“It is Unbearable to Breathe Here”: Air Quality, Open Incineration, and Misinformation in Blantyre, Malawi

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# Introduction

Built in 1964, Malawi’s year of independence, Queen Elizabeth Hospital (QECH), or Queen’s, as it’s known locally, is the country’s largest public hospital. Designed in the Tropical Modernism style of architecture popular within Africa in the late colonial period, Queen’s open-plan design sprawls across a broad swath of central Blantyre, with dozens of wards, specialised facilities, and administrative buildings, linked together by a bewildering maze of covered walkways. A hive of around-the-clock activity, Queen’s bustles from dawn to dusk with a constant stream of patients, drawn from across the country, and maintains a city-like feel even after dark as staff as stay-in family members cook and care for their in-patient dependants. Yet, for the first-time visitor, it’s not the architecture or the crowds that are the most striking when entering the grounds, but the smell. Immediately noticeable, even from the road outside the hospital, Queen’s is smothered by an acrid-smelling, white smoke, which hangs over the grounds day and night: the product of several constantly burning fires spread across the campus. Breathing this air, when a significant amount of burning is occurring, primarily at night when the smoke is less visible, can be incredibly discomforting. Moreover, the tropical architecture, designed to let air and light circulate, means that even indoors, within patient wards, surgery, and treatment areas, the air quality can also be unbearable. Poor air quality associated with burning, through released particulate matter (PM), has been linked to multiple negative health outcomes like asthma, heart disease, heart failure, stroke, and cancer among others (Anderson et al., 2012; Bell & HEI Health Review Committee, 2012). In a space of healing and recovery, why is such burning occurring, and how can it continue to persist?

Queen’s produces an immense amount of solid waste. The dozens of wards, offices, and kitchens, serving the hundreds of patients and staff, generate a massive amount of potentially infectious medical waste, mixed domestic and office waste, and kitchen waste, which needs to be removed and disposed of daily. Some individual wards implement waste separation, binning medical wastes separately from general waste, however separation ends at the point of collection. Queen’s is not served by regular municipal waste collection. What municipal collection that is done is ad-hoc, sporadic, and based on the hospital’s available financial resources. Rather, most hospital waste (infectious and non-infectious) is gathered by grounds staff and burnt *at* the hospital’s incinerator, located at a central point within the hospital campus[[1]](#endnote-1) (Tilley & Kalina, 2020). However, the vast majority of the deposited waste is *not* incinerated, as a new incinerator provided by the Ministry of Health in late 2019, is only able to handle a small percentage of the hospital’s waste. Furthermore, the incinerator is frequently inoperable, under repair, or without power,[[2]](#endnote-2). Rather, the waste is openly burned, in a constantly smouldering pile to the side of the incinerator building, sending up the aforementioned clouds of smoke, which choke the grounds (Figure 1). Innumerable other, smaller, fires, scattered across the QECH campus (Figure 2) contribute their part, as grounds and maintenance staff habitually burn leaves and other garden refuse. Furthermore, caregivers[[3]](#endnote-3) who reside separately on hospital grounds, cook for themselves throughout the day and night using biomass (charcoal or wood), and burn their own domestic waste. As a result, air quality at the hospital is often hazardous, with patients, staff, and caregivers struggling to cope, when just breathing is, as the quote[[4]](#endnote-4) used in the title of this article, ‘unbearable.’

Utilising a mixed-methods approach, including a network of custom-designed air quality monitors and qualitative fieldwork with hospital staff, patients, and caregivers, the purpose of this investigation was to gain a multi-dimensional understanding of the impacts of the open burning of the various solid and organic waste fractions at QECH. Specifically, this work aimed to intensively and longitudinally measure the air quality, in particulate matter (PM), at multiple locations at and surrounding the central burning point. Furthermore, we also aimed to qualitatively understand how affected individuals perceive air quality at QECH and understand potential health impacts.

This research responds to a several specific gaps within the body of academic air quality literature: Although there has been ample discussion of air quality challenges in African cities (>>>>>>>>>), there is a paucity of data on air quality impacts linked to trash burning. In particular, within African cities, there has been a total dearth of scholarship on the burning of medical waste, or on air quality within hospital contexts. Furthermore, while the voices of the citizens of Northern cities (>>>>>>>>>) have been well documented on localised air quality issues, the voices of African urban dwellers have not been given the same consideration, and there remains a pressing need to understand how these populations experience the impacts of the open burning of trash within their communities and understand potential risks.

Fig. 1: Open burning at QECH, with the old incinerator building in the background (Authors).

Findings suggest……

Summary of quantitative results… Shit’s bad

Interviews show that patients, staff, and caregivers alike, are keenly aware that the air quality at Queen’s is poor, with most respondents reporting frequent respiratory-related illness. Many also linked the smoke to potential long-term health complications and expressed a belief that the pollution could be contributing to other, more potentially life-threatening diseases, such as asthma, cancer, and tuberculosis. Moreover, the tropical design of hospital buildings have rendered most coping mechanisms ineffective, with most staff only finding relief at home: relief that is not available to the hundreds of patients and caregivers who sleep at QECH or are unable to leave.

Snappy concluding sentence or 2,… .further gaps..inequality… set up Saloni?

