Abstract Available evidence concerning the association between indoor air pollution (IAP) from biomass and solid fuel combustion and preeclampsia/eclampsia is not available in developing countries. We investigated the association between exposure to IAP from biomass and solid fuel combustion and symptoms of preeclampsia/eclampsia in Indian women by analyzing cross-sectional data from India’s third National Family Health Survey (NFHS-3, 2005–2006). Self-reported symptoms of preeclampsia/eclampsia during pregnancy such as convulsions (not from fever), swelling of legs, body or face, excessive fatigue or vision difficulty during daylight, were obtained from 39,657 women aged 15–49 years who had a live birth in the previous 5 years. Effects of exposure to cooking smoke, ascertained by type of fuel used for cooking on preeclampsia/eclampsia risk, were estimated using logistic regression after adjusting for various confounders. Results indicate that women living in households using biomass and solid fuels have two times higher likelihood of reporting preeclampsia/eclampsia symptoms than do those living in households using cleaner fuels (OR = 2.21; 95%: 1.26–3.87; P = 0.006), even after controlling for the effects of a number of potentially confounding factors. This study is the first to empirically estimate the associations of IAP from biomass and solid fuel combustion and reported symptoms suggestive of preeclampsia/eclampsia in a large nationally representative sample of Indian women and we observed increased risk. These findings have important program and policy implications for countries such as India, where large proportions of the population rely on polluting biomass fuels for cooking and space heating. More epidemiological research with detailed exposure assessments and clinical measures of preeclampsia/eclampsia is needed in a developing country setting to validate these findings.

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Introduction
Preeclampsia is a pregnancy-induced hypertensive disorder characterized by high blood pressure and proteinuria after the 20th week of pregnancy (Sibai et al., 2005). Eclampsia is defined as the occurrence of generalized seizures/convulsions and/or unexplained coma during pregnancy or postpartum in a preeclamptic woman in the absence of other neurologic conditions (such as epilepsy) (Aagaard-Tillery and Belfort, 2005; Sibai, 2005). Preeclampsia/eclampsia is thus a potentially fatal disorder in pregnant women.  

Practical Implications
The findings from this study have important program and policy implications for countries such as India, where large proportions of the population rely on polluting biomass fuels for cooking and space heating, and have an additional burden of high maternal and infant mortality and morbidity, and preeclampsia/eclampsia is one of a major cause for this high burden. With the target of the Millennium Development Goals in sight, preeclampsia/eclampsia needs to be identified as a priority area in reducing maternal mortality and morbidity in developing countries including India.
and remains one of the leading causes of maternal mortality and morbidity worldwide and is associated with adverse pregnancy outcomes including perinatal death, preterm birth, and intrauterine growth retardation (Sibai et al., 2005). Established risk factors for preeclampsia/eclampsia reported in high-income country settings include young and old maternal age, obesity prior to pregnancy, being unmarried, excessive weight gain during pregnancy, multiple gestation, nulliparity, chronic hypertension, low socioeconomic status, prolonged birth interval, lack of prenatal care, and current smoking (Ansari et al., 1995; Baeten et al., 2001; Chesley, 1984; Coghill et al., 2011; Douglas and Redman, 1994; Saftlas et al., 1990; Zwart et al., 2008).

An emerging risk factor for preeclampsia/eclampsia, particularly in low- and middle-income countries (LMICs), is the indoor air pollution. Indoor air pollution, from traditional fuels (such as biomass and coal) and cooking stoves, is associated with an increase in the incidence of respiratory infections, including pneumonia, tuberculosis and chronic obstructive pulmonary disease, low birthweight, cataracts, cardiovascular events, and all-cause mortality both in adults and children (Bruce et al., 2000; Fullerton et al., 2008; WHO, 2014). According to WHO (2014), an estimated 4.3 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels (from 2012 data). Among these deaths, 12% are due to pneumonia, 34% from stroke, 26% from ischemic heart disease, 22% from chronic obstructive pulmonary disease (COPD), and 6% from lung cancer. The poorest and most vulnerable populations in developing countries are generally the most exposed to indoor air pollution from biomass combustion (Mishra, 2003; Agrawal, 2012; Smith et al., 2013). Exposure levels are usually much higher among women as they do most of the cooking (Behera et al., 1988) and among young children because they are often carried or held on their mother’s back or lap during cooking times (Albalak, 1997).

Recent studies in India (Epstein et al., 2013; Lakshmi et al., 2013) suggest that household use of coal and kerosene was also associated with an increased risk of low birthweight, still births, and neonatal deaths.

