et al.* 1989), but according to Regan & Rai (2000) this estimate should be seen as just the tip of the iceberg of total reproductive loss. Ford & Schust (2009) also noted that approximately 15% of all clinically recognized pregnancies result in spontaneous loss. Wilcox *et al.* (1988) studied the risk of early pregnancy loss by measuring urinary concentrations of human chorionic gonadotropin (hCG) in healthy women with the use of an immunoradiometric assay and estimated the total rate of pregnancy loss after implantation including clinically recognized spontaneous abortions at 31%. Forbes (1997), however, suggested that this estimate should probably be viewed as the low-end estimate because the procedure used to detect pregnancy is conservative, with embryos that fail to produce enough hCG to reach a woman's urine remaining undetected. Spontaneous abortions can present enormous physical and emotional stress for couples especially when faced with recurrent losses (Ford & Schust 2009).

2.5 Pathways for the influence of air pollution exposure on fetal growth and development

Air pollutants can either exert their effects directly on fetal growth by passing across the placenta or indirectly by impairing maternal health (Glinianaia *et al.* 2004). Fetuses are highly susceptible to environmental toxicants because of their differential exposure pattern and physiologic immaturity (Perera *et al.* 1999). The high rate of cell proliferation and changing metabolic mechanisms during the critical phase of fetal development have been identified as the physiological process that renders the developing fetus extremely vulnerable to environmental toxicants (Calabrese 1986).

CO is a notable reproductive toxicant with the potential to interfere with oxygen delivery to the developing fetus. CO reduces the oxygen-carrying capacity of maternal hemoglobin, which could adversely affect oxygen delivery to fetal circulation (Salam *et al.* 2005). CO crosses the placental barrier (Sangalli *et al.* 2003) and with fetal hemoglobin having greater affinity for binding CO than does adult hemoglobin (Longo 1977), oxygen delivery to fetal tissues is further compromised (Di Cera *et al.* 1989). The resultant tissue hypoxia has the potential to reduce fetal growth (Bosley *et al.* 1981, Salam *et al.* 2005). Little is known about the mechanisms through which PM exposure influences fetal growth and development. Kannan *et al.* (2006) have, however, suggested that PM exposure may cause oxidative stress, induce pulmonary and placental inflammation, alter blood coagulation factors, influence endothelial functions, and trigger hemodynamic responses, all of which restrict fetal growth through impaired transplacental oxygen and nutrient exchange. Glinianaia *et al.* (2004) also stated that maternal exposure to particulates during pregnancy can result in decreased efficiency of the transplacental function with consequent deterioration in fetal growth and development. Mishra (2004) has suggested that PM and other pollutants in biomass smoke may increase the risk of adverse pregnancy outcome by reducing maternal lung function and increasing the risk of maternal lung disease, and in turn reducing oxygen delivery to the fetus.

Regarding the effects of PAHs, Dejmek *et al.* (2000) have indicated that PAHs may directly affect early trophoblast proliferation due to their reaction with placental growth factor receptors, thereby hampering feto-placental exchange of oxygen and nutrients, and consequently impairing fetal growth. Others have also hypothesized that PAHs and/or their metabolites may bind to the aryl hydrocarbon receptor resulting in antiestrogenic effects, thereby disrupting the endocrine system and interfering with uterine growth during pregnancy (Carpenter *et al.* 2002, Bui *et al.* 1986). Fetal toxicity from DNA damage and resulting activation of apoptotic pathways have also been proposed (Nicol *et al.* 1995). According to Perera *et al.* (1999), the finding of higher DNA adduct levels in the infant compared with the mother suggests an increased susceptibility of the developing fetus to DNA damage.

3 Aims and hypotheses of the study

The overall aim of the research was to investigate the effects of household air pollution exposure, and street vending activities and associated exposures on fetal growth and pregnancy outcomes, and to elaborate the role of environmental exposures in the influence of socioeconomic deprivation on pregnancy endpoints so as to improve adverse pregnancy outcomes in Ghana and similar developing country settings.

The specific objectives were to:

1. Investigate the associations between determinants of indoor air quality, such as cooking fuel choices, cooking sequence and patterns, and garbage burning at home, and birth weight (Study I)
2. Establish the outdoor air pollution exposure experiences of a select occupational group and the consequences for gestational length and birth weight (Study II)
3. Ascertain the importance of socioeconomic status for gestational length and birth weight, and establish the mediating role of biomass fuel use in the effects of socioeconomic deprivation on these pregnancy outcomes (Study III)
4. Systematically review studies evaluating the effects of household fuel combustion on pregnancy outcomes so as to ascertain the strength of available evidence on causality and to identify gaps in knowledge (Study IV)

The hypotheses of the study are the following:

1. Use of solid fuels and garbage burning at home will lead to low birth weight and other unfavorable pregnancy outcomes (Studies I and IV)
2. Traffic-related exposures independent of household air pollution adversely impact on gestational length and birth weight (Study II)
3. Effects of socioeconomic deprivation on gestational length and birth weight are mediated by environmental exposures (Study III)

4 Methods

4.1 Study design and site

A cross-sectional study of mother-infant pairs accessing postnatal services at the Maternity Department of the Korle Bu Teaching Hospital (KBTH) in Accra and the Reproductive and Child Health (RCH) clinics of the four main health facilities – Regional Hospital, Metropolitan Hospital, University Hospital, Adisadel Urban Health Center – in Cape Coast was conducted. Accra is the capital city of Ghana with a total land size of 185 square kilometers and a population of 1,848,614 according to the 2010 census. Accra is also the capital of the Greater Accra Region of Ghana, and the Accra Metropolitan Area. KBTH is located in the south-western part of Accra (Figure 2) and serves as the national referral center for southern Ghana. The catchment area of KBTH's Maternity Department includes communities in the south-western corridor of Accra. The comprehensive and specialist services on offer at KBTH as a whole see the majority of mothers residing in the south-western part of Accra preferring this facility to others in the area that equally provide RCH services. Mothers from other parts of Accra and surrounding areas also access RCH services at KBTH for the very same reason or because they have been referred for an underlying health risk.

Cape Coast covers an area of 122 square kilometers with the 2010 census estimating the population to be 169,894. Cape Coast is the capital of the Central Region of Ghana and the smallest of the six metropolitan areas in Ghana. Cape Coast is principally a fishing community, and although it is primarily urban, there is a fairly large rural population component which is estimated at 30.3% (Cape Coast Metropolitan Assembly 2013). The location of the health facilities visited in Cape Coast is shown in Figure 3.

Fig. 1. Map of Ghana showing the location of Accra and Cape Coast.

Fig. 2. Map of Accra showing the location of Korle Bu Teaching Hospital.

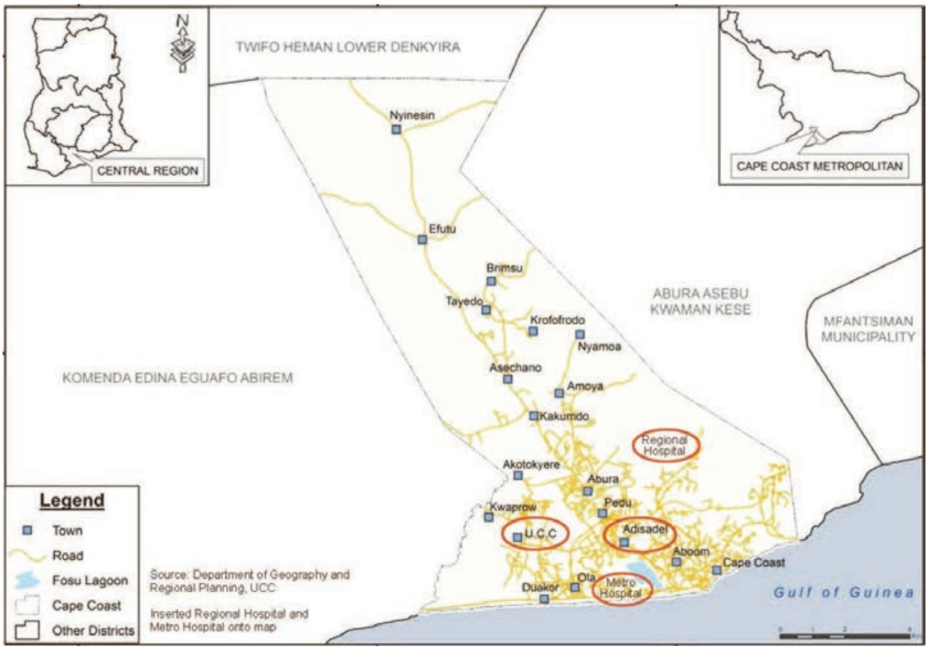

Fig. 3. Map of Cape Coast showing the location of the four health facilities.

4.2 Study population and sampling procedure

The source population comprised all mothers residing in Accra and Cape Coast who have given birth. In KBTH, 647 mothers who had singleton deliveries with no gross anatomical deformities were randomly sampled from a shortlist provided by the facility. In Cape Coast, 680 mothers were sampled from registers provided by the four facilities. Selected mothers who visited the postnatal clinics were interviewed after verifying that they were non-referral patients (in the case of KBTH), and resided in their respective cities and neighborhoods throughout the duration of the pregnancy. The Accra study population included 592 mother-infant pairs (response rate 91.5%) while the Cape Coast study population comprised 559 mother-infant pairs (overall response rate 82.2%). Of the Cape Coast study population, 141 (25.2%) were from the Regional Hospital, 131 (23.4%) from the Metropolitan Hospital, 139 (24.9%) from the University Hospital and 148 (26.5%) from the Adisadel Urban Health Centre.

4.3 Exposure assessment

In the Accra study (Studies I and II), the independent and joint effects of (1) charcoal use and garbage burning at home, and (2) street vending activity patterns and traffic density in the working area, on fetal growth and gestational length were studied. The following exposure information was collected using a structured questionnaire: type of cooking fuel, ventilation rating of cooking enclosure, frequency and duration of cooking activities, amount of time spent in cooking area during cooking sessions, garbage burning practices at home, occupation of mothers during pregnancy, working sequence and patterns, and traffic density and point sources of ambient air pollution in or around the working area.

Households using LPG only without garbage burning constituted the reference category in Study I. The two main household fuels (Charcoal and LPG) were used alone and in combination. To study the independent and joint effects of these together with garbage burning the following exposure categories were used: (1) charcoal use only, (2) charcoal and LPG use, (3) garbage burning only, (4) LPG use and garbage burning, and (5) charcoal use and garbage burning.

For charcoal use and for garbage burning, the ordinal scale exposure parameter – low, moderate and high – was also applied. The level of exposure was defined as follows. For use of charcoal, step one involved (a) classifying the following as high household air pollution (HAP) practices: cooking up to the seventh or ninth month of pregnancy, cooking frequency of four or more times per week, staying in cooking area throughout the whole duration of each cooking session, and cooking area ventilation ratings of poor or satisfactory, and (b) classifying the following as low HAP practices: cooking up to the sixth month of pregnancy, cooking frequency of less than four times per week, staying in cooking area for up to about half the duration of each cooking session, and cooking area ventilation ratings of good, very good or excellent. Step two involved (a) classifying maternal report of all four high HAP practices or a combination of any three high HAP practices and any one low HAP practice as high exposure; (b) classifying maternal report of a combination of any two high HAP practices and any two low HAP practices as moderate exposure, and (c) classifying maternal report of all four low HAP practices or a combination of any three low HAP practices and any one high HAP practice as low exposure.

With regards to garbage burning, step one involved (a) classifying the following as high HAP practices: garbage burning frequency of four or more times per week, and regular presence in household during combustion, and (b) classifying the following as low HAP practices: garbage burning frequency of less than four times per week, and occasional presence in household during combustion. Step two involved (a) classifying maternal report of the two high HAP practices as high exposure, (b) classifying maternal report of a combination of any one high HAP practice and any one low HAP practice as moderate exposure, and (c) classifying maternal report of the two low HAP practices as low exposure.

In Study II, mothers qualified for inclusion if they reported working during the index pregnancy with job category (street vendor vs. reference) used as a measure of occupational exposure. Housewives, unemployed mothers and hairdressers were excluded from the reference group (Figure 4). The ordinal scale exposure parameter (low, moderate and high) was also applied on the street vending activity patterns data. The level of exposure to traffic-related air pollution was defined as follows. Step one involved (a) classifying the following as high vending activities: working up to the seventh or ninth month of pregnancy, working frequency of 4 or more times per week, and working for more than 8 hours during each working session, (b) classifying the following as moderate vending activities: working up to the fourth or sixth month of pregnancy, working frequency of 2–3 times per week, and working for 5–8 hours during each working session, and (c) classifying the following as low vending activities: working up to the third month of pregnancy, working once per week or occasionally, and working for up to 4 hours during each working session.

