Research article

Household air pollution exposure and respiratory health outcomes: a narrative review update of the South African epidemiological evidence

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Abstract
One of the greatest threats to public health is personal exposure to air pollution from indoor sources. The impact of air pollution on mortality and morbidity globally and in South Africa is large and places a burden on healthcare systems for treatment and care of air pollution-related diseases. Household air pollution (HAP) exposure attributed to the burning of solid fuels for cooking and heating is associated with several adverse health impacts including impacts on the respiratory system. The researchers sought to update the South African evidence on HAP exposure and respiratory health outcomes from 2005. Our quasi-systematic review produced 27 eligible studies, however, only four of these studies considered measures of both HAP exposure and respiratory health outcomes. While all of the studies that were reviewed show evidence of the serious problem of HAP and possible association with negative health outcomes in South Africa, no studies provided critically important information for South Africa, namely, local estimates of relative risks that may be applied in burden of disease studies and concentration response functions for criteria pollutants. Almost all of the studies that were reviewed were cross-sectional, observational studies. To strengthen the evidence of HAP exposure-health outcome impacts on respiratory health, researchers need to pursue studies such as cohort, time-series and randomised intervention trials, among other study designs. South African and other researchers working in this field need to work together and take a leap towards a new era of epidemiological research that uses more sophisticated methods and analyses to provide the best possible evidence. This evidence may then be used with greater confidence to motivate for policy-making, contribute to international processes such as for guideline development, and ultimately strengthen the evidence for design of interventions that will reduce HAP and the burden of disease associated with exposure to HAP in South Africa.

Keywords
environmental health, air quality, household emissions

Introduction
While episodes of unusually high air pollution attract attention and public health concern, the greatest damage to public health is associated with long-term exposure to air pollution (HEI 2017). Outdoor and indoor personal exposure to air pollution, combined, comprise the largest environmental risk factor for mortality, responsible for 6.4 million deaths in 2015 (11% of global deaths) (Cohen et al. 2017).

The costs of air pollution in Africa are high - estimated at around USD450 billion in 2013 (Roy 2016). The economic impacts include life years lost, increased healthcare (and subsequent demand on government) and lost worker productivity due to air pollution impacts on health.

Globally, epidemiological studies and systemic reviews have shown associations between exposure to household air pollution (HAP) and a variety of diseases and symptoms (Jedrychowski et al. 2017; Tanaka et al. 2012; Koo et al. 2011; Pope et al. 2010). The indoor environment represents an important microenvironment in which people spend approximately 90% of their time each day (WHO 2014a).

According to the World Health Organization (WHO), HAP is responsible for more than 1.6 million annual deaths globally, and 2.7% of the global burden of disease (WHO 2014b). HAP is reported to increase irritation of the airways, coughing, irregular heartbeat, difficulty breathing and premature death in people with heart and lung disease (Gurley et al. 2013; Laumbach and

Kipen, 2012; Ritz and Wilhelm, 2008). Exposure further worsens existing respiratory diseases such as bronchitis, cardiovascular disease and emphysema (Laumbach and Kipen, 2012; Fisk et al. 2010; Rinne et al. 2006). Exposure to solid fuel burning indoors has also been associated with tuberculosis (TB) (Jafta et al. 2015; Lin et al. 2014), cataract (Ravilla et al. 2016) and adverse birth outcomes (Wylie et al. 2017; Pope et al. 2010).

HAP is derived from multiple indoor sources (Colbeck and Nasir 2010) varying from one building to another and depending on fuels used for heating and cooking, smoking habits and use of a wide variety of consumer products and building materials (Shezi et al. 2017; Jafta et al. 2017; Tanaka et al. 2012; Verma et al. 2010). This is also influenced by time activity patterns i.e. cooking period, number of meals cooked, single or multiple fuel use and number of cigarettes smoked and further compounded by confounding variables such as outdoor air pollution sources near the homes (Shezi et al. 2017; Colbeck and Nazir 2010). In developing countries, the most significant indoor air quality issue is exposure to pollutants released during combustion of solid fuels used for cooking and heating in the home (Wylie et al. 2017; Pope et al. 2010).

The measured mean concentrations of the HAP vary depending on the sources, for example, average particulate matter with an aerodynamic diameter of 2.5 ($PM_{2.5}$) concentration in households using solid fuels has been reported to range from 133.5 μg/m^3 to 670 μg/m^3 (Balakrishnan et al., 2015; Balakrishnan et al., 2013; Clark et al., 2010), while the carbon monoxide (CO) average concentrations have been reported to range from 2.7 ppm to 14.3 ppm. The average $PM_{2.5}$ concentrations in households using cleaner fuels have been reported to range from 10 μg/m^3 to 38 μg/m^3 (Shezi et al. 2017; Tunno et al., 2015; Evans et al. 2000). Studies conducted in South Africa have also reported high mean concentrations in households using both clean and dirty fuels (Jafta et al. 2017; Shezi et al. 2017; Wernecke et al 2015; Rollin et al. 2004) which exceed the guidelines set out by the WHO for indoor air quality in households; South African indoor air quality guidelines pertaining to household air pollution are under review and have not yet been promulgated.

