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Indoor and Outdoor Air Pollution- related Health Problem in Ethiopia: Review of Related Literature

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Abstract

Background—The health effects of air pollution are generally global problems, but they have, since recently become issues of particular concern for developing countries. This review assessed the situation of air pollution and related health effects in the context of Ethiopia.

Methods—The materials reviewed in this publication are published scientific papers from online search engines, unpublished government reports and academic theses/dissertations. In addition, interview data obtained from authorities and experts involved in the management of air quality were analyzed, interpreted and reported in the article.

Results—Review of the few studies conducted in Ethiopia showed that average concentrations of $PM_{2.5}$ reached as high as 280 μg/m^3 for 24-hour measurements (range: 2,417–12,739 μg/m^3). Indoor carbon monoxide (CO) levels were universally higher than regulatory limits for the United States and were found to be much higher among households using traditional stoves and solid biomass fuels. The use of traditional stoves and solid biomass fuels was reported in >95% of the households considered. High average levels of NO_2 (97 ppb) were reported in a large longitudinal study. The ambient PM_{10} level was below the WHO guideline values in the majority of the samples. About 50% of the on-road CO samples taken from traffic roads in Addis Ababa were found to be less than the guideline values while the number of motor vehicles in Ethiopia is reported to be increasing by more than 9% per annum. There is a very limited air quality monitoring capacity in the country. The co-ordination between stakeholders in this regard is also inadequate. The limited evidence available on health effects of air pollution indicates that the prevalence of acute respiratory illness among children living in households using crude biomass fuels is significantly higher than the national average figures.

Conclusion—The limited evidence reviewed and reported in this article indicates high levels of indoor air pollution and trends of worsening outdoor air pollution. This tentative conclusion carries with it the urgent need for more evidence-based research and capacity building in the areas of indoor and outdoor air pollution

Introduction

Air pollution has been a challenging and ubiquitous problem in both Low and Middle Income Countries (LMIC) and non-LMIC settings, with significant variations between the two settings in terms of sources and magnitude.

In the non-LMIC setting, air pollution arises mainly from industrial and motor vehicle sources as households use clean fuel/energy source for cooking and heating (1). The abundance of long-term continuous pollution monitoring stations and trained manpower allowed higher-income countries to generate the necessary data on levels of air pollutants and their associated health effects. The resulting evidence was used to set the world's air quality guidelines by environmental regulatory bodies as well as by the World Health Organization (WHO). A lack of evidence that is locally pertinent, however, generally characterizes the Low and Middle Income Countries. Most crucially, there is a shortage of experts and equipment to measure and monitor levels of air pollution in the LMIC settings.

Air pollution in the non-LMIC setting is characterized by the double burden of widespread use of solid biomass and unclean liquid fuels. Using such fuels excessively affects the health of women and children.

Pollution due to emissions from motor traffic and the emerging trend towards industrialization also have their own major share in polluting the environment. The lack of air quality data makes policy decisions in the LMIC setting heavily dependent on potentially irrelevant evidence generated from the non-LMIC settings. Nonetheless, governments of LMIC routinely adopt these guidelines to use in their settings (2). The lack of primary data in sub-Saharan Africa may even make the global estimation models inaccurate for the region, as the models use input data from a different context (3).

This situational analysis and needs assessment (SANA) was conducted to systematically review the available scientific literature on air pollution and health in the Ethiopian context. Based on this analysis, gaps were identified with the help of expert views to inform the regulatory bodies, policy makers, implementers and researchers about the issues that need training, capacity building and future research in the area of air pollution. The ultimate goal of the SANA for Ethiopia was to prioritize the training, monitoring, research and the overall agenda of capacity building in environmental and occupational health.

Review Methods

The review method used in this publication involved systematic review and synthesis of relevant peer-reviewed articles and related literature. Data from key informants from various Federal Offices such as the Ministry of Health, the Ministry of Environment and Forest, the Ministry of Labor and Social Affairs, etc., were used in the review to determine pressing issues and current needs. Key questions and responses were entered into a common GEOH health database that could make information readily available and facilitate storage for future use. This database, organized in spreadsheet format, encompassed several key elements such as review questions, type of data source, study design, study setting, etc., among others. Themes were generated and used to complete the writing up of the review.

Results

The Status of Indoor Air Pollution

Indoor Air Pollution (IAP) has been studied in Ethiopia more than has outdoor air pollution been although the basis of the evidence may be inadequate. Most IAP studies used cross-sectional designs. Many of the studies tried to link IAP to human health not through direct measurement of pollutant concentration and health ascertainment but through associating the type of fuel used for cooking with the health outcome. The pollutants considered in indoor environments included particles ($PM_{2.5}$), gases (Nitrogen dioxide - NO_2, Poly Aromatic Hydrocarbon - PAH, and Carbon monoxide – (CO).

Indoor Particulate Matter (PM)

A cross-sectional study conducted in 2012 in 59 slum neighborhood homes of Addis Ababa measured 24-h indoor $PM_{2.5}$ using the UCB particle monitor. The studies reported a geometric mean of 818 μg/m^3 (SD=3.61), with the highest 24-h geometric mean of $PM_{2.5}$ concentration in homes predominantly using solid fuel, followed by kerosene and clean fuel with means and standard deviations (SD) of 1,134 μg/m^3 (SD=3.36), 637 μg/m^3 (SD=4.44), and 335 μg/m^3 (SD=2.51), respectively (4).

A study on levels of $PM_{2.5}$ from kitchens of 69 homes in Shiro-Meda, Addis Ababa, (5) reported that all monitored homes exceeded both US EPA and WHO guidelines (6) with 24-h average $PM_{2.5}$ level of 1,580 μg/m^3 (Range: 136– 12, 737 μg/m^3).

