# Inventory of Sources of Air Pollution in Rwanda

## Determination of Future Trends and Development of a National Air Quality Control Strategy

19 January 2018

Rwanda Environment Management Authority

Rwanda Environment
Management Authority
P.O. BOX 7436
Kigali

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# Executive summary

REMA appointed Mott MacDonald to undertake consulting services to develop the understanding of air quality in Rwanda by identifying sources of pollution, establishing the current baseline and to develop related strategy and policy recommendations to address air pollution issues.

Poor air quality is considered the world's "largest single environmental health risk"[1];; in 2012, over three million premature deaths globally were attributed to poor ambient air quality. Approximately 87% of these deaths occurred in low and middle-income countries[2].

Air pollutants can come from a variety of anthropogenic (man-made) and natural sources. In Rwanda, the main sources of anthropogenic air pollution are road traffic, domestic fuel burning and industry.

Key pollutants of concern in Rwanda are:

- Nitrogen oxides (including oxides of nitrogen ($NO_x$) and nitrogen dioxide ($NO_2$))
- Sulphur dioxide ($SO_2$)
- Particulate matter (including particulate matter with an aerodynamic diameter of less than 10 microns ($PM_{10}$) and 2.5 microns ($PM_{2.5}$))
- Ozone ($O_3$)
- Carbon monoxide (CO)

The study has reviewed the existing regulatory system and supporting air quality related standards in Rwanda. The review of the current system has identified that:

- Existing East Africa Standards adopted in Rwanda for ambient air quality standards are unsuitable for achieving effective regulation.
- Current emission standards are not tailored to Rwanda's need where there is more small-scale power generation rather than large combustion plants.

The study has identified that no one sector is the biggest contributor to air pollution within Rwanda as the levels of air pollution in a specific area are dependent on its location in relation to pollution sources. For example, in locations adjacent to busy road, vehicle emissions are the biggest contributor to poor air quality whereas in residential areas away from busy roads the biggest contributor is domestic stoves. Power plants may have higher emission rates of pollutants compared to domestic stoves but their effects on air quality in areas where there is high population density is low because the plants have stacks to aid dispersion and they not located in residential areas.

This study does not provide details of mass emissions of each pollutant from the sectors considered (road traffic, power generation, industrial and domestic sources) because not all the necessary data was available. However, where possible the study has quantified emissions from the power generation sector based on reasoned assumptions and internationally recognised emission factors. In addition, emission calculations related to road traffic have been presented based on percentage contributions of the types and the age of vehicles to

[1] WHO (2014). WHO press release. http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

[2] WHO (2016). Ambient Air Pollution: A global assessment of exposure and burden of disease. http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf

demonstrate which ones have the biggest impact on air quality, and to demonstrated how policy interventions could reduce the mass emissions of pollutants released. The report provides a qualitative commentary on emissions related to industrial and domestic sources based on existing literature that is available.

To establish more detailed mass emissions for each of the sectors, information required includes: miles travelled by the national vehicle fleet broken down according to engine and fuel types; operating philosophy, hours of operation and loading of thermal power plants; fuel type, combustion process details and hours of operation of industrial processes; and domestic fuel types and quantities consumed. A review of data collected for the study and existing air quality data indicates that the main pollutants of concern are:

- $PM_{10}$ and $PM_{2.5}$
- $NO_2$

Monitoring data has shown that the main areas where $NO_2$ concentrations are high and above international standards is close to busy and congested roads within Kigali. Monitoring data for $NO_2$ has indicated that concentrations are not significantly elevated across the whole country.

Monitoring data has indicated that background concentrations of $PM_{10}$ and $PM_{2.5}$ in Kigali are elevated and are likely to be above standards adopted by other countries around the world. A review of the data and the main emissions sources indicates that domestic stoves are likely to be heavily influencing background concentrations but road traffic is also a large contributor to high PM concentrations near busy roads.

PM concentrations in rural areas although not generally as high as in Kigali are still elevated and for some periods can be above standards adopted by other countries for the protection of health. This indicates that there are lots of regional sources and existing practices such as agriculture and localised burning of biomass in domestic stoves raising the baseline to high levels which is added to and elevated further by localised naturally occurring sources.

Following a review of the evidence base strategy recommendations and an institutional framework have been developed. The targeted strategy measures are:

- Refresh existing air quality standards
- Apply strict import regulations on vehicles
- Smooth traffic flows around traffic hotspots
- Reduce emissions from bus fleet
- Invest in public transport systems
- Reduce emissions from domestic stoves
- Develop renewable energy generation
- Manage freight movements across Kigali

The report has recommended that air quality monitoring should be continued and a national air quality monitoring network should be established. The monitoring network should be developed to gather additional data to understand where there is poor air quality and to allow REMA to track how air quality changes over time and assess the success of the implementation of future strategy measures.

