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ASSESSMENT OF INDOOR CARBON MONOXIDE EMMISSION AND PARTICULATES PRODUCED BY COMBUSTION OF BIOMASS FUELS AND THEIR HEALTH IMPLICATIONS ON RURAL HOUSEHOLDS IN MANYATTA EMBU COUNTY KENYA

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Abstract: *Majority of rural households in developing countries use biomass fuels (wood, dung and crop residues) for cooking and heating. This is done in open fire places or simple stoves, mostly located in poorly ventilated kitchens indoors, and without chimneys. The study examined the fuel and stove types used by the households; ventilation conditions of the cooking areas; some indoor air pollutants emitted from smoke namely carbon monoxide and total suspended particulates and the associated health implications in the rural households in Manyatta sub County of Embu County Kenya. Household interviews, observations as well as Key informant interviews with Health workers managing the nearby health facilities were employed to answer research questions on the stove and fuel types used and the health implication of the indoor smoke. Carbon monoxide load was determined quantitatively by volumetric methods and total suspended particulates by use of filter paper traps. Percentages, means, analysis of variance within and between categories and significance testing were done to test the differences among categories. Results from the study show that, seventy percent of the households use biomass for their cooking of which eighty six percent of the households used firewood with high moisture content (not dried). These are burnt in inefficient stoves: mainly earthen or metal jikos in kitchens which are poorly ventilated. The pollutant load from the households using alternative fuels (biogas or kerosene) was lower compared to those using wood fuel (firewood or charcoal). The Total Suspended Particulates and carbon monoxide load in mg/m3 was low in the well ventilated kitchens as compared to poorly ventilated once. e.g. Total Suspended Particulates load in well ventilated conditions from households using firewood, charcoal, kerosene and biogas was 0.11, 0.04, 0.04 and 0.002 mg/m3 respectively as compared to 0.14, 0.12, 0.05 and 0.02mg/m3 from poorly ventilated condition. Children under the age of five, the aged (>60 years) and women especially expectant mothers were found to be the most vulnerable to health risks associated with indoor smoke at thirty seven percent , eighteen percent and fourteen percent respectively. Seventy three percent of the households sampled were not aware of the health hazards associated with exposure to indoor air pollutants resulting from smoke. The study findings calls for greater action oriented research, including an adoption of efficient biomass cooking stoves, advocacy on associated health hazards, policy attention and commitment to provision of effective indoor air pollution mitigation strategies such as energy switching for the rural households.*

Key words: *Indoor, Emission, Fuels, Health, Rural Households, Kenya*

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I. Background

Worldwide, more than one third of the world's population relies on biomass as a source of cooking energy (IEA, 2014). While two thirds of all households in developing countries and about 80% of all households in sub Saharan Africa rely primarily on the biomass fuels for their daily cooking and heating needs. This is consumed using inefficient burning technologies and in poor indoor environment (IEA, 2017). Kenya is highly dependent on biomass energy as over 80% of Kenya household relies on biomass as the primary source of cooking energy and heating. Firewood contributes 68.7% and charcoal 13.3% (GOK, 2016).

Biomass fuels constitute an energy source: which is locally accessible, affordable and reliable based on the rural life style in Kenya. However, it is the use of inefficient cooking stove technology and usage in poorly ventilated housing environment this results into exposure to indoor air pollutants and subsequently occurrence of incidences of associated diseases. Studies have indicated that less than 37 % of households in Kenya use improved cooking energy technology and mostly the common cooking devices used have low thermal energy efficiency ratios and high negative health impacts associated with indoor air pollution (Basu, *et al*, 2016).

Studies in Kenya by WHO (2009) and Government of Kenya (2016) have all indicated that over 4,300 deaths occur annually because of indoor air pollution due to the use of biomass fuels for cooking with a direct impact on the health of 14.6 million other Kenyans. Therefore the importance of Air quality control cannot be underscored.