A cross-sectional study conducted in rural Jimma (Oct. 1999 to Feb. 2000) on a sample of 82 households in 13 Kebeles (i.e., sub-cities) assessed the type of fuel used at home. The study quantified pollutants by type and identified environmental determinants of IAP. The study noted that the levels of suspended particulates (TSP), CO and PAH exceeded the respective limits set by the WHO (1987) guidelines. Sixty-one percent of the sampled households exceeded the recommended limit of 120μg/m^3 set by WHO for TSP WHO, 1987. Women and young girls involved in cooking were exposed to the pollutants for up to 4-hrs. This by far exceeds the allowed exposure period of only one hour (28.8 μg/m^3) (7). A study in rural Tigray measured IAP in 11 traditional kitchens with some ventilation. The average indoor TSP concentration was 20mg/m^3 (Range: 83–175 mg/m^3). A fairly lower concentration was observed in kitchens with chimneys (8).

A pilot study carried out in Gimbie, West Wollega, Oromia Region, compared PM concentration in homes that use or that do not use biomass fuels for cooking. The study noted that concentrations of respiratory suspended particulate (RSP) in biomass-fuel-using-homes were 130 times higher than the air quality standards. This suggests a major risk for public health (9).

A study conducted in Shebedino, Southern Ethiopia, correlated household fuel use with acute respiratory infections in children and reported results from higher exposure to fine particulate matter (10). In another study conducted in Arsi-Negele in the Central Rift Valley of Ethiopia, the indoor concentrations of CO and $PM_{2.5}$ were monitored using HOBO-CO loggers and UCB-PM monitors, respectively, while Areqe was being distilled inside the houses. The average PM and CO concentrations measured in the 8-hr average period was 1.22 μg/m^3 and 50 ppm, respectively (11). This shows that there is a high level of PM exposure for women involved in this liquor production. (Distilling areqe using biomass fuel during the night is a major occupation of women in the Central Rift Valley of Ethiopia such as Arsi-Negele.)

Another pilot study conducted in 10 homes in Addis Ababa focused on inhaling the smoke of roasted coffee beans during traditional coffee ceremony. The study showed high PM exposure, with a geometric mean of PM_4 concentration of >1000 μg/m^3 (12). (Traditional coffee ceremony, which often involves inhaling the smoke of roasted coffee beans, is a short but recurring household activity (i.e., happening 2–3 times daily) in Addis Ababa.

Indoor Nitrogen Dioxide

Nitrogen Dioxide (NO_2) was the only pollutant tracked longitudinally with 24-hour measurements every three months for over two years on a large sample of rural households (i.e., 3,300 households) that have under-5-year-old children. The mean annual 24-hr concentration was found to be 97μg/m^3 (SD = 91μg/m^3). This is twice as high as the WHO guidelines for mean annual 24-hr concentration. This indicates that children and caretakers, mostly mothers, are exposed to high IAP concentrations in rural Ethiopia (13).

Indoor Carbon Monoxide

The Shiro-Meda study carried out in 54 Addis Ababa homes reported that the 8-hr average CO concentration was 16 ppm [Range: 0.66 – 69 ppm]. This exceeds the US EPA's 8-hr average CO level of 9 ppm in 48% of the households (5).

Although a high CO in kitchens [Range: 310 – 600 ppm] was reported in the study carried out in rural Tigray, a lower average concentration (44ppm) was also observed and very low concentrations (5 ppm) were recorded in homes that have kitchens with chimneys. When dung is used, the CO concentration could exceed 4000 ppm (8) due to low energy efficiency.

The findings from the above discussed studies are summarized in Table 1 below.

Household Energy Use: Patterns and Sources of IAP and Stove/Fuel Efficiency

According to the 2011 Welfare Monitoring Survey, biomass fuel is used by 95% of Ethiopian households. The great majority (85%) of these homes use firewood for cooking. A wide variation was observed between rural (90%) and urban (54%) areas in using firewood as the primary source of energy. Charcoal is used in urban areas as the second most (18%) common fuel for cooking compared to its negligible use in rural areas (0.2%). The use of cleaner fuel sources such as kerosene, LPG, and electricity for cooking is nearly non-existent in rural settings. However, kerosene (5%) and gas/electricity (7.7%) are used in smaller proportions for cooking. Kerosene is used for lighting by a majority (88%) of the households in rural areas while only 64% used it in urban settings (14).

In Addis Ababa, households use three times more clean energy for cooking than the average national urban proportion of the households. The access to electricity (88%) among urban dwellers is very high compared to their (4.9%) rural counterparts. The average national coverage of electricity is estimated to be 22.5% (15).

A study conducted in Addis Ababa and *Kebribeyah* compared levels of $PM_{2.5}$ and CO before and after an intervention that substituted ethanol for kerosene fuels. In Addis Ababa, there were reductions in the average, maximum, and highest 15-min. average levels of $PM_{2.5}$ by 64%, 57%, and 68%, respectively. A similarly significant reduction of about 76% was recorded on measured mean CO concentrations. In *Kebribeyah*, there was a significant reduction in average $PM_{2.5}$ and maximum CO concentrations of 94%and 72%, respectively (16, 17).

Health Consequences of IAP

Due to high concentration of IAP in Ethiopia, the national estimates of the burden of diseases such as acute lower respiratory infection and chronic obstructive pulmonary diseases is high (18, 19). According to the report of the MoH, 1,262,908 (5%) cases of acute upper respiratory infections and a 5% of pneumonia cases (this accounts for 7% of hospital admissions) that might be linked to air pollution occurred in 2010/11.

Moreover, 2% of hospital admissions in the same year were due to tuberculosis (20). Put roughly, air pollution is thought to have been the cause of these hospital admissions. The toll of outpatient cases and hospital admissions due to respiratory diseases is very high among under-five children. Pneumonia is the leading cause of hospital admissions and the second cause of morbidity. For example, it accounted for 23% of the under-five-year olds hospital admissions and 13% of their morbidity in 2010/11. (20).

A study carried out recently revealed that 42% of 1565 deaths occurred in Addis Ababa in the years 2006–2009 were due to communicable diseases. Tuberculosis and respiratory tract infections caused 12% and 3% of the deaths, respectively. Non-communicable diseases accounted for 51% of the deaths, with asthma being the primary cause. Data for the study was obtained from burial surveillance using verbal autopsy.