Over 200 studies that have measured air pollution levels in developing country households across all WHO regions (The Global Indoor Air Pollution Database), provide clear evidence of extreme exposures in solid cooking fuel using settings, often manifold higher than recommended WHO Air Quality Guidelines (AQGs) (Bonjour et al., 2013; World Health Organization Regional Office for Europe, 2005). The burning of solid fuels indoors in open fires or traditional cooking stoves (chulhas) results in high levels of toxic pollutants in the kitchen area (Dufllo et al., 2008; Smith et al., 2000, 2004, 2012). Poor ventilation likely worsens the adverse health effects of indoor air pollution (Reddy et al., 2004). Findings from India’s third National Family Health Survey (NFHS-3, 2005–2006) showed that 90% of rural and 32% of urban households (overall 71%) in India use biomass and solid cooking fuels that generate smoke and unhealthy conditions when inhaled (IIPS & Macro International, 2007). Additionally, 74% of households cook their meals in the house. About one-third of households that cook inside the house do not have a separate room for cooking. In both urban and rural areas, 9 in 10 households that use solid fuels and cook on an open fire also lack chimneys to divert smoke (IIPS & Macro International, 2007). Smith (1999) reported between 400 000 and 550 000 premature deaths annually among adult women and children aged <5 years in India arising from exposure to indoor air pollution. Using a disability-adjusted lost life-year approach, the total is 4–6% of the Indian national burden of disease, placing indoor air pollution as a major risk factor in the country (Smith, 2000). It has been estimated that, exposure to indoor air pollution may be responsible for nearly 2 million excess deaths in developing countries and for some 4% of the global burden of disease (Bruce et al., 2000).

In India, biomass and solid fuels are typically burned indoors in simple household cook stoves, such as a pit, three pieces of brick, or a U-shaped construction made from mud, which burn these fuels inefficiently and do not often include flues or hoods. Under these conditions, high levels of health-damaging airborne pollutants, including PM10, CO, NOx, SOx (more from coal), formaldehyde, and dozens of toxic polycyclic aromatic hydrocarbons (e.g. benzo[α]pyrene) and other organic matter, can be generated indoors. The individual peak and mean exposures experienced in such settings are often much greater than guideline levels recommended by the World Health Organization (WHO, 1997; World Health Organization Regional Office for Europe, 2005; Bonjour et al., 2013). A recent study by Balakrishnan et al. (2013) reported that the measured mean 24-h concentration of PM2.5 in solid cook fuel-using households ranged from 163 µg/m³ (95% CI: 143–183; median 106; IQR: 191) in the living area to 609 µg/m³ (95% CI: 547–671; median: 472; IQR: 734) in the kitchen area. After extrapolating the household results by state to all solid cooking fuel-using households in India covered by the NFHS 2005–2006, the same study found an estimate of 450 µg/m³ (95% CI: 318–640) and 113 µg/m³ (95% CI: 102–127) for national average 24-h PM2.5 concentrations in the kitchen and living areas, respectively (Balakrishnan et al., 2013).

Previous findings regarding the association between air pollution and preeclampsia/eclampsia, mostly conducted in developed countries, are limited and have been inconsistent (Lee et al., 2013; Pereira et al., 2013;
Rudra et al., 2011; Wu et al., 2009). Several recent studies have reported positive associations between preeclampsia and air pollutants including nitrogen oxides (NOx), nitrogen monoxide (NO), nitrogen dioxide (NO2), carbon monoxide (CO), ozone (O3), particulate matter <2.5 μm in aerodynamic diameter (PM2.5), and particulate matter <10 μm in aerodynamic diameter (PM10) (Lee et al., 2012; Wu et al., 2009, 2011), but others have reported no association with PM2.5 or CO (Rudra et al., 2011) or inconclusive findings for PM10 and NO2 (van den Hooven et al., 2011). Two studies have reported positive associations between gestational hypertension (a risk factor and early symptom of preeclampsia) and air pollutants [PM10 and PM2.5 (Vinikoor-Imler et al., 2012) and NO2 and PM10 (van den Hooven et al., 2011)]. A study in Spain also observed an increased risk of preeclampsia associated with exposure to fine particulate air pollution (Dadvand et al., 2013).

It is seen from the above discussion that biomass and solid fuels are a major source of indoor air pollution, but in low- and middle-income countries such as India, the adverse health effects, including preeclampsia/eclampsia, of exposure among pregnant women are poorly understood. To our knowledge, very few/no epidemiological studies have examined associations between indoor air pollution and preeclampsia/eclampsia among Indian women. In the present study, we aimed to examine the effect of exposure to cooking smoke from biomass and solid fuel combustion on the risk of preeclampsia/eclampsia using data from a large-scale cross-sectional nationally representative sample of adult women in India.