# Literature Review

## Air Quality in African Cities

## Medical waste/disposal/burning

### Solid waste

* Lots of it, and increasing
* No services, no money, no options

Waste generation and collection in urban area of Africa for the year 2012 (Scarlat et al. 2015)

Table

Description automatically generated

### Medical Waste- what it is, how much, etc

### Trash burning (extent, quantification)

* Despite the obvious need for trash disposal, and the obvious solution that burning provides, trash burning was not considered as a major source of air pollution until recently and the evidence of it’s extent and impact remains limited.
* Domestic burning is a frequent technique to eliminate household waste due to unavailable transport services, cost to pay for waste collection, and low collection coverage
* Estimate 2400Tg burned annually,; 620 at residential and 350 at dump sites=970Tg or 41% of waste is burned openly; NO MENTION OF MEDICAL FACILITIES (Wiedinmyer, 2014)
* Measure 4 landfill sites in Mexico: estimate that \_2000 Tg/y of garbage are generated globally and about half may be burned, making this a commonly overlooked major global source of emissions (Christian, 2010)
* In india: we measured the spatial frequency of MSW-burning incidences. In winter, we found an average of 130 incidences km−2 day−1 in BP, 60 incidences km−2 day−1 in SJEand 30 incidences km−2 day−1 JPE (Nagpure, 2016)

Some of the early evidence on trash burning came from Mexico, where the practice is widespread, and highly visible, especially in the capital, Mexico City, where the bowl-shaped topography contains, and seems to concentrate the mega-city’s filth. Based on measurements at 4 landfill sites, Christian (2000) estimated that approximately 1000Tg of trash are burned every year, contributing significantly to PM. Later work from the same cities determined that although trash burning contributed less than 1% of the PM2.5 mass in the city centre, contrations in surrounding poorer areas were higher as a result of increased trash burning (Hodzic, 2012).

Building on the work of Christian (2020), Wiedinmyer (2014) developed global estimates for PM emissions for openly burned waste and proposed that 2400Tg of trash was burned openly and contributed 29% of global antrophogenic PM2.5 emissions. However, experimental work from India has also highlighted the spatial and seasonal heterogeneity of trash-burning, and the potential for localized impacts not captured in global models. The first mortality estimates for chronic exposture to PM2.5 from trash burning were not presented until 2016 (Kodros, 2016). The authors estimate that 270 000 premature adult mortalities (ischaemic heart disease, cerebrovascular disease (or stroke), chronic obstructive pulmonary disease, and lung cancer) are the result of waste combustion every year, or about 9% of adult mortalities from exposure to ambient PM2.5 reported in the Global Burden of Disease Study 2010. Though Kodros produced country-level estimates, Marais (2016) reminds us that emission inventories of pollutants in Africa are highly uncertain and likely underestimated, particularly in urban centers (Marais, 2016)

## Health impacts of trash burning

Particulate matter, or PM, is not specific to plastic or trash burning, but rather the product of any type of incomplete combustion.

Indeed, it is one of the most commonly measured indicators for air quality and is tracked through two Sustainable Development Goal indicators: Indicator 11.6.2 “Annual mean levels of fine particulate matter (PM2.5) in cities (population-weighted); and Indicator 3.9.1 : Mortality rate attributed to household and ambient air pollution (reference). PM is measured in terms of it’s particle size and generally classified into PM with particle sizes less than 10mm (PM10) and those with sizes less than 2.5mm (PM2.5). One way of measuring the severity of air pollution is by expressing the mass of PM per volume of air (mg PMx/m3 air), especially because it is one of the components of air pollution that has been reliably linked to human health and is one of the most harmful (Pope et al. 2002, Hua et al. 2014).

* According to the World Health Organization (2014), air pollution levels in Dakar exceeded the permissible PM10 levels by a factor of 7. In Lagos and Accra, the exceedance factor was six and five times, respectively (WHO 2016a). As shown in Fig. 1, the reported averages exceed 26 μg m−3 for PM2.5 more than half of the African continent, the Sahelian region being the most affected. PM2.5 pollution led to approximately 125,000 premature deaths in West Africa in 2013 (Naré and Kamaté 2017).
* among the 47 countries of Sub-Saharan African region, only six provide data on airborne PM in 16 cities (WHO 2014).

#### Health impacts

PM has been linked to multiple negative health outcomes like asthma, heart disease, heart failure, stroke, and cancer among others (Anderson et al, 2012; Bell et al 2012). Despite its importance, the WHO only collects data from 10 African countries (covering 39 cities) (WHO, 2016). Similarly lacking are robust epidemiological data from and for the African context (Coker, 2018) though emerging data show worrying results: analysis of 30 countries indicated that PM2.5 concentrations exceeding minimum exposure levels were responsible for 22% of infant deaths (Heft-Niel, 2018).

#### Sources

Modelling sources of diffuse and inefficient sources of combustion (including biomass, charcoal and fuel burning, but excluding trash), Marais and Widimyer (2016) estimate an additional contribution varies across the African continent but annual mean surface fine particulate matter (PM2.5) is greatest (>5 μg m−3) populous Nigeria. Additionally, biomass burning, which is responsible for 90% of energy consumption in Sub-saharan Africa, produces significant levels of PM2.5 indoors (Das et al, 2017). In Malawi, where biomass is the primary cooking fuel, indoor air quality, especially in rural homes, consistently exceeded WHO limits for air quality, and often far exceeded it (Fullerton et al, 2009), affecting primarily women and children. However, given the seasonality of both cooking (i.e. hot food) and the location of cooking (outdoors when possible), the exposure to PM2.5 also varies accordingly (Ni, 2016).

* What kind of baseline exposure are these people are already dealing with?