In sum, tuberculosis, respiratory tract infections and asthma collectively accounted for about 17% of all deaths in Addis Ababa (21). All are diseases which may have direct link with indoor or outdoor air quality.

Another recent study reported tuberculosis and respiratory infections as the second (11%) and third (8%) causes of the deaths that occurred in public and private hospitals in Addis Ababa for the study period of 2006–2009. This is roughly equal to the deaths caused by HIV/AIDS (11%) (21, 22).

High levels of fine PM are thought to be linked to respiratory problems such as ALRI, especially among children (15). A country-wide survey (15) reported a 7% national prevalence of ARI while a study focused on Addis Ababa in 2012 reported a higher prevalence of ARI (23.9%) among the under five-year-old children (4). A study conducted in 2006 in the rural Shebedino district, Southern Ethiopia, reported a similarly high proportion of ARI (21%) among children of less than 5 years old (23). The study showed that children living in homes burning biomass fuel are 3 times more likely to get exposed to ARI than those living in homes using clean energy [OR=2.96, 95% CI: 1.38, 3.87] (4, 23). The discrepancy in the proportion of ARI between the national average prevalence and the reported small scale studies might be due to the nature of the areas selected for inclusion in the study. It is important to note that findings of the studies carried out in areas where the population is more vulnerable to malnutrition need to be handled with care.

In poorly ventilated kitchens that use biomass fuels and unimproved stoves in Ethiopia (5), women are heavily exposed (7) to smoke for prolonged periods of time (often 1–3 hrs). About 91% of women are estimated to be involved in cooking in the rural areas in Ethiopia. Clearly, cooking exposes women and their young children to IAP and the associated health problems such as ALRI (4, 12, 23). In rural areas in particular, unavailability of ventilation, overcrowding and family members' sharing of spaces in the houses with domestic animals raise the peoples' exposure to diseases (24).

The Status of Outdoor Ambient Air Pollution in Ethiopia

Not many studies seem to have been carried out on outdoor/traffic-related/ambient air pollution in Ethiopia. The only longitudinal study conducted in Addis Ababa was on traffic-related air pollution in July 2007 (wet season) and in January 2008 (dry season). The study covered 40 roadside sampling locations on 20 major road networks in weekdays and on Saturdays from 7:00am to 6:00pm (25). The results are indicated in the subsequent section. The specific results are described separately below under the carbon monoxide sub-title.

A pilot study was conducted at 12 sites in Addis Ababa using 21 samples in a dry season (January-February 2004). The purpose of the study was to assess ambient air quality by measuring PM_{10}, CO, and O_3. In the study, the concentrations of 40 elements in the sampled particles taken from two (one urban and one sub-urban) areas (26) were compared. The results are described below under the sub-title of elemental constituents of PM_{10}

An experimental study assessed the spatial-temporal aspects of TSP and PM_{10} in dry and wet seasons. In the study, 66 samples were collected from 7 sites located within 5km (urban) and at a 10km (sub-urban) distance from the city center, respectively (27).

Strange as this might seem, no nowhere else other than in Addis Ababa, has any research been conducted and published in Ethiopia on the magnitude and composition of ambient air pollution levels.

Particulate Matter: Magnitude and Chemical Composition in Ambient Air

A study conducted in Addis Ababa found that PM_{10} mass concentrations measured in urban areas in the dry months (January/February) were higher (<100 μg/m^3) than those in sub-urban areas (40 μg/m^3). PM_{10} lead (Pb) concentrations in all of the samples collected for the study were < 0.1 μg/m^3. This finding was reported shortly after the government banned importing leaded gasoline. The study anticipated depletion of the stocks to be at the end of the year 2003.

Up to two-thirds (i.e., 34%–66%) of the total mass of PM_{10} reconstructed chemical composition was derived from geological materials, probably from unpaved roads and road shoulders. The contributions of carbon compounds (i.e., elemental carbon (EC) and organic carbon (OC) to the measured PM_{10} at sub-urban sites (EC vs. OC: 24% vs. 26%) were reported to be less than the contributions made by urban sites (EC vs. OC: 31% vs. 60%) (26).

Ozone in Ambient Air

The O_3 concentrations measured near mid-day were all <45ppb. The non-volatile particulate nitrate (NO_3), which is a lower limit for atmospheric NO_3, measured <5% and 7% for PM_{10} at urban and sub-urban sites, respectively (26).

Carbon Monoxide in Outdoor Traffic-related Environment

A study carried out in Addis Ababa reported a significant difference in the 15-minute concentrations of CO between the wet and the dry seasons with means of 2.1ppm (Geometric Mean, GM=1.3) and 2.8ppm (GM=2.2), respectively. The study, however, reported a similar temporal and spatial profile between the wet and the dry seasons. The mean CO concentration of all on-road collected samples was 5.4ppm (GM=5.3). Fifteen percent of the samples collected on the roadside and all (100%) on-road samples were measured at greater than 50% of the 8-hour CO WHO guideline value. Daily maxima of CO concentration were observed in early mornings and late afternoons during the study periods (25).

Elemental Constituents of PM_{10}

The study carried out in Addis Ababa noted that the mean of TSP concentration of 195µg/m^3 (SD 141) exceeded the WHO safe guideline value (120 µg/m^3). In contrast, PM_{10} concentration was reported to be within the range of 17 to 285 µg/m^3 and 79% of the PM_{10} values. This was found to be below the WHO guideline value (26).

Sources and Peak Exposure Times of Air Pollutants

High pollutant peaks coincided with high traffic congestion segments of the day. Daily maxima of CO concentration in Addis Ababa were observed in the early mornings and late afternoons (25). The peak hour for PM_{10} and CO levels was 7:00a.m. This is followed by secondary peaks in the late afternoons and early evenings. High traffic (i. e,. vehicle traffic) and cooking/heating activities are estimated to be the causes of such peak hours for PM_{10} and CO levels. This may have been affected by inversion of the temperature during cold nights (26).