To implement the strategy measures a cross department working group focussing on implementation is recommended.

It is recommended that additional data is gathered to allow a quantitative analysis of mass emissions from the sectors identified as contributors to poor air quality in Rwanda.

# 1 Introduction

## 1.1 Overview

The Rwanda Environment Management Authority (REMA) have received a credit from the International Development Association (a part of the World Bank) as part of the Lake Victoria Environmental Management Project. REMA has appointed Mott MacDonald to undertake consulting services to develop the understanding of air quality in Rwanda by identifying sources of pollution, establishing the current baseline and to develop related strategy and policy recommendations to address air pollution issues.

## 1.2 Purpose of this report

The purpose of this report is to provide a summary of the key findings from the study and to present a framework air quality strategy. The study has been undertaken in accordance with the methodology presented in the Inception Report issued to REMA on the 7 November 2017 which took account of comments received from REMA and other interested parties at the Inception Report validation workshop held on the 28 and 29 September 2017.

Table 1 presents an overview of the reporting structure and the main contents of each chapter.

**Table 1: Structure and contents of this report**

| No | Chapter | Contents |
|---|---|---|
| 1 | Introduction | • Overview of the report structure |
| 2 | Literature review | • Summary of air quality and why it is important<br>• Summary of the key pollutants<br>• Summary of existing air quality studies undertaken in Rwanda<br>• Impacts of air pollution of human health |
| 3 | Overview of current legislative and policy framework to manage air quality in Rwanda | • A summary of national ambient air quality standards and emission standards<br>• An overview of the regulation process in Rwanda<br>• A summary of existing policy put in place for managing air quality |
| 4 | Review of air quality standards and policy interventions in other countries and if appropriate their air quality strategies | • A review of standards for other countries around the world<br>• A revised set of standards which could be adopted as national ambient standards for Rwanda<br>• A review of air quality policy and interventions in the UK, France and China. |
| 5 | Identification of the main sources of air pollution in Kigali | • Quantification of number and type of vehicles in Kigali and how age and speed of vehicles affect air quality<br>• Summary of the main air quality issues associated with stoves used for domestic purposes and the types used<br>• Summary of licenced activities<br>• Summary of likely emissions per sector |
| 6 | Detailed description of the monitoring network established for the study | • Equipment used and its limit of detection<br>• Location of sampling points<br>• Pollutants monitored |
| 7 | Analysis of monitoring data undertaken in Kigali and the two rural monitoring locations to set the baseline. Qualitative analysis of likely baseline conditions in two other cities | • Presentation of data collected as part of study<br>• Review of existing ambient monitoring data<br>• Analysis of data to compare against air quality standards<br>• Analysis of data to help identify major sources of pollution<br>• Analysis of rural data to understand regional background concentrations |

| No | Chapter | Contents |
|---|---|---|
| | | • Qualitative assessment of air quality in two other cities, Bugarama a city at low altitude, and Rubavu a city at high altitude. This is based on our understanding of pollution in Kigali and a comparison of the size of cities the types of industries present, number of vehicles<br>• Identifies the main sources of pollution in Rwanda and identifies the key areas which need policy interventions in the shortest timescale |
| 8 | Discussion on likely future trends | • Considering the main sources of pollution and likely future development in Kigali; this section suggests which sources are likely to continue to dominate future air quality<br>• This has been done assuming a business as usual approach and if the policy inventions that have been recommend are introduced effectively |
| 9 | Air quality control strategy | • This sets out the proposed air quality measures to be implemented based on the evidence collected as part of the study<br>• It sets out an institutional framework to identify who is responsible for implementation of the strategy measures, and a target timeframe |
| 10 | Identified gaps and recommendations | • Gaps and recommendations based on the findings of the study are identified |
| - | Appendix A | • International ambient air quality standards |
| - | Appendix B | • International emission limits |
| | Appendix C | • Vehicle emission factors used in calculations |
| | Appendix D | • Emissions of particulates from road vehicles |
| - | Appendix E | • Existing thermal power locations |
| - | Appendix F | • Continuous air quality monitoring locations |
| | Appendix G | • Passive air quality monitoring locations |

## 1.3 Stakeholder engagement

Table 2 provides a list of stakeholders that we have consulted with and the status of gathering information.