**Methods**

**Data**

Cross-sectional data from India’s third National Family Health Survey (NFHS-3), conducted during 2005–2006, were used for this analysis. NFHS was designed along the lines of the Demographic and Health Surveys (available at www.measuredhs.com) that have been conducted in many LMICs since the 1980s. The NFHS has been conducted in India for three successive rounds, each at an interval of 5 years. The most recent NFHS, that is NFHS-3, collected demographic, socioeconomic and health information from a nationally representative probability sample of 124 385 women aged 15–49 years residing in 109 041 households. The sample is a multistage cluster sample with an overall response rate of 98%. All states of India are represented in the sample (except the small Union Territories), covering more than 99% of the country’s population. Full details of the survey have been published (IIPS & Macro International, 2007) and also available at www.nfhsindia.org. The analysis presented in this study focuses on 39 657 women from the total sample who reported being ever married and who had a live birth in the 5 years preceding the survey.

**Response variable**

NFHS-3 included several questions related to health problems of women during pregnancy for the most recent live birth in the 5 years preceding the survey. Mothers were asked if at any time during their last pregnancy they experienced symptoms of convulsions (not from fever), swelling of the legs, body or face, excessive fatigue, have difficulty with vision during daylight, or vaginal bleeding. According to the WHO criteria for assessing the occurrence of preeclampsia symptoms, women who reported difficulty with vision during daylight, and swelling of the legs, body, or face were coded as having symptoms of preeclampsia (WHO, 2003a), whereas those who reported experiencing convulsions (not from fever) were coded as symptomatic of eclampsia (WHO, 2003a). We used this as a proxy measure for preeclampsia/eclampsia. However, it was not possible to confirm clinical diagnosis of these symptoms. Data on blood pressure and proteinuria during pregnancy, which are typical clinical diagnostic markers of preeclampsia (Roberts et al., 2003), were not available in the NFHS-3. Data on physician reported diagnosis of convulsions/seizures were also not available in the NFHS-3 to verify a self-reported diagnosis.

**Predictor variable**

Exposure to cooking smoke was determined indirectly by the type of fuel used for cooking in the household. The survey used a 10-item classification of cooking fuel: electricity, liquefied petroleum gas (LPG)/natural gas, biogas, kerosene, coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crop waste, dung cakes, and a residual category of other fuels (unknown). The question asked was, ‘What type of fuel does your household mainly use for cooking?’, followed by the above list of fuels. We used information from the above questions to group households into two categories representing the extent of exposure to cooking smoke: high- and medium-exposure group (households using either biomass fuels—such as, wood, straw/shrubs/grass, agricultural crop waste, dung cakes, or others—or solid fuels—such as coal/lignite and charcoal); and low-exposure group (households using only cleaner fuels—such as kerosene, LPG/natural gas, biogas, or electricity).

**Covariates/confounders**

Preeclampsia/eclampsia is a complex disease, likely to be influenced by several other factors, so we included...
potential covariates and confounders in the models which were selected on the basis of previous knowledge of their association with preeclampsia/eclampsia. The following maternal reproductive risk factors were evaluated: parity (1, 2–3, 4+); type of pregnancy (singleton, twin); history of a terminated pregnancy (no, yes). Health- and lifestyle-related factors included body mass index (BMI) kg/m² categories (Indian adult population standard) (Indian Consensus Group, 1996): \(<18.4\ \text{kg/m}^2\) (underweight), 18.5–22.9 kg/m² (normal), 23.0–24.9 kg/m² (overweight), \(\geq25\ \text{kg/m}^2\) (obese); current tobacco smoking (no, yes); alcohol use (no, yes); self-reported diabetes (no, yes); self-reported asthma (no, yes); anemia level (not anemic, mild, moderate, severe). Studies have shown that women with preeclampsia had a higher BMI, and higher systolic and diastolic blood pressure (Kaaja et al., 2005), but a protective effect of prenatal alcohol consumption with preeclampsia was found in some studies (Salihu et al., 2011; Kiondo et al., 2012; McCarthy et al., 2013). Anemia during pregnancy is a major health problem, and some studies found that the greater the severity of the anemia during pregnancy, the greater was the risk of preeclampsia (Ali et al., 2011). Some studies also suggest that asthematics, particularly those who are symptomatic during pregnancy, may be at a higher risk of developing preeclampsia (Rudra et al., 2006). Socio-demographic predictors included age (15–29, 30–39, 40–49 years); education (no education, primary, secondary, higher); religion (Hindu, Muslim, Christian, Sikhs, others); caste (scheduled castes, scheduled tribes, other backward class, others); wealth index (measured by an index based on household ownership of assets and graded as lowest, second, middle, fourth, and highest) which was computed using previously described methods (see Data S1 for the advantage and disadvantage of using the wealth index and items used to compute wealth index in NFHS-3); place of residence (urban, rural); and geographic regions (north, northeast, central, east, west, south). For definition of selected variables see, Table 1. Table S1 gives the descriptive statistics of the covariates and the main predictor variable, that is, household cooking fuel use.