### PM from trash Burning

* use PM2.5=9.8g/kg burned, PM10 11.9 g/kg; PM2.5 emissions=29% of global anthropogenic emissions (Wiedinmyer, 2014)
* We estimate a fine particle emission factor (EFPM2.5 ) for garbage burning of \_ 10.5± 8.8 g/kg ((Christian, 2010)
* Mexico City fires are also very small and cannot be detected from satellites, and therefore are not included in typical biomass burning emission inventories: trash burning represents less than 1% of the PM2.5 mass in the city center where the PM2.5 concentrations are the highest, from 2 to 7% in the prevailing outflow region north and northeast of the city, and about 15% in the strongest emission hotspot which experiences average PM2.5 levels of 5−8 μg m−3 (Hodzic, 2012)

### Health impacts from pm2.5 from waste burning

* (Kodros, 2016): provide the first estimates of mortality due to chronic exposure to PM2.5 from domestic-waste combustion.
* we estimate that waste-combustion emissions result in 270 000 (5th–95th 213 000–328 premature adult mortalities per year
* Our central estimate equates to 9% of adult mortalities from exposure to ambientPM2.5 reported in the Global Burden of Disease Study 2010. Exposure to PM2.5 from waste combustion increases the risk of premature mortality by more than 0.5% for greater than 50% of the population.

----last paragraph talk about perceptions

# Methodology

This study utilised a mixed-methods approach to both quantitatively measure the air quality of the open incineration of waste at QECH, and to qualitatively investigate its relationships and perceived impacts amongst staff and caregivers. Although, the work was conducted over one sustained period in late 2019, it must be contextualised within five years’ experience of research and activism within QECH by the authors. All relevant permissions were obtained from QECH beforehand, through consultations with administration and staff, and the research was approved by the National Committee On Research In The Social Sciences And Humanities in Malawi, Protocol NO. P.03/19/356.

## Study site

What new can we say about Queens that wasn’t already stated in the intro?

### Locations of the sensors

The sensors were located in consultation with hospital management. The goal was to locate sensors across the campus with a range of distances and directions from the incinerator, though the final decision was based on accessibility, the permission of the unit’s head, and convenience. Each of the locations is briefly described below:

* Administration: the operational hub of the campus, containing mostly offices and meeting rooms.
* Lions Sight First Eye Hospital (LSFEH):
* The Blantyre Lighthouse Trust clinic is one of four operating across Malawi; the clinics work in collaboration with the the Ministry of Health (MOH) to provide integrated HIV testing, treatment and care for people living with HIV.
* Blantyre Malaria Project was started over 40 years ago by Terrie Taylor and Malcolm Molynieux
* Moyo Nutritional Rehabilitation and Research Unit: The Moyo Nutritional Rehabilitation & Research Unit is a 57-bed nutritional rehabilitation unit (NRU) for treating infants and children with severe malnutrition and acute illnesses. It is one of 104 operational NRUs in Malawi. It also has an outpatient therapeutic feeding program (OTP) for children with malnutrition who can be treated outside of the hospital.
* 6B: men’s ward:
* Mercy James Insitute for Pediatric Surgery and Intensive Care (MJC) was opened in 2017 by the NGO Raising Malawi, which was founded by Madonna. With 3 operating rooms and 50 beds, it is the first and only first dedicated pediatric surgery hospital in Malawi. prior to its opening, QECH had fewer than 10 intensive care beds.
* Guardian Shelter: When a patient arrives at QECH, she or he will usually arrive with a guardian: someone to cook for them, buy medicine, do their laundry and help them bathe. A gender-separated concrete floor shelter for sleeping along with a cooking pavilion and toilet/shower block are maintained by a local NGO (Chira fund). Though simple, the facility is secure and offers one of the only free/accessible toilet facilities for visitors on the QECH campus.
* <map of sensors within Queens>
* Background on groundkeeping, janitorial procedures--- will pull from interviews

## Measuring Air Quality

### Hardware and Software

The device centers around a Raspberry Pi 3 Model B single-board computer. We have chosen this board over something cheaper (Arduino for example) because this board is basically a mini-computer complete with an operating system and storage space. This makes the board far more accessible, both in terms of networking and operation as well as in terms of computer skills and experience. The added advantage of storage space is that the data are not lost if the internet connection breaks down. One advantage that the Arduino has over the Raspberry Pi is that the Arduino can read both analog and digital signals, while the Pi can only read digital. This is problematic as some sensors have an analog output. In order to be able to read these sensors, we needed to include an analog-to-digital (ADC) converter. The amount of dust is measured by a Nova PM SDS011 High Precision Laser sensor. This sensor measures particles at 2.5 and 10 micrometers in diameter in mg/m3. A list of the specific hardware and software components can be found in Appendix XXX

### Installation

The air quality sensors were installed in eight buildings around Queens Elizabeth Hospital (Q.E.C.H). The eight buildings consisted of the Administration block, Lion Eyesight, Mercy James, Umoyo, Malaria Alert Centre, Light House, Ward 5B and Guardian Shelter. The locations were purposively chosen to cover the whole campus to capture a range of distances from the main incinerator. Ultimately, the central administration and the responsible person from the unit decided which sites were selected. The position of the sensors were also carefully selected: four air quality sensors were installed on the outside of buildings (name them here) while the remaining four sensors were installed inside (name them here). The air quality sensors were mounted to a wall at a height of approximately two meters from the ground with the help of Q.E.C.H maintenance department personnel. This height was chosen to prevent the public from tampering with the equipment when they visit the hospital. Additionally, we assured that each pipe that inhaled ambient air was freely protruding in the building (room) in order to capture the air quality.

<photos of air sensors>

Summary of what was inside and what was outside

The air quality sensors had to be up and running for the whole duration of the project scope. To achieve this, each sensor unit was equipped with an extra battery in addition to the standard external battery of 5000mAh. Each battery powered an air quality sensor unit for three days continuously. To avoid any down time, we changed the batteries every two days. Data were also collected from the sensor at the time of battery replacement. The sensors were capable of being connected to WIFI, a feature which enabled us to download the data into our computers wirelessly. The data were downloaded into pre-organized folders by building name and by week number to make the data analysis process easier for the study team.