The United Nations Environment Assembly in its resolution 1/7 of 2014, made a resolve to strengthen its role in Promoting Air Quality". Delegates from around the world unanimously agreed to encourage governments to set standards and policies across multiple sectors to reduce air pollution emissions and manage the negative impacts of air pollution on health, the economy, and overall sustainable development. Kenya developed the Environmental Management and Co-ordination (air quality) regulations of 2009. The regulations set emission control standards for mobile, stationary and other sources. It provides a framework for air quality control and monitoring.

Different stakeholders have been involved in air quality studies focusing on emissions from motor vehicles and industries. However, the sole measure of outdoor concentrations of air pollutants is not sufficient to assess total exposure to air pollution. Indoor air quality significantly affects household health as there are numerous indoor pollutant sources among them: heating, cooking, cleaning and smoking, as well as the use of a wide variety of consumer products, building materials and furnishings (MENR, 2013). Thus indoor concentrations are a complex interaction of various factors such as outdoor concentrations, indoor sources and sinks, pollutants, depletion, filtration and ventilation. The present study mainly focused on indoor air pollution as associated with the typical cooking typology in the study area.

II. Statement of the Problem

Indoor air pollution studies in Kenya are limited. This is particularly so in the rural countryside of Kenya where the levels of indoor air pollution and its health implications have not been factually established. In many of the rural households, fuel is burned indoors on open fires or poorly functioning and inefficient stoves, often with no means of ventilation or smoke extraction. As a consequence, large numbers of women and young children are exposed to high levels of indoor air pollution risks within their dwellings. The exposure is rarely quantified and not epidemiologically associated with the high incidences of a number of community health conditions.

The study area represents a typical rural scenario in rural Kenya, where the risks are poorly quantified as limited studies have examined the concentration of carbon monoxide (CO) and total suspended particulates (TSP) based on fuel types used and the ventilation condition of the cooking areas in the rural households. The health implications of carbon monoxide and total suspended particulates as a result of indoor air pollution have also not been assessed to satisfactory levels especially in rural households of Kenya. These issues were examined in Manyatta sub County of Embu County in Kenya. This was done by determining the pollution load of carbon monoxide and total suspended particulates based on the fuel types used and the ventilation condition of the cooking areas. The health implication of these pollutants was also assessed.

Research Questions

The study addressed the following research questions

1. What are the main types of fuel and stoves used in Manyatta sub county of Embu County and why?
2. How does the type of fuel used for cooking in Manyatta sub County of Embu County influence the concentration of carbon monoxide and total suspended particulates emitted?
3. How does ventilation of the cooking areas influence the level of concentration of the two pollutants?
4. What is the level of awareness of the households on the health implication associated with indoor air pollutants in the Division?

Study Objectives

The overall objective of this study was to examine the level of indoor air pollution in rural households using different biomass fuel types for cooking at different ventilation conditions and the health implications of the pollutants.

Specific objectives included:

1. Examine the fuel types and stoves used by the households in Manyatta, Embu County
2. Determine the concentration of carbon monoxide and total suspended particulates emitted based on the type of fuel used for cooking
3. Determine the influence of ventilation of cooking places on the levels of the concentration of carbon monoxide and total suspended particulates emitted in the households based on energy sources used for cooking
4. Assess the level of awareness of the households on the health implications associated with carbon monoxide and total suspended particulates in the households

Assumptions of the Study

The following assumptions were made;

i. Indoor air pollution in rural households is from cooking activities.

ii. The concentration of indoor air pollutants is determined by the type of fuel, stove type and ventilation of the cooking area.