Statistical analysis

Because our response variable—preeclampsia/eclampsia—is dichotomous, we used logistic regression to estimate the effects of cooking smoke (from biomass and solid fuel use relative to cleaner fuel use) with seven socioeconomic and demographic variables, three maternal factors, and six health- and lifestyle-related factors mentioned above. Results are presented as odds ratios with 95% confidence intervals (OR with 95% CI). The estimation of confidence intervals takes into account design effects due to

| Characteristics | Sample distribution | Preeclampsia/Eclampsia | \(\chi^2\) value |
|-----------------|---------------------|------------------------|-----------------|
| Household cooking fuel use | | | |
| Clean fuel | 7969 | 22.1 | 34 | 0.4 | <0.0001 |
| Biomass and solid fuel | 28 158 | 77.9 | 397 | 1.4 | |
| Maternal factors | | | |
| Parity | | | |
| 1 | 10 453 | 26.4 | 85 | 0.8 | <0.0001 |
| 2–3 | 18 199 | 45.9 | 184 | 1.0 | |
| 4+ | 11 005 | 27.8 | 187 | 1.7 | |
| Type of pregnancy | | | |
| Singleton | 39 298 | 99.1 | 446 | 1.1 | 0.003 |
| Twin | 395 | 0.9 | 11 | 3.1 | |
| Terminated pregnancy | | | |
| No | 32 319 | 81.5 | 350 | 1.1 | 0.005 |
| Yes | 7338 | 18.5 | 108 | 1.4 | |
| Health and lifestyle factors | | | |
| Body mass index | | | |
| Underweight (\(<18.5\ \text{kg/m}^2\)) | 11 592 | 30.5 | 183 | 1.3 | 0.001 |
| Normal (18.5–22.9 kg/m²) | 20 714 | 54.4 | 224 | 1.3 | |
| Overweight (23.0–24.9 kg/m²) | 2770 | 7.3 | 23 | 0.8 | |
| Obese (\(\geq25.0\ \text{kg/m}^2\)) | 3226 | 14.7 | 15 | 0.5 | |
| Current tobacco smoking | | | |
| No | 39 049 | 98.5 | 446 | 1.1 | 0.164 |
| Yes | 608 | 1.5 | 10 | 1.7 | |
| Drinks alcohol | | | |
| No | 38 735 | 97.7 | 433 | 1.1 | <0.0001 |
| Yes | 911 | 2.3 | 24 | 2.8 | |
| Diabetes | | | |
| No | 39 123 | 98.7 | 448 | 1.1 | 0.240 |
| Yes | 160 | 1.3 | 8 | 1.6 | |
| Asthma | | | |
| No | 39 163 | 98.8 | 434 | 1.1 | <0.0001 |
| Yes | 470 | 1.2 | 22 | 4.7 | |
| Anemia level | | | |
| Not anemic | 14 939 | 40.1 | 129 | 0.9 | <0.0001 |
| Mild | 15 082 | 40.4 | 200 | 1.3 | |
| Moderate | 6616 | 17.7 | 101 | 1.5 | |
| Severe | 652 | 1.7 | 6 | 0.9 | |
| Background factors | | | |
| Age | | | |
| 15–29 | 29 190 | 73.6 | 309 | 1.1 | 0.013 |
| 30–39 | 9421 | 23.8 | 134 | 1.4 | |
| 40–49 | 1047 | 2.6 | 14 | 1.3 | |
| Education | | | |
| No education | 18 783 | 47.4 | 294 | 1.6 | <0.0001 |
| Primary | 9550 | 14.0 | 66 | 1.2 | |
| Secondary | 12 959 | 32.7 | 91 | 0.7 | |
| Higher | 2385 | 6.0 | 5 | 0.2 | |
| Religion | | | |
| Hindu | 31 280 | 78.9 | 362 | 1.2 | 0.027 |
| Muslim | 6482 | 16.3 | 68 | 1.1 | |
| Christian | 814 | 2.1 | 6 | 0.7 | |
| Sikhs | 514 | 1.3 | 4 | 0.8 | |
| Others | 568 | 1.4 | 14 | 2.5 | |
| Caste/tribe | | | |
| Scheduled caste | 7945 | 20.1 | 99 | 1.2 | <0.0001 |
| Scheduled tribes | 3742 | 9.5 | 84 | 2.2 | |
| Other backward class | 15 878 | 40.2 | 173 | 1.1 | |