## Qualitative Methods

Qualitative data collection consisted of 26 semi-structured interviews with caregivers and hospital staff (including janitorial and maintenance staff, nurses, doctors, and administrators). According to Bjorholt and Farstad ([2012](#_ENREF_6" \o "Bjorholt, 2012 #313)) semi-structured interviews follow a framework of themes, but do not constrain the respondent to a particular topic. This type of interview allows for greater flexibility in questioning, and respondents are allowed greater scope for “elaboration and general discussion rather than just being presented with a set of fixed questions or questions demanding only fixed responses” ([Robinson, 1998, p. 413](#_ENREF_32" \o "Robinson, 1998 #289)). This format gave respondents the opportunity to address issues that they considered important and allowed for themes to emerge that may not have been identified during the pilot phase. From a constructivist perspective, meaning, developed through a conversation or interview, is seen as the product of co-production between the interviewer and the interviewee ([Denzin et al., 2017](#_ENREF_9" \o "Denzin, 2017 #15)). So, although responses gathered through interviews were to some degree, a response to the positionality of the interviewer, the open-ended nature of questions allowed respondents the freedom to craft their own replies, without being limited by narrow or leading questions ([Kitchin & Tate, 2001](#_ENREF_22" \o "Kitchin, 2001 #450)).

Interview respondents were chosen using a purposive or judgement sampling regimen, i.e. a subjective sampling method in which respondents are selected based on their ability to effectively contribute to the study’s research objectives ([Kitchin & Tate, 2000](#_ENREF_21" \o "Kitchin, 2000 #280)). Interviews were conducted in the local language (Chichewa), audio recorded, and transcribed into English. Participation was voluntary, and responses were recorded anonymously. Collected data were analysed thematically. Broadly, thematic analysis is a methodology used for identifying, analysing, and reporting patterns or themes within data ([Braun & Clarke, 2006](#_ENREF_7" \o "Braun, 2006 #297)). Interview data were stored, transcribed, and then coded within the software programme Nvivo, which organises materials and assists with the coding process.

# Results and Discussion

##What are the first and last days of data?

##What are the total number of days in the sample?

## Air Quality Measurements

Every data point at each location for both pm10 (top) and pm2.5(bottom) over 3 months is plotted in Figure XXX. (maybe appendix). The maximum scale is set to 1000ug/m3 as this was the maximum value that could confidently be recorded (any values beyond this were truncated to 1000), and to allow for consistent comparison between locations. Consistently high values were recorded at both the HIV/AIDS unit and the Guardian shelter though for different reasons: the HIV/AIDS unit is directly beside the incinerator building while the Guardian shelter is actually beyond the official perimeter, though it is the site of continuous charcoal-based cooking by the (mostly) women who stay there while attending to a patient. The PM10 values at the Administration Building and the Eye clinic are very low and likely represent background levels of city-wide pollution (especially since the hospital is located directly on the largest highway in Blantyre). The PM2.5 values at this location have a larger range of values but are still contained within a narrow band, while the results at the Malaria, Malnutrition, Men’s, and ICU units all have obvious peaks (for both parameters) beyond a similar baseline, indicating that localized burning or blowing smoke from the main incinerator is being recorded.

### Peaks

Due to localized variation (air movement in the immediate area) and the density of the observations, the plotted 5-minute data obscure persistent trends. The full set of 5-minute data are plotted and presented in Appendix XA1. However, the number of measured values that exceeded the hazardous limit for both parameters are summarized in Table XR1.

Table XR1. Number of peaks exceeding the hazardous limit for PM10 (>850) and PM2.5 (>500) are summarized for each location.

Graphical user interface, text, application, email

Description automatically generated

##What was the number of observations between start and end (what were the starting days and times)?

Over the course of the two-month study, the hazardous limits for both parameters were exceeded at all locations except for the Lions Eye hospital. The limits were exceeded fewer than 50 times at five of the locations, and only the monitors at the HIV/AIDS clinic and the Guardian Shelter recorded more than 50 instances above the hazardous limits. At the HIV/AIDS clinic, the PM10 limit was exceeded almost twice as often as the PM2.5 limit, while at the Guardian Shelter, the reverse is true. Because the HIV/AIDs clinic is within 50 m of the incinerator, the number and predominance of PM10 peaks is characteristic of incomplete combustion and dust that is typical for the area and the open burning that occurs there. The residents at the Guardian Shelter however are mostly cooking within contained clay stoves that have designed to improve combustion of the coal and wood that is burned within them. The fewer number of PM10 peaks is a testament to this intervention, though the frequency of PM2.5 peaks is still beyond acceptable.

### 24-hour averages

The 24- hour averaged values (logged every 5 minute) are presented for each location, for both PM10 and PM2.5 in Figure XD1. As well as dampening local variation and peaks, the WHO air quality guidelines are also based on 24-hour averages which are the standard against which the health risks can be judged (refer to section XXX)

Overall, PM2.5 values remained below 100 ug/m3 at 6 of 8 locations (Administration, Eyes, Malari, Malnutrition, Mens, and Surgery/ICU); PM10 values were consistently below 100ug/m3 at the same locations, but with several average values extending slightly above, and then infrequently.

The daily averages at both the HIV/AIDS ward and the Guardian ward are both consistently higher for both parameters and the two averages closely followed the same general trends. Though the peaks at the HIV/AIDs ward were higher than the Guardian Shelter, the low values were consistently lower, indicating more times of little or no burning, unlike the Guardian Shelter emissions which were relatively constant. However, further analysis of 12 hour averages (8:00-15:59 (working hours) and 16:00-7:59 (evening)) did not indicate clear differences between the time periods; stated differently, the data did not clearly point to more or less burning in the day or at night.

