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Comparative Assessment of Ambient Air Standards in Rural Areas to Uganda City Centers

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ABSTRACT

Background: Little quantitative data has been collected to reflect the ambient air quality in Uganda city centers. This is particularly important as the World Health Organization (WHO) reported in 2014 that 3.7 million people worldwide die prematurely from toxic air quality. This study investigated ambient air quality in Kampala, Uganda and compared it to nearby rural forest reserves.

Methods: Over the course of six months, from November 2013 to April 2014, we measured carbon monoxide, oxidants, sulfur dioxide, and nitrogen dioxide at five different sites using an impinge air quality testing apparatus. This data was compared to the Environmental Protection Agency, WHO, and Ugandan standards for air quality. Additionally, the data was calculated using an Air Quality Index that reflected a range of health risks relating to elevated exposure of individual parameters.

Results: We found that the air quality in the city center, particularly at a taxi holding station, was hazardous for inhalation due to elevated carbon monoxide, sulfur dioxide and nitrogen dioxide. Likely, this can be accredited to lethargy, asthmatic conditions, and other related respiratory and cardiovascular health problems of Ugandans who routinely work and live in such polluted environments.

Conclusions: Ambient air quality is largely ignored as an environmental concern in Uganda. The limited data set presented in our study suggests that there is a need for more qualitative and quantitative data collection to link vehicle abundance and inadequate traffic distribution patterns to ambient air pollution. Moreover, further investigations of cardiovascular and respiratory problems of urban Ugandans may be the stimulus needed to promote the integration of environmental concerns and health considerations into future urban planning.

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INTRODUCTION

Ambient air pollution is estimated by the World Health Organization (WHO) to cause 3.7 million premature deaths per year worldwide [1-3]. This mortality is linked to particulate matter and toxic inhalation of greenhouse gases (e.g. ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide) which cause cardiovascular and respiratory diseases including cancer [3,4].

Outdoor air quality originates from many sources including: residential, industrial combustion, vehicles, garbage burning, chemical releases from industry, and dust from road construction. In developing countries, like Uganda, environmental regulation (and enforcement) has not yet caught up with the demands of population sprawl in urban city centers, namely the capital city, Kampala. The first environmental legislation made in Uganda occurred in 1994 with the National Environmental Act. In 2005, the National Environment Management Agency (NEMA) of Uganda drafted air quality standards and vehicle emission standards for the country (Table 1), although they have yet to be implemented [5]. This comes before NEMA reported that 75% of air pollution in Uganda is due to transport-related activities [5]. This is of particular concern as it has been projected that within the next decade Uganda is expected to have the highest population growth in the world [6]. Currently, Uganda's growth rate is 3.1% annually compared to a worldwide average of 1.2%.

Air quality deteriorates with fast paced economic development [7-9]. With a growing middle class in Uganda, there is a push for the modern convenience of vehicle transportation. The primary modes of transportation in the city center are by motorcycle (termed boda-boda) or by the cheaper alternative using a 15-passenger taxi (termed matatu) that predominantly operates on leaded fuel. The vehicular fleet is comprised of 20+ year old, imported, second-hand, and reconditioned vans that are unregulated for exhaust emissions. In 2012, the number of vehicles registered in Uganda was reported at 96,598 for that year [10]. Other studies estimate the total number to be 700,000, with 400,000 of this traversing 30 mi^2 of paved and unpaved city routes daily [11-13]. Private cars have also become more popular than public transport in part because they are a reliable mode of transport. Legislative considerations by the Uganda National Roads Authority, Uganda Taxi Operator and Driver Association, and Ministry of Works and Transport regarding transition from mini-bus taxis to a formal bus network (termed Bus Rapid Transit) remains in the discussion phase although funding has been secured by the World Bank [13].

Reports discussing air pollution in Uganda remain unreliable [5,13-15]. In 2014, Schwander et al [16] began to focus on the relationship between airborne particulate matter and ischemic heart disease within the Kampala area. This pioneering study builds off that by identifying links between gaseous pollutants in Kampala City Center. Both, particulate matter and gaseous pollutants have been linked to respiratory distress and cardiovascular problems [4,17]. As an example, over the past decade it has been reported that there has been an increase in patients being treated for asthma [18,19] at the Mulago Hospital, Kampala. In light of the above, this study investigated ambient air quality in Kampala, Uganda and compared it to the nearby rural forest reserves.