South Africa is a middle-income country burdened by poverty and inequality where many South Africans are exposed to biomass fuels used for cooking and heating indoors. Many families live in close proximity to industrial areas and major roads (Albers et al. 2015; StatsSA 2012; Norman 2007) where outdoor pollutants may also be transported indoors (Colbeck and Nasir 2010). Vulnerable groups such as people who are elderly, women, young children, people with pre-existing diseases and people living in poverty are more susceptible to air pollution health impacts (Barnes 2014).

The WHO comparative risk assessment determined the mortality burden and Disability Adjusted Life Year (DALYs) due to HAP. HAP associated with household solid fuel use for cooking and heating caused 0.5% of all deaths in South Africa in 2000 (uncertainty 0.3% -0.6%) (Norman et al., 2010). More than 10 years ago, Wichmann and Voyi (2005) published a review of the air pollution and health epidemiological studies in South Africa, focussing on methodological issues and the need for quantitative intervention studies. In 2014, Barnes (2014) described behavioural change studies for reduction of HAP in developing countries, calling for more rigorous study design and interventions grounded in behavioural change theory. In recent years, anecdotal evidence suggests that studies on the impact of HAP and associated respiratory health outcomes has been growing in South Africa (Barnes et al., 2009). In this narrative review, evidence from the recently published South African studies that considered HAP exposure and associated respiratory health outcomes to augment our current knowledge is collated. An attempt to identify research gaps and suggest directions for further studies is made.

Review methods

A quasi-systematic (i.e. following the guidelines for systematic review but with slight differences in methods to accommodate all available evidence) review of the South African evidence on HAP (term group 1) and associated respiratory health outcomes (term group 2) was conducted using the PRISMA guidelines (Moher et al. 2009). PubMed, Web of Science, Science Direct and Google Scholar were searched for studies with full text in English, published between 2005 and 2017. The term groups listed in Table 1 were used for the separate searches and in various combinations. The reference lists of included papers were searched to ensure that no studies were omitted.

Table 1: *Search strategy applied to retrieve published articles reporting on household air pollution and respiratory health outcomes associated with household air pollution in South Africa.*

Term group 1	Term group 2	Combinations
Household air pollution OR indoor air pollution OR air pollutants OR biomass OR solid fuel OR cooking fuel OR heating fuel OR wood smoke OR wood burning OR paraffin OR dung OR coal burning OR indoor air OR particulate matter OR carbon monoxide OR nitrogen dioxide OR sulphur dioxide	Respiratory health outcomes OR asthma OR bronchitis OR wheeze OR pneumonia OR runny nose OR cough OR lower respiratory tract infection OR upper respiratory tract infection	Term from Group 1 plus Term from Group 2 until all combinations exhausted

To be eligible, studies had to have been carried out in South Africa. All epidemiological study designs including cross-sectional studies, cohort studies, longitudinal studies, case-cross-over studies, intervention studies etc. were eligible. All studies that provided estimates of HAP exposure concentrations (by indicator, proxy or actual measurements) as well as respiratory health outcomes found to be associated with HAP exposure were included. We noted whether the correlate and health outcome was measured at the level of the individual, household or community. The review was not restricted by defining a minimal study sample size and studies of all sample sizes were included.

Results

After removing all ineligible articles, mostly since they were studies unrelated to South Africa, our searches using both formal methods (described above) and informal means (such as personal communication with researchers) produced a total of 27 articles. Of this total, only 4 studies measured HAP exposure (mainly by proxy/indicators of air pollution exposure) and respiratory health outcomes. Ten studies assessed HAP but no respiratory health outcome(s) and the remaining 13 studies did not measure HAP, instead used ambient AQ monitoring station data (or other) for exposure assessment.

Table 2 describes in brief the four studies that included HAP exposure monitoring and associated respiratory health outcomes by type of study, setting, sample size, methods, exposure information and outcome results. None of the studies measured HAP, instead, they used indicators or proxies for exposure, such as presence of environmental tobacco smoke (ETS) and fuel used for cooking and / heating in the home. Elf et al. (2017) used passive samplers to measure ETS. All of the studies were cross-sectional epidemiological study designs and the largest sample size was ~ 3 000 schoolchildren (Shirinde et al., 2014) with the other three studies having sample sizes of less than 1 000 individuals (no sample size calculations were provided). One study did not set out to measure HAP but rather focussed on ETS exposure.

