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Rice Husk Handling and Combustion in Rural Areas: Assessment of Household Proximity to Exposure Risk in Nigeria

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Abstract

Exposure to rice husk particles and its combustion emissions may pose health risk. This study evaluated the effect of households' distance to exposure risk in rural rice milling communities in Nigeria. The method involves administration of a questionnaire interview in collaboration with the local health department. Four rice mill clusters were selected; 240 selected respondents were living within 1 km of the rice mill clusters. The study hypothesis predicted an inversely proportional relationship between household distance and health symptoms. Household distance of the respondents to the rice mill clusters, had a significant effect on exposure risk. For Lafia rice mill cluster, strong negative correlation was found with symptoms such as eye irritation (-0.71), chest pain (-0.67), skin irritation (-0.67), itchy throat (-0.66), cough (-0.65), nausea (-0.60). For Otukpo rice mill cluster, the symptoms include chest pain (-0.76), eye irritation (-0.75), nausea (-0.74), headache (-0.72), shortness of breath (-0.71), itchy throat (-0.69). In Makurdi rice mill cluster, the symptoms include nausea (-0.92), itchy throat (-0.89), headache (-0.83), shortness of breath (-0.83), sneezing (-0.71) and skin irritation (-0.65). In Aliade rice mill cluster, the symptoms include dizziness (-0.84), chest pain (-0.79), nausea (-0.76), headache (-0.66), shortness of breath (-0.63) and eye irritation (-0.61). In conclusion, the current mills established in the locations poses significant health risk. Replacement of these technologies with modern integrated milling system is recommended. Filtration systems should be installed. Moving rice mill clusters further away from residential areas, especially when setting up new rice mill clusters. Frequent monitoring of PM and tougher sanctions for noncompliance with the air quality regulation is recommended.

Keywords: rice husk combustions, particulate matter (PM),

health symptoms, household distance, rice husk dust, exposure risk.

Introduction

To respond the increasing emissions of greenhouse gases and the rapid occurrence of climate change effects, the United Nations (UN) sustainable development goal no. 13 (SDG 13) was established. The need to lessen this effect is a vital point stressing the critical role of smart energy sources such as biomass, solar, wind, hydroelectric and geothermal energy. The utilization of biomass fuels for heating has been associated with air pollution and emission of toxic pollutants. Pollutants emitted during biomass combustion include carbon monoxide, nitric oxides, hydrocarbons and particulate matter (PM), which constitute air pollution (Juntarawijit et al., 2014).

Pollution, which is closely associated with climate change, is among the primary causes of disease and early death globally. Air pollution from household fuel poses the most critical global environmental health risk (WHO, 2014). It accounted for about 9 million deaths in 2015 (Landrigan et al., 2018). Human contact with biomass pollutants increases the possibility of pneumonia and other lung illness and were among the causes of '800,000 deaths in children' below the age of 5 (June et al., 2011; Emmelin et al., 2007). A World Bank report in 2012, showed that outdoor air pollution in Africa accounted for 49,000 deaths yearly, and Sub-Saharan Africa with the most recorded deaths (Dieter, 2012). Nigeria is one of the countries that suffer such health exposures and symptoms due to outdoor airborne particulate matter (PM) from a biomass generating facility or the combustion of agricultural residues such as rice husk in open air.

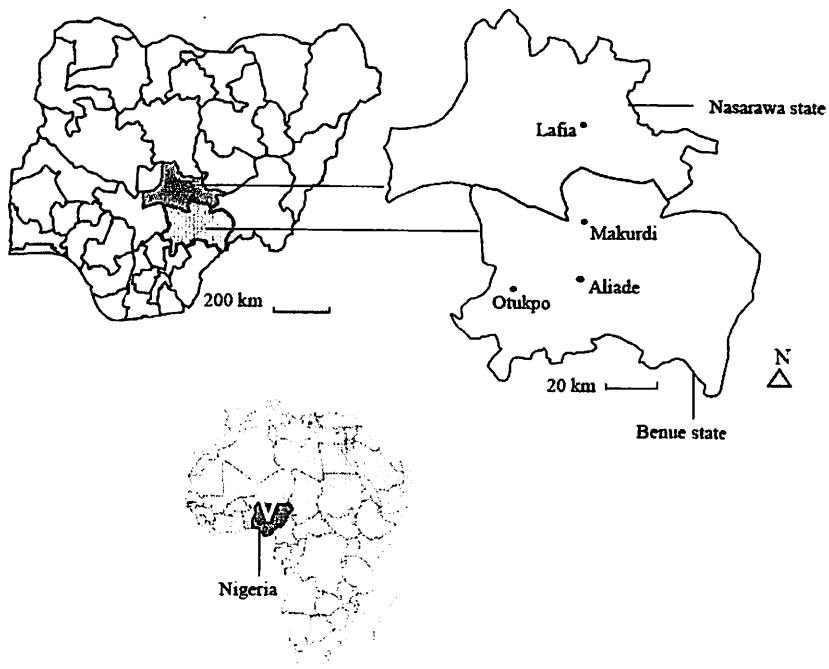
There is a risk of human exposure to particulates and smoke due to biomass generation and combustion (Iwegbue et al., 2018; Chakraborty et al., 2017). The risk of exposure is severe in rural rice milling areas due to their over-reliance on old milling technologies and the uncontrolled burning of rice husk. Therefore, necessitating the need for continuous health impact assessment of clusters of rice mills in the rural areas. Paying attention to the minimization of airborne particulates and other toxic pollutants is a crucial step towards achieving a "biomass material recycling and clean society" (Shinichi et al., 2017).