MATERIALS AND METHODS

Study Duration and Sites

The data for this study was collected at five site locations (Figure 1) over the course of six months from November 2013 to April 2014. Two of the sample sites were within the city center of Kampala (C1, C2), one of the sample sites was located in the suburban area of Kampala (S1), and two other sample sites were located in forest reserves outside of Kampala (R1, R2). Site C1 (elevation 1350 m) was located at Makerere University outside of a Food Science Building. The topography is such that this building is located on top of a hill. Site C2 was located within Kampala's largest taxi park. This park acts as a staging station for all of taxis that depart from Kampala to other destinations outside of the city center. The taxis often idol until they are at full occupancy. At any given time, there are hundreds of taxis awaiting departure. Additionally, C2 (elevation - 912 m) was located

Table 1. Optimal Air Quality Standards (Averaging Time - 1 Hour)			
Chemical Parameters	**EPA (ppm)**	**WHO (ppm)**	**Uganda (ppm)**
Carbon Monoxide (CO)	35.0	35.0	9.0
Oxidants	0.12	0.12	N/A
Sulfur Dioxide	0.15	0.14	0.15
Nitrogen Dioxide	0.1	0.1	0.1

EPA - Environmental Protection Agency; WHO - World Health Organization

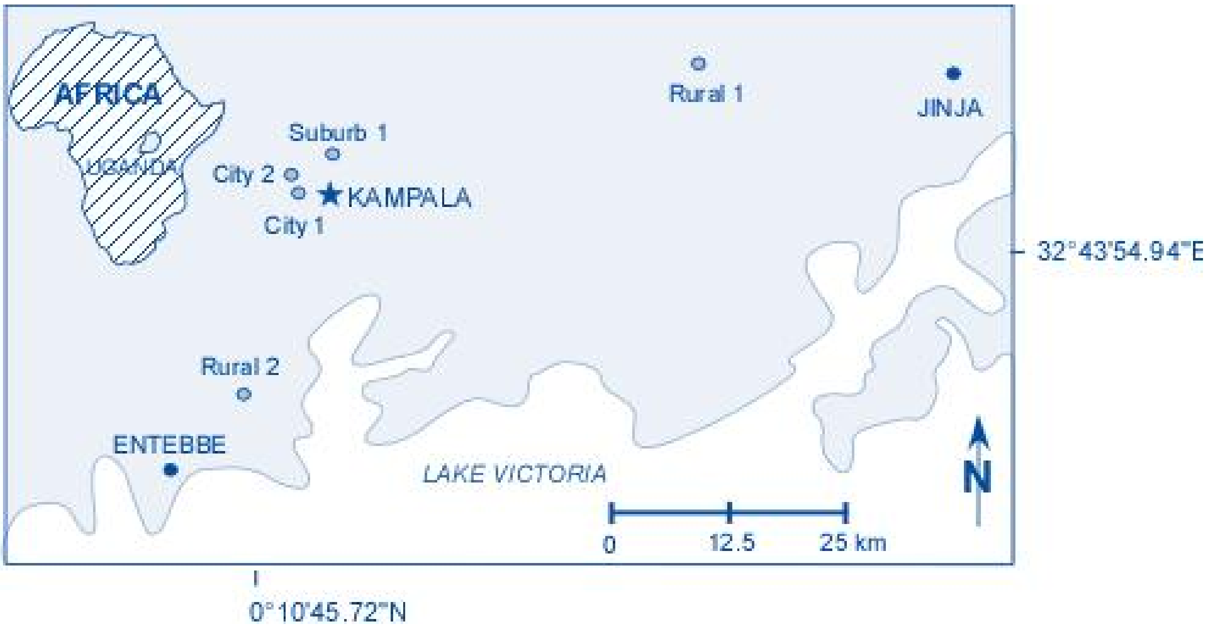

Figure 1: Sites Location Map, Uganda

in a valley. Smog in the air was both visibly evident and by odor. Site S1 (elevation - 1243 m) was located within a neighborhood. Residents often burn their trash nightly. This location was also on top of a hill. Site R1 (elevation - 1263 m) was located in Mabira Forest and Site R2 (1163 m) was located in Zika Forest. These forests are some of the last remaining reserves that buffer the city of Kampala from Lake Victoria.