Inter-comparison of the findings of the studies is difficult due to the heterogeneity in the study design, target population and health outcomes of interest. Both Albers et al. (2015) and Shirinde et al. (2014) found that among schoolchildren (albeit of different ages) there was an association between respiratory outcomes (most notably wheeze) and use of non-electrical heating sources. Elf et al. (2017) and du Preez et al. (2011) consider TB as a health endpoint and ETS and solid fuel use, and ETS, respectively, in relation to TB.

Tables 3 and 4 summarise the remaining studies that the researchers reviewed as part of this review exercise. These studies did not meet the study inclusion criteria; however, they do provide useful information on the levels of various air pollutants in the indoor and outdoor environments of different parts of South Africa. Since they did not mention respiratory health outcomes, the researchers do not discuss them in detail here, but included them as a reference for future research.

Of the twenty-three studies listed in Table 3 and 4, two studies were review articles, six studies used questionnaires and interviews which are methods of assessment that are based on self-report and recall. Either indoor and / or outdoor pollutants were measured in 15 studies and some of the studies measured multiple pollutants. Particulate matter with an aerodynamic diameter of 10 (PM_{10}) was measured in twelve studies while $PM_{2.5}$ and particulate matter with an aerodynamic diameter of 4 (PM_4) were measured in four and two studies, respectively. Two studies measured respiratory particulate matter (RPM). NO_2 was measured in five studies; NO_x in one study and volatile organic compounds were also measured in one study. Three studies measured CO and seven studies measured sulphur dioxide (SO_2). Ozone (O_3) was measured in one study and total reduced sulphur was also measured in one study. Indoor undisturbed dust samples were undertaken in one study to analyse for dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyl-dichloroethylene (DDE) and dichlorodiphenyl-dichloroethane (DDD), while settled dust and airborne fungal sampling was also conducted in one study.

Discussion

Few published studies conducted in South Africa in recent years have sought to show associations between HAP and respiratory health outcomes. All of the studies that did so used cross-sectional study design. This is unfortunate since most international systematic reviews for HAP exposure and health outcome association only use data from cohort, time series, long-term panel (longitudinal) and case-crossover studies. Our studies are therefore not contributing to international evidence on this important topic, nor are they providing reliable evidence that is generalizable to others parts of South Africa. While cross-sectional studies are typically less expensive and easier to implement compared to other epidemiological study designs, the data produced from cross-sectional studies is not as useful and the lack of randomisation, among other shortfalls, prohibits generalisation. Researchers need to work towards larger, more complex epidemiological studies and also use of existing, high quality (where possible) data in South Africa that will help to address the problem of HAP and respiratory health. While it will likely cost more, other study designs beside cross-sectional studies, will provide opportunities for HAP monitoring over substantial periods of time to provide exposure information that can then be associated with health outcomes, preferably diagnosed by a health professional (and not self-reported or parent-reported) for more precise results, in a more meaningful way.

It is also important to account for potential biases and critical confounders, including age, sex, and individual socio-economic status, among others, when planning a HAP and respiratory health study, and also when reporting study results as failure to control for confounding variables can lead to erroneous associations between HAP and respiratory outcomes.

While the reviewed studies predominantly report on combustion generated variables (type of fuel used for cooking or heating and active or passive smoking) with PM, CO and NO_2, being products of incomplete combustions, other sources of indoor air pollutants not necessarily emitted by incomplete combustion such as building materials, ventilation characteristics and cleaning agents may not be ignored.

While, exposure data misclassification and validity of exposure are often overlooked or underestimated and not critically discussed (Wichmann and Voyi, 2005), the lack of direct exposure measurement such as the use of home monitors and personal monitors present results that are in some part questionable.

None of the studies reviewed provided concentration response functions for the criteria air pollutants in South Africa (DEA, 2009). This point was made by Wichmann and Voyi (2005) and it still holds true in 2017. This is still a major gap in our knowledge in both South Africa and on the continent. South African researcher continue to use the international literature and WHO evidence, without making contribution to this important body of knowledge.

Another shortfall is that only one study reviewed in this exercise was an intervention study (under real life conditions). The WHO calls for the support of research that is driven by interventions and searching actively for solutions, in particular for urban settings, in relation to air pollution and health (WHO 2014). In South Africa, research partnerships and consortia may assist to create large research teams to lead intervention studies to address HAP and adverse health impacts in areas of greatest concern.

