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Research Article

Characterizing Emission of Particulate Matter from Combusting Different Products of Mosquito Coils in Southern Sierra Leone

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Abstract

The use of biomass produced mosquito repellants would continue to remain one of the intervention measures in the foreseeable future to prevent malaria which remains one of the biggest killers in sub-Saharan Africa. Burning these products in homes with little ventilation may result in harmful levels of particulate matter in the indoor micro environment. $PM_{2.5}$ and PM_{10} are well known and important pollution indicators that hinder human health and they are usually released during the burning of mosquito coils. To gain insight into the levels and distribution of these indicators, a realtime study on the emission of $PM_{2.5}$ and PM_{10} among seven different products of mosquito coils combusted in the outskirt of Bo in southern Sierra Leone was carried out for two weeks. Results indicated that greater fraction of particulate matter was in the PM_{10} mode comprising 62%-73% for all the products. In most cases the difference between $PM_{2.5}$ and PM_{10} were considerable. Premium and Djimba products were noted to be high emitters of $PM_{2.5}$ and PM_{10} but Wanmali product was recorded to be the least emitter. Few products showed good agreement between $PM_{2.5}$ and PM_{10} linear regression model fit and the $PM_{2.5}/PM_{10}$ ratio was noted to be consistent in values for most products except one. Our results support the view that the use of inexpensive devices to monitor household air pollution in developing countries is plausible.

INTRODUCTION

Mosquito coils have long been used for several decades in developing tropical countries where the incidence rate of malaria is high. It is estimated that close to two billion people worldwide use mosquito coils as an effective repellant for the female anopheles mosquito, the vector of the malaria parasite. Human behavior involving burning mosquito coils results in the rapid generation of significant amount of toxic air pollutants that produce non-stop fragrance of smoke during the long, slow and incomplete combustion process. It should be noted that other components of mosquito coils such as colour pigment and fragrant smelling chemicals induces the type of particulates emitted. This would eventually condense onto the surfaces of primary particles by nucleation [1,2]. A mosquito coil would usually consists of insecticides like pyrethrium or synthetic pyrethroid, binders, organic fillers, dyes and other additives that are capable of smoldering as well as burning without flame [3]. There is overwhelming evidences of Particulate matter (PM) pollution in other indoor air sources in recent years [4,5]. On the other hand, particulate pollution due to burning mosquito coils and other fragrance substances are receiving attention nowadays [6,7] considering the relevance of $PM_{2.5}$ in recent epidemiological evidences [8-10]. This is because PM with smaller size fractions passes through to the distal respiratory system with resultant irritation of respiratory and cardiovascular diseases [11].

There are important health implications for smoke emitted from burning mosquito coils. In a recent study in Ghana, high incidence of malaria >80% was reported in a group that usually applied mosquito coils as an effective means to control malaria [12]. The same study also further mentioned that mosquito coils are not included in Malaria Control Program and the same is true for malaria intervention programs in Sierra Leone. Given this current circumstance, the usage of mosquito coils would remain in force in the foreseeable future. This is against the backdrop that in rural areas people transformed treated mosquito bed nets as fishing nets which is one of the main occupations for local communities. A separate previous study also reported high incidence rate of several diseases in Thailand [13]. Exposure levels during the smoldering state of combusting coils could be acute for children and the elderly who are considered vulnerable to indoor air pollution. Smoke released from burning mosquito coils, incense and candles has been empirically proven to contain volatile organic compounds, aromatic and aliphatic hydrocarbons, combustible gases, heavy metals, particulate matter as evident in the various studies that have been earlier reported [14-18]. The findings reported for the majority of these studies are that these sources of indoor air pollution are a major source of public health concern.