III. Study Area

The study was done in Manyatta sub County of Embu County in the central part of Kenya as shown in Figure 1.2. The study area lies approximately between latitudes 0^{o} 8’ m and 0^{o} 35’ South and longitudes 37^{o} 19’ and 37^{o} 42’ East and occupies a total area of about 107.1 km 2. The area is between 1500-4500 meters above mean sea level with annual mean temperature of 10-15^{o}C and annual rainfall of 2200-2400 mm per annum. The rainfall is bimodal with the long rains starting in mid-March while the short rains start in mid-October (GOK, 2013). The study area is a characteristically a rich arable land described as an Upper Highland (tropical Alpine), mainly producing, tea and dairy (GOK, 2013). Manyatta is the most densely populated sub county in Embu as per the 2012 projections; the density was 605 persons per square kilometer (Embu County Integrated Development Plan, 2013-2017). Small scale but commercially viable farming were the main activities including; vibrant zero grazing livestock production and mixed farming of cash and food cropping. The animals in zero grazing are mainly sheep and dairy cattle thus significant animal manure (biomass) production (GOK, 2013).

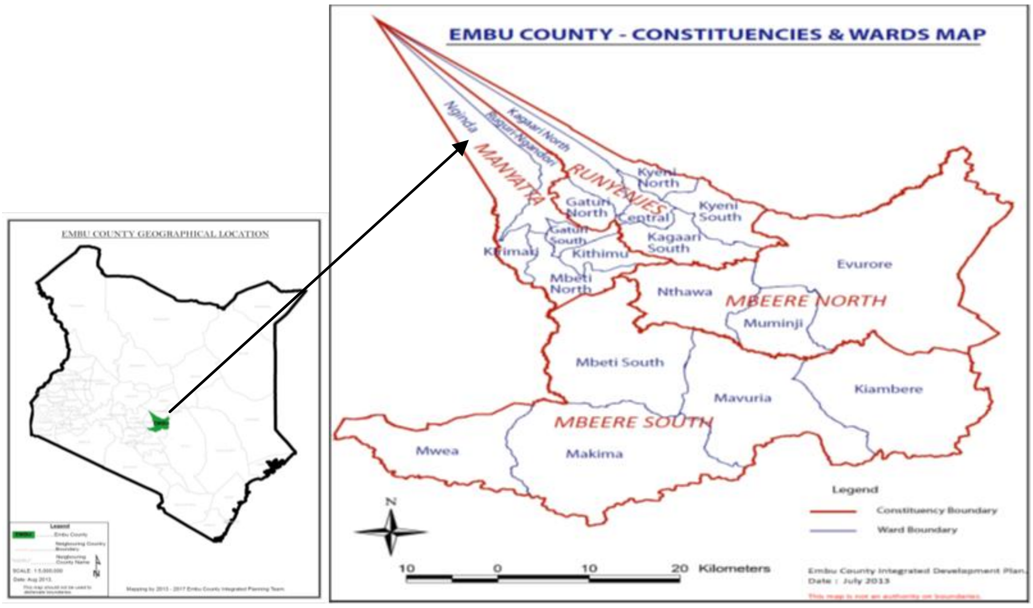

Figure 1: Location of the study area Manyatta Sub County in Embu County (source Embu County Integrated Development Plan, 2013-2017).

IV. Materials and Methods

. A stratified random sampling procedure was employed where the households were categorized into 2 strata depending on the source of energy used for cooking and on ventilation status of the households. A sample size of 190 households was used in the study.

The study examined the effects of the fuel used and the ventilation of cooking areas on the concentration of indoor air pollutants. For this study, the level of concentration of carbon monoxide and total suspended particulates were determined. The study also assessed the level of awareness of the households on the health implications associated with carbon monoxide and total suspended particulates in the households.

Household and health facilities questionnaires were used to meet the study objectives on the stove and fuel types used and the level of awareness on the health implication of the indoor smoke. Carbon monoxide load was determined quantitatively through volumetric methods and total suspended particulates by use of filter paper traps. Percentages, averages, analysis of variance within and between groups and significance testing were done to test the differences in the groups.

V. Results And Discussion

Fuel Types used for Cooking

Results from the study show that, seventy percent of the households use wood fuel for their cooking either inform of charcoal or fire wood (Figure 2).