Our study had some limitations. There were very few studies to critically review hence the researchers opted to describe them descriptively instead. Wichmann and Voyi (2005) provided a critical synthesis of the evidence in this field up to 2005. The authors did not find a substantial number of studies to add to that body of literature beyond 2005. The authors set out to find studies that had measured HAP and simultaneously measured respiratory health outcomes. The authors may have not identified all studies relevant to the review inclusion criteria, although they tried to avoid this by searching the literature regularly and speaking with South African researchers in the air pollution and health fields. The authors did not consider mortality as an end-point. Wichmann and Voyi (2006) found that exposure to cooking and heating smoke from polluting fuels was significantly associated with 1–59-month mortality, after controlling for mother's age at birth, water source, asset index and household crowdedness (RR=1.95; 95% CI=1.04, 3.68).

Conclusions

The South African studies on HAP and respiratory health outcomes do provide some evidence of the serious impacts of HAP and especially the use of solid fuels in the home on respiratory health in the country, but the studies are few and limited. South African and other researchers working in this field need to work together and take a leap towards a new era of epidemiological research that uses sophisticated methods and analyses to provide the best possible evidence. This evidence may then be used with greater confidence to, for example, motivate for policy-making, contribute to international systematic reviews for guideline development and other purposes, and ultimately strengthen interventions that will reduce HAP and the burden of disease associated with exposure to HAP in South Africa.

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Table 2: *Findings from studies on household air pollution exposure (most often using a proxy) and associated respiratory health outcomes in South African settings.*

Author(s) (year)	Study design	Population/Setting	Sample size	Exposure	Reported associations between HAP and respiratory outcomes
Elf et al (2017)	Convenience sample of homes and household members participating in an ongoing active case-finding study	All adults (≥ 18 years of age) and children between 7-17 years of age living in the same household as the index tuberculosis (TB) case, including the index cases themselves in Matlosana district townships surrounding Klerksdorp were included in this air pollution study.	124	The household survey assessed the primary and secondary fuel use, duration of use for both heating and cooking in the households. Individual questionnaire collected information on tobacco use and environmental tobacco smoke (ETS) exposure. Passive and nicotine monitors were placed in the common living space of each home for a period of 14 days.	A high prevalence of air pollution from second hand smoke, solid fuels, and kerosene among individuals in homes with a case of prevalent active tuberculosis disease was observed. Adults in 40% of homes reported a daily smoker in the home, and 70% of homes had detectable air nicotine. In homes with a history of previous TB (prior to but not including the index case) as compared to those without previous tuberculosis, both second hand smoke (83% vs. 65%, respectively) and solid / kerosene fuel use for more than 1 h/day (27% vs. 21%, respectively) were more prevalent.
Albers et al (2015)	Cross-sectional study	Children 9-11 years old in grades 4 and 5 in six randomly selected primary schools in eMalahleni and Middelburg, Mpumalanga.	627	Type of energy sources and associated respiratory outcomes were collected using a structured questionnaire completed by parents/guardians of the children.	Past 6 months doctor-diagnosed bronchitis 66/422 (15.6 %); 'Ever' during childhood to date doctor-diagnosed asthma 39/551 (7.1 %); self-reported chest wheeze 59/519 (11.4 %); chest cough 45/445 (10.1 %); phlegm on the chest 123/481 (25.6 %); any respiratory health condition 214/627 (34.1 %). Overall prevalence of respiratory ill-heath was 34.1%. The prevalence of respiratory ill-health conditions was significantly elevated among children from households using non-electrical fuels v. electricity for cooking (43.9% v. 31.6%; adjusted p-value 0.005). The same was noted among those using non-electrical fuels for heating (37.8% v. 29.0%).
Shirinde et al (2014)	Cross-sectional study	Children (12 - 14 years) from 16 randomly selected schools in Thembisa and Kempton Park in the Ekurhuleni Metropolitan Municipality.	3 424	Information on active and passive smoking at home and at school, type of energy sources for cooking and heating at home, transportation mode to school and frequency of trucks passing near residences was collected using a questionnaire.	Exposure to ETS at school was associated with wheeze ever (OR 1.22 95% CI: 1.03-1.45) and current wheeze (OR 1.33 95% CI: 1.08-1.64). In households that reported frequent use of gas for residential heating, the likelihood of wheeze ever increased by 47% (OR 1.47 95% CI: 1.15-1.88). An increased likelihood of wheeze ever (OR 1.32 95% CI: 1.01-1.73), current wheeze (1.61 95% CI: 1.15-2.24) and current severe wheeze (OR 2.22 95% CI 1.28-3.77) was associated with trucks passing near homes for almost the whole day during weekdays.
du Preez et al (2011)	Cross-sectional study	Children based in Cape Town, aged 3-15 years who had contact with an adult starting clinic-based anti-TB treatment in the preceding 3 months were recruited.	196	Questionnaire was used to collect information on ETS exposure.	From the 65.3% children that reported ETS exposure, 49.5% were *M. tuberculosis* infected of these 63.3% were exposed to ≥2 household smokers.