Step two involved (a) classifying maternal report of all three high vending activities or a combination of any two high vending activities and any one moderate vending activity as high exposure; (b) classifying maternal report of all three moderate vending activities, or a combination of any two moderate vending activities and either any one low or high vending activity as moderate exposure, and (c) classifying maternal report of all three low vending activities or a combination of any two low vending activities and any one moderate vending activity as low exposure.

Finally, the street vending activity patterns and traffic density data were used to categorize mothers into four exposure groups: (1) moderate activity & low traffic, (2) high activity & low traffic, (3) moderate activity & high traffic, and (4) high activity & high traffic. Traffic density in/around the working area (low vs. high) was ascertained by asking the mothers to indicate whether or not their workplace was located close to or their work was conducted along busy roads/heavy traffic corridors which were classified as areas of high traffic density.

Tables 3 a) and b) summarizes the exposure assessment protocol.

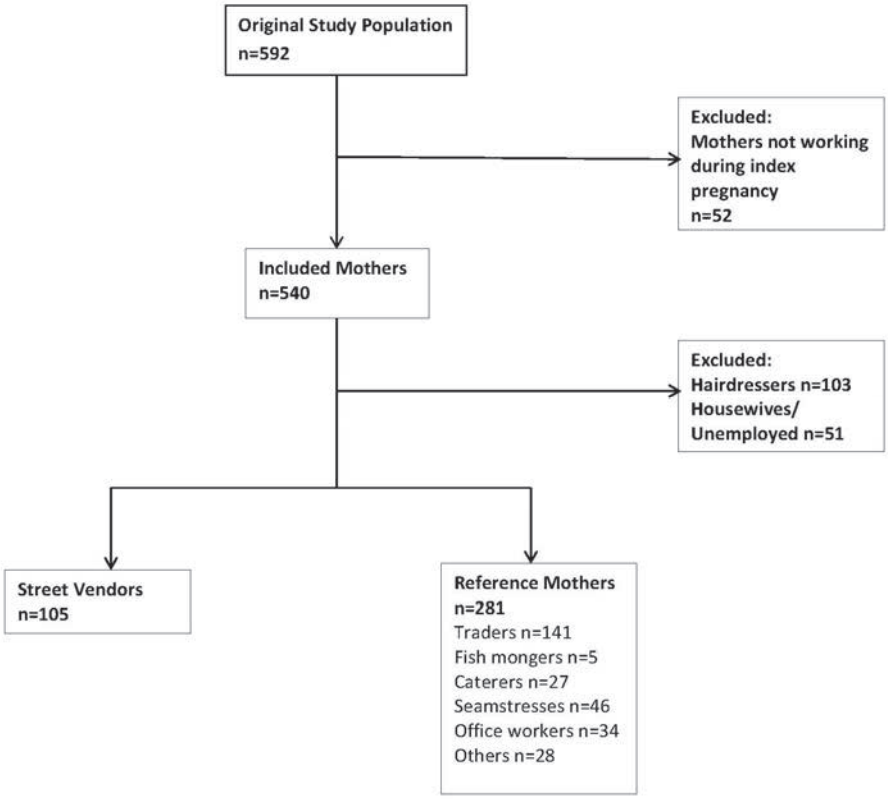

Fig. 4. Sampling protocol for Study II.

Table 3. a) Exposure assessment protocol for Study I.

Charcoal use		Garbage burning	
Step 1	Step 2	Step 1	Step 2
4 High HAP practices and 4 Low HAP practices categorized	High exposure All 4 High HAP practices Any 3 High HAP practices and Any 1 Low HAP practice	2 High HAP practices and 2 Low HAP practices categorized	High exposure All 2 High HAP practices
	Moderate exposure Any 2 High HAP practices and Any 2 Low HAP practices		Moderate exposure Any 1 High HAP practice and Any 1 Low HAP practice
	Low exposure All 4 Low HAP practices Any 3 Low HAP practices and Any 1 High HAP practice		Low exposure All 2 Low HAP practices

Table 3. b) Exposure assessment protocol for Study II.

Step 1	Step 2	Step 3
3 High vending activities, 3 Moderate vending activities and 3 Low vending activities categorized Traffic density in vending area (Low and High) categorized	High exposure All 3 High vending activities Any 2 High vending activities and Any 1 Moderate vending activity Moderate exposure All 3 Moderate vending activities Any 2 Moderate vending activities and Any 1 High vending activity or Any 1 Low vending activity Low exposure All 3 Low vending activities Any 2 Low vending activities and Any 1 Moderate vending activity	Moderate vending activity and Low traffic density High vending activity and Low traffic density Moderate vending activity and High traffic density High vending activity and High traffic density

4.4 Construction of socioeconomic status index

In Study III, area of residence, educational attainment and income levels of the mothers were combined into a socioeconomic status (SES) index with four levels

– low, middle, upper middle and high. Information on the socioeconomic measures was collected using a structured questionnaire. The levels of SES were constructed as follows. Step one involved assigning scores to the three socioeconomic measures in the following ways: (a) for area of residence, scores of 1, 2 and 3 were assigned to poor, middle class and affluent neighborhoods, respectively, (b) for income, scores of 1, 2, 3 and 4 were assigned to monthly incomes of < GH¢100 ($71 at the time of study), GH¢100 – 500 ($71 – 357), GH¢501 – 1000 ($357 – 714) and > GH¢1000 ($714), respectively, and (c) for education, scores of 0, 1, 2, 3 and 4 were assigned to no, primary, junior high, senior high and tertiary education, respectively. Step two involved summing up the scores for each participant with the total SES scores ranging from 2 to 11. Step three involved classification of mothers with total SES scores of 2, 3 and 4 as low SES; 5, 6 and 7 as middle SES; 8 and 9 as upper middle SES; and 10 and 11 as high SES.

4.5 Outcomes of interest

The main outcomes were (1) fetal growth measured both as birth weight in grams and low birth weight (birth weight below 2,500 grams) and (2) length of gestation in completed weeks. Information on birth weight and gestational age was retrieved from hospital records. Birth weight of newborns was measured immediately after delivery at all the selected health facilities with a regularly calibrated weighing scale which measures birth weight in kilograms. In all the facilities visited, gestational age was estimated by the health staff using the last menstrual period method.

4.6 Covariates

Age, social class, marital status and gravidity of the mothers and sex of the newborn were treated as potential confounders in studies I and II. In Study II, in addition to these core covariates, household air pollution exposure assessed by type of cooking fuel and garbage burning at home during pregnancy was also treated as a potential confounder.

Covariates treated as potential confounders in Study III included maternal age, parity and sex of the newborn. Reported episode of malaria during pregnancy, pre-pregnancy body mass index and cooking fuel used during pregnancy were treated as mediating factors.

4.7 Systematic review and meta-analysis

Study IV was conducted and reported in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Moher *et al.* 2009)

Four electronic databases – PubMed, Ovid Medline, Scopus and CINAHL – were searched from their time of inception up till the end of April 2013 with no language restrictions imposed. Medical Subject Heading (MeSH) terms and free text words were used to identify relevant studies from the databases. The search words applied are provided in Table 4. The search process combined the exposure and outcome terms systematically. Articles were initially screened for eligibility based on the title and abstract. Articles were considered for inclusion if they were (a) original studies, (b) conducted in a human population and (c) investigated the relation between any of the exposures and outcomes listed in Table 4. Selected articles were retrieved in full and further assessed for eligibility. Studies were included if they either (a) reported mean estimates for birth measurements among exposed and unexposed groups or mean differences between the two groups, or (b) reported effect estimates for the relation between an exposure and an outcome, or the proportion of cases of any outcome among exposed and unexposed groups. The reference list of all included studies and the three previous reviews (Pope *et al.* 2010, Misra *et al.* 2012, Bruce *et al.* 2013) were also reviewed to identify additional eligible studies. The process for selecting included studies is depicted in Figure 5.

Data from eligible studies were extracted onto a form. Data from studies published in languages other than English were extracted with the help of a translator. Authors were contacted for clarifications where needed. Methodological quality of the included studies was assessed by using the original Newcastle-Ottawa scale (NOS, maximum of 9 stars) for case control and cohort designs, and an adapted NOS (maximum of 6 stars) for cross-sectional designs. Adequacy of confounding control was evaluated by compiling a shortlist of main confounders that need to be adjusted for in the analysis including maternal age and obstetric history, maternal nutrition and anthropometry, socioeconomic status, smoking status and second-hand smoke exposure.

Table 4. Search words for Study IV.

Exposure		Outcomes
MeSH terms	Free text words	MeSH terms
"indoor air pollution"	household air pollution	"pregnancy outcome"
"biofuels"	household fuel	"birth weight"
"biomass"	domestic fuel	"low birth weight"
"coal"	cooking fuel	"premature birth"
"wood"	cooking smoke	"premature infant"
"charcoal"	solid fuel	"fetal growth retardation"
"cooking"	firewood	"fetal development"
	crop residue	"gestational age"
	biomass fuel	"small for gestational age"
	biomass smoke	"fetal mortality"
	wood fuel	"fetal death"
	wood smoke	"perinatal mortality"
	charcoal smoke	"stillbirth"
		"embryo loss"
		"spontaneous abortion"
		"congenital abnormalities"
		"neural tube defects"

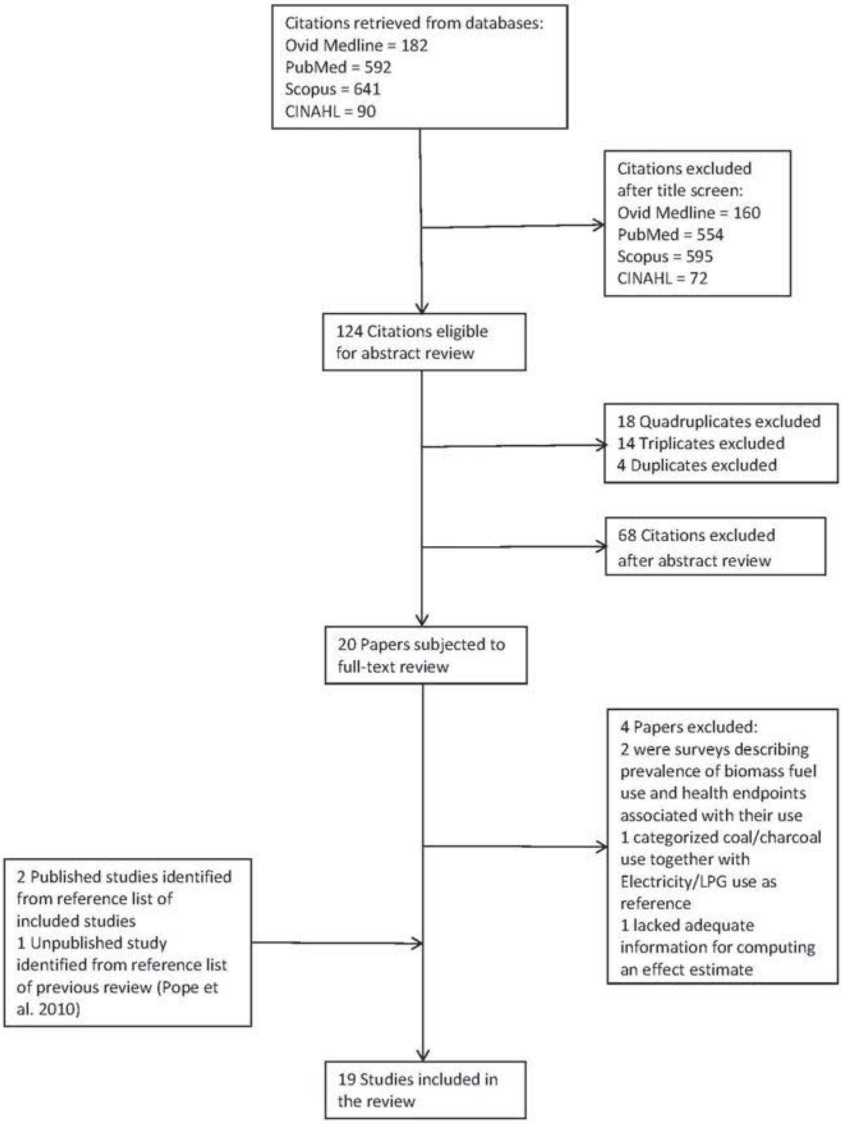

Fig. 5. Flowchart of study selection process in Study IV.