Health Effects of Exposure to Outdoor Traffic-related Pollutants

A study carried out in Jimma investigated the effects of living near traffic-bearing roads on respiratory symptoms and allergic sensitization. Traffic volume and distance of household location from the nearest heavily-trafficked roads were considered as factors in the assessment of the effects of exposure. The study reported a significant linear relation among those living within a 150 m distance from the road (AOR=1.17 per 30 m proximity, 95% CI: 1.01 –1.36 m). This shows an increased risk in the prevalence of wheeze (28, 29) among the residents considered in the study. (This is the only study conducted in the area in this country).

Policy and Legal Framework

The Constitution of the Federal Democratic Republic of Ethiopia provides a favorable policy environment for air quality (Article 44/1). In the Constitution, all persons are granted fundamental rights to have a clean and healthy environment (30). The government's share of responsibility in ensuring the right of citizens to live in a healthy environment is also stated in the Constitution. In addition, environmental policy which outlines the activities needed to prevent pollution of land, air, and water in cost-effective ways is issued. Recognition has also been given to the salient role water resources play in meeting the country's energy demand. A more encouraging environment has also been created to promote training and improve the working conditions of researchers under the specific objective of preventing pollution.

The health policy (31), in particular, contains statements about the prevention of environmental pollution from hazardous chemical wastes. For air pollution, the provisions cover environmental policy on ambient air quality standards and on the need for regulatory limits for both stationary and mobile air pollution sources (2).

Ambient Air Quality Monitoring and Regulating Capacity

The MEF has now set the country's first ever air quality standard (i.e., the Ambient Environmental Quality Standards) to regulate emissions by point sources such as industries. However, very few strategy documents are available on air pollution to implement the policies, legal provisions, regulations, or guidelines of environmental standards. Climate Resilient Green Economy strategy is the only strategy issued to adapt and mitigate climate change so far. Apparently, the federal MEF controls large state development industries/ factories while regional offices undertake the rest of the activities.

The offices of MEF available at all levels have limited human and institutional capacities. For example, there is a shortage of laboratory facilities to analyze samples. These impediments retard the capacity of the MEF offices to discharge their responsibilities according to the guidelines. The Ministries of Agriculture, Mines, Water and Energy, Trade, and Industry work together with the federal EPA/MEF in selected key areas. A notable example of the collaboration is that they carry out environmental audits and undertake impact assessments using their own experts. They report results to EPA/MEF. However, due to their own other equally essential priorities, the offices may not fully commit themselves to achieving goals shared with other offices. For example, the MoH has a limited focus on health effects of air pollution due to other competing priorities. This makes the need for more concerted efforts among the concerned stakeholders absolutely necessary.

The findings reported in the SANA suggest the existence of very little coordination in the areas of air pollution among EPA/MEF, NMSA and the Ministry of Health. However, there is a general understanding among the ministries that the responsibility of monitoring and enforcing laws of standards on ambient air pollution falls within the domain of EPA/MEF while the mandate of generating data on climate and air quality goes to NMA. It is essential that there is a systematic ambient air quality management activity especially in Addis Ababa.

Apparently, the installation of gas monitoring equipment for air quality monitoring and surveillance that has recently taken place in Addis Ababa arose from this recognition. Needless to say, the generated data on air quality is generally expected to inform police decisions. For this to happen, it is important that efforts are not duplicated and resources are efficiently utilized among concerned parties.

Indoor Air Monitoring and Surveillance

Monitoring IAP does not so far seem to be a responsibility given to any particular office or organization in Ethiopia. In fact, the MoH promotes healthy housing conditions through health extension workers. On the other hand, the MoWIE/MoA encourages households to use clean, fuel-efficient stoves. It is important, however, to note that there is yet an urgent need for a more coordinated effort to prevail in the area of monitoring indoor air pollution among all concerned bodies.

Transport Sector Policy Implementation and Air Pollution Control

According to the statistics released in July 2012 (FTA), the number of vehicles that was estimated to be available in the country was 474,140. Addis Ababa held nearly a half (46.2%) of these vehicles. Benzene and gasoline are the fuel sources in use for vehicles. Benzene has been blended with ethanol and used for fuel for vehicles since 2008. Initially, the blending began with 5% of ethanol. Shortly afterwards, the share of the blended ethanol rose to 10% with the intention to 25% in subsequent years.

Until recently, the gasoline imported from the Sudan used to be rich in sulfur content, and this contributed to the pollution of ambient air. According to the Annual Report of the National Bank of Ethiopia, 2.6 million metric tons (MT) of petroleum products were imported in the year 2014. Diesel accounted for 60% of the imported fuel. Half of the imported fuel was used to transport goods between Addis Ababa and Djibouti.

The electric railroad which was expected to be completed in early 2016 was hoped to effectively replace half of the country’s need for fuel for transportation and the problems associated with the emissions. According to the data obtained from Addis Ababa City Administration, there are six hundred City Buses that are currently in use in the city. These buses daily consume 35 MT of diesel. The buses daily travel about 54,000 km in the city and provide transportation services to 1.5 million residents. The recently introduced light trains and railway in Addis Ababa have already become operational. There is also a plan to introduce electric buses to be used at least on the streets in Addis Ababa in the next few years. All these can be taken as expressions of attempts designed to put a curb on city air pollution.

Energy Sector Policy Implementation and Air Pollution Control

Energy Policy was issued in Ethiopia in 1994. The purpose of the police was to ensure that the guiding principles that underlie the development and utilization of energy sources are compatible with the principles that inspire protection of the environmental. Thus, the policy gives priority to environmental protection in the attempts needed to be made to realize the transition from the traditional sources of energy to the more modern ones.

Obviously, forests are viewed as sources of fuel wood in Ethiopia while hydropower can be considered as the backbone of the country's energy source. In addition to hydro-electric power, the other sources of energy considered in the policy include geothermal, coal, natural gas, solar and wind. The policy also emphasizes the importance of reducing the use of petroleum as the major source of energy needed for the country's overall development.