Table 3: *Findings from studies that assessed indoor pollution exposure in South African settings but did not quantify respiratory health outcomes and / or investigate the association between household air pollution exposure and respiratory health outcomes.*

Author(s) (year)	Study design	Population/Setting	Sample size	Exposure	Reported associations between HAP and respiratory outcomes
Jafta et al. (2017)	Cross-sectional study	Children (<15 years of age) who participated as cases or controls in the TB study within eThekwini Municipality.	246 house-holds	Homes were assessed using a walkthrough checklist and indoor monitoring was conducted in 105 homes over a period of 24 hours for PM with an aerodynamic diameter of 10 (active) and 82 homes were monitored for SO_2 and NO_2 (passive) for a period of 2-3 weeks.	Mean indoor concentrations of PM_{10}, NO_2 and SO_2 were 64 µg/m³ (range 6.6–241.0); 19 µg/m³ (range 4.5–55.0) and 0.6 µg/m³ (range 0.005–3.4), respectively.
Shezi et al. (2017)	Cross-sectional study	Households of pregnant females from the north and the south of Durban participating in the mother and child in the environment (the MACE cohort study).	300 house-holds	Walk-through indoor assessment and post-activity questionnaire were used to collect information on the household building materials, occupant activities and outdoor sources such as industries and major roads in the vicinity of the homes. Indoor $PM_{2.5}$ levels were measured in 300 homes for a period of 24 hours.	The $PM_{2.5}$ levels ranged from 1.4 to 162.0 µg/m³. The mean (SD) of these levels was 38.3 (31.1) µg/m³, and the median was 28.0 µg/m³.
Nkosi et al. (2017)	Cross-sectional study	Children, including 10 asthmatics 13-14 years of age, a subset of the 2012 International Study of Asthma and Allergies in Children (ISAAC) from 10 schools in Gauteng and the North-West Province were included. Five schools were within 1- 2 km from a mine dump in Gauteng or the North-West Province and 5 were 5 km or further from a mine dump in these provinces.	100 children	Personal air sampling was performed in the breathing zone of 10 asthmatics learners randomly selected from each school, outdoor SO_2 and PM_{10} were measured for 8-h at each school.	Indoor respiratory dust in the classroom differed significantly between exposed (0. 17mg/m³) and non-exposed (0. 01 mg/m³) among children with asthma. Outdoor SO_2 levels were 0.002 ppb for exposed children and 0.01 ppb for unexposed children ($p<0.001$). Outdoor PM_{10} was 16.42 mg/m^{-3} and 11.47 mg.m^{-3} for exposed and unexposed, respectively.
Language et al. (2016)	Panel study	KwaDela, Mpumalanga, South Africa	20 house-holds	Indoor (PM_4) and ambient ($PM_{2.5}$, PM_{10}) air pollution monitoring in 20 households over two years: two summers and two winters (10-12 weeks each); 207 household questionnaires were administered to determine household energy use and perceived quality of life.	The majority (97.10%) of households had access to electricity, however, there was still a high rate of solid fuel use – coal (75.36%) and wood (63.28%). 40.57% of households used a combination of these fuels. Ambient PM_{10} concentrations were 102.1 ± 76.96 and 99.29 ± 61.39 (µg/m³), respectively, and summer concentrations were 50.43 ± 29.59 and 66.03 ± 25.86 (µg/m³). $PM_{2.5}$ concentrations showed less seasonality compared to PM_{10}. Finer aerosols were lower than the coarse fraction by a factor of 4 to 5 (winters) and 2 to 3 (summers).

Table 3 continued ...