The use of rice husk in modern boilers with advanced particle removal systems (Jaehong et al., 2017), can generate enough heat energy needed for the parboiling and drying of paddy, thereby, reducing the overreliance on wood fuel. Previous studies have linked rice milling activities to occupational health issues (Juntarawijit et al., 2013; 2014). Especially manual handling of rice husk or separation of bran from broken (Farukh et al., 2005). However, a case study dedicated for Nigeria is required due to the geographical, cultural and technological differences.

Having site-specific knowledge of rice mill clusters and emission sources that pose health risk is needed for continuous assessment to improve the environmental conditions of rice mills and its operating conditions. One such way of getting reliable environmental data is through health impact assessment. It is an organized procedure for evaluating health effects of projects and policies in the non-health sector (Lock, 2000). This may include real-time measurement of PM and field observations. Also, health impact assessment takes qualitative data of public opinion into account for a wider and comprehensive view of impacts (Morgan, 2003; Wright et al., 2005).

The high level of open burning of rice husk in large heaps among some rural communities in Nigeria is of significant concern and is environmentally unsustainable. The noncompliance with environmental protection guidelines and

Fig. 1 Descriptive map of Nigeria, showing the target states (Nasarawa and Benue) and the four study locations



lack of tougher sanctions have led to an increased number of airborne particles. Which exceeds the world health organization (WHO) guidelines ($PM_{2.5}$: 25 μg/m³ for 24-hour mean and PM10: 50 μg/m³ for 24-hour mean). Thus, putting nearby residents at risk of exposure. Therefore, it is highly necessary to assess the severity and risk of exposures, physical symptoms and public opinions of people living close to these rice mill clusters.

This paper focuses on evaluating health risk from rice mill clusters, using residents' perception on health issues. The study evaluates the hypothesis that households' proximity to the rice mills have significant effects on exposure risk in the rural rice milling communities. It will affect the symptoms and will have an inversely proportional relationship with the symptoms. The study integrated real-time PM measurement techniques, field observation, and public opinion in collaboration with the local health department for evaluation.

Methods

Study Design and Site Selection

Two states were purposively selected from the middle belt region of Nigeria namely; Nasarawa state and Benue state because rice cultivation and its milling are highly practiced in these states (**Figure 1**). Within the two states, four rice mill clusters were purposively selected as case studies based on the background of public complaints and the nearby residents required for the study. The selected rice mill clusters are Lafia, Otukpo, Makurdi and Aliade (**Figure 2**). A rice mill cluster is defined as an area mapped out for multipurpose activities such as rice milling, selling and distribution. A rice mill is a place for business interactions between farmers, millers, traders and consumers. The trading commodity is paddy rice or milled rice. Farmers and rice traders bring their paddy rice for milling. Nearby residents and people from other cities come to buy the milled rice in wholesale or retail. A rice mill cluster is a crucial rice distribution centre in the rice value chain of Nigeria.