4.8 Ethical considerations

The Ghana Health Service Ethical Review Committee approved the study conducted in Accra. The Cape Coast study was approved by the Research Committee of the Department of Human Biology, University of Cape Coast, Cape Coast. Approval was also sought from the management of all the selected facilities before the commencement of data collection. An informed consent form attached to the questionnaires was used to seek the consent of all participants before inclusion in the study.

4.9 Statistical analysis

Mean birth weight and gestational age, and the risk of LBW and PTB according to categories of charcoal and garbage burning-related, and occupation-related exposure was compared using t-test and Chi-square test to assess the role of chance. Chi-square test was also used to investigate the differences in cooking fuel choices of mothers according to their socioeconomic characteristics. Multivariate methods were applied to assess the relations of interest. First, multiple linear regression was used to estimate the effects of charcoal use and garbage burning, working as street vendor and associated exposure to traffic-related air pollution, and socioeconomic characteristics on average birth weight. Second, generalized linear models (PROC GENMOD) with Poisson distribution and log link were applied to estimate the effects of household air pollution, traffic-related air pollution, and the socioeconomic constructs on the risk of LBW and PTB.

In Study III, a causal pathway analysis using the difference method (Judd & Kenny 1981) with computation of mediation fractions (van de Mheen *et al.* 1997) was performed to establish the independent and joint mediating effect of malaria episode during pregnancy, pre-pregnancy BMI, and biomass fuel use during pregnancy in the observed socioeconomic differences in the outcomes of interest.

Pearson's correlation and Mantel-Haenszel linear-by-linear Chi-square test were used for trend analysis of the exposure-response relationships. Sensitivity analysis was performed by restricting the analysis to term births (≥37 completed weeks of gestation). SPSS version 16.0 and SAS version 9.3 were used to perform the analyses.

Regarding Study IV, heterogeneity between the studies was anticipated due to differences in study design and the geographical settings and populations studied.

The random-effects model which accounts for both within- and between-study heterogeneity was therefore applied in computing the summary-effect estimates. For studies providing multiple effect estimates (e.g. wood, coal and other solid fuels), the individual effect estimates were first combined using fixed-effects model and applying the combined estimate in the overall meta-analysis. Heterogeneity was quantified using the Cochran Q (X^2) test and the I^2 statistic with a value > 50% deemed to indicate substantial heterogeneity. Forest plots were also visually assessed. Possible sources of heterogeneity between studies were explored by conducting subgroup analysis and meta-regression. Sensitivity analysis was conducted by limiting the analysis to high-quality studies; 7 or more stars on the original NOS for case control and cohort studies, and 6 stars on the adapted NOS for cross-sectional studies. Publication bias was investigated by visually inspecting funnel plots for asymmetry, and applying the Begg's and Egger's tests. The trim and fill method was used to account for publication bias. Stata version 9.0 was used to perform the analyses.

5 Results

The main results from studies I-IV are presented. More detailed results from the individual studies are presented in the attached original publications.

5.1 Association of charcoal use and garbage burning with birth weight (Study I)

Of the 592 mothers studied, 94% were cooking during pregnancy. Half of the mothers who cooked (51%) used charcoal exclusively with about 29% using LPG only. About 19% of the mothers used a combination of both fuels. The cooking fuel choices of the mothers were dependent on their social class, educational level and occupation. Of the proportion of charcoal users, 66% were identified as low social class. Of the proportion of LPG users, 57% were identified as middle/high social class. Of the proportion of mothers reporting garbage burning at home very few (4.4%) were of high social class. The proportion of mothers using charcoal only for cooking and burning garbage at home simultaneously was 15%.

Charcoal use and garbage burning at home were both determinants of reduced birth weight (Table 5). The estimated reduction in birth weight was 243g (95% CI: −11, 496) and 178g (95% CI: −65, 421) for use of charcoal and garbage burning at home, respectively. The associations were, however, not statistically significant. An exposure-response relationship was nonetheless noted, with high exposure from charcoal use and garbage burning associated with an increased reduction in birth weight. A linear trend test of the association was statistically significant. The use of charcoal together with garbage burning at home was associated with further reductions in birth weight.

Use of charcoal and garbage burning at home were determinants of LBW (Table 6). Garbage burning at home resulted in a 195% increased risk of LBW. High exposure from garbage burning was also associated with a 359% increased risk of LBW. A linear trend test of the association was statistically significant. Charcoal use generally was associated with a small and statistically insignificant increase in the risk of LBW. However, applying the ordinal scale exposure parameter for charcoal resulted in a statistically significant association, albeit an inverse trend was observed with high exposure associated with decreased risk. Charcoal use together with garbage burning at home was associated with further increase in the risk of LBW. The analysis restricted to term births produced similar results but with slightly lower effect estimates generally.

Table 5. Association of charcoal use and garbage burning at home with mean birth weight (All births, n = 592).

Exposure category	Unadjusted β (95% CI)	Adjusted β (95% CI)
Charcoal use only (n = 282)	−267 (−518, −15)	−243 (−496, 11)
Low (n = 40)	−237 (−450, −24)	−262 (−477, −47)
Moderate (n = 106)	−300 (−451, −150)	−289 (−442, −137)
High (n = 136)	−363 (−503, −223)	−381 (−523, −239)
	Trend p value = 0.000	
Charcoal use and LPG use (n = 104)	−146 (−441, 149)	−109 (−406, 188)
Garbage burning only (n = 160)	−153 (−395, 88)	−178 (−421, 65)
Low (n = 57)	−144 (−322, 44)	−140 (−331, 50)
Moderate (n = 60)	−488 (−673, −304)	−489 (−676, −302)
High (n = 43)	−386 (−594, −178)	−383 (−596, −170)
	Trend p value = 0.000	
LPG use and garbage burning (n = 30)	−153 (−396, 90)	−169 (−415, 77)
Charcoal use and garbage burning (n = 90)	−420 (−584, −255)	−429 (−599, −259)

Abbreviation: CI, Confidence interval. Effect estimate (β) is in grams

Trend test is for charcoal use only and garbage burning only exposure categories

LPG users (n = 161) served as reference category for all exposure categories

Effect estimates adjusted for age, social class, marital status and gravidity of mothers, and sex of the newborn

Table 6. Association of charcoal use and garbage burning at home with low birth weight (All births, n = 592).

Exposure category	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Charcoal use only (n = 282)	1.28 (0.58, 2.84)	1.41 (0.62, 3.23)
Low (n = 40)	2.42 (1.14, 5.11)	2.89 (1.34, 6.21)
Moderate (n = 106)	2.63 (1.46, 4.73)	2.70 (1.51, 4.84)
High (n = 136)	2.29 (1.28, 4.09)	2.41 (1.34, 4.35)
	Trend p value = 0.003	
Charcoal use and LPG use (n = 104)	0.97 (0.37, 2.58)	1.09 (0.41, 2.93)
Garbage burning only (n = 160)	2.91 (1.12, 7.56)	2.95 (1.10, 7.92)
Low (n = 57)	2.30 (0.96, 5.49)	2.50 (1.03, 6.04)
Moderate (n = 60)	3.88 (1.82, 8.28)	4.32 (2.03, 9.20)
High (n = 43)	4.06 (1.84, 8.97)	4.59 (2.01, 10.48)
	Trend p value = 0.000	
LPG use and garbage burning (n = 30)	2.91 (1.12, 7.56)	2.80 (1.04, 7.54)
Charcoal use and garbage burning (n = 90)	3.72 (1.81, 7.66)	4.16 (2.02, 8.59)

Abbreviation: CI, Confidence interval; LBW, Low birth weight; RR, Risk ratio.

Trend test is for charcoal use only and garbage use only exposure categories

LPG users (n = 161) served as reference category for all exposure categories

Risk ratios adjusted for age, social class, marital status and gravidity of mothers, and sex of the newborn

5.2 Association of traffic-related air pollution with birth weight and preterm birth (Study II)

Of the mothers who reported working during the index pregnancy (n = 540), 19% were street vendors. About 74% of the street vendors were classified as low social class. About 66% of the street vendors used charcoal for cooking during pregnancy. The majority of the street vendors (62%) reported working up to the seventh or ninth month of pregnancy. About 61% of the street vendors reported high traffic density in the area where they normally operated. More than half (55.2%) of the reference mothers also reported high traffic density around their workplace. About 16% of the street vendors mentioned the presence of point sources of air pollution within the area where they operated. The proportion of reference mothers reporting the presence of point sources of air pollution around the workplace was 14%.

Street vending was associated with a 177g (95% CI: 31, 324) reduction in birth weight (Table 7). There was no indication of an exposure-response relation; the point estimates in the high exposure categories were lower than estimates in the moderate exposure categories for both the activity patterns and traffic density exposure measures. The analysis restricted to term births produced similar results but with much higher effect estimates. In the joint analysis, the high activity and high traffic density category recorded the lowest point estimates in both the full and term births analysis.

Street vending resulted in a 35% (RR = 1.35; 95% CI: 0.87, 2.12) increased, albeit statistically not significant risk of LBW (Table 8). In the joint analysis, the category of moderate activity and high traffic density was associated with an 84% (RR = 1.84; 95% CI: 1.05, 3.24) increased risk of LBW. Similar results were observed among term infants but with slightly higher effect estimates. An exposure-response relation was noted when the traffic density exposure parameter was applied (Table 8). Street vending was not associated with PTB (RR = 1.03; 95% CI: 0.67, 1.58) (Table 9).

Table 7. Association of street vending and traffic density at vending site with mean birth weight (All births, n = 386).

Exposure category	Unadjusted β (95% CI)	Adjusted β (95% CI)	
		Model 1	Model 2
Street vendors (n = 105)	−218 (−359, −78)	−202 (−346, −58)	−177 (−324, −31)
Activity patterns*			
Moderate (n = 66)	−213 (−381, −45)	−202 (−373, −31)	−200 (−376, −24)
High (n = 38)	−214 (−426, −1)	−192 (−405, 21)	−132 (−346, 82)
Traffic density			
Low (n = 41)	−253 (−459, −48)	−253 (−459, −47)	−252 (−462, −42)
High (n = 64)	−196 (−366, −26)	−168 (−342, 6)	−127 (−305, 51)
Activity patterns and traffic density			
Moderate activity & Low traffic (n = 23)	−206 (−473, 61)	−203 (−470, 64)	−224 (−503, 55)
High activity & Low traffic (n = 17)	−288 (−595, 19)	−301 (−606, 40)	−271 (−573, 30)
Moderate activity & High traffic (n = 43)	−217 (−418, −15)	−199 (−403, 4)	−182 (−389, 25)
High activity & High traffic (n = 21)	−154 (−432, 125)	−102 (−381, 178)	−7 (−294, 280)

Abbreviations: CI, confidence interval. Effect estimate (β) is in grams.

*Low exposure (n = 1) excluded from analysis.

All other mothers with the exception of hairdressers and housewives/unemployed mothers (n = 281) served as reference in all the analyses.

Model 1 adjusted for age, social class, marital status and gravidity of mothers, and gender of the infant.

Model 2 further adjusted for cooking fuel used and garbage burning at home.

Table 8. Association of street vending and traffic density at vending site with low birth weight (All births, n = 386).

Exposure category	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	
		Model 1	Model 2
Street vendors (n = 105)	1.45 (0.94, 2.24)	1.49 (0.96, 2.29)	1.35 (0.87, 2.12)
Activity patterns*			
Moderate (n = 66)	1.57 (0.97, 2.56)	1.61 (0.98, 2.62)	1.54 (0.92, 2.58)
High (n = 38)	1.13 (0.55, 2.31)	1.15 (0.57, 2.34)	0.97 (0.46, 2.06)
Traffic density			
Low (n = 41)	1.19 (0.61, 2.34)	1.29 (0.67, 2.49)	1.28 (0.67, 2.45)
High (n = 64)	1.62 (1.00, 2.64)	1.60 (0.98, 2.63)	1.40 (0.82, 2.39)
Activity patterns and traffic density			
Moderate activity & Low traffic (n = 23)	0.80 (0.27, 2.36)	0.85 (0.29, 2.50)	0.89 (0.31, 2.56)
High activity & Low traffic (n = 17)	1.44 (0.59, 3.52)	1.59 (0.67, 3.80)	1.55 (0.66, 3.63)
Moderate activity & High traffic (n = 43)	1.99 (1.20, 3.30)	1.97 (1.18, 3.28)	1.84 (1.05, 3.24)
High activity & High traffic (n = 21)	0.87 (0.30, 2.57)	0.83 (0.29, 2.40)	0.55 (0.15, 1.97)

Abbreviations: CI, confidence interval; RR, risk ratio.

*Low exposure (n = 1) excluded from analysis.