##can we calculate AVERAGE values from beginning to end? Add onto figure?

##include the 12-hour averages in the appendix?

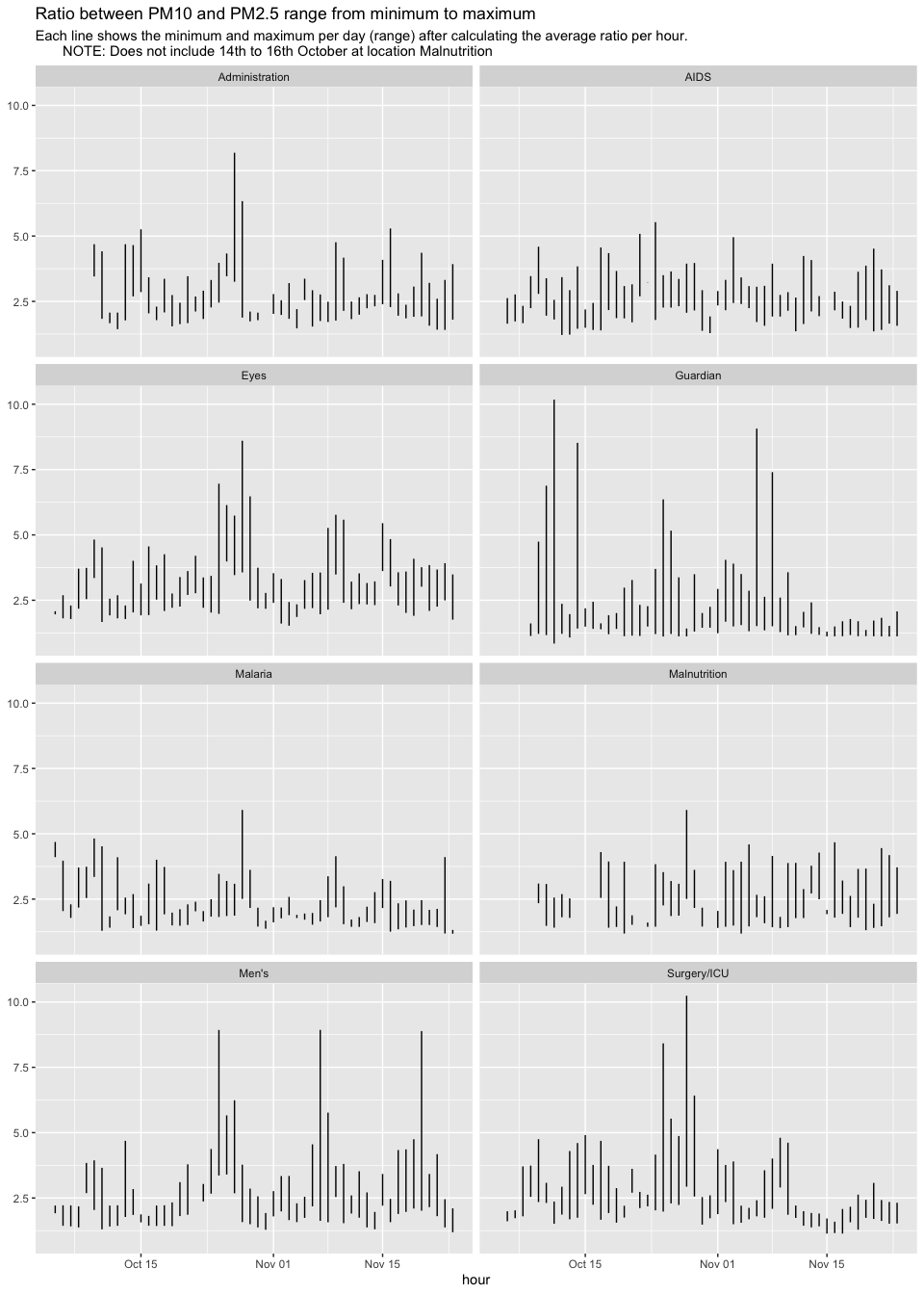
Chart, histogram

Description automatically generated

**Figure XD1.** Average 24-hour PM10 and PM2.5 at 6 monitoring stations over 2 months

### PM ratios

Given that the type of fuel and the type of burning (contained vs. open) produce very different particulate fingerprints, the ratio of PM10 to PM2.5 values were examined to determine if a clear difference between locations, and therefore source, could be identified. The results are presented in Figure XD2.



**Figure XD2.** PM10:PM2.5 values for each location. Each line shows the minimum and maximum ratio for the day based on ratios calculated hourly.

The results presented in Figure XD2 illustrate two concepts: the presence of PM10 relative to PM2.5 as well as the range of values over which that ratio is observed.

Unlike the peak values presented in Table XD1, the high values presented in Figure XD2 indicate the relative presence of larger (PM10) particles to smaller ones (PM2.5) regardless of their concentration: the ratio of two low concentrations can be the same as the ratio of two high concentrations and is therefore more indicative of source than of proximity.

In general, the calculated ratios are concentrated between 1.25 with few values exceeding 7.5. Three from each the Guardian Shelter and the Men’s Ward exceeded 7.5 though the most values exceeding 5 were at the Guardian Shelter. It is interesting to note that despite the large daily variations at the HIV/AIDs ward, the parameter ratios there were fairly consistent with few spikes, and only 2 days with ratios above 5.