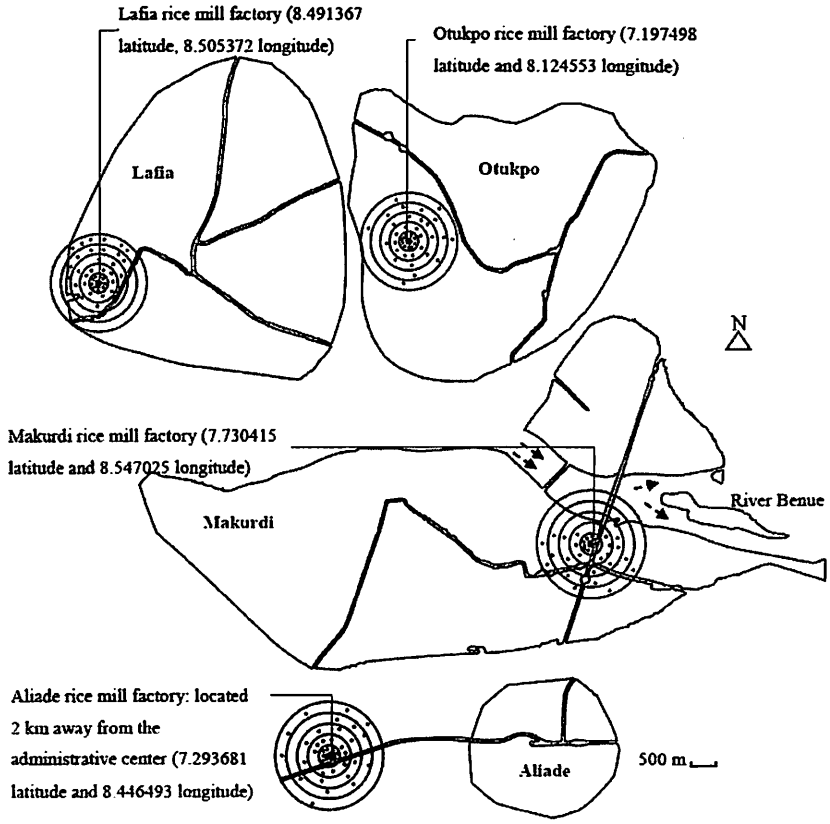
Annual rice production in Nigeria increased from 5.5 million tonnes in 2015 to 5.8 million tons in 2017. With a consumption rate of 7.9 million tons, the production rate has increased to 5.8 tons per year (RIFAN, 2017). Therefore, the continuous expansion of rice mill clusters or the establishment of new rice mill clusters is expected to continue. In Nigeria, local milling involves the removal of the husk (de-husking), bran and some portion of the endosperm in one cycle of operation. Small-scale milling machines such as the Amuda and Engelberg steel hullers were used in all four locations. The rice husk is grinded in the process. Therefore, its combustion efficiency in fixed bed or bottom vent combustion system is poor due to the smaller rice husk particles. This affects the inter-particle space between the husk particles and leads to low air-fuel mixing. Thus, the husk is either used as farm manure or burnt openly.

Lafia rice mill cluster is in Lafia, a town in Nasarawa state. The population of Lafia was estimated at 330,712 inhabitants (Census, 2007). Otukpo rice mill cluster is in Otukpo, a town in Benue state. The town has a population of 261,666 people. Makurdi rice mill cluster is in Makurdi, a town in Benue state and has a population of 300,377 people. Aliade rice mill cluster is situated in Aliade, a town in Benue state. The town has a population of 163,647 people.

Questionnaire Survey, Study Subjects and Data Collection

To test the acceptance or rejection of the study hypothesis, a survey was carried out to examine the level

Fig. 2 Survey location map of the 4 rice mill clusters



of open combustion of rice husk, and the type of milling systems used in these rice mill clusters. The survey was carried out in the year 2018. Collected data include household cooking, health symptoms, tobacco smoking, use of medication, rice consumption, age, education, occupation and sampling of $PM_{2.5}$. This survey was permitted by the Nigeria Ministry of Agriculture and Rural Development. Each of the locations are geographically and culturally different from each other.

In order to evaluate accurately, the impact of the rice mills activities on public health, each study area was limited to 1 km diameter for purposive sampling. The eligibility criteria for participation was that, participants must either be working in the rice mill clusters or are living within 1 km diameter of the rice mill clusters. Those working in the rice mills are grouped as rice mill workers. This was done to cut out unnecessary factors that may interfere with the study outcome. For the sampled residents for each of the four locations (Lafia, Otukpo, Makurdi and Aliade), at every 200 m, 8 respondents were randomly interviewed, one per household. The survey team consist of a local health worker, a staff of the ministry of agriculture and rural development (agricultural/environmental engineer) and a community volunteer. The respondents must be more than 15 years old. 40 residents and 20 rice mill workers were interviewed for each location, making a total of 240 participants.