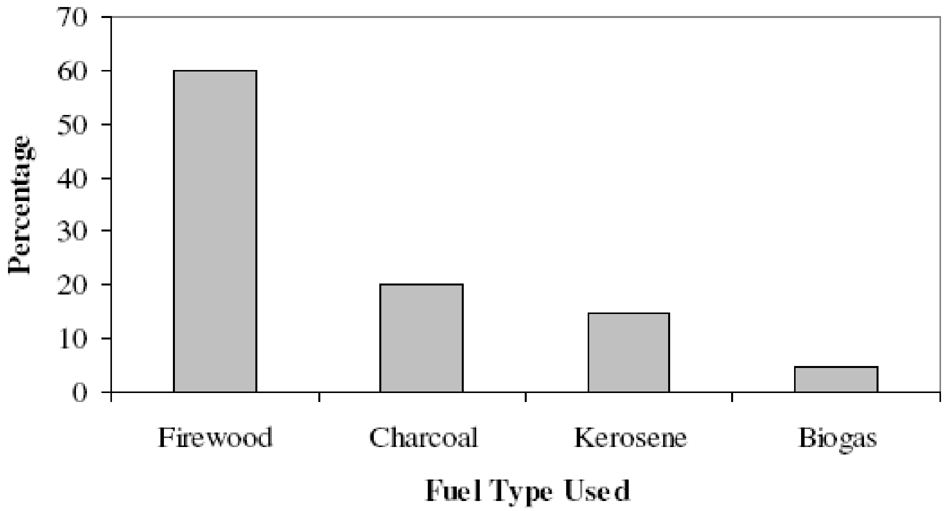

Figure 2: Fuel types used by the households.

The study results show similarity with various studies undertaken in similar circumstances in Kenya (GOK, 2016). Thus due to the dominance of biomass as the key energy resource for cooking and heating, the Kenya country action plan (2016), indicates that the government intends to ensure that at least 57.7% of households countrywide will have access to improved cook stoves by 2030. This is aimed at improving biomass efficiency and pollution reduction. The Draft National Energy Policy 2017 envisages having 55.3% of all households using biomass while use of electricity, bioethanol and biogas for cooking is projected to reach 7.6% by 2030.

In many developed countries, bioenergy is still deployed to reduce fossil fuel use and improve security of supply, reduce greenhouse gas emissions and/or create new employment. But in some cases even modern biomass use may turn out to be more expensive than its fossil competitors, however, and there is evidence that biomass, unless produced sustainably, could have significant negative environmental and socio-economic impacts (Kampman, et al., 2010).

Why Firewood is Preferred to Other Fuel Types

The reasons given by the households as to why they preferred firewood, to other fuel types varied from availability, cost and ease of use (Table 1).

Table 1: Reasons of preference of firewood

Reason for preference	Ranking
Readily available	1
Cost for other fuel prohibiting	2
Easy to use with the existing stove/ technology	3
Obtained from the forest at minimal monthly fee	4

As an energy source, biomass in the study area is utilized in either; directly by burning (fuelwood) or indirectly by converting it into solid charcoal.

The reliance on solid fuels for cooking and heating is an indicator of energy poverty ((Abhishek *et al*, 2015; UNDP 2009). But cooking with wood fuels is so deeply ingrained in the study area local cultures that other fuels have little appeal, even when the potential health and environmental benefits are recognized by users. The prevalence of wood fuel in the study area may be explained by the fact that it is still the most readily available, affordable or even cost-free cooking and heating fuel. It should be recognized that access to modern energy services including electricity and clean fuels is pivotal to the achievement of the sustainable development goals.

Eighty six percent of the household use firewood which is not dried (Table 2). Yet fuelwood with high moisture content is associated with high smoke emissions thus increasing the risk of indoor air pollution related incidences.