In Sierra Leone, burning of mosquito is not only restricted to the very small middle level class but extended to the lower class who happens to make the overwhelming majority of the recently reported seven million one hundred thousand population of the country (Statistics Sierra Leone 2015 Census). An earlier study on the release of combustible gases in Sierra Leone reported that the burning of mosquito coils in a less ventilated environment was an environmental health risk [19]. Despite the strides been made by the Environment Protection Agency Sierra Leone towards addressing environmental issues, relevant baseline information for such important indicators of pollution (particulate matter) remain a challenge and such a gap would hinder policies geared towards addressing public health issues in the country. Hence, providing information on the characterization of particulate matter (PM) released from an important source of indoor air pollution cannot be over emphasized. This is because the information obtained would help to improve the knowledge base to influence and support urgently needed policies aimed at improving health through the usage of alternative means to prevent malaria. The overall goal of this study was to characterize $PM_{2.5}$ and PM_{10} emissions from various imported mosquito coil repellants sold around the second largest city of Sierra Leone.

MATERIALS AND METHODS

Study area

The study was conducted in the periphery of Bo city commonly known as Bo Town, in Southern Sierra Leone. Beside Freetown the capital city of Sierra Leone, Bo Town is the second largest city in the country and a leading financial, educational, commercial and urban center of Sierra Leone. It is located about 249 km southeast of the capital, Freetown. It lies along latitude 7.955º N and longitude 11.741º W. The city serves as the administrative hub not only for the Southern Province but also for Bo District. Bo District has a population of 575,478, and the city of Bo has a population of 174,369 (Statistics Sierra Leone, 2015). Like the rest of Sierra Leone, Bo has a tropical climate characterized by rainy and dry seasons. Both the outskirts of Bo Town and the township itself are characterized by low lying scattered swamps that usually recharges during the rainy season (May to October). This landscape pattern and characterization provides conducive breeding ground right through the year for mosquitos. The city is administered by the Bo City Council, and it is expanding at an alarming rate that the city now covers more than the two initial chiefdoms; namely Kakua and Tikonko. Bo District is surrounded by Kenema District to the east, Tonkolili District to the north, Moyamba District to the west, Bonthe District to the Southwest and Pujehun District to the South. Mining, business transactions and agricultural activities are the predominant occupations of the local population in the district. More than 40% of all outpatient visits in Bo government hospital and other health centers are for malaria and typhoid fever which could probably be the reason for the different products of mosquito coil products being sold.

Study design and instrumentation

Twenty three households burning mosquito coils in the outskirts of Bo town were initially identified for the study but only ten household heads consented to have one of their rooms monitored for particulate matter emitted from this combustion activity. The two research assistants (RAs) assigned to the study politely asked the household heads that consented to advise their family members to cease activities such as cooking, smoking, sweeping unpaved floor etc for a while during the monitoring because these activities would potentially prejudice the research. These households were selected on the basis of similarity in feature such as materials used in the construction, acceptance of burning mosquito coils, ventilation pattern such as a room having a door and window. Tested mosquito coils were for seven brands purchased from retailers in Bo commercial business district. They include; Premium, Tigerhead, Touba, Superchoice, Tap Tap, Wanmali and Djimba. They were shown to the head of the households that agreed to take part in the study. Tigerhead and Touba were products from China while the rest did not indicate origin of manufacture. The RAs made repeated prior visits to the household heads to acquaint them of how the study would be conducted with respect to the times of their visits during the monitoring period. For example, monitoring was conducted in household A in the morning period for a given product of mosquito coil and at the end of the exercise, the RAs will move to household B or C depending on the field arrangements with the household heads to carry out monitoring for another product. RAs would again come back to household A after two to three hours time lapse of the same day to monitor for a different product of mosquito coil. In such a case, the door and window of the room were opened to disperse any potential presence of particulates after the first monitoring exercise. This then followed a quality assurance procedure preceding the seconding monitoring activity and readings from the device were mostly between 0 $\mu g/m^3$ to <5 $\mu g/m^3$. This pattern of monitoring was performed for the seven products of mosquito coils identified in the ten households for two weeks. Forty nine (49) monitoring exercises with seven (7) per activity for each product were carried out.