Symptoms influence how participants assess their health condition. Deciding on a disease is a difficult task as it is not only subjected to physical factors but also mental factors (Juntarawijit et al., 2014). From a miller and farmer's perspective, symptoms and signs often indicate changes in their bodies and probably changes in their environment. To understand the likelihood of health risk from the rice mills activities, we asked about their encountered health symptoms. Also, whether these signs were confirmed by the local health department personnel in relation to their activities or work. The frequency of occurrence of the symptoms was divided into three categories name; level A (more than 12 days per month), level B (3-12 days per month), and level C (less than 3 days per month).

Annual Rice Husk Production and Material Flow

In order to calculate the annual rice husk production, annual paddy milling data was collected from the record files of each rice mill cluster. The rice husk was estimated as 20% of the paddy. Therefore, a husk to grain ratio of 0.2 was used in the calculation (Garba and Zangina, 2015). Annual rice husk production for each rice mill was calculated using the equation;

$$H_{pro} = PR_{pro} \times HGR \quad (1)$$

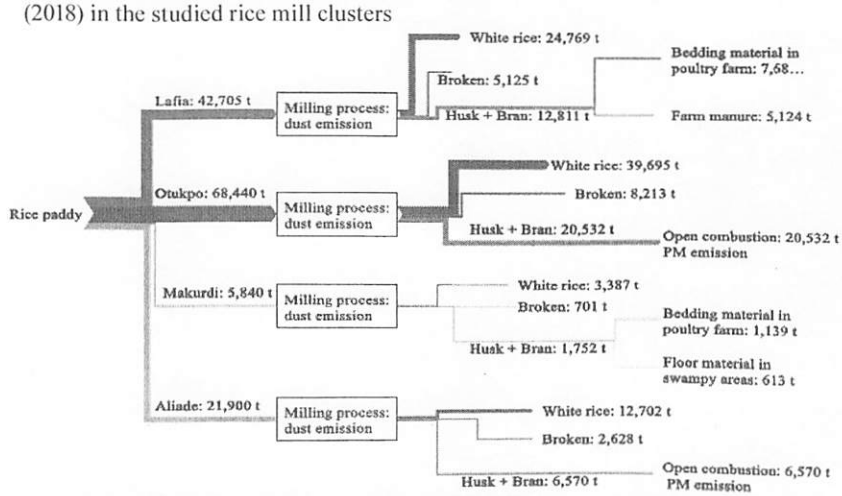
Where H_{pro} is the quantity of rice husk in ton per year (t/year), PR_{pro} is the paddy rice production in ton per year (t/year), HGR is the husk to grain ratio. Percentage of white rice, broken grain, bran was estimated based on data from the field survey and information from rice knowledge bank (IRRI, 2019) and the food and agriculture organization website (FAO, 2019). The material flow of rice milling, generated rice husk and its combustion/utilization was calculated (**Figure 3**). The rice milling process generates husk dust, while the combustion of rice husk leads to the emission of particulate matter and gaseous emissions.

Real-time Airborne Particulate Matter Sampling

On-site measurement of $PM_{2.5}$ was limited to two locations where rice husk disposal is open combustion. This measurement is essential in understanding the trend of $PM_{2.5}$ emission in the context of open combustion, in real-time. Furthermore, to know if the on-site values exceed the WHO limits, which is 25 $\mu g/m^3$ for 24-hour mean (WHO, 2019). The measurement is critical as it may affect the commonly encountered symptoms. A single channel aerosol counter (Dust Track II analyzer), was used to record levels of $PM_{2.5}$ in the atmosphere at the husk burning sites.

The dust track II analyzer is a real-time aerosol measuring instrument and uses impactors (size-selective inlet conditioners) to narrow down the particle size entering the instrument (Abah et al., 2018).

Fig. 3 The material flow of rice paddy milling and generated rice husk per year (2018) in the studied rice mill clusters



Note: In the studied rice mill factories, husk and bran were removed in one process. Thus, the husk is mixed with bran, hence the use of "Husk + Bran" to represent the waste

The instrument was program to the log mode for an aggregated one-hour sampling (12 tests with each test duration of 5 minutes). The experiments were conducted between 11:00-16:00 April 3rd and 4th, 2018. Prior to the sampling, multiple field visit of the sites was carried out to carefully observe the daily husk combustion volumes and to decide on the sampling day to ensure that the sampling is representative.