An examination of the range of ratios is used to better understand the variability within a single day. For example, several of the calculated values at the Guardian shelter have a range of more than 5, and one day had a range of close to 10 i.e. the minimum ratio recorded for that day was close to 1 and the maximum value was over 10. The composition of emissions recorded at that location ranged significantly, and likely reflects a range of burning styles and/or fuel type.

## Exposure Data

Following the previous guidelines which had been published in 2005 (World Health Organization. Regional Office for Europe, 2006) new, more stringent recommendations were released in September 2021(World Health Organization, 2021). The relevant particulate matter targets are presented in Table XD2.

Table XD2. Revised 2021 particulate matter targets from the WHO

Table

Description automatically generated

##Lars please update to the new WHO interim targets

The Malawi Bureau of Standards is the national agency responsible for setting and publishing all standards in the country. At the time of writing, the official website ([www.mbsmw.org](http://www.mbsmw.org)) was not available. However, published work that reference Malawian standards (Kutlar Joss et al., 2017; Mapoma et al., 2014) indicate that the maximum 24-h PM10 value is 25 ug/m3 and the maximum annual PM2.5 value is 8 ug/m3. There is no daily maximum value for PM2.5. It should be noted that both of these values are at, or below, the new level-4 interim WHO targets are were previously far below the 2015 values.

## “The Air We Breathe is Not Good”: Perspectives from QECH

As the previous section has described, the open incineration of waste at QECH has created hazardous conditions for those occupying the space. These risks were not lost on staff and caregivers, as interviews demonstrated broad and near universal awareness of the poor air quality within the hospital grounds. Overwhelmingly, within interviews, both caregivers and staff were quick to decry the poor quality of the air, generally without prompting. The few exceptions were those staff posted on the peripheries of the hospital grounds, at a distance from the spaces of incineration. However, even those who did not experience the impacts of the burning, were aware of it, and considered themselves fortunate to be posted in a section of the hospital where it was less of a problem[[5]](#endnote-5). Furthermore, according to caregivers and staff who work night shifts, air quality can be particularly bad at night and in the early morning, despite the smoke being less visible, due to the habit of janitorial staff concentrating their burning during the late hours. The poor air quality on hospital grounds is also a frequent cause for complaint by patients and visitors, with nearly every staff member interviewed being able to recall having received a complaint, and in turn, complaining to administration. One of the staff members responsible for the burning said that he personally, had received hundreds of complaints, but was powerless to affect meaningful change, aside from burning at different hours, until the incinerator could be repaired[[6]](#endnote-6).

Nonetheless, despite this consensuses that air quality caused by the burning of waste within the hospital was a problem, significant differences emerged between respondents over their understandings of potential impacts, the effectiveness of various coping mechanisms, and their problematisations linked to the burning of specific waste materials. In addition, interviews revealed that these understandings were informed by a significant amount of misinformation, even amongst trained medical staff, which may contribute to them being less able to mitigate potential risks for themselves and those who rely on their care.

### Impacts, Problematisations, and Misinformation

The poor air quality within QECH was responsible, according to respondents, for a wide array of health impacts. The most common ones cited included: coughing and sneezing, sore throat, stinging eyes, breathing difficulties, and persistent cold and flu. Nausea was also mentioned, but was not a commonly described impact[[7]](#endnote-7). Only one respondent, of the 26 total interviewed, did not describe lingering health impacts which they could ascribe to the smoke, however, they also described having chronic eye irritation, but did not believe the smoke was a contributing factor[[8]](#endnote-8).

In addition to these impacts, which respondents bear on a daily basis, many also believed that the smoke could contribute to a number of more serious, long-term health complications. For instance, nearly a quarter of respondents raised concerns of the potential impact that the smoke could have on patients or staff with asthma. Others flagged poor air quality as a potential risk factor for certain cancers, lung disease, or heart problems. For a few, the smoke posed an unknown danger, they were not sure what types of impacts it could have, but they were sure it was harmful in some way[[9]](#endnote-9).

Also, understandably, given the large tuberculosis ward present within the hospital grounds, and the high prevalence of the disease within Malawi (CITATION), there was significant concern (more than half of respondents) about the impact the poor air quality could have on the infected. However, there also persisted a belief among several respondents, including several nurses, that the smoke could be a cause of the disease itself. As one staff member (20/11/2019) stated, “I believe breathing this air for a long time can cause Tuberculosis.” This, however, was only one of the few instances of misinformation which staff members held regarding air quality and health. Another example, voiced by several respondents, included a belief that some staff members were immune to ill-health impacts of the smoke, because they had received vaccinations from the hospital[[10]](#endnote-10). Nonetheless, they were concerned about the impacts of the smoke on patients and visitors, as one staff member (18/11/2019) expressed:

*Personally, I have never experienced [eye discomfort] because I get vaccinated and I am protected including other staff. However, we realize that the air can badly affect other people and patients who come to this place.*

Another interesting misconception that emerged, which may be tied partly to translation and transcription, was a different cultural understanding of smoke versus smells. More than half of the respondents appeared to conflate the two, with some expressing a belief that it was the odour of what was being burnt that was harmful, rather than the smoke being given off. This has led many to specifically problematise the burning of certain wastes, such as plastics, medicines, and other medical wastes, which give off distinctive or less pleasant odours, as opposed to the burning of other items, such as garden refuse, which may produce significant smoke, and contribute to higher recorded values of particulate matter, but produce a less pungent, or more normalised, odour.