In this connection, it may be encouraging to note that on the one hand, the hydropower generation capacity in the country has steadily been increasing over the last few years. On the other hand, seven more new power generation projects (including the Grand Energy Renaissance Dam) are, at the moment, nearing completion. This will raise the total power generating capacity from renewable sources to 8000 MW by the end of Growth and Transformation Plan (GTP-II) period (2015/16– 2019/20 0). In addition, new power-generating projects; namely, seven wind power plants and one geothermal power-generating plant, have been planned to start in the coming few years.

Bio-fuel production is an important strategy to be used to decrease dependence on imported petroleum fuel. The goal in the GTP-I was to reach a target production capacity of 64.38 million liters of bio-ethanol per annum, with a 25% ethanol blending proportion. Access to electricity was expected to reach around 75% by 2015. In this connection, it is important to note that Ethiopia's energy policy emphasizes the care needed to ensure the sustainability of the environment both in the development and in the utilization of energy sources.

Industrial Sector

Ethiopia's economy is in the process of transformation from a predominantly agricultural basis to industrialization, placing priority on the developement of manufacturing industries. The Growth and Transformation Policy strives to raise the country's economy to the level of the economy of the middle-income countries within the next 15–20 years (32). To make this happen, sectors of particular focus such as textile, leather, cement, chemical and food industries have been identified. This priority for development has been made alongside the focus given to the ongoing development activities that are taking place in housing and road infrastructure, among others.

The MEFh has adopted a strategy to promote cleaner production through giving proper treatment to wastes discharged from the industries into the environment. In this regard, the Ministry has set water and air quality standards to be met following the environmental policy and regulation frameworks (33). However, the progress achieved so far in adopting waste water treatment facilities seems to lag behind the target period. In addition, there is an inadequate supply of air treatment plants in the industrial sectors that emit pollutant to the environment.

Yet, another area to which attention needs to be drawn is the failure observed so far to use biomass and crude fuel for boilers and external combustion.

Clearly, industrialization is closely associated with urbanization. This means that the population of urban community which has an annual growth rate of 16% at present is, for example, expected to grow to 35% in 2030. This indicates about a 5% growth rate of an annual increase in urban population size (34).

Discussion

This review indicates that the levels of IAP indicators in Ethiopia significantly vary and are unacceptably high compared to the WHO guideline values (35, 36). For instance, the level of indoor $PM_{2.5}$ is found to be 2–10 times higher than the WHO guideline value (36). Exposure levels corresponding to TSP were also very high. A similar magnitude of exposure to $PM_{2.5}$ is observed in other African countries (37, 40). Mothers, children, and the elderly who traditionally spend much of their time in the place where cooking takes place are exposed the most to PM2.5.

The level of NO_2 as a proxy indicator of IAP throughout Ethiopia was found to exceed the WHO guideline values (41). This observation is similar to the observation reported in other developing countries like Pakistan and Kenya (42, 43). This is not surprising given the massive use of biomass fuel in cooking in poorly ventilated settings. The level of indoor CO was much higher (5 to 500 times) than the international standard (9 ppm for 8 hrs). This varied significantly by the type of fuel used.

Charcoal is the common type of fuel in use in the Ethiopian context. However, the household use of charcoal is relatively low. For example, about 7.7% of households in urban areas (i.e., 30% of urban dwellers) and 1.2% of the rural population (15) use charcoal.

Factors such as the fuel type used the presence/absence of ventilation and the quality of housing considered, among other factors, can be held responsible in the cases where seasonal variations are observed in the levels of internal air pollution.

Given the large family sizes that generally characterize rural Ethiopia, it may not be surprising if many traditional houses are reported not to have sufficient space for air per individual. However, minimizing potential interactions of pollutants and biological agents in congested houses is difficult (24).

NO_2, CO, and PM are relatively higher when wood, charcoal, and cow dung are used as sources of fuel for household (44). The quality and the type of the stove used also determine the level of IAP (45–47). Both have the potential to affect the efficiency of the fuel used. The traditional three-stone stove called *Sost-gulicha* in Amharic is predominantly used in rural households and in many disadvantaged households in urban settings. Nearly about 97% of the households in rural areas are estimated to make use of this traditional fuel-inefficient three-stone supported cooking ‘stove’ (48). However, some hope appears to be within sight – i.e., improved stoves are appearing as replacements. The MoWIE (49), research and development centers (50) as well as NGOs (51) are working hard to speed up the pace of transition from the more traditional stove type to the less traditional one. Temporality in the magnitude of IAP has been observed due to the amount and type of fuel used and the intensity of the cooking and heating practiced.

$PM_{2.5}$ and NO_2 have the potential to penetrate the lung's defensive barrier and to affect the airways and the alveoli (52, 53). Air pollutants generally irritate mucosal membrane of the respiratory tract and affect host defenses. This increases the risk of infection of respiratory organs. According to the data available, the prevalence of acute respiratory infection among children is high still despite the existence of evidence that confirms the decline in the expansion of the infection. For example, relevant data consulted in this regard indicates that acute respiratory infection among children declined from 13% in 2005 to 8% in 2011 (15, 48).

In addition to biological agents, acute respiratory disorders among children in Ethiopia can be linked to exposure to IAP. Similarly, indoor exposure to CO could asphyxiate highly exposed individuals and cause death (54). Numerous examples that demonstrate deaths caused by CO from using charcoal in poorly ventilated houses can be found in many communities all over the country.

The limited studies on ambient air pollution in the few major cities such as Addis Ababa and Jimma showed levels that are generally less than the WHO standard values as measured by PM10, CO and ozone in high traffic areas. It is important to expect an increasing pattern of traffic air pollution due to the growing traffic density and the deteriorating quality of urban road infrastructure. The growth observed in the number of vehicles (e.g., an increase at a rate of 7.7% or about 5000 vehicles a year) calls for the need to monitor near-road ambient air quality in the cities (55). Evaluating on or near-road PM has an optimum advantage in the context where a large number of diesel engine vehicles can be found.