Results

Demographic Characteristics of the Respondents

Table 1 presents the participants information and the meteorological data of the four locations. The information includes age groups, education, occupation, smoking, and use of medication and meteorological data. The middle age group (31-45 yrs.) is the highest with 43.8%, followed by the old age group (>45 yrs.) 28.3%, and lastly by the young age group (15-30 yrs.) 27.9%. Respondents with no education is 26.3%, those with primary education is 33.3%, while 27.9% had secondary education. Also, 12.5% have tertiary education. Rice mill worker and farming constitute over half of the occupation of the respondents (33.3%, and 28.3%). Trading is 26.3%, and civil service as 12.1%. Rice was consumed as a staple food and 6.3% of the respondents were on medication, and 93.7% were not on medication. Also, 92.1% have no history of smoking. Therefore, the use of medication and smoking have no significant impact on the outcome of the study.

Significance of Household Distance to Health Symptoms

The combine number of respondents for the four study locations was 240 and referred to both rice mill workers (33.3%) and residents (66.7%) and satisfies the eligibility criteria of working or living within 1 km of the rice mill clusters. For each location, the respondents were asked about symptoms (such as eye irritation, chest pain, itchy throat, headache, skin irritation, shortness of breath, dizziness, nausea, sneezing, cough and catarrh) and by using the occurrence category explained in the questionnaire section.

Table 1 Participants' information and meteorological data for the study locations

Respondents particulars		Lafia	Otukpo	Makurdi	Aliade	Total (%)
Age (Years)	15-30	20	15	16	16	67 (27.9)
	31-45	27	22	32	24	105 (43.8)
	>45	13	23	12	20	68 (28.3)
Education	No education	19	15	10	19	63 (26.3)
	Primary	23	20	15	22	80 (33.3)
	Secondary	12	18	24	13	67 (27.9)
	Tertiary	6	7	11	6	30 (12.5)
Occupation	Farming	17	18	10	23	68 (28.3)
	Trading	15	17	18	13	63 (26.3)
	Rice mill worker	20	20	20	20	80 (33.3)
	Civil service	8	5	12	4	29 (12.1)
Smoking	Yes	6	4	5	4	19 (7.9)
	No	54	56	55	56	221 (92.1)
On medication	Yes	3	4	6	2	15 (6.3)
	No	57	56	54	58	225 (93.7)
Temperature °C		27.5	27.2	27.2	26.7	
Yearly rainfall (mm)		1,316	1,723	1,248	1,471	
Elevation(m)		176	170	83	168	
Wind speed (m/s)		2.5	2.4	3	3	
Mill capacity (ton/day)		72-162	125-250	20-May	40-80	

Encountered Symptoms by Rice Mill Workers

Table 2 presents the symptoms encountered by rice mill workers. Distance 0.0 km represents rice mill workers. Respondents highlighted the physical symptoms they encountered. Rice mill workers experienced multiple symptoms. For Lafia rice mill cluster, positive response was obtained on common symptoms such as eye irritation (85%), itchy throat (70%) and skin irritation (85%). For Otukpo, positive response for symptoms reported include eye irritation (90%), skin irritation (90%) and itchy throat (75%). For Makurdi, 80% and 65% positive response was recorded for headache and eye irritation respectively. For Aliade, eye irritation had 85%, 90% for chest pain and 70% for skin irritation.

Encountered Symptoms by Nearby Residents

The total number of nearby residents interviewed for each rice mill cluster was 40, about 8 persons for every 200 m from the rice mill cluster. Therefore, all participants were living within 1 km of the rice mill clusters. Also, their socio-economic activities were within the study locations. Distance 0.2-1.0 km in **Table 2**, represents the positive responses to symptoms reported by the nearby residents of the four locations. The number of those who experienced these symptoms varies from household to household and may be affected by the respondent's household distance to the rice mill clusters. Hence, necessitating Pearson's correlation analysis.

Correlation Between Household Distance of Respondents and Encountered Symptoms

To determine whether the participants living distance to the rice mill cluster had significant effect on each encountered symptom, and to accept or reject the study hypothesis, the Pearson's correlation analysis was employed. The study hypothesis predicted an inversely

proportional relationship (negative correlation) between distance and health symptoms. **Figure 4** shows the effect of distance (independent variable) on symptoms (dependent variable). As predicted by the study hypothesis, households distance had a strong (negative) correlation with the symptoms.