Author(s) (year)	Study design	Population/Setting	Sample size	Exposure	Reported associations between HAP and respiratory outcomes
Wernecke at al. (2015)	Case study	KwaDela, Mpumalanga, South Africa.	1 house-hold	Indoor (PM_4) and ambient ($PM_{2.5}$, PM_{10}) air pollution monitoring in 20 households in winter 2013 and 2014 and summer 2014 and 2015; data presented for winter 2014.	Mean outdoor $PM_{2.5}$ and PM_{10}, indoor PM_4 and personal PM_4 concentrations were 27±18 and 48±122 and 17±23 and 16±7 μg/m^3, respectively.
Gaspar et al. (2015)	Cohort study	Households of women from the VHEMBE study on indoor spraying for malaria and health effects.	50 house-holds	Indoor undisturbed dust samples analysed for dichlorodiphenyltrichloroethane (DDT), and its degrading products, dichlorodiphenyl-dichloroethylene (DDE) and dichlorodiphenyl-dichloroethane (DDD) to determine dust loading levels and compared these levels to paired serum concentrations of p,p′-DDT-and p,p' DDE in women residents.	p,p′-DDT and p,p′-DDE had the highest detection frequencies in both dust (58% and 34% detection, respectively) and serum samples (98% and 100% detection, respectively). Significantly higher detection frequencies for o,p′-DDT, p,p′-DDE, and p,p′-DDD were observed in dust samples collected in buildings that had been previously sprayed for malaria control. Significant, positive association between dust loading and serum concentrations of p,p′-DDT and p,p′-DDE (Spearman's rho=0.68 and 0.54, respectively) was observed.
Vanker et al. (2015)	Prospective cohort study	Pregnant women (20–28 weeks' gestation) from the Drakensberg Child Health study (DCHS) an African birth cohort.	633 women	Indoor air monitoring of PM_{10}, CO was conducted for a period of 24 hours, while indoor NO_2 and volatile organic compounds (VOC) were conducted for a period of 2 weeks.	31% were active and 44% passive smokers. Of HAP measured, benzene (VOC) was significantly above ambient standards with median 5.6 μg/m^3 (IQR 2.6–17.1). There were significant associations between the use of fossil fuels for cooking and increased benzene [OR 3.4 (95% CI 2.1–5.4)], CO [OR 2.9 (95% CI 1.7–5.0)] and NO_2 [OR 18.6 (95% CI 3.9–88.9)] levels. A significant seasonal association was found with higher benzene and CO levels in winter.
Jafta et al. (2012)	Cross-sectional study	Households of children (20 children from each of 7 schools, Grades 3-6) (mainly asthmatics) who took part in the South Durban Health Study.	135 house-holds	Observation (walk through survey), sampling and analyses of settled dust and airborne fungal sampling.	Asp f1 allergen was detected in all homes, and Bla g1 allergen was detected in half of the homes. Detection frequencies varied from 51% for Bla g1 to 100% for Asp f1. House dust allergens, Der f1 and Der p1 exceeded concentrations associated with risk of sensitization and exacerbation of asthma in 3% and 13%, respectively, of the sampled homes, while Bla g1 exceeded guidance values in 13% of the homes. Although airborne fungal concentrations in sleep areas and indoors were lower than outdoor concentrations, they exceeded 1 000 colony forming units per cubic meter of air in 29% of the homes.

Table 3 continued ...

Author(s) (year)	Study design	Population/Setting	Sample size	Exposure	Reported associations between HAP and respiratory outcomes
Pelzer et al. (2011)	Cross-sectional study	Secondary analysis of the Global Youth Tobacco Survey conducted in South Africa among current non-smoking school going adolescents (aged 11-18 years). A two-stage cluster sample design was used to produce representative data.	6 412	Exposure assessment data on active and passive smoking was extracted from the Global Youth Tobacco Survey for analysis.	25.7% of students were exposed ETS at home, 34.2% outside of the home. Parental and close friend smoking status, allowing someone to smoke around you and perception that passive smoking was harmful were significant determinants of adolescent's exposure to both ETS at home and outside of the home.
Barnes et al. (2011)	Intervention study	The study took place in two poor rural villages in the North-West Province.	Interven-tion group (n=36) and control group (n=38)	The study employed a quasi-experimental before and after study design with a control group. Baseline data was collected during winter in both the intervention and control group. Follow-up data was collected from both groups 12 months later. The intervention was implemented immediately after the baseline data collection in the intervention group only. The following were promoted (burn outdoors when possible, if fires are burned indoors, open at least two sources of ventilation during peak emission times, reduce the amount of time that children spend in the burning room while fires are burning).	Both groups reduced indoor air pollution indicators between baseline and follow-up. In the intervention group, the median before-after reduction in PM_{10} equalled 17% ($p<.01$), CO equalled 11% ($p=.15$) and CO (child) equalled 47% ($p=.02$). In the control group, the median reduction in PM_{10} equalled 28% ($p=.01$), CO equalled 21% ($p=.46$) and CO (child) equalled 57% ($p=.09$).