All other mothers with the exception of hairdressers and housewives/unemployed mothers (n = 281) served as reference in all the analyses.

Model 1 adjusted for age, social class, marital status and gravidity of mothers, and gender of the infant.

Model 2 further adjusted for cooking fuel used and garbage burning at home.

Table 9. Association of street vending and traffic density at vending site with preterm birth (n = 386).

Exposure category	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	
		Model 1	Model 2
Street vendors (n = 105)	1.11 (0.75, 1.64)	1.08 (0.72, 1.61)	1.03 (0.67, 1.58)
Activity patterns*			
Moderate (n = 66)	1.18 (0.76, 1.85)	1.15 (0.73, 1.82)	1.12 (0.69, 1.83)
High (n = 38)	0.90 (0.47, 1.73)	0.87 (0.46, 1.64)	0.80 (0.40, 1.58)
Traffic density			
Low (n = 41)	0.63 (0.29, 1.35)	0.64 (0.29, 1.41)	0.57 (0.24, 1.38)
High (n = 64)	1.43 (0.95, 2.15)	1.37 (0.89, 2.09)	1.33 (0.84, 2.10)
Activity patterns and traffic density			
Moderate activity & Low traffic (n = 23)	0.93 (0.37, 2.31)	0.95 (0.38, 2.40)	0.87 (0.31, 2.42)
High activity & Low traffic (n = 17)	0.00	0.00	0.00
Moderate activity & High traffic (n = 43)	1.32 (0.73, 2.40)	1.28 (0.69, 2.38)	1.29 (0.68, 2.46)
High activity & High traffic (n = 21)	1.63 (0.78, 3.40)	1.55 (0.72, 3.30)	1.46 (0.65, 3.29)

Abbreviations: CI, confidence interval; RR, risk ratio.

*Low exposure (n = 1) excluded from analysis.

All other mothers with the exception of hairdressers and housewives/unemployed mothers (n = 281) served as reference in all the analyses.

Model 1 adjusted for age, social class, marital status and gravidity of mothers.

Model 2 further adjusted for cooking fuel used and garbage burning at home.

5.3 Association of maternal socioeconomic status with birth weight and preterm birth, and the mediating role of biomass fuel use (Study III)

About 36% of the mothers were classified as low SES. The proportion of mothers categorized as high SES was 6%. About 44% of the mothers used biomass fuels (charcoal, firewood or combination of both) as cooking fuel during pregnancy with 18% of the mothers using LPG. The proportion of infants born preterm and LBW was 41% and 17%, respectively.

Low SES was associated with a 292g (95% CI: 145, 440) reduction in birth weight, with biomass fuel use mediating 32% of the observed effect (Table 10). Middle SES was also associated with a 219g (95% CI: 81, 357) reduction in birth weight, with biomass fuel use mediating 26% of the observed effect. The mediation fraction in the joint models for low SES and middle SES was 47% and 42%, respectively (Table 10).

Low and middle SES, respectively, was associated with a 357% (RR = 4.57, 95% CI: 1.67, 12.49) and 278% (RR = 3.78, 95% CI: 1.39, 10.27) increased risk of LBW, with biomass fuel use mediating 42% and 31% of the observed effects in both relations, respectively (Table 11). The mediation fraction in the joint models for both low SES and middle SES was 64% and 61%, respectively (Table 11). Low and middle SES was associated with a 26% (RR = 1.26, 95% CI: 0.91, 1.73) and 16% (RR = 1.16, 95% CI: 0.85, 1.59) increased, although not statistically significant, risk of PTB, respectively (Table 12).

Table 10. Association of maternal socioeconomic status with mean birth weight.

SES	Unadjusted	Adjusted β (95% CI)				
	β (95% CI)	Model 1	Model 2	Model 3	Model 4	Model 5
Low	−328 (−474, −182)	−292 (−440, −145)	−258 (−405, −111)	−248 (−406, −90)	−199 (−360, −37)	−154 (−328, 20)
Middle	−220 (−360, −80)	−219 (−357, −81)	−185 (−324, −47)	−203 (−348, −57)	−162 (−306, −18)	−128 (−282, 27)
Upper middle & High	Reference	Reference	Reference	Reference	Reference	Reference

Abbreviation: CI, confidence interval; SES, socioeconomic status.

Effect estimate (β) is in grams.

Model 1 adjusted for maternal age, parity and gender of the newborn

Model 2 adjusted for malaria infection in addition to the Model 1 covariates

Model 3 adjusted for pre-pregnancy BMI in addition to the Model 1 covariates

Model 4 adjusted for cooking fuel used in addition to the Model 1 covariates

Model 5 adjusted for all the mediating variables in addition to the Model 1 covariates

Mediation fractions (%).

Low SES: Malaria (11.6), Pre-pregnancy BMI (15.1), Cooking fuel (31.8), Joint (47.3).

Middle SES: Malaria (15.5), Pre-pregnancy BMI (7.3), Cooking fuel (26.0), Joint (41.6).

Table 11. Association of maternal socioeconomic status with low birth weight.

SES	Unadjusted	Adjusted RR (95% CI)				
	RR (95% CI)	Model 1	Model 2	Model 3	Model 4	Model 5
Low	4.90	4.57	3.83	3.64	3.09	2.29
	(1.82, 13.17)	(1.67, 12.49)	(1.42, 10.34)	(1.33, 10.01)	(1.12, 8.55)	(0.81, 6.48)
Middle	3.58	3.78	3.28	3.02	2.91	2.09
	(1.33, 9.67)	(1.39, 10.27)	(1.23, 8.79)	(1.11, 8.26)	(1.06, 7.97)	(0.75, 5.78)
Upper middle & High	1.00	1.00	1.00	1.00	1.00	1.00

Abbreviation: CI, confidence interval; RR, risk ratio; SES, socioeconomic status.
Model 1 adjusted for maternal age, parity and gender of the newborn
Model 2 adjusted for malaria infection in addition to the Model 1 covariates
Model 3 adjusted for pre-pregnancy BMI in addition to the Model 1 covariates
Model 4 adjusted for cooking fuel used in addition to the Model 1 covariates
Model 5 adjusted for all the mediating variables in addition to the Model 1 covariates
Mediation fractions (%).
Low SES: Malaria (20.7), Pre-pregnancy BMI (26.1), Cooking fuel (41.5), Joint (63.9).
Middle SES: Malaria (18.0), Pre-pregnancy BMI (27.3), Cooking fuel (31.3), Joint (60.8).

Table 12. Association of maternal socioeconomic status with preterm birth.

SES	Unadjusted	Adjusted RR (95% CI)				
	RR (95% CI)	Model 1	Model 2	Model 3	Model 4	Model 5
Low	1.23	1.26	1.26	1.16	1.05	1.06
	(0.90, 1.69)	(0.91, 1.73)	(0.91, 1.74)	(0.84, 1.62)	(0.73, 1.51)	(0.74, 1.51)
Middle	1.15	1.16	1.16	1.24	1.07	1.20
	(0.84, 1.57)	(0.85, 1.59)	(0.85, 1.60)	(0.91, 1.69)	(0.76, 1.49)	(0.86, 1.67)
Upper middle & High	1.00	1.00	1.00	1.00	1.00	1.00

Abbreviation: CI, confidence interval; RR, risk ratio; SES, socioeconomic status.
Model 1 adjusted for maternal age and parity
Model 2 adjusted for malaria infection in addition to the Model 1 covariates
Model 3 adjusted for pre-pregnancy BMI in addition to the Model 1 covariates
Model 4 adjusted for cooking fuel used in addition to the Model 1 covariates
Model 5 adjusted for all the mediating variables in addition to the Model 1 covariates

5.4 Quantification of the effects of household solid fuel use on pregnancy endpoints (Study IV)

5.4.1 Characteristics of included studies

Seven studies applied a cross-sectional design, five studies, a cohort design, with six studies employing a case control design. One study was a randomized controlled trial (RCT). Ten studies were conducted in South Asia with two studies conducted in sub-Saharan Africa.

With the exception of the RCT (Thompson *et al.* 2011) HAP exposure was assessed indirectly through the use of questionnaires to collect information on primary cooking fuels. Thompson *et al.* (2011) measured CO levels in households but obtained very few measures, and as a result relied on the actual stove type (chimney stove vs. open fire) used. Six studies (Study I, Yucra *et al.* 2011, Boy *et al.* 2002, Siddiqui *et al.* 2008, Li *et al.* 2011, Abusalah *et al.* 2012) collected other exposure data, such as cooking habits and practices, and ventilation of cooking area, in an attempt to properly characterize exposures.

Birth weight was ascertained by 14 studies with stillbirth ascertained by five studies. Three studies investigated PTB with gestational age estimated by the last menstrual period method in all the studies. One study investigated SGA with two studies measuring miscarriage. Two studies assessed term LBW, a proxy for IUGR, with one study ascertaining neural tube defect.

5.4.2 Methodological quality of included studies

Selection bias was generally minimized in all the included studies. Information bias was a potential problem in all the studies due to the reliance on interview methods in assessing HAP exposure. Of the case-control studies, only one study (Abusalah *et al.* 2012) blinded interviewers to case/control status in the ascertainment of exposure.

Outcomes were objectively measured at home/hospital or ascertained from hospital records for the majority of the included studies. There is a strong potential for outcome measurement bias in two studies (Sreeramareddy *et al.* 2011, Mishra *et al.* 2004) that relied on maternal recall of child size at birth to respectively estimate birth weight of 47% and 84% of the infants due to unavailability of health cards. Epstein *et al.* (2013) also included only infants that had birth weights recorded on health cards with obvious implications for sample representativeness and generalizability of study findings. The time of measurement of birth weight of infants delivered at home in the community-based studies (Thompson *et al.* 2011, Tielsch *et al.* 2009, Boy *et al.* 2002, Siddiqui *et al.* 2008) raise doubts about their acceptability as the actual birth weight of these infants.

All but two studies (Stankovic *et al.* 2011a, 2011b) adjusted for a range of potential confounders in the analysis. Based on the *a priori* criteria, of the included studies that adjusted for potential confounders, confounding control was considered inadequate in four studies (Mishra *et al.* 2005, Siddiqui *et al.* 2005, Thompson *et al.* 2011, Samaraweera & Abeysena 2010).

Overall, applying the NOS scale, two studies were rated as very high quality (case control/cohort – 8 or more stars), three studies as high quality (case control/cohort – 7 stars; cross-sectional – 6 stars), twelve studies as satisfactory quality (case control/cohort – 5 or 6 stars; cross-sectional – 5 stars) and two studies as low quality (< 5 stars for both case control/cohort and cross-sectional).

5.4.3 Summary-effect estimates, evidence of statistical heterogeneity and publication bias

On the relation of solid fuel use with average birth weight, Study I reported the highest effect size (243g) with an Indian study (Sreeramareddy *et al.* 2011) reporting the lowest effect size (39.9g). On the relation of solid fuel use with LBW, the study conducted in Peru (Yucra *et al.* 2011) reported the highest and most extreme estimate (OR = 3.73, 95% CI: 1.14, 12.1). The summary-effect estimate was 86.43g (95% CI: 55.49, 117.37) and 1.35 (95% CI: 1.23, 1.48) for birth weight and LBW, respectively. We observed evidence of low statistical heterogeneity in both analyses. We also found evidence of publication bias in both analyses (Figure 7). Both sensitivity analyses resulted in an increase in the summary-effect estimate with no evidence of heterogeneity observed (EE = 92.84; 95% CI: 64.47, 121.20; $I^2 = 0.0\%$ and EE = 1.49; 95% CI: 1.30, 1.70; $I^2 = 0.0\%$ respectively).

Regarding the other outcomes investigated, with the exception of miscarriage, we observed no evidence of statistical heterogeneity in the analysis (Table 13). For PTB, IUGR and stillbirth, the summary-effect estimate was 1.30 (95% CI: 1.06, 1.59), 1.23 (95% CI: 1.01, 1.49) and 1.29 (95% CI: 1.18, 1.41), respectively. The summary-effect estimate for miscarriage (EE = 1.65; 95% CI:

0.74, 3.67) was substantially elevated but not statistically significant. Evidence of publication bias was noted in the stillbirth analysis (Figure 7).

5.4.4 Sources of heterogeneity between included studies

Results of the sub-group analysis are presented in Tables 14 and 15. For birth weight, the summary-effect estimates for the South Asian studies were much lower than the estimates for the Sub-Saharan African studies. The opposite was noted for the LBW outcome. Regarding the study setting (rural vs. urban), for both outcomes, the combined estimate for studies conducted in urban areas was higher than the combined estimate for studies conducted in rural areas. Also for both outcomes, the summary-effect estimates computed for studies applying cohort design was higher than the estimates summarized for studies applying a cross-sectional design.