In **Table 3** and for Lafia rice mill cluster, participants household distance had strong correlation with symptoms such as eye irritation (-0.71), chest pain (-0.67), skin irritation (-0.67), itchy throat (-0.66), cough (-0.65), nausea (-0.60). For Otukpo rice mill cluster, strong correlation was found with symptoms such as chest pain (-0.76), eye irritation (-0.75), nausea (-0.74), headache (-0.72), shortness of breath (-0.71), itchy throat (-0.69). In Makurdi rice mill cluster, strong correlation was found with nausea (-0.92), itchy throat (-0.89), headache (-0.83), shortness of breath (-0.83), sneezing (-0.71) and skin irritation (-0.65). In Aliade rice mill cluster, strong correlation was found with dizziness (-0.84), chest pain (-0.79), nausea (-0.76), headache (-0.66), shortness of breath (-0.63) and eye irritation (-0.61).

Figure 5 compares the percentage of positive response to symptoms from rice mill workers and residents of the rice mill clusters. Rice mill workers reported to have more health concerns compared to rice mill residents. This is because, the rice mill workers are at zero distance (R 0) to the rice mill clusters and their economic activities is within the rice mill clusters.

Real-time Airborne Particulate Matter Measurement

From the results of the $PM_{2.5}$ sampling at Otukpo and Aliade rice mills, Otukpo rice mill recorded higher $PM_{2.5}$ emission than Aliade. This is because of the higher quantity of rice husk generated and combusted. The maximum 1-hour mean $PM_{2.5}$ concentration was 93.2 mg/m^3 at Otukpo and 65.4 mg/m^3 at Aliade (**Figure 6**).

Discussion

Significance of Household Distance to Health Symptoms

The rice milling technology found in the locations generated smaller rice husk particles that was breathable. Thus, posing health risk. The poor handling of rice husk was confirmed by the encountered symptoms among rice mill workers and nearby residents. Participants whose activities were within the rice mill clusters (rice mill workers) experienced symptoms more frequently. Since they spent an average of 9 h at the rice mill clusters and are exposed to higher concentration of the pollutants. Eye/skin or throat irritation and respiratory problems was predominant among rice mill workers from all four locations. Besides their work schedule, another factor was the use of similar old and inef-

Table 2 Number of positive responses reported health symptoms from rice mill workers and residents and their corresponding household distances

Location	Distance (km)	Eye irritation	Chest pain	Itchy throat	Headache	Skin irritation	Shortness of breath	Dizziness	Nausea
Lafia	0.0 (workers)	17	14	14	11	17	9	5	9
	0.2	6	3	5	4	5	4	3	4
	0.4	5	5	3	4	2	5	5	5
	0.6	5	3	6	8	6	3	3	5
	0.8	8	4	4	0	4	6	4	0
	1.0	2	3	4	5	3	5	4	5
Otukpo	0.0 (workers)	18	17	15	11	18	15	11	13
	0.2	6	4	3	4	4	4	4	3
	0.4	8	4	6	4	3	2	2	2
	0.6	6	3	4	5	2	5	4	4
	0.8	5	2	5	5	5	3	4	3
	1.0	5	2	2	2	3	2	3	0
Makurdi	0.0 (workers)	13	9	10	16	13	7	8	7
	0.2	4	4	5	5	5	5	4	5
	0.4	3	5	5	6	5	5	5	5
	0.6	3	4	5	4	2	6	5	5
	0.8	6	5	3	2	4	4	3	2
	1.0	2	4	2	2	5	3	5	2
Aliade	0.0 (workers)	17	18	15	13	14	12	6	8
	0.2	6	5	2	4	5	5	4	3
	0.4	5	8	2	6	2	5	5	5
	0.6	6	6	5	6	6	3	3	5
	0.8	8	2	3	0	3	5	2	2
	1.0	5	3	3	5	5	5	3	2

Table 3 Comparative evaluation of Pearson's correlation analysis of the recorded symptoms vs household distances across the four study locations

Location	Eye irritation	Chest pain	Itchy throat	Headache	Skin irritation	Shortness of breath	Dizziness	Nausea	Sneezing	Cough	Catarrh
Lafia	-0.71	-0.67	-0.66	-0.54	-0.67	-0.41	-0.23	-0.60	-0.42	-0.65	-0.39
Otukpo	-0.75	-0.76	-0.69	-0.72	-0.65	-0.71	-0.63	-0.74	-0.59	-0.80	-0.52
Makurdi	-0.64	-0.63	-0.89	-0.83	-0.65	-0.83	-0.57	-0.92	-0.71	-0.55	-0.57
Aliade	-0.61	-0.79	-0.57	-0.66	-0.59	-0.63	-0.84	-0.76	-0.52	-0.49	-0.55

ficient milling technologies that was found in all the locations. Thus, exposing them to higher concentration of small rice husk particles generated during milling at concentrations, which exceeds the WHO limit of 25 $\mu g/m^3$ for $PM_{2.5}$.