Air Quality Sampling

The air quality was sampled using a portable LaMotte Model BD Air Sampling Pump. This instrument is a diaphragm vacuum pump that draws the air sample through absorbing reagents in an impinger at a constant rate between 0 and 2.0 liters per minute (lpm). An integral flowmeter regulates the air flow rate to control the amount sampled. Absorbing reagents were used for the following variables tested: oxidants, nitrogen dioxide, sulfur dioxide, and carbon monoxide. The manufacturer's recommendations for flow rate and test duration were followed in order to produce optimal results. Typically, each test ran for 1-hour at 2.0 lpm. These settings were consistently used over each sampling period. At each location, the air sampling pump was placed 2 m above the ground surface. Additionally, all samples were collected at the same position and at the same time of day. The sampling period occurred over six months and captured the parameter data from both the rainy and dry seasons.

Comparative Assessment of Air Quality

Values obtained from the monthly monitoring of the air quality parameters (carbon monoxide, oxidants, nitrogen dioxide, sulfur dioxide) were compared to the U.S. Environmental Protection Agency (EPA) and WHO standards for clean air (Table 1) [5,20,21] and to the standards set by NEMA of Uganda [5]. This data was also interpreted by the Air Quality Index (AQI) prepared with EPA air quality standards to determine the level of health concern for people breathing the ambient air. The AQI is a unitless scale ranging from 0 to 500; the higher the value the worse the ambient air condition [22]. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly adverse health effects. For example, calculated AQI values within the range of 301-500 indicate hazardous conditions and are recommended to impede strenuous activity outdoors.

Ethical Considerations

This research was a collaborative project with the US Fulbright Foundation and Makerere University.

Data Analyses

SPSS (IBM, NY, USA) and Microsoft Excel were used for data compilation and analyses.

RESULTS

Sites' Air Quality and Comparative Assessments

Sulfur dioxide always exceeded EPA, WHO and Ugandan minimum recommended exposure levels of 0.14 ppm at sites C1, C2, and R2 (Tables 2 and 3). There was no signature ever recorded for nitrogen dioxide at sites C1, S1, R1 and R2. Site C2 always recorded nitrogen dioxide levels slightly above (0.2 ppm) EPA, WHO, and Ugandan standards, however, this still met AQI levels for good air quality. The oxidants reported at all sites were within 0 ppm (R2) and 0.54 ppm (C2). Oxidant levels at C1, C2, and R1 exceeded minimum standards for EPA and WHO throughout the duration of the study; there are not yet limits set for this parameter by Ugandan legislation. Moreover, the oxidant levels at C1, C2, and R1 were reported to be unhealthy according to AQI standards during the duration of the study, except in March when C2 reached hazardous levels. Sites C1, C2, S1, and R1 never met the minimum requirement for Uganda air quality standards for carbon monoxide. Additionally, the carbon monoxide levels recorded reflect unhealthy to hazardous conditions at these locations. The EPA, WHO, and Ugandan recommended exposure levels of 35 ppm were never met at C2; the highest recorded value at C2 was 267 ppm.

Climate Parameters in Kampala, Uganda

The daily climatic conditions during the sampling periods are presented in Table 4. Mean temperatures from November 2013 to April 2014 ranged from 18.0 °C to 23.0 °C. Mean wind speeds were recorded between 8.0 and 10.0 km/hr.

DISCUSSION

The data collected at sites C1, C2, and S1 in this six-month study confirms that the growing city center of Kampala, Uganda is challenged with hazardous ambient air quality. Specifically, the air quality in the congested taxi staging station (C1) is alarming, and undoubtedly, places commuting Ugandan citizens and nearby proprietors at risk. Particularly, the exposure to elevated levels of carbon monoxide can lead to decreases in the amount of oxygen carried by hemoglobin in red blood cells. If this occurs then vital organs, such as the brain, nervous tissues and the heart, do not receive enough oxygen to work properly [23]. Minimally, carbon monoxide exposure causes lethargy, headaches, and lack of concentration, however, cardiovascular failure and permanent damage to fetus development can also be consequential. In December 2013, we recorded carbon monoxide levels at the taxi staging station to be 10 times that of the recommended exposure levels by the EPA and WHO. The poor health and fatigue of the daily