PM has a high capacity to stay suspended in the air close to its source. This happens to be more observable in the areas where there is poor ventilation such as on the streets that lie between high rising buildings. This was observed when ambient concentration of CO was evaluated in some of the sampling points (45) (44). This evidence was substantiated in the diurnal daily variation of CO on roads. The implication of this observation lies in the need for proper development of roads in the rapidly growing cities of Ethiopia.

The effort being made in the country to develop green economy is an important step towards increasing access to clean energy (56). Ethiopia is aiming to grow the current energy of 4000 Megawatt to about 10,000 MW over the next few years (32).

It may be important to expect more deadly effects of pollutions on health in major African cities particularly in the context where evidence from non-LMIC countries holds local sources of air pollution as the major causes of illnesses and deaths (57, 58).

According to the Goals of Sustainable Development, access to clean air and energy, water, sanitation and hygiene are key targets in making cities resilient (59, 60). In line with this, developing countries and emerging cities are encouraged to align their strategies with measurable goals.

The insufficient monitoring of air pollutants around sources of pollution and associated changes in the ambient environment needs attention. The need for monitoring air pollutants is clear on the one hand. On the other hand, however, implementation of the monitoring process appears to need taking yet several strides to meet the urgent need for monitoring air pollutants. It is important to point out that there is a lack of capacity in the measurement, analysis and interpretation of the data needed in this regard.

Conclusions and Recommendations

This review pointed out limitations that are available in research, training and capacity in monitoring, management and regulating air pollution. Similar limitations are likely to characterize many countries in the Eastern African Sub-region. The scarcity of the data and the needed expertise calls for regional collaboration among member countries. It is important for member countries of the region to pull the available meager data and expertise together and use them as baseline evidence to identify gaps and prioritize needs in monitoring, research, training and capacity building (61).

The regional integration around environment and health through the recently funded GEO Health Hub for eastern Africa is hoped to facilitate research projects and training efforts to build capacity towards a common regional agenda. This can be done with the collaboration of international partners such as the University of Southern California (USC), University of Wisconsin-Madison and the South Coast Air Quality Management District.

The monitoring and surveillance aspect requires building capacity in research, human resource and in air monitoring infrastructures. Raising output-oriented awareness among investors and the general public as well as promoting policy advocacy may be among the important issues in promoting a safe living environment.

Specific Recommendations

1. Establishing a center to develop, test, and train experts on prevention and control of air pollution;
2. Soliciting research funds and conduct studies to address the problem of air pollution in Ethiopia.
3. Establishing monitoring sites to regularly monitor ambient and indoor air quality.
4. Initiating formal and on-the-job opportunities for short and long term training on air pollution.
5. Giving priority to air pollution control through organizational structure, budget, and expertise.
6. Creating partnership between academia and implementing/regulatory organizations to facilitate evidence-based decisions.
7. Opening reference laboratories for air quality monitoring at the national and regional levels.

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References

1. Martin WJ 2nd, Glass RI, Araj H, Balbus J, Collins FS, Curtis S, et al. Household air pollution in low-and middle-income countries: health risks and research priorities. PLoS Med. 2013; 10(6): 1001455.
2. Federal Democratic Republic of Ethiopia. Environmental Pollution Control Proclamation. In: Gazeta, FN., editor. Proclamation No. 300/2002. Addis Ababa, Ethiopia: 2002.
3. Noubiap JJ, Essouma M, Bigna JJ. Targeting Household Air Pollution for Curbing the Cardiovascular Disease Burden: A Health Priority in Sub-Saharan Africa. J Clin Hypertens (Greenwich).
4. Sanbata, H. Indoor Air Pollution and Acute Respiratory Illness among Children from Household fuel use in Addis Ababa, Ethiopia [MSc]. Addis Ababa, Ethiopia: Addis Ababa University; 2012. p. 98
5. Graham, MA. Mixed Methods Approach to Assessing Indoor Air Pollution Among Women in Addis Ababa, Ethiopia. Global Health Department, Emory University; 2011.
6. World Health Organization. Air Quality Guidelines. Copenhagen, Denmark: World Health Organization; 2006. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide.
7. Faris K. Survey of Indoor Air Pollution Problems in the Rural Communities of Jimma, Southwest Ethiopia. Ethiop J Health Sci. 2002; 12(1):1–8.
8. Usinger J. Indoor Air Pollution in Rural Tigray. GNU Free Documentation License. 2008
9. Dyjack D, Soret S, Chen L, Hwang R, Nazari N, Gaede D. Residential environmental risks for reproductive age women in developing countries. J Midwifery Womens Health. 2005 Jul-Aug;50(4): 309–14. [PubMed: 15973268]
10. Desalegn B, Suleiman H, Asfaw A. Household fuel use and acute respiratory infections among younger children: an exposure assessment in Shebedino Wereda, Southern Ethiopia. African Journal of Health Sciences. 2011; 18:31–36.
11. Gezahegne, G. Evaluating the Efficiency of Improved Local Liquor (AREKE) Distilling Stove by Measuring the Indoor Air Emission, in Environmental Science. Addis Ababa University; Addis Ababa: 2008. p. 88
12. Keil C, Kassa H, Brown A, Kumie A, Tefera W. Inhalation exposures to particulate matter and carbon monoxide during Ethiopian coffee ceremonies in Addis Ababa: a pilot study. J Environ Public Health. 2010; 2010:213960. Published online 2010 Sep 21. doi: 10.1155/2010/213960 [PubMed: 20886061]
13. Kumie A, Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, et al. Magnitude of indoor NO2 from biomass fuels in rural settings of Ethiopia. Indoor Air. 2009; 19:14–21. [PubMed: 19191924]
14. Centeral Statistical Agency, Ethiopia. Welfare Monitoring Survey. Addis Ababa, Ethiopia: 2011.
15. Central Statistical Agency Addis Ababa Ethiopia, ICF International Calverton Maryland USA. Ethiopia Demographic and Health Survey 2011. 2012
16. Gaia Assocaition. Indoor Air Pollution Monitoring Summary for The Gaia Association CleanCook Stove Tests in Addis Ababa, Ethiopia. Addis Ababa, Ethiopia: 2007a.
17. Gaia Association. Indoor Air Pollution Monitoring Summary for The Gaia Association CleanCook Stove Tests in the Kebribeyah Refugee Camp, Somali Regional State, Ethiopia. 2007b
18. World Health Organization. Indoor Air Pollution: National Burden of Disease Estimates. 2007
19. Institute for Health Metrics and Evaluation (IHME). Globakl Burden of Diseasese Database. University of Washington; Seattle, WA: 2014.
20. Ministry of Health, Federal Democratic Republic of Ethiopia. Health and Health-related Indicators (EFY 2003). Ministry of Health; Addis Ababa: 2010/11.