For each experimental run, a mosquito coil within the coil packet was lit on the metal stand and placed in the middle of the sized room. The average room area for all the rooms monitored was 11.4 ft by 10.8 ft (123.1ft^2). The monitoring device was placed a meter away and above ground from the coil that was lit. At the start of each monitoring exercise, the door and window were closed to simulate a typical scenario of combusting mosquito coils in Sierra Leone. Measurements or readings were taken after the coil was lit for 15 minutes and recorded values taken for 1 hour. The selected mosquito coil products were burned at different times in the households selected. The HoldPeak 5800F $PM_{2.5}/PM_{10}$ formaldehyde monitor was used during the study. It is a small, light and easy to use which makes it very ideal for field monitoring in areas where conventional monitoring requirements are somehow restricted. The monitor has a resolution of 1$\mu g/m^3$ with a recording range of 1$\mu g/m^3$ to 999 $\mu g/m^3$ with a minute by minute reading potential. Ten minutes interval readings were recorded for an hour and the data were manually collated for further processing. Prior to the commencement of monitoring each time, the HoldPeak 5800F was calibrated with TES 5322 Air Quality Monitor for $PM_{2.5}$ by observing parallel readings. This process was done each time a set of measurement was made.

Data analyses

Descriptive statistics was used to analyze the data by summarizing the mean, standard deviation and proportion of mass concentration between $PM_{2.5}$ and PM_{10} size fractions. The mean and standard deviation values are presented in the form of chart and error bars. $PM_{2.5}/PM_{10}$ ratio was used to determine fingerprint options and a t-test assuming unequal variance was used to compare the $PM_{2.5}/PM_{10}$ ratios whether there were significant differences between the investigated products. The level of significance was taken at a threshold of 0.05. Simple linear regression was carried out between PM_{10} and $PM_{2.5}$ to study the potential relationships between these indicators for the different products. The coefficient of determination above 0.7 was considered strong and significant at a cutoff point of 0.05 significance level.

RESULTS AND DISCUSSION

The distribution profile of $PM_{2.5}$ and PM_{10} for seven different mosquito coil repellants is presented in Figure 1. Evidently, higher levels of PM_{10} were observed across all of the different products of mosquito relative to $PM_{2.5}$. The levels of PM_{10} are significantly higher than that of $PM_{2.5}$ as manifested in the standard error bars. The overlap of error bars in the comparison of two variables signifies no significant difference in their means and the reverse is true when the error bars do not overlap. Premium and Djimba products of mosquito coils represented the two most polluted products while Wanmali product represented the least polluted. Taking the least polluted product (Wanmali) as a reference product, our results showed a significant percentage reduction if this reference product were to be used at all times. The percentage reduction when Wanmali product is used is in the range of 82% to 91% for $PM_{2.5}$ and 73% to 86% for PM_{10}. It should be noted here that there were few (six) readings during the monitoring with levels exceeding 999 μg/m^3 for Premium and Djimba products. Even though we considered them to be 999 μg/m^3 which were factored in the analysis, the mean and standard deviation could have been under reported for these two products.

All but one product showed levels that are not within the 24 hr World Health Organization (WHO) guideline standard for public health even though our results are recorded for an hour. The levels of Djimba and Premium products could be elevated by more than one order of magnitude when the reference WHO standard that is 25 μg/m^3 and 50 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively is considered. The fact that PM_{10} dominate $PM_{2.5}$, would imply that a high level of PM_{10} would potentially result in high levels of $PM_{2.5}$ which is a hazard to occupants in homes burning mosquito coils. Such comparison should be taken with caution considering that monitoring was done for an hour and a probable reason as to why PM_{10} predominate over $PM_{2.5}$ could be associated with the very little smoke released during the burning process.