Regarding information collected on solid fuel types used in households, for both outcomes, the combined estimate recorded for studies that grouped the various fuels together was lower than the estimate summarized for studies that assessed one specific fuel or investigated the fuels independently. For the LBW outcome, the summary-effect estimates increased as the quality of the studies increased (Table 15). An inconsistent trend was observed for the birth weight outcome (Table 14).

In the meta-regression models; study design (cross-sectional: $\beta = -0.240$, $p = 0.022$), exposure assessment ($\beta = -0.342$, $p = 0.037$) and study quality ($\beta = -0.160$, $p = 0.086$) were the covariates associated with heterogeneity observed in the LBW analysis. None of the covariates was statistically associated with the observed heterogeneity in the birth weight analysis.

Table 13. Summary-effect estimates (EE) for the relation of solid fuel use with adverse pregnancy outcomes.

Outcome	No. of studies	Random effects model EE(95% CI)	Heterogeneity Cochran X^2	Heterogeneity p value	I^2 (%)
Birth weight	10	86.43 (55.49, 117.37)	15.73	0.073	42.8
LBW	12	1.35 (1.23, 1.48)	15.46	0.163	28.8
Stillbirth	5	1.29 (1.18, 1.41)	3.73	0.443	0.0
PTB	3	1.30 (1.06, 1.59)	1.84	0.398	0.0
IUGR	2	1.23 (1.01, 1.49)	0.02	0.892	0.0
Miscarriage	2	1.65 (0.74, 3.67)	4.46	0.035	77.6

Table 14. Summary-effect estimate (EE) for the relation of solid fuel use with mean birth weight stratified according to the study characteristics.

Study Characteristics	No. of studies	Random effects model EE (95% CI)	Heterogeneity		
			Cochran X^2	p value	I^2 (%)
Geographic location					
South Asia	4	74.81 (32.65, 116.97)	8.65	0.034	65.3
Latin America	2	68.93 (13.76, 124.10)	0.15	0.698	0.0
Sub-Saharan Africa	2	188.30 (76.19, 300.42)	0.22	0.637	0.0
Eastern Europe	1	99.1 (4.1, 194.1)			
Middle East	1	186 (19, 354)			
Study setting					
Rural	3	100.49 (68.69, 132.28)	0.25	0.882	0.0
Urban	3	132.06 (53.47, 210.65)	1.60	0.450	0.0
Study design					
RCT	1	89 (−27, 204)			
Cohort	3	101.18 (69.94, 132.41)	0.21	0.900	0.0
Case control	1	186 (19, 354)			
Cross-sectional	5	75.91 (28.88, 122.93)	7.49	0.112	46.6
Primary study	2	109.38 (−44.91, 263.68)	1.82	0.177	45.2
Secondary analysis	3	81.22 (10.96, 151.48)	5.14	0.077	61.1
Exposure assessment (Handling of solid fuel data)					
Grouped together	6	79.72 (44.24, 115.21)	11.75	0.038	57.4
Separated/Specific fuels studied	4	114.96 (52.79, 177.13)	2.20	0.532	0.0
Outcome ascertainment (Place of measurement)					
Hospital	5	113.71 (57.75, 169.68)	2.11	0.715	0.0
Home	3	100.49 (68.69, 132.28)	0.25	0.882	0.0
Quality score					
Very High	2	101.43 (68.35, 134.50)	0.21	0.647	0.0
High	2	68.93 (13.76, 124.10)	0.15	0.698	0.0
Satisfactory	6	101.56 (43.49, 159.64)	10.64	0.059	53.0

Table 15. Summary-effect estimate (EE) for the relation of solid fuel use with low birth weight stratified according to the study characteristics.

Study Characteristics	No. of studies	Random effects model EE (95% CI)	Heterogeneity		
			Cochran X^2	p value	I^2 (%)
Geographic location					
South Asia	6	1.36 (1.24, 1.50)	8.62	0.125	42.0
Latin America	3	1.47 (0.89, 2.44)	3.26	0.196	38.7
Sub-Saharan Africa	2	1.15 (0.86, 1.56)	0.26	0.610	0.0
Middle East	1	2.30 (1.20, 4.70)			
Study setting					
Rural	3	1.52 (1.29, 1.78)	0.71	0.701	0.0
Urban	4	1.66 (1.14, 2.41)	4.87	0.182	38.4
Study design					
RCT	1	1.35 (0.60, 3.03)			
Cohort	3	1.56 (1.34, 1.82)	1.16	0.559	0.0
Case control	3	1.86 (1.07, 3.22)	4.87	0.088	58.9
Cross-sectional	5	1.22 (1.13, 1.33)	0.74	0.946	0.0
Primary study	2	1.23 (0.92, 1.66)	0.12	0.734	0.0
Secondary analysis	3	1.22 (1.12, 1.34)	0.63	0.731	0.0
Exposure assessment (Handling of solid fuel data)					
Grouped together	7	1.29 (1.18, 1.41)	8.43	0.208	28.8
Separated/Specific fuels studied	5	1.75 (1.40, 2.18)	1.19	0.880	0.0
Ascertainment of Outcome (Place of measurement)					
Hospital	5	1.39 (1.18, 1.64)	5.60	0.231	28.6
Home	3	1.52 (1.29, 1.78)	0.71	0.701	0.0
Quality score					
Very High	2	1.52 (1.29, 1.80)	0.63	0.428	0.0
High	3	1.42 (1.10, 1.85)	2.38	0.305	15.9
Satisfactory	7	1.29 (1.16, 1.43)	8.08	0.232	25.7

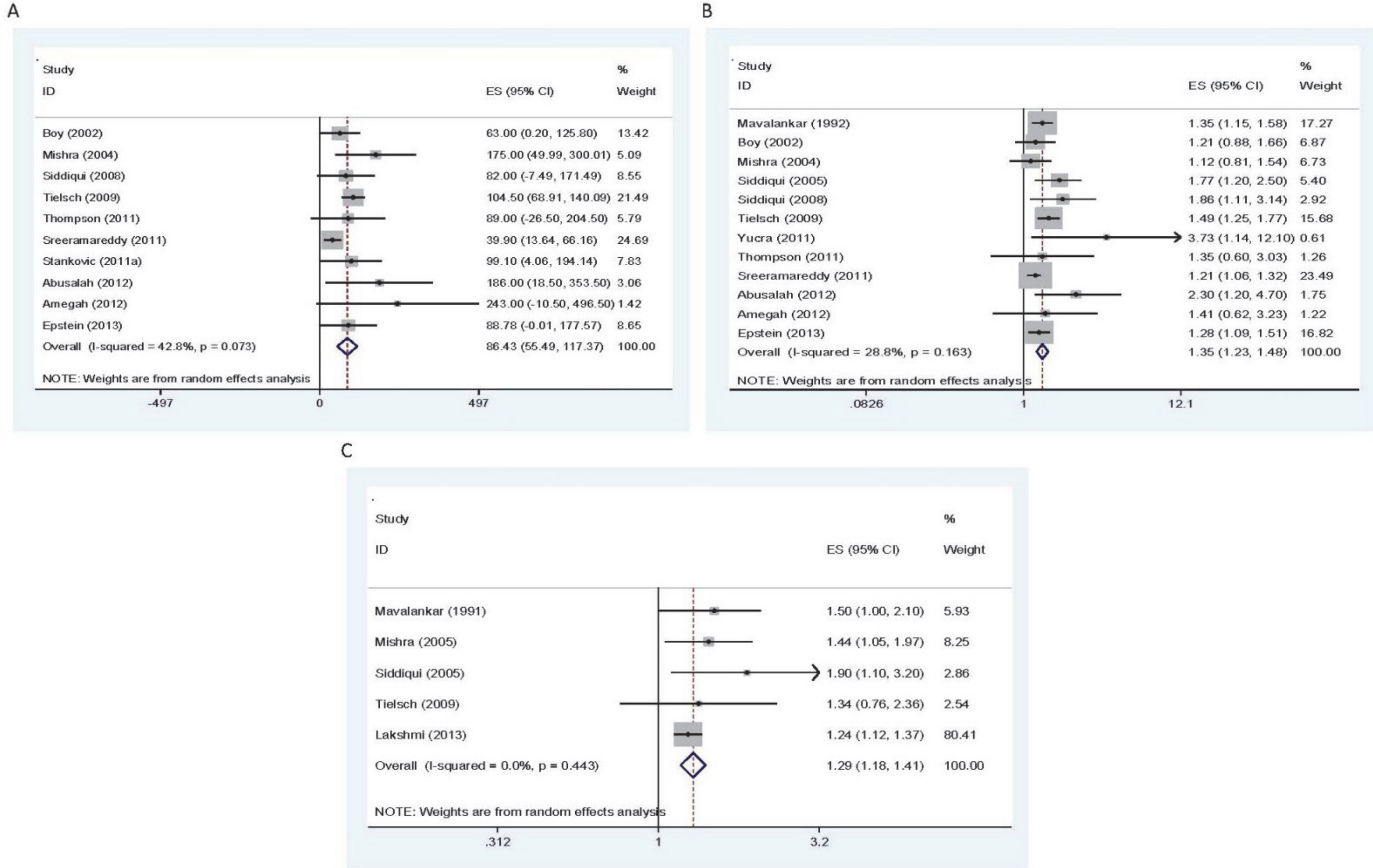

Fig. 6. Forest plot showing the effect of household solid fuel use on birth weight (A), LBW (B) and stillbirth (C).

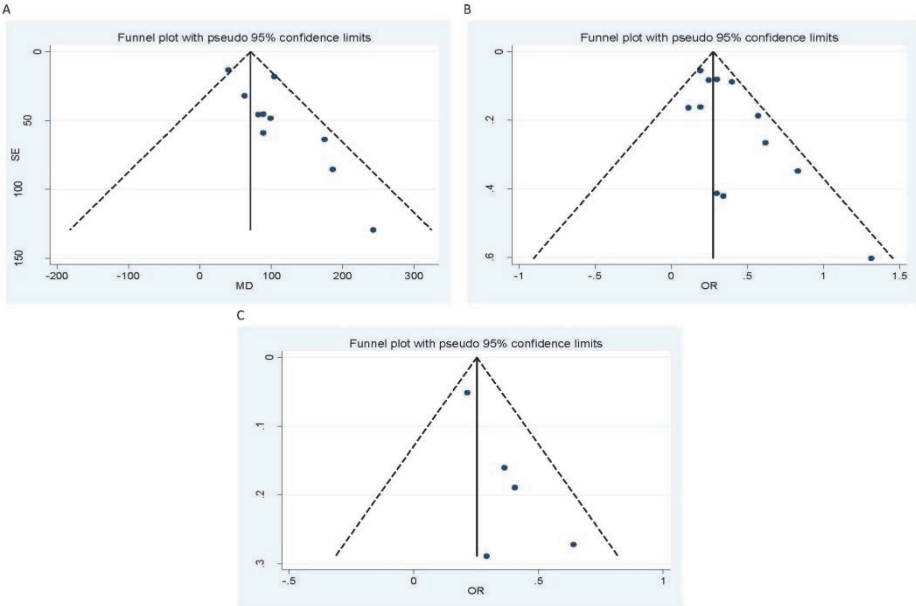

Fig. 7. Funnel plot for the relation between household solid fuel use and birth weight (A), LBW (B) and stillbirth (C).

5.5 Summary of main findings

Table 16. Key findings from studies I-IV.

Study	Exposures	Outcomes		
		Birth weight	LBW	PTB
		β (95% CI)	RR (95% CI)	RR (95% CI)
I	Charcoal use	−243 (−496, 11)	1.41 (0.62, 3.23)	
	Garbage burning	−178 (−421, 65)	2.95 (1.10, 7.92)	
	Charcoal use & Garbage burning	−429 (−599, −259)	4.16 (2.02, 8.59)	
IV	Solid fuel use*	−86.43 (−117.37, −55.49)	1.35 (1.23, 1.48)	1.30 (1.06, 1.59)
II	Street vending	−177 (−324, −31)	1.35 (0.87, 2.12)	1.03 (0.67, 1.58)
	Moderate activity	−200 (−376, −24)	1.54 (0.92, 2.58)	1.12 (0.69, 1.83)
	High traffic density	−127 (−305, 51)	1.40 (0.82, 2.39)	1.33 (0.84, 2.10)
	Moderate activity & High traffic	−182 (−389, 25)	1.84 (1.05, 3.24)	1.29 (0.68, 2.46)
III	Low SES	−292 (−440, −145)	4.57 (1.67, 12.49)	1.26 (0.91, 1.73)
	Middle SES	−219 (−357, −81)	3.78 (1.39, 10.27)	1.16 (0.85, 1.59)

*Values are summary-effect estimates (EE) from a random effects meta-analysis

Maternal use of charcoal as cooking fuel and garbage burning at home during pregnancy were associated with birth weight. Charcoal use was associated with a 243g reduction in birth weight and a 41% increased risk of LBW. Garbage burning was also associated with a 178g reduction in birth weight and a 195% increased LBW risk. Joint evaluation of these two exposures resulted in further reductions in birth weight and additional increase in the risk of LBW. Combining the result for charcoal use and the results of related studies in the meta-analysis indicated an 86.43g reduction in birth weight and a 35% increased risk of LBW for the use of solid fuels. A 30% increased risk of PTB for the use of solid fuel was also noted in the meta-analysis.