Encountered symptoms level for nearby residents was less compared to those experienced by rice mill workers. As predicted by the study hypothesis, distance of residents' households to the rice mill clusters had significant impact on the reported symptoms. Distance was inversely proportional to symptoms (-ve correlation). A decrease in household distance causes an increase on the reported symptoms due to high exposure risk.

Lafia had the lowest (-ve) correlation between households' distance and symptoms, with an average value of -0.54. This is because of the cultural and geographical characteristics of the location and the inhabitants. A cultural food made from rice (tuwo chinkafa) is highly consumed. The food is made by manually beaten paddy to remove the husk. This further exposed individuals to breathable rice husk particles. The vegetation type is the guinea savannah, influenced by the north-east trade wind. Ugwanyi et al. (2016) reported high levels of PM10 in Lafia rice mill, which exceeds set standard of the national air quality guidelines.

Otukpo had the second highest (-ve) correlation between households' distance and symptoms, with an average value of -0.68. This is partly because of the vegetation and housing pattern, which makes it more difficult for particulate matter to be evenly dispersed over distances. In addition, uneven exposure levels of open combustion of rice husk was highly practiced.

Makurdi had the highest (-ve) correlation between household distance and symptoms, with an average value of -0.71. Makurdi rice mill cluster is located closer to the River Benue. The river acts as barriers to the transport and even distribution of air pollutants over long distances because some particles will acquire moisture and dissolved before reaching further distances. Therefore, causing significant uneven distribution and exposure levels.

Aliade had the third highest (-ve) correlation between households' distance and symptoms, with an average value of -0.64. Aliade vegetation is like that of Otukpo however, with a dispersed settlement pattern. Thus, favouring uneven exposure levels. Residents closer to the rice mill cluster encounter more symptoms.

Generally, and starting from the highest, symptoms that had the highest correlation with households' distances across the four locations are nausea (-0.76), chest pain (-0.71), itchy throat (-0.70), headache (-0.69), eye irritation (-0.68), shortness of breath (-0.65), skin irritation (-0.64) and cough (-0.62). The bottom three are dizziness (-0.56), sneezing (-0.56) and catarrh (-0.51).

Fig. 4 Household distance vs symptoms Pearson's correlation (r) analysis

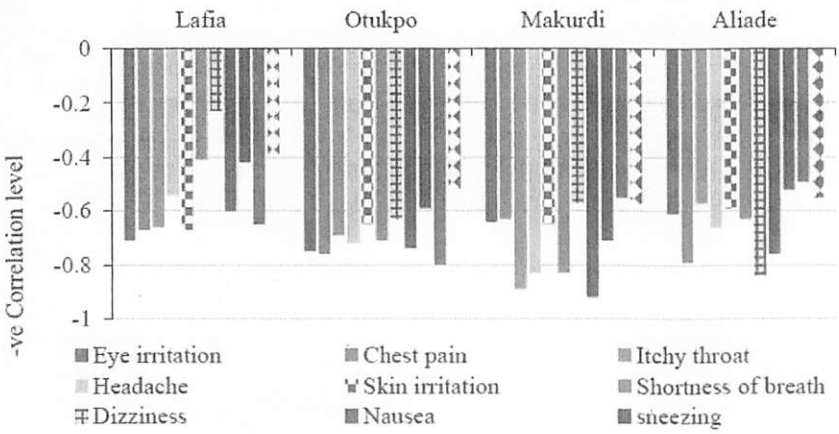
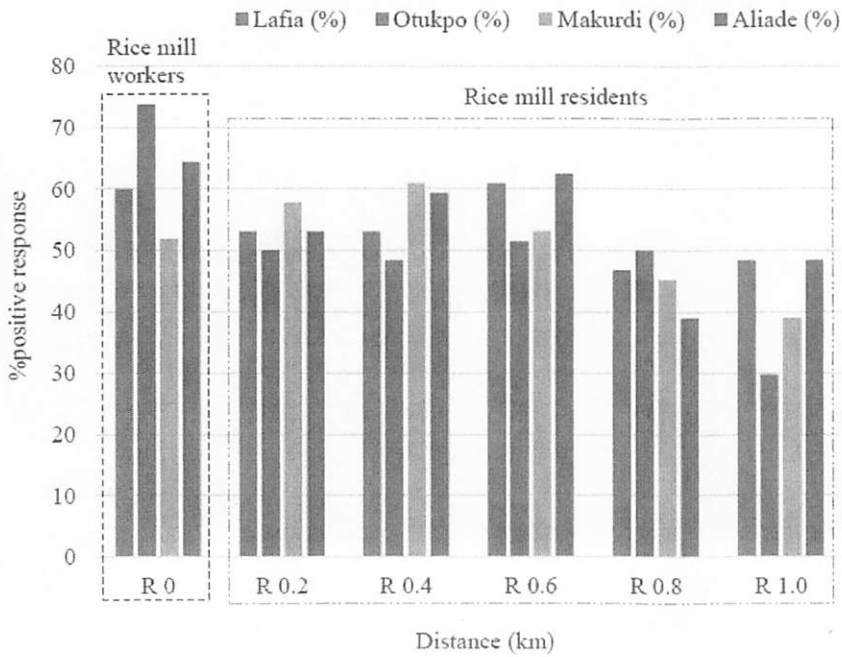