Our results are relatively lower than a study previously conducted in a chamber where the reported average levels were greater than what the current study reported for $PM_{2.5}$ and PM_{10} [20]. Another study with a different design that was not entirely specified in the methodology also reported higher levels of $PM_{2.5}$ than what we have reported [21]. It has been argued that pollutants levels are generally high when a steady state of burning is reached [14]. However, the reported average levels for $PM_{2.5}$ and PM_{10} for few products in this study are comparable with a study conducted in India [22] and this could probably due to similarity in certain conditions between the two studies. The nature of the base material used to make mosquito coils could be a strong reason for the information in the preceding sentence. This could however influence the aromatization process of the organic (base) material because the burning process involves a complex reaction resulting in different emission rates.

Figure 2 provided the profile of the arithmetic mean of $PM_{2.5}$/ PM_{10} mass ratios for the measured duration for the different products studied. It could be seen that the mass ratios were highest for Tigerhead even though Premium and Tap Tap mass ratios appeared to be similar in region for Tigerhead. Wanmali mass ratio was observed to have the lowest among all of the mosquito products. The $PM_{2.5}$ constituted for 26%-38% of the total particulate matter concentration measured for this study which goes to support the reported values in Figure 1 where PM_{10} was the dominant mass produced from burning mosquito coils. The $PM_{2.5}/PM_{10}$ mass ratio did not fluctuate significantly within each product category but there was a significant reduction in the $PM_{2.5}$/ PM_{10} mass ratios between Premium and Wanmali products ($p<0.0001$); Tigerhead and Wanmali products ($p<0.0001$) and Tap Tap and Wanmali products ($p<0.0001$). This further suggests that the emission of $PM_{2.5}$ from Wanmali product was relatively low compared when compared with the other products. Nonetheless, the overall $PM_{2.5}/PM_{10}$ mass ratio for the seven products was 54%, an indication that the majority of particulate matter emission was in the PM_{10} mode. This observation is in sharp contrast with a previous study [20]. In consideration of

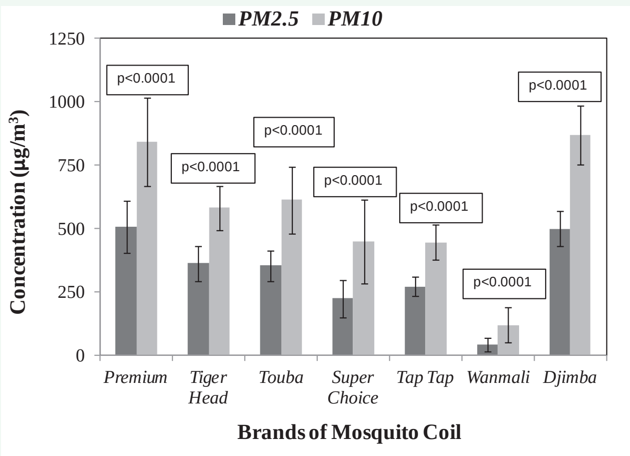

Figure 1 Mean concentrations of the seven investigated mosquito coil products. Error bars represent one standard deviation from the mean and p-values in rectangular boxes represent differences in mean $PM_{2.5}$ and mean PM_{10}.

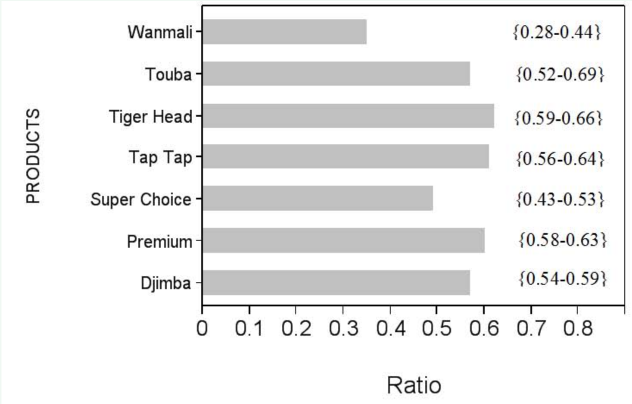

Figure 2 Ratio of $PM_{2.5}/PM_{10}$ for the seven products; values in parenthesis represent the range of value of $PM_{2.5}/PM_{10}$ ratio.

public health perspective, a previous study has shown that $PM_{2.5}$ poses a greater health risk than the same mass of PM_{10} [23].