Street vending during pregnancy was also associated with birth weight and short gestational length. The average birth weight of babies delivered among street vendors was 177g lower compared to babies of reference mothers. Street vending was also associated with a 35% increased risk of LBW. High traffic density in the vending area was associated with a 33% increased, albeit statistically not significant risk of PTB. Moderate activity patterns and high traffic density jointly resulted in an 84% increased risk of LBW.

Evidence of an association of maternal socioeconomic disadvantage with birth weight and short gestational length was also noted, with biomass fuel use substantially mediating the observed association. Low SES was associated with a 292g reduction in birth weight and a 357% increased risk of LBW. Middle SES was also associated with a 219g reduction in birth weight and a 278% increased LBW risk. Biomass fuel use mediated 26–42% of the observed effects of socioeconomic disadvantage on birth weight.

6 Discussion

6.1 Validity issues

Consecutive mothers that gave birth in a teaching hospital in Accra and the main health facilities in Cape Coast and accessing postnatal services were selected, with a high response rate achieved in both settings. There is nonetheless a potential for selection bias in the study due to the inability to enroll mothers giving birth at home and possibly not seeking postnatal care. However, in Ghana patronage of postnatal services is high in urban areas due to the ease of access to reproductive and child health (RCH) services. Many mothers in several urban areas of Ghana do not have to travel long distances to access RCH services thanks to the wide distribution of health services as a whole in these areas. The majority of mothers are even able to walk to these RCH service provision centers without the need for transport. According to the 2008 Ghana Demographic and Health Survey (GDHS), 82.4% of births in urban areas of Ghana take place in health facilities. Also in urban Ghana, 86.7% of mothers access postnatal services, with distance to health facilities and having to rely on transport to access maternal health care a concern of only 16.4% and 15.2% of mothers, respectively, in these areas (GDHS 2008). Based on the GDHS 2008 estimates, selection bias can be assumed to be minimal in the study. The potential selection bias is likely to underestimate the true effect as mothers giving birth at home and possibly not seeking postnatal care for reasons such as poverty, sociocultural, access and ignorance are most likely to be the very same mothers patronizing biomass fuels for cooking, burning garbage at home and engaging in street vending activities.

The outcomes of interest were measured and recorded independently from the studies and represent a well-defined and objective variable with a negligible measurement error. There are limitations with the use of the last menstrual period (LMP) method for estimating gestational age, such as late ovulation, bleeding during early pregnancy and in many developing countries, inaccurate recall of LMP date due to the late access of antenatal services by most mothers. This can obviously result in invalid estimate of gestational age by midwives and could explain the high rate of preterm births recorded in Study III. The potential misclassification of outcomes associated with the use of the LMP method in estimating gestational age would be non-differential as ascertainment of gestational age by health staff was undertaken independent of the study and was not related to the exposure status of the mothers. This potential information bias underestimates the true effect.

Information on exposure and potential confounders was collected retrospectively. Misclassification of exposure is thus possible in the study due to the inability to undertake air quality measurements. The potential exposure misclassification is also likely to be non-differential with the true effect similarly biased towards the null. This is because ascertainment of mothers' exposure experiences during the interviews was undertaken with no reference to the outcome measures. An attempt was made to minimize exposure misclassification in the study by collecting several types of household- and traffic-related air pollution exposure information including cooking and garbage burning practices and patterns, and street vending activity patterns and traffic density in the vending area, and quantifying them into an ordinal scale exposure variable. This ordinal scale exposure parameter was sensitive to a certain amount of measurement error but was not likely to be related to the outcome of interest.

In the Cape Coast study (Study III), the SES construct combines data on mothers' area of residence, an area-based measure, and their educational attainment and income levels, individual-level measures, and is a context-specific, culturally sensitive objective variable that reflects reasonably well the social and economic standing of mothers in this population.

Establishment of a temporal relation may be problematic in some research settings with the use of cross-sectional study design. This should not, however, be a concern in this study because it is clear that exposure to household combustion and traffic-related pollutants was present during pregnancy among charcoal users and mothers burning garbage at home, and street vendors, respectively. It is possible that some women using charcoal during most of the duration of pregnancy might have reported use of LPG as their primary fuel. This information bias would also tend to underestimate the true effect.

In Study II, housewives and unemployed mothers, and hairdressers were excluded from the reference group because their similarity to the exposed group with respect to the distribution of all factors that may be related to the outcome of interest except the determinant under investigation as required in the design of epidemiologic studies was in doubt. Housewives and unemployed mothers were practically not working during pregnancy and thus differ from the exposed group with respect to physical exertions and stress at work, which are potentially related to the outcomes under evaluation. Hairdressers are exposed to a variety of chemical agents with potential reproductive toxicity through their work and are thus not comparable to the exposed cohort. Studies (Kersemaekers *et al.* 1997, Rylander *et al.* 2002, Rylander & Kallen 2005, Halliday-Bell *et al.* 2009) have associated the work of hairdressers with adverse pregnancy outcomes.

Multivariate methods were applied to adjust for the potential confounding effect of age, social class, marital status and gravidity/parity of the mothers, and the gender of the newborn in the analysis. In Study II, in an attempt to quantify the effect of street vending activities on pregnancy outcomes, HAP exposure assessed by cooking fuel used during pregnancy and garbage burning at home was further controlled in the analysis. In Studies I and II, the birth weight analysis was restricted to term births, a decision based on a work by Wilcox *et al.* (2011) that reported gestational age as a collider on the causal pathway and provided evidence of the likely bias produced by adjustment for gestational age in statistical analysis. The consistent results produced from this sensitivity analysis confirm the associations observed. The effect of other determinants of birth weight and gestational duration such as maternal nutrition and anthropometry, malaria and sexually transmitted infections, and second-hand smoke exposure at home or at the workplace was not examined. Maternal smoking is another important determinant of fetal growth, but in Ghana only few women smoke. The 2008 GDHS estimated the proportion of women smoking cigarettes and other tobacco products to be 0.4%. In the Cape Coast study, only 0.7% of the mothers were found to be smoking during pregnancy while in the Accra study none of the mothers reported smoking. Maternal smoking can therefore not be considered as a serious threat to validity in the study.

Regarding Study II, it is possible that the reference mothers were exposed to ambient air pollution from traffic sources per their outdoor mobility patterns and/or proximity of their home/workplace to busy roads and heavy traffic corridors. For instance, more than half (55.2%) of the reference mothers reported traffic density around their workplace to be high. The street vendors were also likely to experience ambient air pollution exposures from traffic sources at home and/or per their mobility patterns unrelated to work. An assumption of this study was that all the included participants had similar baseline ambient air pollution exposure experiences on the basis of a further assumption that there is less spatial variability in air pollution levels within the city of Accra. Study II therefore sought to quantify the effects of the added traffic-related air pollution exposures among the street vendors per their street vending activity patterns and traffic density in the working area as against reference mothers who were not in direct contact with traffic-related exposures per the work they were engaged in.

Study IV is based on much more information (> 50%) than the previous reviews and certainly has much higher statistical power. A major validity concern of meta-analysis is the tendency of overestimating the magnitude of the true effect size due to publication bias. Publication bias was therefore investigated and accounted for where evidence of its presence was found. With regards to the LBW and stillbirth outcomes, the adjusted estimates obtained after controlling for publication bias were quite similar to the crude estimates. Regarding the birth weight outcome, the adjusted estimate obtained was attenuated.

6.2 Synthesis with previous evidence

In this section, the results of Study I are compared to the evidence reviewed in Study IV whilst also comparing Study IV findings with previous reviews on the subject matter. The results of Study II are discussed in the context of the urban Ghana air pollution evidence and the evidence on ambient air pollution exposures among street vendors. A comparison of the findings with previous epidemiologic evidence is also made. The results of Study III are compared to previous findings whilst also drawing upon the evidence adduced in Study I to support the observations.

6.2.1 Household air pollution as determinant of birth weight

The reduction in birth weight and increased risk of LBW with charcoal use in households observed in Study I is consistent with previous studies reviewed in Study IV. The average birth weight reported (243g) is, however, quite larger than the previous estimates even though charcoal is considered to be the least polluting of all the biomass fuels. However, this study and the previous studies reviewed did not actually measure the quantity of biomass combusted and the amount of pollutants released for which the mothers were exposed. It is therefore reasonable to assume that participants in this study might have on average combusted large quantities of charcoal during pregnancy with the cumulative adverse effect reflected in the large effect size reported. This assertion is to some extent confirmed by the significant exposure-response relationship observed. It must, however, be emphasized that unmeasured confounding, and residual confounding by social class due to its strong effects on health outcomes could contribute to the large effect size reported in spite of efforts to eliminate this potential confounding from the study.

This study is the first to examine the contribution of garbage burning to HAP, and its relation with fetal growth. A systematic literature search did not identify any study that has examined the relationship. Garbage burning releases dioxins, hazardous chemical substances that have been shown in animal studies to severely impair fetal growth even at low levels of exposure. Studies in human populations have also reported associations of low-level dioxin exposure during pregnancy with decreased birth weight (Konishi *et al.* 2009, Patandin *et al.* 1998, Tajimi *et al.* 2005, Vartiainen *et al.* 1998).

Combining the result for charcoal use and the results of related studies investigating similar or other biomass fuels, or coal in Study IV resulted in a summary estimate of 86g. Accounting for publication bias reduced the effect size to 54g, suggesting a possible overestimation of the summary estimate in the meta-analysis. Pope *et al.* (2010) previously reported a 95.6g reduction in birth weight for HAP exposure from solid fuel use, with no evidence of publication bias found. The results of the present study, however, show that the effect estimate varies from one population to another and also along the rural-urban divide (Table 14), possibly due to the exposure intensity which is dependent on the fuel choices. For instance, whereas charcoal use is widespread in Sub-Saharan Africa especially in urban areas, wood, which is more polluting than charcoal, is commonly used in South Asia. Rural African settings mostly patronize wood and crop residues. Zulu & Richardson (2013) reported charcoal use to be widespread in urban areas of Sub-Saharan Africa with more than 80% of urban households using this fuel as their primary cooking fuel. A multi-country study reported South Asian women to commonly use wood (49.1–89.7%), crop residue and animal dung as domestic fuel, with African women using mostly charcoal (85.4–93.5%) (Kadir *et al.* 2010).

The composition of the studies included in the meta-analysis may therefore influence the summary-effect estimate. Ironically, in the sub-group analysis (Table 14) the summary estimate for studies conducted in Sub-Saharan Africa was quite larger than the estimate obtained for the South Asia studies. Also the summary estimate computed for studies conducted in urban settings was higher than the estimate reported for studies conducted in rural settings. This finding could be attributed in part to the grouping together of the individual fuels in the assessment of HAP exposure and the inconsistent categorization of kerosene. The 35% (EE = 1.35; 95% CI: 1.23, 1.48) increased risk of LBW for solid fuel use estimated in the meta-analysis is consistent with the findings of the three previous reviews (Pope *et al.* 2010, Misra *et al.* 2012, Bruce *et al.* 2013), albeit the study by Misra *et al.* (2012) reported a slightly higher estimate. However, the estimate reported captures a significant number of important new evidence published either prior to or since the conduct of these previous reviews.

In Study IV, solid fuel use was also found to be associated with a 29% (EE = 1.29; 95% CI: 1.18, 1.41) increased risk of stillbirth, which is quite lower than the effect estimate previously reported by Pope *et al.* (2010). In addition to the four studies reviewed by Pope and colleagues, the search strategy applied also identified one other recent study (Lakshmi *et al.* 2013) which provided two estimates (wood and other solid fuels use) for the meta-analysis. This study was the largest and also reported the smallest and most precise estimates (Combined Prevalence Ratio = 1.24, 95% CI: 1.12, 1.37), thereby gaining the bulk of the weight (80.41%) in the meta-analysis and pulling the summary estimate towards the null as a result. When this study and two other studies (Mishra *et al.* 2005, Mavalankar *et al.* 1991) were excluded from the sensitivity analysis, a much higher stillbirth risk of 61% (EE = 1.61; 95% CI: 1.09, 2.38) was noted. It is therefore possible that the summary-effect estimate computed might have been underestimated by these large and yet low-quality studies. Pope *et al.* (2010) also reported that their summary-effect estimate might have been underestimated by the study of Mishra and coworkers (Mishra *et al.* 2005). Bruce *et al.* (2013) reported no new evidence on stillbirth in their updated review.