21. Misganaw A, Haile-Mariam D, Araya T. The Double Mortality Burden Among Adults in Addis Ababa, Ethiopia, 2006–2009. CDC - Preventing Chronic Disease. 2012; 9(11_0142):1–10.
22. Misganaw A, HaileMariam D, Araya T, Ayele K. Patterns of mortality in public and private hospitals of Addis Ababa, Ethiopia. BMC Public Health. 2012; 12(1007)
23. Biruck D. Household fuel use and acute respiratory infections among younger children: an exposure assessment in Shebedino Wereda, Southern Ethiopia. African Journal of Health Sciences. 2011; 18
24. Kumie A, Yemane B. Crowding in a traditional rural housing ("Tukul") in Ethiopia Ethiopia. Ethiopian Journal of Health Development. 2002; 16(3):303–308.
25. Kumie A, Charles K, Berehane Y, Emmelin A, Ali A. Magnitude and variation of traffic air pollution as measured by CO in the City of Addis Ababa, Ethiopia. Ethiop. J. Health Dev. 2010; 24(3):156–166.
26. Etyemezian V, Tesfaye M, Yimer A, Chow JC, Mesfin D, Nega T, et al. Results from a pilot-scale air quality study in Addis Ababa, Ethiopia. Atmospheric environment. 2005; 39(40):7849–7860.
27. Gebre G, Feleke Z, Sahle-Demissie E. Mass Concentrations and Elements Composition of Urban Atmospheric Aerosols In Addis Ababa, Ethiopia. Bull. Chem. Soc. Ethiop. 2010; 24(3):361–373.
28. Venn AJ, Yemaneberhan H, Bekele Z, Lewis SA, Parry E, Britton J. Increased Risk of Allergy Associated with the Use of Kerosene Fuel in the Home. Am J Respir Crit Care Med. 2001; 164:1660–1664. [PubMed: 11719306]
29. Brunekreef B. Out of Africa. Occupational and Environmental Medicine. 2005; 62(6):351. [PubMed: 15901878]
30. Federal Government of Ethiopia. The Constitution of Federal Democratic Republic of Ethiopia. 1994
31. The Transitional Government of Ethiopia, Minsitry of Health. Health Policy. Addis Ababa, Ethiopia: 1993.
32. Federa Democratic Republic of Ethiopia, Ministry of Finance and Economic Development. Growth and Transformation Plan-2010/11–2014/15. 2010; 1 mani text.
33. Federal Democratic Republic of Ethiopia. Environmental Protection Authority. Guideline on Ambient Environment Standards for Ethiopia; Addis Ababa, Ethiopia: 2003.
34. Antonio, G. Urbanization and Urban Population. In: Antonio, GoliniMohammed, SaidOliviero, CasacchiaCecilia, ReynaudSara, BassoLorenzo, Cassata, Massimiliano, Crisci, editors. Migration and Urbanization in Ethiopia, with Special Reference to Addis Ababa. Central Statistical Agency:Addis Ababa, Ethiopia, and Institute for Population Research – National Research Council; Roma, Italy: Available from: http://www.irpps.cnr.it/etiopia/pdf/MigrationChap4.PDF
35. World Health Organization. Global update 2005. World Health Organization; Copenhagen, Denmark: 2006. WHO Air Quality Guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.
36. World Health Organization. WHO Guidelines for Air Quality. WHO Publications; Geneva, Switzerland: 1999.
37. Yamamoto SS, Louis VR, Sie A, Sauerborn R. Biomass smoke in Burkina Faso: what is the relationship between particulate matter, carbon monoxide, and kitchen characteristics? Environ Sci Pollut Res Int. 2014; 21(4):2581–91. [PubMed: 24197962]
38. Chafe ZA, Brauer M, Klimont Z, Van Dingenen R, Mehta S, Rao S, et al. Household cooking with solid fuels contributes to ambient PM2.5 air pollution and the burden of disease. Environ Health Perspect. 2014; 122(12):1314–20. [PubMed: 25192243]
39. Van Vliet ED, Asante K, Jack DW, Kinney PL, Whyatt RM, Chillrud SN, et al. Personal exposures to fine particulate matter and black carbon in households cooking with biomass fuels in rural Ghana. Environ Res. 2013; 127:40–8. [PubMed: 24176411]
40. Dionisio KL, Howie SR, Dominici F, Fornace KM, Spengler JD, Adegbola RA, et al. Household concentrations and exposure of children to particulate matter from biomass fuels in The Gambia. Environ Sci Technol. 2012; 46(6):3519–27. [PubMed: 22304223]
41. Kumie A, Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, et al. Magnitude of indoor NO_2 from biomass fuels in rural settings of Ethiopia. Indoor Air. 2009; 19(1):14–21. [PubMed: 19191924]