Given that $PM_{2.5}$ and PM_{10} were supposed to be emanating from the same source i.e. burning of mosquito coils, a linear regression was performed between $PM_{2.5}$ and PM_{10} concentrations. The coefficient of determination was used as an indicator of the degree to which fine particles are related to respirable particles. Figure 3(a,b,d) representing Premium, Tigerhead and Superchoice products showed very good estimates of PM_{10} concentrations as reflected in their respective coefficient of determination R^2 (0.944; 0.816 and 0.849), respectively. Wanmali and Touba products revealed the lowest estimates of PM_{10} concentrations with R^2 (0.555 and 0.486), respectively as reflected in Figure 3(c,e,f,g). It is important to note that the data set used for the regression curve in the present study was forty nine (n=49) and there is a possibility that the coefficient of

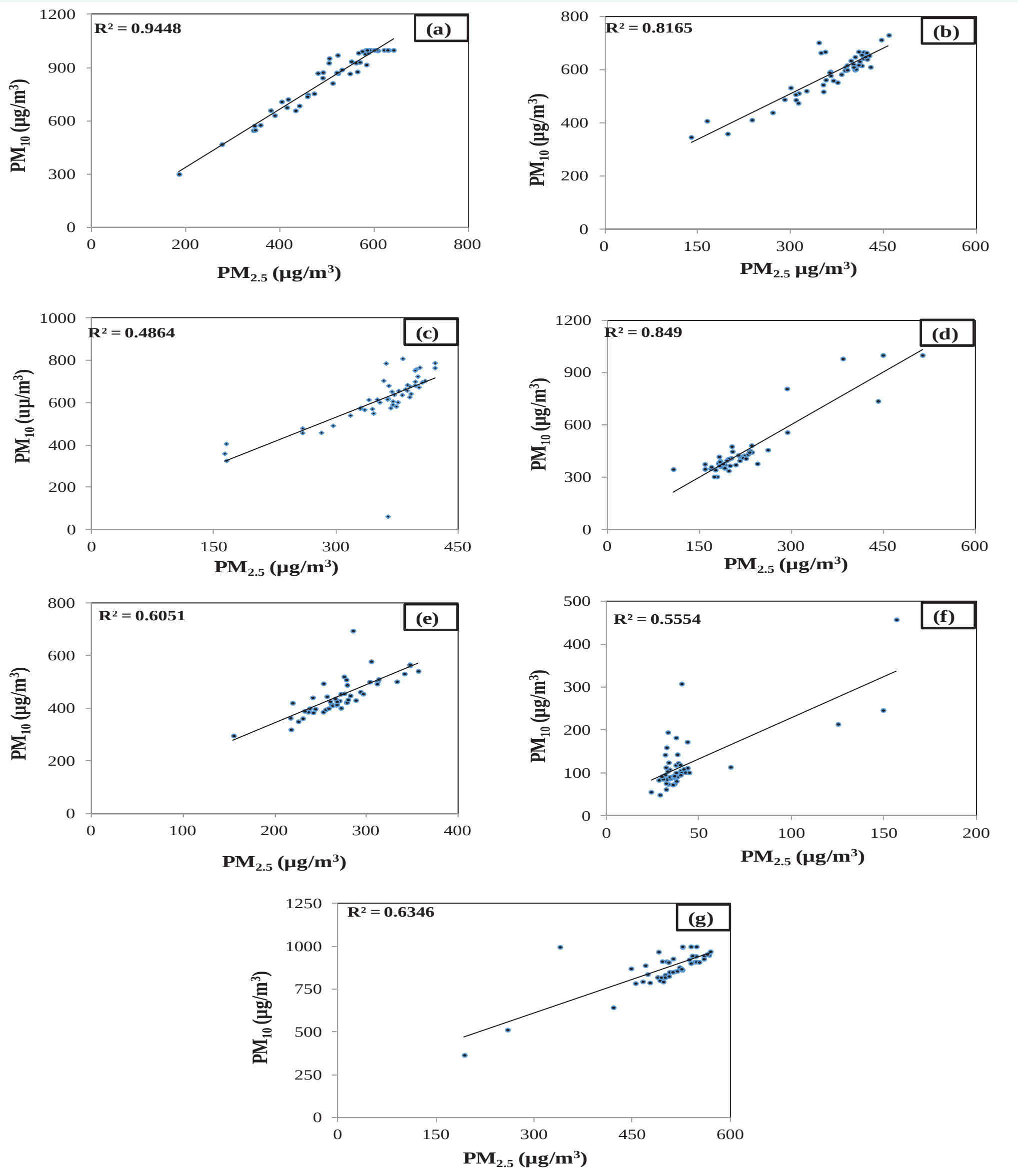

Figure 3 Linear regression between $PM_{2.5}$ and PM_{10} mass fractions for the seven products .

determination was significantly affected by extreme values of the data which might have accounted for the relatively low R^2 values detected for the two products (Touba and Wanmali). In this regard, interpretations of the regression results should be taken as suggestive rather than definitive.

Burning mosquito coils would continue to remain a key preventive approach against malaria in developing tropical countries where the burden remains to be high among millions of people. In this regard, the consumption rate would also remain high and the risk of contracting several disease outcomes remains a reality. For instance, [12] reported high incidence rate of malaria to a group applying mosquito coils (86%); and the same study also revealed high incidence of cough (53%) with further evidences of shortness of breath. Recent toxicological evidence has pointed an increased risk of lung cancer among certain people who burn mosquito coils when compared with the control group 38.1% vs. 17.8%; p<0.01, [24]. Recognizing the base materials (biomass) that are used to produce mosquito coils, and are purposefully designed to smolder, several incombustible pollutants are emitted during the burning activity. Several studies have found that large suite of volatile organic compounds, heavy metals, persistent organic pollutants etc, all of which are carcinogenic and suspected carcinogenic compounds during the burning process [7,14,17].