The present study is the first to review the available evidence on household solid fuel use and PTB, IUGR and miscarriage. Even though the findings reported are weakened by the small number of studies reviewed they are consistent with the findings of previous reviews assessing the effects of ambient air pollution (Maisonet *et al.* 2004, Glinianaia *et al.* 2004, Sapkota *et al.* 2012, Stieb *et al.* 2012) and second-hand smoke (Salmasi *et al.* 2010, Leonardi-Bee *et al.* 2011) on these pregnancy endpoints.

6.2.2 Traffic-related air pollution as determinant of birth weight and gestational length

It is evident from the urban Ghana air pollution studies (Arku *et al.* 2008, Dionisio *et al.* 2010a, 2010b, Rooney *et al.* 2012, Essumang *et al.* 2006, Obiri *et al.* 2011, 2013) and the studies investigating air pollution exposures among street vendors (Table 2) that street vending predisposes to high levels of several air pollutants from vehicle emissions. Street vendors are also exposed to non-tailpipe emissions from brakes, tires and road surfaces, which have according to

Brunekreef *et al.* (2012) in recent years been shown to contribute significantly to fine and in particular coarse particles measured at roadside. Street vendors trade either in between moving vehicles, by the roadside or on the sidewalks, and also mostly center their operations at road junctions and traffic lights where vehicular jams are at their greatest and consequently, traffic-related exposures are at their highest. The Ghana Environmental Protection Agency (EPA) has also reported high levels of air pollution in Accra, particularly at roadside and commercial locations, with levels exceeding national and WHO guidelines by wide margins (Nerquaye-Tetteh 2009). The roadside air monitoring sites of the Ghana EPA include locations along the Bus Rapid Transit (BRT) pilot route which stretches from beyond Mallam Junction through Odorkor, Kaneshie and the Graphic Road to the Central Business District (see Figure 2) and is one of the heavily congested routes in the metropolis. Daily traffic volume along the Graphic Road, for instance, has been estimated to reach 40,000 (Department of Urban Roads *et al.* 2010, Okoye *et al.* 2010). The BRT route is a very popular corridor for street vending activities due to the heavy vehicular traffic along the route. Even though data on the locations where the street vendors operated were not collected, there is some certainty that a high proportion of them operated along the BRT route, especially considering the close proximity of the route to the south-western part of the city where the majority of the study participants resided.

Studies in Vancouver, Canada (Brauer *et al.* 2008); Montreal, Canada (Genereux *et al.* 2008); East Kaohsiung, Taiwan (Yang *et al.* 2003); Rotterdam, Netherlands (van den Hooven *et al.* 2009); Shizuoka, Japan (Yorifuji *et al.* 2011, 2013); and Queensland, Australia (Barnet *et al.* 2011) that applied measures of road proximity in assessing exposure to traffic-related air pollutants have associated these proxy measures with adverse pregnancy outcomes including SGA, LBW and PTB. In the Queensland study (Barnet *et al.* 2011) no associations were found with distance to road, but the number of road segments around the mother's home was associated with shorter gestation time. For every 10 extra main roads within 400m of the home, gestation time was reduced by 1.1% (95% CI: −1.7, −0.5). The association of street vending with LBW and PTB noted by this study is consistent with these traffic-related air pollution studies. The 177g reduction in birth weight among infants delivered to street vendors is, however, quite larger compared to the effect sizes reported by the study in Rotterdam, Netherlands (van den Hooven *et al.* 2009) and studies on second-hand smoke, ambient air pollutant measures and pregnancy outcomes. The study in Rotterdam, Netherlands reported a 41g (95% CI: −69, −12) reduction in birth weight of infants delivered to mothers residing within 100–150m of a major road (van den Hooven *et al.* 2009). A study summarizing the available evidence on second-hand smoke exposure and perinatal outcomes (Salmasi *et al.* 2010) reported a 60g (95% CI: −80, −39) reduction in birth weight among exposed infants. A comprehensive review of the evidence on ambient air pollution, and birth weight and preterm birth (Stieb *et al.* 2012) reported a decrease in birth weight of 11.4g (95% CI: −6.9, 29.7), 28.1g (95% CI: 11.5, 44.8), 16.8g (95% CI: 13.3, 20.2) and 23.4g (95% CI: 1.4, 45.5) per 1ppm CO, 20ppb NO_2, 20µg/m^3 PM_{10} and 10µg/m^3 $PM_{2.5}$ respectively. The present study is, however, the first report of an association between street vending and pregnancy outcomes in the epidemiological literature.

Two major differences exist between the present study and the previous studies reviewed in terms of the way exposures were characterized, which further posits street vending activities during pregnancy as a real threat to optimal fetal growth in the research setting and similar areas of developing countries. Firstly, in the studies reviewed, exposure assessments were based on maternal residential history and proximity of participants' homes to major roads and highways whereas in this study the street vendors per their mode of operation were in direct contact with traffic-related air pollutants for several hours and days during pregnancy. Secondly, exposure assessment in the studies reviewed was based on the assumption that pregnant women lived at the reported residential address throughout the course of pregnancy (for most studies), spent a substantial amount of time at home, and that a significant portion of traffic-related air pollutants infiltrated their homes, whereas this study relied on actual exposure experiences of participants during pregnancy as reported by the mothers during the interviews. It is, however, worth mentioning that street vending is physically demanding involving daily standing posture for several hours and in most cases whilst carrying the goods being sold on the head as well as lifting of objects, which can also contribute to reduced fetal growth. Prolonged standing (Klebanoff *et al.* 1990, Snijder *et al.* 2012), long working hours (Snijder *et al.* 2012, Jansen *et al.* 2010), and heavy lifting and twisting/bending (Wergeland *et al.* 1998) have all been reported to adversely affect pregnancy outcomes. Traffic also creates noise, which may increase stress and disturb sleep (Barnett *et al.* 2011). Disturbed sleep during pregnancy may be a risk factor for adverse birth outcomes (Okun 2009, 2012).

About 74% of the street vendors were identified as low social class, confirming the common assumption that disadvantaged groups and populations are most likely to engage in activities or live in areas with potentially hazardous environmental exposures. Sexton *et al.* (1993) stated that people with less wealth are more likely to be employed in dirtier occupations. Adler & Newman (2002) also asserted that exposure to damaging agents in the environment varies with SES and that those lower on the SES hierarchy are more likely to live and work in worse physical environments. In a large Swedish study, Lundberg (1991) assessed different environmental and behavioral factors believed to account for SES gradients in health and found the strongest predictor of the gradient to be poor working conditions, defined as heavy lifting or tasks with repetitive strain plus daily contact with toxins, fumes, dust, explosives, vibration, and the like.

6.2.3 Socioeconomic differences in adverse pregnancy outcomes and important mediating factors

Area of residence, education, occupation and income were determinants of birth weight and gestational length in the Cape Coast population. In applying the construct of maternal SES, low and middle SES were found to be associated with statistically significant reductions in birth weight and increased risk of LBW in this population. Malaria infection, poor pre-pregnancy nutritional status and biomass fuel use jointly explained between 42% and 64% of the observed effects in the models. Biomass fuel use, however, appears to be the most important mediating factor, explaining between 26% and 42% of the observed associations in the models. Studies in India (Dehmukh *et al.* 1998, Mumbare *et al.* 2012), Nigeria (Olusanya & Ofovwe 2010) and Mexico (Torres-Arreola *et al.* 2005) using different proxies and constructs of SES have also associated low SES with reduced birth weight and risk of LBW. A study in Accra, Ghana, found use of biomass fuel and cooking area particulate matter levels to be high in two low SES neighborhoods of the city (Zhou *et al.* 2011).

In Study I, low social class mothers were identified as the group mostly patronizing biomass fuels and frequently burning garbage at home, and certainly most exposed to HAP. Of the proportion of charcoal users in Study I, 66% were identified as low social class. Also of mothers burning garbage at home, 56.2% were classified as low social class. Only 2.5% and 4.4% of charcoal users and mothers burning garbage at home, respectively, were classified as high social class. Cooking fuel choices were statistically related to the social class ($p < 0.0001$), educational level ($p < 0.0001$) and occupational attainment ($p < 0.0001$) of the mothers. Studies in Ethiopia (Mekonnen & Köhlin 2008), Cameroun (Njong & Johannes 2011) and Kenya (Pundo & Fraser 2006) have also associated household cooking fuel choices with employment, income, education and social class of women.

The Cape Coast area as a whole is a deprived urban settlement. Deprived zones of Ghanaian urban settlements including Cape Coast are noted for deplorable social and environmental conditions with attendant poor indoor and outdoor air quality, high malaria transmission levels and repeated infections. Poor nutritional practices and associated nutritional deficits due to widespread poverty and ignorance are also common in these areas. All these factors are proposed mediators through which neighborhood and socioeconomic deprivation can impact on birth outcomes. Malaria infection during pregnancy and poor pre-pregnancy nutritional status independently explained about 12–21% and 7–27% of the observed SES effect, respectively. Previous studies have found women living in deprived areas delivering the majority of LBW infants (Pattenden *et al.* 1999, Dibben *et al.* 2006, Thompson *et al.* 2006).

7 Conclusions

The results provide evidence that maternal use of solid fuels for cooking and burning of garbage at home are strong determinants of fetal growth and risk of adverse pregnancy outcomes. Street vending during pregnancy predisposes mothers to traffic-related air pollutants mostly and was associated with adverse reproductive endpoints in the study setting. Socioeconomic deprivation which was also found to be associated with adverse pregnancy outcomes appears to be the main driver of HAP and occupation-related outdoor exposures in the study area. This is depicted by the high number of low social class mothers patronizing biomass fuel and working as street vendors in the study area as well as the finding of HAP as the most important pathway through which socioeconomic disadvantage impacts fetal growth and gestational duration in the study setting.

8 Recommendations and policy implications

Scaling up household waste collection services in urban areas, expanding LPG production facilities and distribution networks and curbing their competing use in motor vehicles are important in reducing maternal exposure to HAP and improving birth outcomes in Ghana and similar developing countries. This recommendation requires a sustained effort on the part of metropolitan authorities in refining waste management strategies and supporting private sector initiatives in the sector, energy ministries in ensuring continuous supply and easy access to LPG by addressing bottlenecks on the supply chain, and vehicular licensing authorities in imposing heavy fines on garages and vehicle owners refitting vehicles to use LPG.

Biogas is another great potential to reduce over-dependence on solid fuels in developing countries. Metropolitan areas of developing countries are beset with numerous waste management problems. Central governments should therefore consider building biogas plants at strategic locations within metropolitan areas to process this waste which also poses threats to environmental and human health into biogas for domestic use.

Improved cookstoves have traditionally been promoted in developing countries as the surest way to reduce HAP exposure from solid fuel use thanks to better combustion efficiencies and should be scaled up. However, issues with achieving emissions low enough to translate into health benefits means that cleaner fuels such as LPG should be promoted where key barriers to their adoption such as poverty and erratic supply can be eliminated. Standardizing the testing of improved cookstoves is important to maximize their health benefits. Developing country governments should therefore ensure the implementation of the International Standards Organization (ISO) International Workshop Agreement (IWA 11:2012) guidelines for evaluating cookstove performance.

Educating mothers about behavioral changes required to minimize HAP exposure such as cooking outdoors when the cooking area is poorly ventilated, spending minimal time in the cooking area, keeping the kitchen door open while cooking and avoiding burning garbage at home is also very important. This requires reorienting health workers on environmental health issues so they can advise mothers appropriately during their contact with them.

Easing traffic congestion in Accra and similar cities of developing countries and minimizing traffic-related exposures among commuters and outdoor workers requires central government efforts in expanding road infrastructure to meet the ever-increasing vehicle ownership and implementing Bus Rapid Transit (BRT) systems on all heavily congested routes. The Metro Mass Public Transport system is helpful, but the intra-city component needs to be scaled up with an injection of more buses to cover every route in a timely and reliable fashion. Metropolitan authorities in collaboration with the Police service should devise new strategies to strictly enforce traffic regulations and crack down on the indiscipline of commercial drivers which also contributes to the traffic congestion in Accra.