Table 2: Condition of fire wood used by the households

Reason for preference	Respondents (%)
Readily available in their farms	40
Costs for other fuels is prohibitive	26
Easy to use with the traditional stoves	19
Obtained from the forest at minimal monthly fees	15

Eighty six percent of the household use firewood which is not dried (table 3). Wet firewood is associated with high pollutant emissions thus posing a great risk of indoor air pollution related incidences. Wood can be collected well in advance and stored to dry before it is used for cooking as an intervention on user behaviour to reduce the moisture content. This can minimize pollutant emissions and improve on the burning efficiency

Table 3: Condition of fire wood used by the households

Fire wood condition	Respondents (%)
Dry (Harvested dry or dried by households)	14
Green/freshly harvested or rained on	86

This may also be an indicator of biomass resource scarcity of the resource and inadequate supply of wood fuel in these rural areas. When readily available fuel wood is either collected dry or collected well in advance or stored to dry before it is used for cooking. The failure of past large-scale fuelwood plantations and improved stoves programs has generally created pessimism in the development community about the relevance and effectiveness of interventions on household energy access. Altogether, this has affected the level of policy attention considerably and consequently the allocated resources for interventions. This situation is gradually changing.

Stove Types and Ventilation Conditions of Cooking Areas

Households using traditional stoves put little effort to improve on the ventilation conditions of their cooking areas which influences the concentration of pollutants and consequently increases the households susceptibility to health hazards associated with indoor smoke as shown in Figure 3.

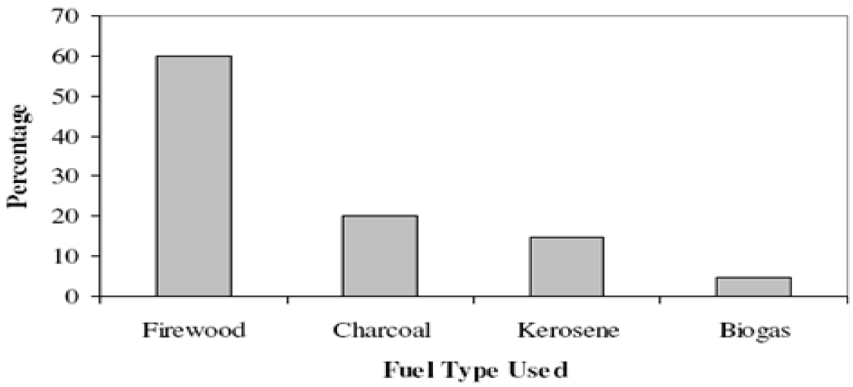

Figure 3: Ventilation conditions of the household's kitchens

These fuels are burnt in inefficient stoves in the form of earthen or metal *jikos* in kitchens which are poorly ventilated. 64% of the households use inefficient stoves, which is a major concern and hindrance in addressing the problem of indoor air pollution. Improved living environment can reduce exposure to indoor air pollutants from smoke. Earthen stoves are more preferred by the households as it requires minimal or no maintenance cost (Table 4).

Table 4: Stove types used by the households

Stove type	Respondents (%)	Ranking
3 stones	47	1
Metal *jiko*	17	2
Improved *jiko - Kuni mbili)*	12	3
- Ceramic *jiko*	11	4

Households using traditional stoves put little effort to improve on the ventilation conditions of their cooking areas which influences the concentration of pollutants and consequently increases the households susceptibility to health hazards associated with indoor smoke as shown in table 5.