Table 1 Sample distribution and reported unadjusted prevalence of preeclampsia/eclampsia during pregnancy for the most recent live birth in the 5 years preceding the survey among women aged 15–49 years (n = 39 657) according to household cooking fuel use and other selected characteristics, India, 2005–2006
indoor air pollution and preeclampsia/eclampsia

The NFHS-3 received ethical approval from the International Institute for Population Science’s Ethical Review Board and the Indian Government. Participation in the survey was totally voluntary. The survey obtained written informed consent from each respondent (men and women) before asking questions, and separately before obtaining height and weight measurements and before blood collection for hemoglobin measurement. The analysis presented in this study is thus based on secondary analysis of existing survey data with all identifying information removed.

Results

Profile of the respondents and prevalence of symptoms of preeclampsia/eclampsia

Table 1 shows the distribution of the respondents by selected characteristics as well as the reported prevalence of preeclampsia/eclampsia in pregnancy by predictor variables. More than three-fourth of the sample women (78%) live in households using biomass and solid fuels (wood, dung cakes, crop residues or coal/lignite or charcoal) and one of five (22%) live in households using cleaner fuels (kerosene, liquefied petroleum gas/natural gas), coal/lignite or charcoal). In the survey, appropriate adjustments in these cutoff points were made for respondents living at altitudes above 1000 m and respondents who smoke, as both of these groups require more hemoglobin in their blood (Centers for Disease Control and Prevention, 2007). Analyses were conducted using the SPSS statistical software package version 19 (IBM SPSS Statistics, Chicago, IL, USA).

Ethical considerations

The NFHS-3 received ethical approval from the International Institute for Population Science’s Ethical Review Board and the Indian Government. Participation in the survey was totally voluntary. The survey obtained written informed consent from each respondent (men and women) before asking questions, and separately before obtaining height and weight measurements and before blood collection for hemoglobin measurement. The analysis presented in this study is thus based on secondary analysis of existing survey data with all identifying information removed.
nated pregnancy (1.4%); mild to moderate anemia (1.3–1.5%); underweight and normal weight (1.3%); current smokers (1.7%); current alcohol drinkers (2.6%); diabetics (1.6%); asthmatics (4.7%); no education (1.6%); other religion (2.5%); Scheduled Tribes (2.2%); households belonging to lowest wealth quintile (2.0%); residence in rural areas (1.4%) and residence in central part of India (1.7%).

Effects of cooking smoke on preeclampsia/eclampsia

Table 2 shows the estimated effects of household cooking fuel, and selected maternal, health and lifestyle factors and demographic and socioeconomic characteristics on the likelihood of preeclampsia/eclampsia symptoms among women in alternative models. Model 1 in Table 2 shows that unadjusted odds of reporting preeclampsia/eclampsia symptoms were more than three times higher (OR: 3.35; 95% CI: 2.36–4.76; P < 0.0001) among women living in households using biomass and solid fuels for cooking than among those living in households using cleaner fuels for cooking. Even when the seven socioeconomic and demographic variables, three maternal factors, and six health- and lifestyle-related factors are included in Model 2, cooking with biomass and solid fuels still has a large and statistically significant effect (OR: 2.21; 95% CI: 1.26–3.87; P = 0.003) on the likelihood of preeclampsia/eclampsia symptoms among women.

Effects of the confounders on preeclampsia/eclampsia

The discussion of the adjusted effects of the covariates/confounders focuses on the full model (Model 2) in Table 2. With other variables controlled, self-reported asthma (OR = 4.67; 95%: 2.53–8.62; P < 0.001), mild (OR = 1.40; 95%: 1.11–1.77; P = 0.004) and moderate (OR = 1.34; 95%: 1.02–1.76; P = 0.002) anemia, twin pregnancy (OR = 3.08; 95%: 1.64–5.80; P < 0.0001), and terminated pregnancy (OR = 1.44; 95%: 1.14–1.80; P = 0.002) were associated with a higher likelihood of women reporting preeclampsia/eclampsia symptoms. Women belonging to a scheduled tribe (OR = 1.66; 95%: 1.09–2.53; P = 0.002) also had a higher likelihood of reporting preeclampsia/eclampsia symptoms. Women with higher educational attainment (OR: 0.35; 95% CI: 0.13–1.00), and women residing in the western (OR: 0.56; 95% CI: 0.33–0.95) and southern region (OR: 0.25; 95% CI: 0.14–0.47) of India had a lower likelihood of reporting preeclampsia/eclampsia symptoms. The adjusted likelihood of women reporting preeclampsia/eclampsia symptoms did not vary significantly by urban/rural residence, wealth status of the household, religion, age of the women, and the presence of diabetes, alcohol drinking, tobacco smoking, BMI, and parity.