### Coping Mechanisms

Finally, in order to manage the impacts of QECH’s persistently poor air quality, staff and visitors reported having developed a number of coping mechanisms, designed to help them get through their daily routines. These included staying indoors, blocking doors and windows, and taking breaks away from hospital grounds in order to catch some breaths of fresher air. However, for janitorial staff, inside was not necessarily better, as several reported their indoor workspaces as being also insufferable for long periods of time from the smell of cleaning agents and other chemicals[[11]](#endnote-11). Furthermore, amongst respondents there was a general disagreement over the effectiveness of personal protective equipment (PPE), such as face masks, towards mitigating the impacts of the smoke. A few staff described pleading to hospital administration for such equipment, to no avail[[12]](#endnote-12). However, other staff members, who do have access to PPE, noted that even face masks do little to mitigate the impacts of the smoke, describing them as ineffective[[13]](#endnote-13).

Most staff, however, have been unable to find anyway to mitigate the impacts of the smoke, and only found relief once they reached home at the end of their shift, as one of the janitorial staff described, ”we only feel safe when we are home”[[14]](#endnote-14). Of course, this relief is not available for the hundreds of patients and caregivers who sleep at QECH or are unable to leave. Ultimately, most place their hope in the construction of the new incinerator (which had not yet been activated at the time of the interviews), and biding their time as construction drags on; coping as best they can. As one staff member (25/11/2019) described, “we are just hoping we will start breathing good air soon, when the new incinerator is opened.”

# Conclusion and Recommendations

## Limitations

* There were no obvious locations within the city area that could be confidently used as representative background values; trash burning was common even the less dense, leavy suburbs. And although there were several possible areas upwind and outside of town, the logistics and safety involved in accessing them to change the batteries meant that the measured values at Queens could not be compared to a stable background concentration.
* Knowing the wind direction and velocity would have helped in better identifying the potential sources of the measured PM. However, the necessary equipment was not easily available in Blantyre at the time, and as an exploratory study, with uncertain outcomes, the time and expense was not thought of as justifiable at the time.
* The height of the sensors was not standardized across locations
* Knowing the exact burning locations and burning times, especially at the incinerator and the Guardian Shelter, would have helped in better identifying the sources and movements of the plumbs. However, given the size of the campus and it’s 24-hour schedule, a much larger research team would have been required to quantify all the burning.
* The humidity, and the potential for interference was not accounted for; the measurements were not adjusted for humidity.

# ACKNOWLEDGEMENTS

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# Appendix

**Hardware Components**

1. Raspberry Pi 3 Model B single-board computer technical specifications:
   * Broadcom BCM2837 64bit Quad Core Processor powered Single Board Computer running at 1.2GHz 1GB RAM
   * BCM43438 WiFi on board
   * Bluetooth Low Energy (BLE) on board
   * 40pin extended GPIO
   * 4 x USB 2 ports 4 pole Stereo output and Composite video port
   * Full size HDMI CSI camera port for connecting the Raspberry Pi camera
   * DSI display port for connecting the Raspberry Pi touch screen display
   * Micro SD port for loading your operating system and storing data
   * Upgraded switched Micro USB power source (now supports up to 2.4 Amps)
   * Same form factor as the Pi 2 Model B, however the LEDs have changed position
   * RPI3-MODB-16GB-NOOBS
2. Nova PM SDS011 Sensor
   * See Data Sheet attachment for technical specifications
3. MCP3008 microchip
   * analog-to-digital converter (ADC)
4. Romoss Sense8+ 30000mAh QC Type-C
   * Power bank battery
5. Pipe
   * clear rubber pipe attainable from any local hardware store
6. Box
   * any box that can fit all the components comfortbaly can be used. The box will need to have a whole drilled in it for the pipe.

**Software ‘components’ and data management**

1. The Raspberry Pi operating system runs off of Rasbian software on a NOOBS scandisk.
2. Air quality monitoring code is written in Python using the [aqi library](https://pypi.org/project/python-aqi/) (A library of algorithms to convert between AQI value and pollutant concentration). The code is stored on the [Open Data Durban Github](https://github.com/opendatadurban/hospital_stations) account and is free for all to access. To be able to collect data, the device needs to be connected to a reliable wifi network, the SSID and password need to be coded onto the device during step 2 in the building method.
3. Once the whole device has been put together and placed on site, to access that data we use a combination of propgrams:
   1. [Putty](https://www.putty.org/) - this is an SSH client that we use to gain access to the Raspberry Pi from another computer. To be able to access the Raspberry Pi in question, the computer in use and the air quality monitoring device need to be on the same network for the connection to be successful.
   2. [Winscp](https://winscp.net/eng/download.php) - this is an FTP client that we use, in conjunction with Putty, to be able to transfer data files from the air quality monitoring device to one’s computer.
   3. [Remote.it](https://app.remote.it/) - this is an application that supports remote SSH, so this is used when wanting to access data from a device that is not connected to the same network as the computer in use. Remote.it is used together with Putty and Winscp to access the air quality data remotely.

**Connection/building method**

To build the sensor, we followed these steps:

1. Set up the Raspberry Pi with the Rasbian software using the NOOBS scandisk. (insert the scandisk into the Rasberry Pi) A comprehensive start up guide can be found [here](https://projects.raspberrypi.org/en/projects/raspberry-pi-setting-up)**.**
2. Next we load the code onto the Raspberry Pi. The code can be found on the Open Data Durban [Hospital Stations Repository](https://github.com/opendatadurban/hospital_stations) Github. To use it you can follow the steps in the file called Initiate\_WS.txt. Once all the steps have been completed, the Raspberry Pi is now a device that can be connected to a particulate matter monitoring sensor.
3. Connect the hardware compionents
   1. Connect the Raspberry Pi to the Nova PM Sensor using the break out board that comes with the Sensor.
   2. Connect the battery to the Raspberry Pi via the micro port
   3. Attach the rubber pipe to the sensor
   4. Assemble all components inside the box, with the pipe coming out of the drilled hole
   5. To prevent dirt entering the system, close off all openings between the pipe and the box with sillicone putty
   6. Secure box in an elevated position (not too close to the ground) and with the pipe facing the direction of the inflow of the air under investigation.