42. Colbeck I, Nasir ZA, Ali Z, Ahmad S. Nitrogen dioxide and household fuel use in the Pakistan. Sci Total Environ. 2010; 409(2):357–63. [PubMed: 21075427]
43. Wafula EM, Onyango FE, Thairu H, Boleij JS, Hoek F, Ruigewaard P, et al. Indoor air pollution in a Kenyan village. East Afr Med J. 1990; 67(1):24–32. [PubMed: 2354674]
44. Kumie A, Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, et al. Sources of variation for indoor nitrogen dioxide in rural residences of Ethiopia. Environ Health. 2009; 8:51. [PubMed: 19922645]
45. Clark ML, Reynolds SJ, Burch JB, Conway S, Bachand AM, Peel JL. Indoor air pollution, cookstove quality, and housing characteristics in two Honduran communities. Environ Res. 2010; 110(1):12–8. [PubMed: 19922911]
46. Hu W, Downward GS, Reiss B, Xu J, Bassig BA, Hosgood HD, et al. Personal and indoor $PM_{2.5}$ exposure from burning solid fuels in vented and unvented stoves in a rural region of China with a high incidence of lung cancer. Environ Sci Technol. 2014; 48(15):8456–64. [PubMed: 25003800]
47. Kar A, Rehman IH, Burney J, Puppala SP, Suresh R, Singh L, et al. Real-time assessment of black carbon pollution in Indian households due to traditional and improved biomass cookstoves. Environ Sci Technol. 2012; 46(5):2993–3000. [PubMed: 22369148]
48. Central Statistical Agency Addis Ababa, Ethiopia, and ICF International Calverton Maryland, USA. Ethiopia Demographic and Health Survey 2005. 2006
49. Federal Democratic Republic of Ethiopia. Ministry of Water and Energy. Cooking efficiency program overview. Available from: http://www.mowr.gov.et/attachmentfiles/Downloads/Cooking.pdf
50. Horn of Afrca Regional Environment Center and Network. Horn Blower. 2014. Available from: http://www.hoarec.org/docs/newsletter/Horn%20Blower%20%28March%202014%29.pdf
51. German International Cooperation Energy Coordination Office, Energising Development. Ethiopia Improved Cook Stoves (ICS). 2014
52. Zhang Y, He M, Wu S, Zhu Y, Wang S, Shima M, et al. Short-Term Effects of Fine Particulate Matter and Temperature on Lung Function among Healthy College Students in Wuhan, China. Int J Environ Res Public Health. 2015; 12(7):7777–93. [PubMed: 26184254]
53. Amadeo B, Robert C, Rondeau V, Mounouchy MA, Cordeau L, Birembaux X, et al. Impact of close-proximity air pollution on lung function in schoolchildren in the French West Indies. BMC Public Health. 2015; 15:45. [PubMed: 25637259]
54. Lyness JR, Crane J. Carbon monoxide poisoning from disposable charcoal barbeques. Am J Forensic Med Pathol. 2011; 32(3):251–4. [PubMed: 20139755]
55. Addis Ababa City Administration, Addis Ababa Road Authority. Facts about Addis Ababa City transport Addis Ababa Road Authority web site. Available from: http://www.telecom.net.et~aata
56. Federal Democratic Republic of Ethiopia. Ethiopia's Climate-Resilient Green Economy Green economy strategy. 2011
57. Jakubiak-Lasocka J, Lasocki J, Siekmeier R, Chlopek Z. Impact of traffic-related air pollution on health. Adv Exp Med Biol. 2015; 834:21–9. [PubMed: 25310941]
58. Kashima S, Yorifuji T, Tsuda T, Ibrahim J, Doi H. Effects of traffic-related outdoor air pollution on respiratory illness and mortality in children, taking into account indoor air pollution, in Indonesia. J Occup Environ Med. 2010; 52(3):340–5. [PubMed: 20190647]
59. United Nation, Open Working Group proposal for Sustainable Development Goals,. Open Working Group of the General Assembly of Sustainable Development Goals. , editor. United Nations; 2015. Available from: http://undocs.org/A/68/970
60. Osborn, D., Cutter, A., Ullah, F. Undestanding the transformational challenge for developed countries: Report of a study for developed countries. Stakeholder Forum; 2015.
61. Kumie, A., Samet, J., Berhane, K. Air Pollution, Occupational Health and Safety, and Climate Change: Findings, Research Needs And Policy Implications Establishing a GEOHealth Hub for East Africa. Situational Analysis and Needs Assessment for Ethiopia. Aug. 2014 Available from: http://usceh.blogspot.com/2014/05/establishing-geohealth-hub-for-east.html

Table 1

A Summary of Indoor Air Pollutants among homes in selected areas of Ethiopia (Urban, rural) (5, 7, 8, 12, 13, 16, 17, 63)

Author, Year	Study Design	US EPA's Criteria pollutant Magnitude (μg/m^3; ppb)				Sample size	Setting
		CO(PPM)	PM_{10} μg/ m^3	$PM_{2.5}$ (US EPA 35 μg/ m^3)	NOx, μg/ m^3		
Kumie, A., et al. 2009	Longitudinal study				Wood =71.2; Cow dung =67.5; Crop residues =56.1		
						17,215 samples (3300 homes)	Rural
Usinger, J., 2008	UNKNOWN	X=44				11	Rural
Habtamu S. et al 2012	Comparative Cross-Sectional study			X=2417, R=483–2904		60	Urban
Gaia Assoc. 2007	Exposure Assessment	Traditional=80.7, Clean cook =16.7		Traditional =2170, Clean cook =130		11	Rural
Graham, Megan, 2011	Mixed method	X=16.08 R=0.66–69.65		X=1580 R=136– 12,739		69	Urban
Faris, K., 2002	Cross sectional study	82.46	197			382 (18)	Rural
Keil, C., et al. 2010	Cross-sectional Study	Area sample=38 Personal=57		Area= 846 Personal= 905		10	Urban
Kumie, A, et al. 2009	Longitudinal study				NO_2= 97	3300	Rural
Gaia Assoc. 2007	Pre-Post Experimental design	Before=28.2, After=6.8		Before=640, after=280		9	Urban