Table 5: Mean CO emitted in mg/m^3

Fuel type	Time (Hrs)	Well Ventilated (Se)	Poorly Ventilated (Se)
Firewood	7.00 am	0.1518 (0.0151)	0.3891 (0.0165)
	13.00 pm	0.1519 (0.0136)	0.4071 (0.0132)
	19.00 pm	0.1572 (0.0012)	0.4316 (0.0088)
	10.00 am	0.1135 (0.0195)	0.2788 (0.0198)
	16.00 pm	0.1148 (0.0161)	0.2644 (0.0141)
Charcoal	7.00 am	0.1167 (0.0211)	0.2703 (0.0083)
	13.00 pm	0.1103 (0.0083)	0.2775 (0.0009)
	19.00 pm	0.1284 (0.0203)	0.3036 (0.0098)
	10.00 am	0.0729 (0.0223)	0.2358 (0.0072)
	16.00 pm	0.0644 (0.0230)	0.2340 (0.0038)
Kerosene	7.00 am	0.0763 (0.0241)	0.2180 (0.0407)
	13.00 pm	0.0778 (0.0243)	0.2065 (0.0279)
	19.00 pm	0.0783 (0.0245)	0.2203 (0.0436)
	10.00 am	0.0673 (0.0435)	0.1892 (0.0402)
	16.00 pm	0.0677 (0.0340)	0.1970 (0.0231)
Biogas	7.00 am	0.0313 (0.0225)	0.0916 (0.0209)
	13.00 pm	0.0333 (0.0235)	0.0928 (0.0218)
	19.00 pm	0.0360 (0.0252)	0.1046 (0.0260)
	10.00 am	0.0229 (0.0162)	0.0731 (0.0169)
	16.00 pm	0.0236 (0.0181)	0.0849 (0.0227)

Analysis of variance of the mean CO load in mg/m3 showed that there was significant difference at 95% confidence level between well ventilated and poorly ventilated conditions for various fuel types with firewood (p =0.082), charcoal (p =0.390), kerosene (p =0.098) and biogas (p =0.057). As shown in figure 7, the CO load in households which were poorly ventilated and using wood fuel was higher compared to those with good ventilation and using alternative fuels.

Total suspended particulates load in well ventilated conditions from households using firewood, charcoal, kerosene and biogas was 0.11, 0.04, 0.04 and 0.002 mg/m3 respectively as compared to 0.14, 0.12, 0.05 and 0.02 mg/m3 from poorly ventilated condition (Figure 4).

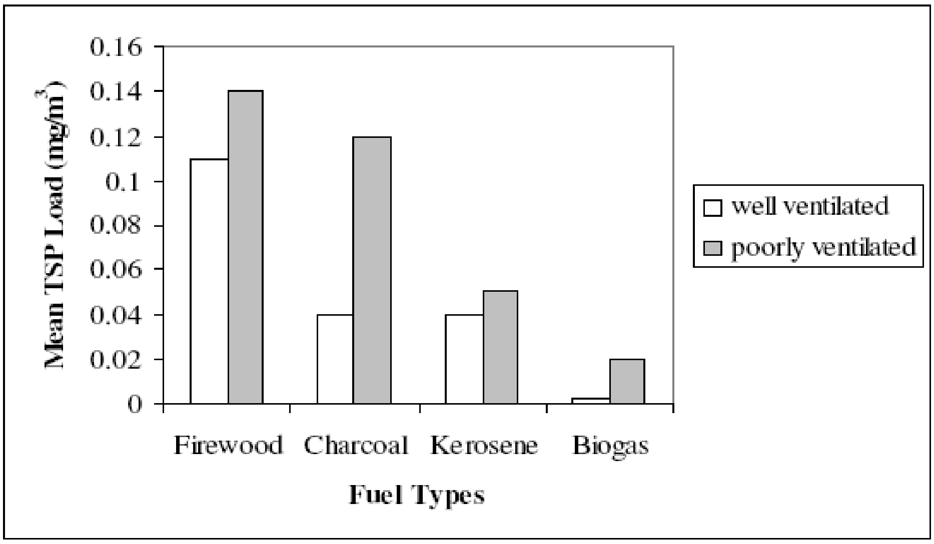

Figure 4: Total Suspended Particulates load in mg/m^3

A similar study Report undertaken by the African Population and Reproductive Health Centre the Nairobi Cross-sectional Slums Survey (NCSS) 2012, revealed that the average levels of fine particulate matter within households were three times more than the WHO recommended maximum level of 25µg/m3. Particulate matter with an aerodynamic diameter of 2.5 microns and below (PM2.5) has been singled out as a pollutant of great concern, owing to its link with adverse effects on human health (Weichenthal, et al., 2013).