1. Sharps are handled and disposed of separately. [↑](#endnote-ref-1)
2. There was an older incinerator on the grounds which failed in 2017. Between 2017 and 2021, when the new incinerator was commissioned, nothing was incinerated at all. [↑](#endnote-ref-2)
3. Patients are required to bring a caregiver for in-patient hospitals stays, usually a family member, who assist with feeding, bathing, and all other non-medical services. [↑](#endnote-ref-3)
4. [↑](#endnote-ref-4)
5. Staff #2 (18/11/2019), Staff #16 (25/11/2019), Staff #23 (28/11/2019). [↑](#endnote-ref-5)
6. Staff #4 (18/11/2019). [↑](#endnote-ref-6)
7. Staff #18 (25/11/2019). [↑](#endnote-ref-7)
8. Staff #1 (18/11/2019). [↑](#endnote-ref-8)
9. Staff #17 (25/11/2019), Staff #18 (25/11/2019). [↑](#endnote-ref-9)
10. Staff #4 (18/11/2019), Staff #24 (28/11/2019). [↑](#endnote-ref-10)
11. Staff #15 (25/11/2019). [↑](#endnote-ref-11)
12. Staff #3 (18/11/2019). [↑](#endnote-ref-12)
13. Staff #19 (26/11/2019). [↑](#endnote-ref-13)
14. Staff #15 (25/11/2019).

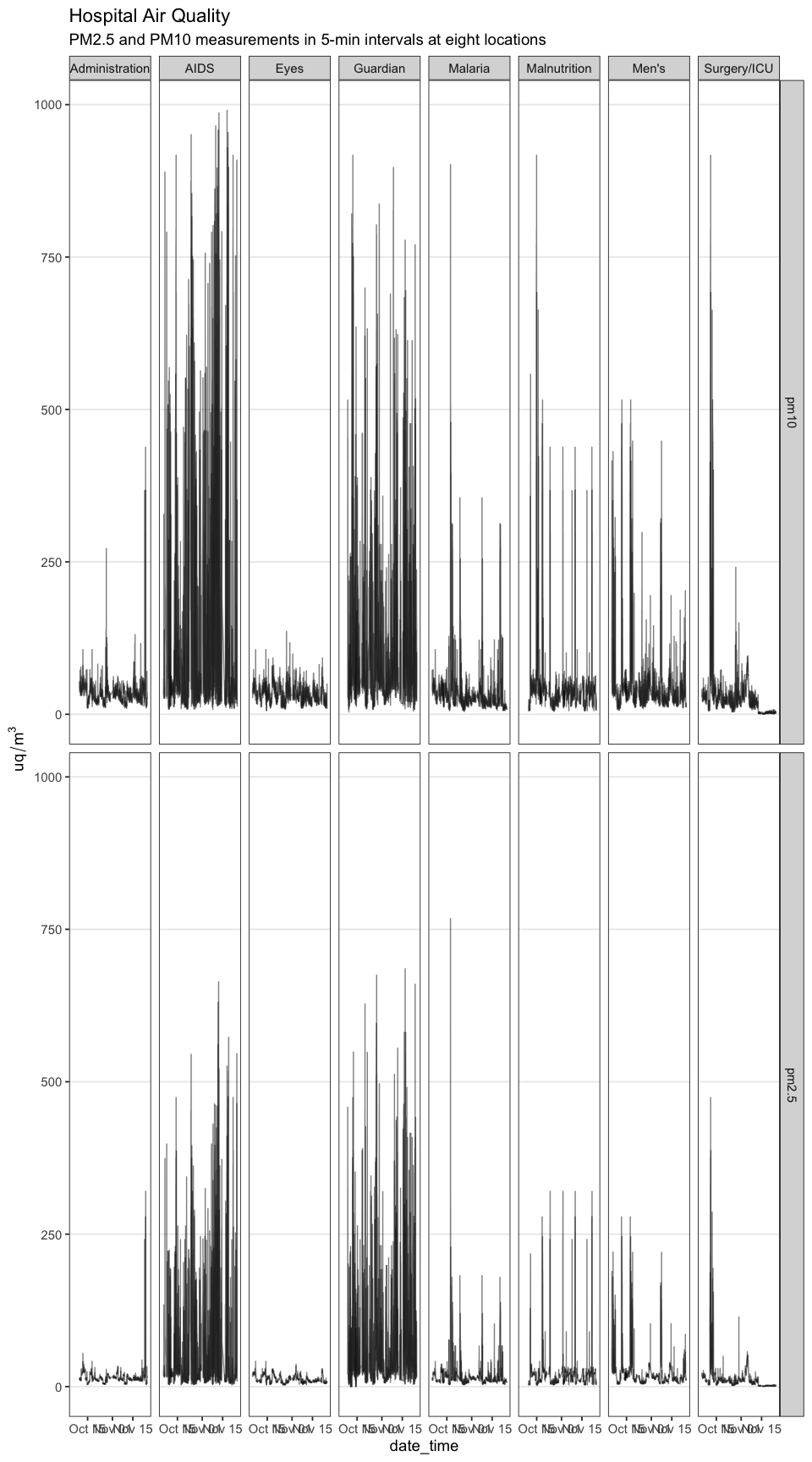
    

    Figure XA1. PM2.5 and PM10 values collected every 5 minutes over 10 months at 8 locations.

    ##Lars can you please fix the x-axis labels so they aren’t squished [↑](#endnote-ref-14)