Even though most studies have pointed deleterious effect of burning mosquito coils, empirical evidence had reported a significant reduction in emission of pollutants from charcoal-based produced mosquito coils [25]. Such a finding has implication for developing countries such as Sierra Leone given the fact that charcoal production is absolutely high across the country. If sustainable charcoal production could be practiced by government and nongovernmental organizations, then such practice cold lure international investment firms or companies engaged in the production of mosquito coils. Then there is a tradeoff between environmental management and economic benefit. Another striking observation obtained from this study was the different mosquito coil repellants sold across different parts of the country which has huge implications for quality assurance issues. The cross border trade could be strongly associated with the divergent market products observed and such activities would have huge national policy implications aimed at market products. We believe that the central government would be limited to assert its authority in eliminating products that are thought to be considerable emitters of air pollutants in the very short term. In the long term, however, the government should further empower custom workers across the various porous border points and include some of these mosquito coil products as banned substances entering the country.

CONCLUSION

In conclusion, we found varying degree of pollution of $PM_{2.5}$ and PM_{10} from burning seven different mosquito coils products commercially sold in Bo. Both premium and Djimba products were the highly polluted products while Wanmali product was the least polluted with respect to particulate pollution. These observations further calls for a detailed study design which would capture the steady state streaming of air pollutants where peak values of emissions recorded. More PM_{10} were released than $PM_{2.5}$ for all the products and a moderate to strong correlation between PM_{10} and $PM_{2.5}$ was observed for all the products. The findings of this study could be pivotal to directing policies geared towards improved health benefits considering the different imported mosquito coil repellants that are consumed in the country. This is in line with the understanding that few of the products sold in the southern region in Sierra Leone were not observed in Freetown, the commercial hub of the country where a recent study was conducted [19].

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