Building market stalls across the length and breadth of cities of developing countries and taking stringent measures to get street vendors into these stalls to sell their goods is the surest way of minimizing traffic-related exposures among this large group of informal workers.

Pregnant women engaged in street vending should also be advised during antenatal visits to give up or minimize working hours in the trade during the period of the pregnancy. Sustainability of this recommendation requires commitment from central government to extend the Livelihood Empowerment Against Poverty (LEAP) cash transfer program to pregnant women engaged in outdoor jobs with potential environmental exposures to enhance their income levels during this period. Developing countries that do not already have such safety net programs running should consider implementing them.

Overall, the study findings reinforce the need for environmental health to be a main feature of medical and nursing training in developing countries to ensure that health workers are adequately informed on the harmful effects of environmental pollutants on human health as a whole, and maternal and fetal health in particular. This action should lead to a sustained effort by health workers to intervene at every opportunity they get to care for pregnant women by sensitizing them on the need to minimize or avoid environmental exposures during this vulnerable period.

9 Implications for future research

On the relation of HAP exposure with adverse pregnancy outcomes, this study, as with the previous ones, applied interview methods in the ascertainment of exposure. This study, however, addressed a major limitation of previous studies by factoring the sequence and patterns of cooking in the household, and other variables, such as ventilation of the cooking enclosure and fuel mixing/stacking in the exposure estimation, as well as investigating exposure-response relationships. Another important methodological challenge of previous studies, i.e., the relative stability of fuel choices during pregnancy, could not be addressed by this study. Future research should therefore incorporate personal exposure monitoring methods and cooking activity diaries, evaluate biomarkers of exposure as well as consider the relative contribution of outdoor air pollution sources to HAP levels and the potency of individual fuels in causing adverse effects. The inconsistent categorization of kerosene in previous studies is also a concern and should be addressed in future studies.

Limitations with the use of the last menstrual period dating method in estimating gestational age in this study and the previous reviewed should be addressed in future studies through the use of ultrasound examination. Also it is important to establish the particular window of pregnancy when air pollution exposure is most harmful to fetal growth and development. Futures studies should therefore consider performing fetal ultrasound measurements during different periods of pregnancy to provide insight into the critical window of exposure and meaning of the birth measures reported.

Finally, the dominant nature of street vending in developing countries means more research with rigorous design that also incorporates personal exposure monitoring methods, and mobility and activity diaries are needed to further quantify their effects on pregnancy and other health endpoints.

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Appendix I Accra study (Studies I and II) questionnaire

Date:	
ID/Folder Number:	
Name of participant:	
Location of participant:	**LOCTN**
BACKGROUND AND PERSONAL CHARACTERISTICS	
1. Age:	**AGE**
2. Ethnic origin: Akan [ ] Ga [ ] Ewe [ ] Hausa [ ] Other (Specify)_________________	**ETHNO**
3. Religion: Christian [ ] Muslim [ ] Traditional [ ] Other (Specify)__________________	**RELGN**
4. Marital status: Married [ ] Casual/Co-habiting [ ] Separated/Divorced [ ] Widowed [ ] Single [ ]	**MARST**
5. Educational level: Primary [ ] Junior High [ ] Senior High/Secondary [ ] Vocational/Technical/Professional [ ] Tertiary [ ] None [ ]	**EDUCA**
6. Occupation: Trader [ ] Street Vendor [ ] Fish Monger [ ] Farmer [ ] Hairdresser [ ] Seamstress [ ] Caterer [ ] Waitress/Bar Attendant [ ] Teacher [ ] Health Worker [ ] Office/Administrative Worker [ ] Housewife/Unemployed [ ] Other (Specify)___________	**OCCUP**
7. Was this your first pregnancy: Yes [ ] No [ ]	**FPREG**
8. If No to 7, how many pregnancies have you had in the past:	**NPREG**
9. What month of your pregnancy did you first attend ANC:	**ANCMT**
10. How often were you attending ANC during your pregnancy: Once/month [ ] 2x/month [ ] 3x or more/month [ ] Occasionally [ ]	**ANCFQ**
11. Do you smoke: Yes [ ] No [ ]	**SMOKE**
12. If Yes to 11, were you smoking during your pregnancy: Yes [ ] No [ ]	**SMKPG**
13. Do you consume alcoholic beverages: Yes [ ] No [ ]	**ACHOL**
14. If Yes to 13, were you consuming alcohol during your pregnancy: Yes [ ] No [ ]	**ACHPG**
15. Do you take illicit drugs: Yes [ ] No [ ]	**DRUGS**
16. If Yes to 15, were you taking illicit drugs during your pregnancy: Yes [ ] No [ ]	**DRGPG**
17. Were you taking nutritional supplements during your pregnancy: Yes [ ] No [ ]	**SUPPL**
If Yes to 17 answer 18 & 19	
18. What supplements were you taking: Iron [ ] Folate [ ] Other (specify)_________ Combination of supplements (specify)______________________	**SUPTP**
19. Were you taking these supplements regularly as prescribed: Yes [ ] No [ ]	**SUPRG**
INDOOR AIR POLLUTION EXPOSURE ASSESSMENT	
20. Were you involved in the household cooking duties during your pregnancy: Yes [ ] No [ ]	**COKHS**
If Yes to 20, answer 21-29	
21. For how long during your pregnancy were you involved in the household cooking duties: 1-3 months [ ] 4-6 months [ ] 7-9 months [ ]	**COKPG**
22. How often were your cooking activities: Daily [ ] 4-5x/wk [ ] 2-3x/wk [ ] Once/wk [ ] 1-2x/month [ ] Occasionally [ ]	**COKFQ**
23. How long were your cooking activities lasting: 1-4 hours [ ] 5-8 hours [ ] >8 hours [ ]	**COKDU**

24.	Where were you carrying out your cooking activities: Enclosed kitchen [ ] Under a shed [ ] Open area/Porch [ ] Combined areas [ ], specify ____________________	**COKPL**
25.	How much time were you spending in the kitchen/cooking area during the duration of a cooking activity: Whole duration [ ] Half of the duration [ ] Quarter of the duration [ ] Less than a quarter of the duration [ ]	**COKTM**
26.	What cooking fuel were you using mostly for your cooking activities: Electricity [ ] LPG [ ] Kerosene [ ] Charcoal [ ] Wood [ ] Crop residue [ ] Animal dung [ ] Combination of fuels [ ], specify ____	**CFUEL**
27.	Did your kitchen/cooking area had a chimney: Yes [ ] No [ ]	**CHMNY**
28.	How many windows did your kitchen possess: None [ ] One [ ] Two [ ] Three [ ] >Three [ ]	**WINDO**
29.	How do you rate the size of the kitchen window: Very large [ ] Large [ ] Medium [ ] Small [ ] Very small [ ]	**WINSZ**
30.	Do you burn rubbish in your house: Yes [ ] No [ ]	**RUBSH**
31.	If Yes to 30, was it still being done during your pregnancy: Yes [ ] No [ ]	**RUBPG**
If Yes to 31, answer 32 & 33		
32.	Where are you whenever rubbish was being burnt in the house during your pregnancy: Always present [ ] Mostly present [ ] Occasionally present [ ] Never present [ ]	**RUBPR**
33.	How often was rubbish burnt in the house: Daily [ ] 4-5x/wk [ ] 2-3x/wk [ ] Once/wk [ ] 1-2x/month [ ] Occasionally [ ]	**RUBFQ**
OUTDOOR ACTIVITY AND MOBILITY PATTERNS		
34.	Were you spending some time outdoors during your pregnancy: Yes [ ] No [ ]	**OUTTM**
If Yes to 34 answer 35-38		
35.	How long were you spending some time outdoors: 1-3 months [ ] 4-6 months [ ] 7-9 months [ ]	**OUTDR**
36.	How often were your outdoor visits/activities: Daily [ ] 4-5x/wk [ ] 2-3x/wk [ ] Once/wk [ ] Once/month [ ] 2x/month [ ] Occasionally [ ]	**OUTFQ**
37.	How many hours were you spending during each outdoor visit/activity: 1-4 hours [ ] 5-8 hours [ ] 9-12 hours [ ] >12 hours [ ]	**OUTHR**
38.	Were you working or conducting your outdoor activities close to any of the following air polluting sources: Busy roads/heavy traffic hotspots [ ] Combustion sites [ ] Polluting industries [ ] Waste disposal/Landfill sites [ ] Power generation stations [ ] No [ ]	**OUTAC**
OUTCOME MEASUREMENT		
39.	Sex of neonate: Male [ ] Female [ ]	**SEXNT**
40.	Birth order of neonate:	**BRTOD**
41.	Birth weight of neonate:	**BRTWT**
42.	Estimated gestational age:	**GESAG**

Appendix II Cape Coast study (Study III) questionnaire

Date:		
ID No.:		**IDNUM**
Name (Optional):		
BACKGROUND AND PERSONAL CHARACTERISTICS		
1.	Age:	**AGE**
2.	Where do you stay:	**LOCAT**
3.	Educational Level: None [ ] Junior High [ ] Senior High/Secondary/Technical [ ] Tertiary [ ]	**EDUCA**
4.	Occupation: Hairdresser [ ] Seamstress [ ] Fish monger [ ] Office worker [ ] Student [ ] Trader [ ] Street vendor [ ] Housewife [ ] Unemployed [ ] Other [ ]	**OCCUP**
5.	Religion: Christian [ ] Muslim [ ] Traditional [ ] Others (Specify)………………………..	**RELGN**
6.	Ethnic Origin: Akan [ ] Ewe [ ] Ga [ ] Hausa [ ] Other southern tribe [ ] Other northern tribe [ ]	**ETNGP**
7.	Marital status: Single [ ] Married [ ] Cohabiting [ ] Divorced [ ] Widowed [ ]	**MARST**
8.	How many children do you have : One [ ] Two [ ] Three [ ] Four [ ] >Four [ ]	**CHLDN**
9.	How long did it take you to get pregnant again after the previous birth: N/A [ ] <6 months [ ] 6-12 months [ ] 12-24 months [ ] >24 months [ ]	**INTPR**
10.	How much do you earn in a month: <GH¢100 [ ] GH¢100-500 [ ] GH¢501-1000 [ ] >GH¢1000 [ ]	**INCOM**
11.	What type of fuel do you use at home: LPG [ ] Firewood [ ] Charcoal [ ] Crop residue [ ] LPG & Charcoal [ ] Charcoal & Firewood [ ] LPG & Firewood [ ] Charcoal, Firewood & LPG [ ]	**COKFUL**
12.	Were you smoking during pregnancy: Yes [ ] No [ ]	**SMOKE**
13.	Were you consuming alcohol during pregnancy: Yes [ ] No [ ]	**ALCOH**
MATERNAL HEALTH CHARACTERISTICS		
14.	What month of pregnancy did you first visit antenatal clinic: 1-3 [ ] 4-6 [ ] 7-9 [ ]	**ANCMN**
15.	How many times did you visit antenatal clinic during your pregnancy: Once/month [ ] Twice/month [ ] 3x or more/month [ ] Occasionally [ ]	**ANCTM**
16.	Were you taking nutritional supplements during pregnancy: Yes [ ] No [ ]	**SUPPL**
17.	If Yes to 16, what type of supplement were you taking: Iron [ ] Folate [ ] Iron & Folate [ ] Other (Specify)……………………………	**SUTYP**
18.	Were you taking the supplements regularly: Yes [ ] No [ ]	**SUREG**
19.	Did you experience any episode of malaria during pregnancy: Yes [ ] No [ ]	**MALAR**
20.	Estimated gestational age:	**GESAG**
MATERNAL ANTHROPOMETRY		
21.	Pre-pregnancy height (Height at first ANC visit):	**HEIGH**
22.	Pre-pregnancy weight (Weight at first ANC visit):	**FSTWT**
23.	Weight at last ANC visit:	**LASWT**
NEONATAL CHARACTERISTICS		
24.	Sex of newborn: Male [ ] Female [ ]	**SEXNT**
25.	Birth weight:	**BRTWT**
26.	Birth order: First [ ] Second [ ] Third [ ] Fourth [ ] >4 [ ]	**BRTOD**

Original publications

I Amegah AK, Jaakkola JJK, Quansah R, Norgbe GK & Dzodzomenyo M (2012) Cooking fuel choices and garbage burning practices as determinants of birth weight: a cross-sectional study in Accra, Ghana. Environ Health 11: 78.

II Amegah AK & Jaakkola JJK (2014) Work as a street vendor, associated traffic-related air pollution exposures and risk of adverse pregnancy outcomes in Accra, Ghana. Int J Hyg Environ Health 217: 354–362.

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