Fig. 5 Rice mill workers vs rice mill resident response analysis



Real-time Airborne Particulate Matter Measurement

$PM_{2.5}$ sampling was limited to Otukpo and Aliade rice mill clus-

ters. This is because, open combustion of rice husk was highly practiced. $PM_{2.5}$ emission at Otukpo and Aliade exceeds the WHO limit of 25 $\mu g/m^3$. The high concentration can be attributed to the moisture content of the rice husk, quantity combusted, and meteorological conditions. The rice husk heaps burn for several days. Wind speed determines the transit period of emissions from a source location to the receptor, and the number of pollutants diluted in the windward direction (Hosler, 2005). Otukpo has an average wind speed of 2.40 m/s compared to Aliade which has an average wind speed of 3.02 m/s. This implies that emitted particles in Otukpo were poorly dispersed compared to Aliade. This could be partly responsible for the higher emissions and symptoms at Otukpo rice mill cluster. Zhang (Wang et al., 2014), reported high PM2.5 values in the winter season in China, and was attributed to unfavorable meteorological conditions rather than increase emission from the emission source. Owoade et al., 2012 and Kothai et al., 2008 reported that mass concentration of pollutants increased in the 'dry season' compared to the 'rainy season'.

Conclusions

This study evaluated the effect of households' distance to exposure risk in rural rice milling communities within 1 km of each rice mill cluster. Rice mill workers reported higher health impacts because of their longer work duration and their socio-economic activities was within the rice mill clusters. The study hypothesis predicted an inversely proportional relationship between household distance and health symptoms. Household distance of the respondents to the rice mill clusters, had a significant effect on exposure risk. Irritation sensation and respiratory symptoms were commonly felt. People living closer to the rice mill clusters were more prone to exposures. As a policy intervention, we recommend moving rice mill clusters further away from residential areas, especially when setting up new rice mill clusters. Also, frequent monitoring of PM is recommended. Tougher sanctions must be implemented for noncompliance of air quality regulations. The health symptoms data was limited to information the respondents in collaboration with the local health departments were willing to share. The $PM_{2.5}$ sampling was limited to one-hour sampling due to the power constraint of the studied locations. The sampling was limited to two locations where open combustion was prevalent.

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Disclosure Statement

The authors declare that they have no conflict of interest.

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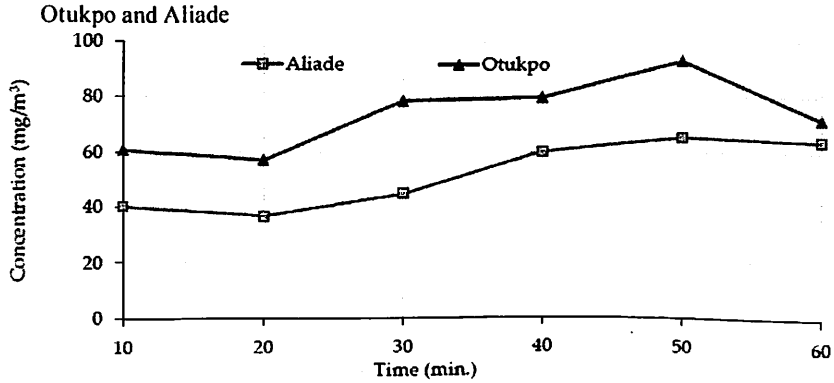
Fig. 6 1-hour mean of $PM_{2.5}$ mass concentration in the rice mill clusters sites of Otukpo and Aliade



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