Table 2

| Characteristics                  | OR  | 95% CI | OR  | 95% CI |
|---------------------------------|-----|--------|-----|--------|
| **Household cooking fuel use**  |     |        |     |        |
| Clean fuel (ref)                | –   |        | –   |        |
| Biomass and solid fuel          | 3.35| 2.36–4.76 | 2.21| 1.26–3.87 |
| **Maternal factors**            |     |        |     |        |
| Total children ever born        |     |        |     |        |
| 1 (ref)                         | –   |        | –   |        |
| 2–3                             | 1.24| 0.96–1.61 | 1.19| 0.88–1.63 |
| 4+                              | 2.10| 1.62–2.72 | 1.29| 0.87–1.92 |
| **Type of pregnancy**           |     |        |     |        |
| Singleton (ref)                 | –   |        | –   |        |
| Twin                            | 2.65| 1.43–4.92 | 3.08| 1.64–5.90 |
| **Ever had a terminated pregnancy** |       |        |     |        |
| No (ref)                        | –   |        | –   |        |
| Yes                             | 1.34| 1.08–1.67 | 1.44| 1.14–1.90 |
| **Health and lifestyle factors**|     |        |     |        |
| Body mass index                 |     |        |     |        |
| Underweight (<18.5 kg/m²)       | 1.01| 0.83–1.23 | 0.92| 0.75–1.13 |
| Normal (18.5–22.9 kg/m²) (ref)  | –   |        | –   |        |
| Overweight (23.0–24.9 kg/m²)    | 0.65| 0.42–1.01 | 0.96| 0.61–1.50 |
| Obese (>25.0 kg/m²)             | 0.41| 0.24–0.69 | 0.86| 0.36–1.22 |
| **Current tobacco smoking**     |     |        |     |        |
| No (ref)                        | –   |        | –   |        |
| Yes                             | 1.50| 0.81–2.79 | 0.97| 0.51–1.83 |
| **Drinks Alcohol**              |     |        |     |        |
| No (ref)                        | –   |        | –   |        |
| Yes                             | 2.34| 1.54–3.57 | 1.29| 0.62–2.31 |
| **Diabetes**                    |     |        |     |        |
| No (ref)                        | –   |        | –   |        |
| Yes                             | 1.34| 0.66–2.72 | 0.87| 0.39–1.92 |
| **Asthma**                      |     |        |     |        |
| No (ref)                        | –   |        | –   |        |
| Yes                             | 4.33| 2.79–6.73 | 4.67| 2.53–8.62 |
| **Anemia level**                |     |        |     |        |
| Not anemic (ref)                | –   |        | –   |        |
| Mild                            | 1.54| 1.23–1.92 | 1.40| 1.11–1.77 |
| Moderate                        | 1.78| 1.37–2.31 | 1.52| 1.16–2.00 |
| Severe                          | 1.06| 0.47–2.42 | 0.89| 0.39–2.03 |
| **Background factors**          |     |        |     |        |
| Age                             |     |        |     |        |
| 15–29 (ref)                     | –   |        | –   |        |
| 30–39                           | 1.35| 1.10–1.66 | 1.04| 0.74–1.40 |
| 40–49                           | 1.25| 0.73–2.16 | 0.82| 0.46–1.45 |
| Education                       |     |        |     |        |
| No education (ref)              | –   |        | –   |        |
| Primary                         | 0.75| 0.59–0.99 | 1.03| 0.72–1.46 |
| Secondary                       | 0.45| 0.36–0.57 | 0.91| 0.64–1.29 |
| Higher                          | 0.14| 0.06–0.33 | 0.35| 0.13–1.00 |
| Religion                        |     |        |     |        |
| Hindu (ref)                     | –   |        | –   |        |
| Muslim                          | 0.92| 0.71–1.20 | 0.96| 0.70–1.32 |
| Christian                       | 0.64| 0.28–1.43 | 0.68| 0.25–1.84 |
| Sikhs                           | 0.68| 0.25–1.81 | 0.98| 0.35–2.77 |
| Others                          | 2.21| 1.30–3.77 | 1.81| 0.99–3.30 |
| **Caste/tribe**                 |     |        |     |        |
| Scheduled caste (ref)           | –   |        | –   |        |
| Scheduled tribes                | 1.81| 1.35–2.43 | 1.66| 1.09–2.53 |
| Other backward class            | 0.87| 0.68–1.12 | 1.14| 0.81–1.61 |
## Indoor air pollution and preeclampsia/eclampsia