Table 4: *Findings from other recently published studies relevant to our understanding of air pollution and health in South Africa but excluded from this review for reasons stated in the right-hand column. Mostly, these studies did not measure household air pollution exposure but are included here for completeness.*

Author(s) (year)	Study design	Population/ Setting	Sample size	Exposure	Estimates	Missing information
Amegah and Agyei-Mensah (2017)	Narrative review paper	Sub-Saharan Africa.	-	Ambient and indoor air pollution.	South Africa and Accra reportedly have the best air quality programmes in the Sub-Saharan region. Lack of political will is likely to be a major challenge and requires World Health Organization and United Nations Environment Programme to continually engage governments to view air pollution as a major environmental and public health problems.	No exposure measurements or health outcomes included in the review.
Morakinyo et al. (2017)	Human health risk Assessment	Pretoria West area situated near the coal-fired power station, metallurgical industries such as a coke plant and a manganese smelter.	-	Ambient air monitoring of PM_{10}, NO_2, SO_2, CO and O_3, was performed using US Environmental Protection Agency human health risk assessment framework.	Mean annual concentrations for PM_{10}, SO_2 and NO_2 were 48.3±43.4, 18.68±25.4 and 11.50±11.6 µg/m^3, respectively. The mean 24-h CO and O_3 concentrations were 618.30±618.30 and 22.15±7.96 µg/m^3, respectively.	Ambient air pollution monitoring data. No IAQ measurements.
Shirinde et al. (2015)	Cross-sectional study	Children (12-14-years) selected from 16 Thembisa and Kempton Park schools in the Ekurhuleni Metropolitan Municipality.	3 424	Questionnaires to determine the association between eczema and exposure to ETS.	The likelihood of eczema ever was increased by exposure to ETS.	Eczema is not a respiratory health outcome.
Nkosi et al. (2015)	Cross-sectional study	Study on wheeze, asthma, and rhino conjunctivitis associated with community proximity to mine dumps. The study focussed on 13-14-year old pupil who attended schools located between 1-2 km from mine dumps and those living >5 km away from the mine dumps in the Gauteng and North-West province.	3 641	Self-administered questionnaire on asthma and rhinitis (among others) was completed by the adolescent living at a certain distance (within 1-2 km -exposed and >5 km -unexposed) from five pre-selected mine dumps.	Living close to mine dumps had an increased likelihood of current wheeze OR 1.38 (95% CI: 1.10-1.71), rhino-conjunctivitis OR 1.54 (95% Cl 1.29-1.82) and a protective association with asthma OR 0.29 (95% CI: 0.23-0.35).	No exposure measurement. Proximity to mine dump proxy for exposure.

Table 4 continued ...

Author(s) (year)	Study design	Population/ Setting	Sample size	Exposure	Estimates	Missing information
Nkosi et al. (2015)	Cross-sectional study	Elderly persons situated near mine dumps 1-2km (exposed) and 5km (unexposed).	2 397	Questionnaire was used to collect information on respiratory outcomes.	Elderly people living 1-2km away from the mine dumps had a significant association with asthma (OR= 1.57, 95% CI: 1.20-2.05), chronic bronchitis (OR=1.74; 95% CI:1.25-2.39), chronic cough (OR=2.02; 95% CI: 1.58-2.57), emphysema (OR=1.75; 95% CI:1.11-2.77), pneumonia (OR=1.38 95% CI 1.07-1.77) and wheeze (OR =2.01; 95% CI: 1.73-2.54).	No exposure measurement. Proximity to mine dump proxy for exposure.
Jafta et al. (2015)	Review and meta-analysis of case-control studies of children <15 years with TB	For years 1953 – 2014, included articles of children below 15 years exposed to indoor air pollution in relation to TB.	11 studies	Studies published in peer reviewed journals and written in English or translated into English related to laboratory-confirmed childhood TB and exposure to ETS and bio-mass fuel smoke were searched from PubMed, Science Direct and Web of Science.	Exposure to ETS was found to be associated with tuberculosis.	Only two South African articles were reviewed and the main author was based in South Africa.
Reddy et al. (2015)	A multistage stratified cluster South African representative sample of households selected from the South African National Health and Nutrition Examination survey.	Adults (>18 years of age) from 10 000 households in all 9 provinces who participated in National Health and Nutrition Examination Survey (2012).	13 897	Information on smoking habits was extracted from the South African National Health and Nutrition Examination Survey.	17.6% (95% CI: 6.3 - 18.9) currently smoked tobacco. Males (29.2%) had a higher prevalence than females.	No IAQ measurements. Active smoking as a proxy for exposure.
Ayo-Yusuf et al. (2014)	Cross-sectional study	Adults aged ≥16 years who participated in the 2010 South African Social Attitudes Survey.	3 094	Secondary data analyses of samples drawn from the 2010 master sample was conducted. Information on the active and passive smoking was drawn from the survey data.	Overall, 55.9% of all non-smokers reported exposure to second hand smoke from at least one source (i.e., in the home, workplace or at a hospitality venue).	No IAQ measurements. ETS as a proxy for exposure.

Table 4 continued ...