Total suspended particulates load in well ventilated conditions from households using firewood, charcoal, kerosene and biogas was 0.11, 0.04, 0.04 and 0.002 mg/m^3 respectively as compared to 0.14, 0.12, 0.05 and 0.02 mg/m^3 from poorly ventilated condition (Figure 8)

Levels of Awareness on Health Hazard Associated With Indoor Air Smoke

Seventy three percent of the households sampled were not aware of the health hazards associated with exposure to indoor air pollutants resulting from smoke Table 6 below

Table 6: Indoor air pollution health implication awareness

Awareness	**Responses (%)**
Respondents who indicated that tier was **no health** effect	53
Respondents who indicated that tier was **health effect**	27
No Idea	20

The respondents were unaware that indoor pollution causes was associated with millions of premature deaths globally each year as documented in previous studies (WHO, 2012, OECD & IEA. 2010) and demonstrated ignorance on what action to take to avoid the situation.

Children under the age of five, the aged (>60 years) and women especially expectant mothers were found to be the most vulnerable to health risks associated with indoor smoke at thirty seven percent , eighteen percent and fourteen percent respectively with the acute conditions being the most reported illness (40%) in the community (Table 6).

Table6: Exposure of households to Indoor air pollution as shown by health facilities

	Disease condition	Respondents (%)
Acute conditions	Headaches/dizziness, fatigue, red watery eyes, chest illness, wheezing, cough and nausea	40
	ALRI (< 5 yrs)	18
Chronic conditions	COPD (adults)	18
	Asthma	7
	Others (TB, Upper airway cancer, low birth weight)	7

This corroborate with similar studies as according to WHO (2006), the five major categories of ill health associated with exposure to biomass combustion pollutants include; chronic obstructive lung disease, heart disease, acute respiratory infections and low birth weight due to maternal exposure which may also result into a range of prenatal and infant disorders, eye disorders and cancer. Acute lower respiratory infections are the single most important cause of mortality in among children aged less than five years.

VI. Conclusion and Recommendations

Conclusion

Exposure to Indoor air pollution (IAP) from the inefficient combustion of biomass fuels with low-quality stoves in poorly ventilated kitchens is a significant public health hazard. Household's exposure to IAP is determined by the concentrations of pollutants in the indoor environment as determined by the type of fuel and type of stove used, kitchen ventilation and the time that individuals spend in polluted environments. We conclude that household in Manyatta sub county, Embu and by extension similar rural areas of Kenya are exposed to high levels of fine particulate matter within their homes, mainly emanating from cooking and lighting fuels (biomass). Most rural population use wood fuel as their major energy source which is used in poorly ventilated kitchens. Indoor air pollution especially from respirable particulates and carbon monoxide is associated with a wide range of health problems in women and children such as chronic respiratory disease, lung cancer, asthma, cataracts and tuberculosis.

Recommendations

The study findings would be important in guiding policy interventions on rural household energy. These interventions should be aimed at empowering households to switch to less polluting fuels or use of improved and efficient stoves as well as improve the kitchen environment. Specific recommendations from the study include:

1. Design of enhanced ventilation at the cooking site: enlarging kitchen windows and installing smoke hoods over open cooking fires as other studies have already demonstrated that simple measures, such as creating windows and eave spaces and removing smoke by installing a hood and chimney over cooking areas, drastically reduce indoor pollution.

2. Promote the use of Fuel efficient stoves: efficient burning of fuel, lowers emissions and potentially, shortens cooking times thus rustically reduces the hazard even without energy switch.

3. Energy switching to other renewable energy sources such as biogas: produced from animal dung provides cleaner energy sources and efficient ways of cooking without the risk of smoke, other alternative fuels for consideration includes; Solar, LPG, or electricity.

4. Community education and awareness creation of household about indoor air pollution, based on an approach of personalized feedback on levels of pollutants to encourage

behaviour change, especially those related to proper ventilation and improvement of cooking and lighting systems will ensure adoption and consistent use of these systems.

5. Policy efforts to remove barriers to efficient biomass use may also lead to reduced health risks. Barriers may range from technological trade and costing issues to political and practical aspects.

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