The biological mechanisms of how air pollution leads to adverse pregnancy health and the exact etiologic mechanism discerning the effect of indoor air pollution on preeclampsia/eclampsia occurrence are not yet well understood partially because the condition is a multi-system disorder of unknown etiology (Sibai, 1998). However, it is known that particulate matter air pollution is capable of augmenting the development and progression of atherosclerosis and may potentially contribute to hypertension (Brook et al., 2010). Preeclampsia and vascular atherosclerosis may share common pathways in relation to pollutants (Dockitt and Harrington, 2005; Kaaja and Greer, 2005). Ambient air pollution has been directly correlated with endothelial dysfunction (Törnqvist et al., 2007), a precursor associated with preeclampsia (Steegers et al., 2010). It is suspected that emissions may also contribute to an anti-angiogenic state (Ejaz et al., 2009) that may in turn contribute to the development of preeclampsia (Young et al., 2010).

The other biological plausibility of air pollution (specifically fine particulate matter) affecting health has been discussed by Pope and Dockery (2006), focusing on exposure effects on blood pressure (Brook, 2008), aspects of substantial relevance to health during pregnancy (Yoder et al., 2009). There is increasing evidence that ambient air pollution may act via systemic inflammation and increased blood pressure (Brook, 2008; Brook and Rajagopalan, 2009; Lee et al., 2012), increasing the risk of cardiovascular mortality, adverse pregnancy outcomes (Rückerl et al., 2011; Stieb et al., 2012; Sun et al., 2010), and adverse birth outcomes (Bobak, 2000; Liu et al., 2003; Malmqvist et al., 2011; Slama et al., 2009; Wilhelm and Ritz, 2003). Other experimental and observational evidence also equally indicates that exposure to ambient air pollution, particularly ultrafine particles, induces oxidative stress and consequently inflammation (Redman and Sargent, 2003; Sibai et al., 2005; Terzano et al., 2010). Through

### Discussion

To our knowledge, our study is the first to empirically estimate the associations of indoor air pollution from biomass and solid fuel combustion and reported symptoms suggestive of preeclampsia/eclampsia in a large nationally representative sample of Indian women. We observed an increased risk of preeclampsia/eclampsia symptoms among women using biomass and solid fuel for cooking and the association remained significant when we adjusted for several maternal, health- and lifestyle-related factors and socio-demographic characteristics.

### Result in context of other studies

Recent studies that have linked ambient air pollution (mainly outdoor) to gestational hypertension, and preeclampsia were primarily based on developed countries (van den Hooven et al., 2009, 2011; Rudra et al., 2011; Lee et al., 2012; Pereira et al., 2013; Vinikoor-Imler et al., 2012; Wu et al., 2009, 2011), and there is limited empirical evidence of this association or association with indoor air pollution from household inefficient cooking fuel use and preeclampsia/eclampsia in India and other developing countries. Increased risk of gestational hypertension and preeclampsia among the mothers exposed to air pollution may explain the relationships between air pollution and adverse birth outcomes such as fetal growth restriction, low birth weight rate and preterm birth (Yurdakök, 2013). A recent US study found an association between first trimester PM10 and O3 air pollution exposures and increased blood pressure in the later stages of pregnancy (Lee et al., 2012). Maternal PM10 exposure was associated with an increased risk of pregnancy-induced hypertension (OR: 1.72; 95% CI, 1.12–2.63, per 10-μg/m3 increase) in 7006 women participating in a prospective cohort study in the Netherlands (van den Hooven et al., 2011). Another epidemiologic study showed that exposure to local traffic-generated air pollution during pregnancy increases the risk of preeclampsia and preterm birth (Pereira et al., 2013). In this study, the risk of preeclampsia increased 33% (OR: 1.33, 95% CI, 1.18–1.49) and 42% (OR: 1.42, 95% CI, 1.26–1.59) for the highest nitric oxides (NOx) and PM2.5 exposure quartiles, respectively.
systemic inflammation, some particles penetrate deeper into the lung are able to interact with immune cells and even exhibit systemic effects entering the bloodstream (Yurdakök, 2013).