Author(s) (year)	Study design	Population/ Setting	Sample size	Exposure	Estimates	Missing information
Thabethe et al. (2014)	Human health risk assessment	Residents of a low-income community near Secunda in Mpumalanga, South Africa.	Community	PM_{10} monitoring for one month during winter and summer.	The residents were exposed to higher concentrations of PM_{10} during winter (24-h exposure of 157.37 μg/m^3).	Ambient air pollution monitoring data. No IAQ measurements.
Naidoo et al. (2013)	Cross-sectional study	Children from randomly selected Grade 4 classrooms in four areas in South Durban (industrial) and three in North Durban (non-industrial) plus all children from grade 3 - 6 in the same schools who were asthmatic between 2004 and 2005.	341	Interviews with children and their caregivers; spirometry, methacholine challenge tests and skin prick tests were conducted by experienced respiratory technicians on all participants. Those without a baseline obstructive pattern underwent methacholine testing. Ambient monitoring of SO_2, NO_x, $PM_{2.5}$ and PM_{10} was conducted.	The adjusted odds ratios (AORs) were elevated ($p<0.05$) for children in the south for 5 of the 13 outcomes investigated: doctor-diagnosed chronic bronchitis (AOR 3.5, 95% confidence interval (CI) 1.6 - 7.7), as well as bronchitis by symptom definitions; watery/ itchy eyes; wheezing with shortness of breath; and marked airway hyper reactivity (AHR). In addition, marked AHR was associated with SO_2 exposure. The prevalence of symptoms consistent with asthma of any severity was 32.1%. Covariate-adjusted prevalence were higher among children from schools in the south than among those from the north for persistent asthma (12.2% v. 9.6 %) and for marked airway hyper reactivity (AHR) (8.1% v. 2.8%), while SO_2 resulted in a two-fold increased risk of marked AHR (95% CI 0.98 - 4.66; p=0.056).	Ambient air pollution monitoring data. No IAQ measurements.
Wichmann and Voyi (2012)	Case cross-over study	All deaths that occurred in the entire Cape Town metropolitan municipality during 2001–2006.	149 667	Investigated all deaths during 2001-2006 in Cape Town to determine the association between average ambient PM_{10}, SO_2 and NO_2 levels and daily respiratory diseases, cardiovascular diseases and cerebrovascular diseases mortality in Cape Town.	Association (excess mortality risk) between PM_{10}, and respiratory disease, cardiovascular disease and cerebrovascular disease mortality of 1.1% (CI −1.1, 3.3), 1.7% (CI −0.1; 3.5 and 3.2% (CI 0.3; 6.2) following a 10 μg/m^3 increase (entire year data) respectively; association between NO_2 and respiratory disease mortality of 1.7% (CI −1.3; 4.7), following a 10 μg/m^3 increase (entire year data) between NO_2, and cardiovascular disease and cerebrovascular disease mortality of 2.6% (CI 0.2; 5.0) and 6.6% (CI 2.4; 11.0) following a 10 μg/m^3 increase (entire year data), respectively.	Ambient air pollution monitoring data. No IAQ measurements.

Table 4 continued ...

Author(s) (year)	Study design	Population/ Setting	Sample size	Exposure	Estimates	Missing information
Reddy et al. (2012)	Cohort study	African children (between 9–11 years old) who formed part of the South Durban Health Study.	129	Questionnaires was administered, information included the presence and severity of asthma, wheezing, coughing, chest tightness, shortness of breath, exposure to cigarette smoke. GSTM1 and GSTP1 genotypes were determined. Intensive monitoring of SO_2, NO_2 and PM_{10} was conducted over a three-week period.	Relatively modest, and not entirely consistent, interaction effects of the GSTM1 and GSTP1 polymorphisms were found. Among the 24 pollutant-lag combinations examined, for GSTM1, in only one of the four that showed statistically significant pollutant-genotype interactions, was the effect in the expected direction of those with GSTM1 null having greater pollution associated increases in FEV1 intraday variability.	Ambient air pollution monitoring data. No IAQ measurements.
Kistnasamy et al. (2008)	Cross-sectional study	The study was conducted at the primary schools situated near industrial areas, the prevalence of symptom-defined asthma and nonspecific bronchial hyper-reactivity was examined.	248	Ambient monitoring of SO_2, oxides of nitrogen, and PM_{10}. Questionnaire was also used to collection information on the number of smokers in the participants' households.	The odds of developing bronchial hyper-reactivity and persistent asthma was 0.64 (95% CI: 0.32 - 1.28) and 1.13 (95% CI: 0.61 - 2.09), respectively among the children with one or more smokers compared to children who lived in households with non-smokers.	Ambient air pollution monitoring data. No IAQ measurements.