Table 2. Recordings of Air Quality at each Site (ppm)					
Months	**Sites**	**Carbon Monoxide**	**Oxidants**	**Sulfur Dioxide**	**Nitrogen Dioxide**
November 2013	C1	27	0.14	0.13	0
	C2	35	0.14	0.06	0.2
	S1	25	.07	0.16	0
	R1	33	0.14	0.19	0
	R2	0	0	0.1	0
December 2013	C1	33	0.07	0.48	0
	C2	267	0.07	0.1	0.3
	S1	33	0.03	0.02	0
	R1	22	0.07	0.04	0
	R2	0	0	0	0
January 2014	C1	27	0.1	0.48	0
	C2	33	0.07	0.57	0.2
	S1	20	0.07	0.2	0
	R1	14	0.07	0.57	0
	R2	0	0	0	0
February 2014	C1	15	0.07	0.48	0
	C2	37	0.14	0.55	0.2
	S1	20	0.03	0.49	0
	R1	10	0.03	0.2	0
	R2	0	0	0	0
March 2014	C1	15	0.18	0.21	0
	C2	133	0.54	0.32	0.2
	S1	32	0.18	0.15	0
	R1	20	0.03	0.2	0
	R2	0	0	0	0
April 2014	C1	32	0.07	0.15	0
	C2	43	0.5	0.41	0.2
	S1	15	0.15	0.14	0
	R1	20	0.18	0.1	0
	R2	0	0	0	0

C1 – Near Food Science Building, Makerere University; C2 - Kampala's largest taxi park; S1 - Suburban area of Kampala on top of a hill; R1 - Mabira Forest Reserve; R2 - Zika Forest Reserve

Table 3. Comparative Assessment of Minimum Standards for Each Site by Month

(The 'x' indicates that the parameter did not meet minimum standards listed in Table 1)

	EPA	WHO	Uganda
SITE: C1 - Makerere University			
November 2013			
CO			x
Oxid	x	x	N/A
SO_2			
NO_2			
December 2013			
CO			x
Oxid			N/A
SO_2	x	x	x
NO_2			
January 2014			
CO			x
Oxid			N/A
SO_2	x	x	x
NO_2			
February 2014			
CO			x
Oxid			N/A
SO_2	x	x	x
NO_2			
March 2014			
CO			x
Oxid	x	x	N/A
SO_2	x	x	x
NO_2			
April 2014			
CO			x
Oxid			N/A
SO_2	x	x	x
NO_2			

CO - Carbon Monoxide; Oxid – Oxidants; SO_2 - Sulfur Dioxide; NO_2 - Nitrogen Dioxide

Table 3 (cont). Comparative Assessment of Minimum Standards for Each Site by Month

(The 'x' indicates that the parameter did not meet minimum standards listed in Table 1)

	EPA	WHO	Uganda
SITE: C2 - Kampala's Largest Taxi Park			
November 2013			
CO	x	x	x
Oxid	x	x	N/A
SO_2			
NO_2	x	x	x
December 2013			
CO	x	x	x
Oxid			N/A
SO_2			
NO_2	x	x	x
January 2014			
CO	x	x	x
Oxid			N/A
SO_2	x	x	x
NO_2	x	x	x
February 2014			
CO	x	x	x
Oxid	x	x	N/A
SO_2	x	x	x
NO_2	x	x	x
March 2014			
CO	x	x	x
Oxid	x	x	NA
SO_2	x	x	x
NO_2	x	x	x
April 2014			
CO	x	x	x
Oxid			NA
SO_2	x	x	x
NO_2	x	x	x

Table 3 (cont). Comparative Assessment of Minimum Standards for Each Site by Month

(The 'x' indicates that the parameter did not meet minimum standards listed in Table 1)

	EPA	WHO	Uganda
SITE: S1 - Suburban Area of Kampala			
November 2013			
CO			X
Oxid			N/A
SO_2	x	x	X
NO_2			
December 2013			
CO			X
Oxid			N/A
SO_2			
NO_2			
January 2014			
CO			X
Oxid			N/A
SO_2			
NO_2			
February 2014			
CO			X
Oxid			N/A
SO_2	x	x	X
NO_2			
March 2014			
CO			X
Oxid	x	x	N/A
SO_2	x	x	X
NO_2			
April 2014			
CO			X
Oxid	x	x	N/A
SO_2	x	x	x
NO_2			