Implications of indoor air pollution for prevention of pregnancy complications in India

The findings from this study suggests that there is an urgent need for public health actions in India, including more vigorous information campaigns designed to inform people about the risks of exposure to cooking smoke and programs to promote improved cooking stoves designed to reduce exposure to smoke by means of improved combustion and increased ventilation (Mishra, 2003) which could in turn thus minimize the adverse health effect including preeclampsia/eclampsia. Interventions that reduce the burden of biomass smoke exposure also are urgently required in India (Salvi and Barnes, 2010). Feasible low-cost measures that could reduce the devastating health outcomes of exposure to indoor biomass smoke include cooking outdoors, cooking for shorter periods, improving ventilation by adding more windows around cooking areas or by building chimneys above stoves, improving stove construction and technology, or encouraging the use of cleaner or energy-efficient fuels such as LPG, ethanol, or biogas (Salvi and Barnes, 2009). Substitution of traditional open fires with locally produced improved stoves has been shown to have significant health benefits (Chapman et al., 2005; Romieu et al., 2009; Smith-Sivertsen et al., 2009). To make community development programs effective, local needs and community participation should be given high priority (Mishra, 2003). Also, programs to reduce exposure to cooking smoke during pregnancy should be promoted, in addition to strengthening asthma prevention and treatment programs. Further, it is also important to increase awareness about the adverse health effects of solid fuel smoke inhalation, particularly during pregnancy, among physicians and health administrators as well (Salvi and Barnes, 2010), which may improve the diagnosis and treatment of affected patients and trigger preventive actions through education, research, and policy change. A focus on community education highlighting the harmful effect of biomass fuel smoke exposure may mobilize demand for improved stove installations and better household ventilation. This may also lead to the further development of community development programs and, specifically, strategies for poverty reduction, which are currently underway in India.

Implications of preeclampsia/eclampsia for prevention of pregnancy complications in India

India is in the midst of a demographic, epidemiological and nutrition transition characterized by a growing population, increasing urbanization, a shift in the patterns of diseases and changes in lifestyle (Shetty, 2002). The past decade has seen a dramatic increase in lifestyle-related non-communicable diseases including obesity, diabetes mellitus, high blood pressure, coronary heart disease, stroke, and cancers (WHO, 2003b). Given that preeclampsia shares many risk factors with cardiovascular disease (obesity, type-2 diabetes, high blood pressure among others), it is expected that the increase in cardiovascular disease risk factors in women of childbearing age could translate into a higher incidence of preeclampsia and its complications (e.g. eclampsia), thus increasing the risk to pregnant women in India. Ten percent of women have high blood pressure during pregnancy, and eclampsia and preeclampsia complicates 2–8% of pregnancies (Duley, 1992, 2009). The Millennium Development Goals have placed maternal health at the core of the struggle against poverty and inequality, as a matter of human rights. Increasing awareness of maternal mortality as a public health priority, for both maternal and child health, has been important and has helped implementation of improved health services in developing countries. Millennium Development Goal 5 calls for a reduction by three-quarters, between 1990 and 2015, in the maternal mortality ratio (www.un.org/millenniumgoals). Thus, with the target of the Millennium Development Goals in sight, preeclampsia/eclampsia needs to be identified as a priority area in reducing maternal mortality and morbidity in developing countries including India.

Strengths and weaknesses of the study

The main strength of the present study is the large nationally representative dataset from the National Family Health Survey, which allowed us to examine the effect of indoor air pollution from biomass and solid fuel combustion along with a range of socioeconomic, maternal, and health and lifestyle factors in relation to preeclampsia/eclampsia risk in the Indian women of childbearing age. A particular strength was that we had individual-level information on socioeconomic status which allowed for further investigations of the exposures and the outcomes of interest. Further, the large sample size provided adequate power to identify various risk factors and compensated for the large ethnic variations in Indian populations. Additionally, the survey was conducted using an interviewer-administered questionnaire in the native language of the respondent using local, commonly understood terms for pregnancy-related health problems. A total of 18 languages were used with back translation to English to ensure accuracy and comparability.

However, due to the general challenges of measuring hypertensive disorders in population-based studies, the
Indoor air pollution and preeclampsia/eclampsia

We observed an increased prevalence of self-reported symptoms suggestive of preeclampsia/eclampsia with exposure to indoor air pollution from biomass and solid fuel combustion in a large nationally representative sample of adult Indian women. These findings have important program and policy implications for countries such as India, where large proportions of the population rely on polluting biomass fuels for cooking and space heating and have an additional burden of high maternal and infant mortality and morbidity. Indoor air pollution is a major public health threat in India which requires greatly increased efforts in the areas of more intensive research and policy-making. Research on its health effects such as preeclampsia/eclampsia should be put forth and strengthened in addition to other health effects. A more systematic approach to the development and evaluation of interventions is required, with clearer recognition of the interrelationships between poverty and dependence on polluting fuels and exposure of vulnerable population.

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Agrawal & Yamamoto

Author's contribution

SA conceived the article. SA conducted the statistical analysis and wrote the first draft. SY reviewed and revised it for important intellectual content.

Conflict of interest

None.

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Agrawal & Yamamoto

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