Table 3 (cont). Comparative Assessment of Minimum Standards for Each Site by Month

(The 'x' indicates that the parameter did not meet minimum standards listed in Table 1)

	EPA	WHO	Uganda
SITE: R1 - Mabira Forest Reserve			
November 2013			
CO			X
Oxid	x	x	N/A
SO_2	x	x	X
NO_2			
December 2013			
CO			X
Oxid			N/A
SO_2			
NO_2			
January 2014			
CO			X
Oxid			N/A
SO_2	x	x	X
NO_2			
February 2014			
CO			X
Oxid			N/A
SO_2			
NO_2			
March 2014			
CO			X
Oxid	x	x	N/A
SO_2			
NO_2			
April 2014			
CO			X
Oxid			N/A
SO_2			
NO_2			

Table 3 (cont). Comparative Assessment of Minimum Standards for Each Site by Month

(The 'x' indicates that the parameter did not meet minimum standards listed in Table 1)

	EPA	WHO	Uganda
SITE: R2 - Zika Forest Reserve			
November 2013			
CO			
Oxid			N/A
SO_2			
NO_2			
December 2013			
CO			
Oxid			N/A
SO_2			
NO_2			
January 2014			
CO			
Oxid			N/A
SO_2			
NO_2			
February 2014			
CO			
Oxid			N/A
SO_2			
NO_2			
March 2014			
CO			
Oxid			N/A
SO_2			
NO_2			
April 2014			
CO			
Oxid			N/A
SO_2			
NO_2			

workers in this area is apparent by visual observations. Of other concerns, rural Mabira Forest Reserve (R1) also recorded high levels of sulfur dioxide, carbon monoxide, and oxidants. Likely, this is due to an environmentally unregulated manufacturing facility. Zika Forest Reserve (R2) provides a baseline data set for air free of contamination.

Although the climate of Uganda is fairly consistent (Table 4), warmer temperatures can promote the production of ozone smog from vehicle emissions (namely nitrogen dioxide and volatile organic compounds) [24,25]. Additionally, wind systems can often help reduce the effects of smog by blowing latent air out of valley depressions. The months of December 2013 (267 ppm) and March 2014 (133 ppm) recorded the highest levels of carbon monoxide in this study although it does not appear to be related to temperature (December mean temperature, 20° C; March mean temperature, 23°C) or wind speed (December mean windspeed, 8 km/hr; March mean windspeed, 15 km/hr).

Ugandan government organizations, like NEMA, would benefit from research as a way to promote law enforcement, the import of fuel efficient cars, and the introduction of a mass transit system in the form of subways, buses, or railways. Additionally, the promotion of mixed land use within the city center (suburb vs. business operation), and a greater street connectivity with proper walking paths have been associated with significantly lower per capita emissions of gases such as nitrogen dioxide [24].

CONCLUSIONS

Ambient air quality is largely ignored as an environmental concern in Uganda. Environmental regulations for air quality that were defined in 2005 by NEMA have not yet been enforced. This limited data set presented in our study suggests that there is a need for more qualitative and quantitative data collection to link vehicle abundance and inadequate traffic distribution patterns to ambient air pollution. Moreover, further investigations of cardiovascular and respiratory problems of urban Ugandans may be

Table 4. Recorded Climate Parameters in Kampala, Uganda						
Climatic Parameters	**November 20, 2013**	**December 5, 2013**	**January 15, 2014**	**February 13, 2014**	**March 6, 2014**	**April 14, 2014**
Mean temperature, °C	20	18	23	23	23	23
Maximum temperature, °C	26	20	25	27	25	26
Minimum temperature, °C	20	18	22	20	19	23
Mean wind speed, km/hr	8	10	9	8	9	10
Maximum wind speed, km/hr	17	19	11	18	15	24

the stimulus needed to promote the integration of environmental concerns and health considerations into future urban planning.

AUTHORS' CONTRIBUTIONS

TJJ conceived and designed the study, analyzed and interpreted the data, and wrote the manuscript. JO and RN facilitated sites set-up and data collection. EN provided support for field work. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST

Authors have declared that no competing interests exist.

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