**Table 2: Stakeholder engagement**

| Stakeholders | Information planned to be obtained during stakeholder meetings | Meetings held / Information received |
|---|---|---|
| Rwanda Environmental Management Authority (REMA) | • The Law governing the preservation of air quality and prevention of air pollution in Rwanda recently gazette in the Official gazette of 06th June 2016.<br>• Access on Air Quality control policy documents. This will assist us to compare the current Rwanda regulations and policies in the region and internationally with examples of best practice.<br>• Implementation of relevant Multilateral Environmental International Agreements that are of relevance to mitigation of air pollution.<br>• Ministerial Order N°003/16.01 of 15/07/2010 on prevention of activities that pollute the atmosphere.<br>• Published reports on air quality<br>• Copies of environmental permits for industrial activities in Rwanda<br>• Any other project related studies, reports, and documentation on air quality in Rwanda | Meeting held with REMA 25 September.<br>Information received included:<br>Study on air pollution in Rwanda<br>The latest air quality laws<br>Rwanda nationally appropriate mitigation actions (NAMAs) sectorial analysis<br>Ministerial orders on vehicles |

| Stakeholders | Information planned to be obtained during stakeholder meetings | Meetings held / Information received |
|---|---|---|
| Rwanda Standards Board (RSB) | • Information on development of national air quality standards | Meeting held on 27 September.<br>We received copies of the three relevant air quality standards:<br>• EAS750: 2010 for Air quality — Emissions to the air by cement factories — Guidelines<br>• EAS 751: 2010 Air quality — Specification<br>• EAS 752: 2010 Air quality — Tolerance limits of emission discharged to the air by factories |
| Rwanda Energy Group (REG) | Gasoline generators<br>There is inadequate electric power supply to households, businesses and industries. The result is that many households, businesses and industries operate small, medium and large capacity fossil fuel electric power generators for electric power supply whose exhaust is a source of air pollution. REG can assist in providing information on power generators.<br>There are sites in Kigali and rural locations where REG is installing generators in case of load shedding (power-cuts) within the country. It would be beneficial to know additional information on the number and size of these.<br>Thermal power plants<br>Thermal power plants are major sources of $PM_{10}$, $SO_2$ and $NO_x$ in Rwanda. We will aim to determine the number and locations of these and the fuel used. | Meeting held on 27$^{th}$ September.<br>We received information on the number of power stations, the technology type, location, fuel used and the installed capacity |
| Rwanda Revenue Authority (RRA), MININFRA and Rwanda Utilities Regulatory Authority (RURA). | Data relating to the number and type of vehicles registered within Rwanda. The release of vehicle exhaust into the air is one of the major sources of air pollution in Rwanda especially in urban centres. The impact assessment of the age limit of imported motor vehicles in Rwanda revealed that 91% of imported vehicles are second-hand and about three quarters (74%) of all imported vehicles are more than 10 years old. Therefore, we will need the updated Information related to the number and type of registered vehicles (fuel)<br>In addition, those institutions will prove us data on both Government (public bus) and private motor vehicles in Kigali City.<br><br>Legal and regulatory framework in the transport sector | Meeting held on 27 September. We have received relevant information relating to the number of registered vehicles in Rwanda. |
| The Minister for Trade and Industry | Information related to licensed industrial activities. | Information gathered from on line literature |
| The National Institute of Statistics of Rwanda (NISR) | Types of stoves used for domestic purposes. More than 80% of Kigali city residents still use solid fuels (biomass and charcoal) for household cooking.<br>A large percentage of the people in the urban and rural areas use fuel wood for cooking and heating. Also small-scale industries such as bakeries and businesses such as restaurants use fuel wood during their production | Information gathered from on line literature |

| Stakeholders | Information planned to be obtained during stakeholder meetings | Meetings held / Information received |
|---|---|---|
| | processes. The result is that burning of wood has become a major source of indoor and outdoor air pollution. More people are using fuel wood due to the absence of alternative, cheap and readily available sources of cooking and heating in the country. | |
| Kigali city council & Local government | Identification of large areas where domestic stoves are used and burning of solid waste occurs. | Meeting took place on 17 November |
| Ministry of Health | Information that can assist us to review current air pollution and its consequences on human health in Rwanda and data on the frequency of diseases related to air pollution in Kigali. | Data was requested. Data used in the study obtained from literature review |
| Rwanda Meteorological Agency | Meteorological data in both urban and rural location. We requested data from the Gitega and International airport sites in Kigali and from the Kirehe and Kaduha meteorological stations in rural locations. | Data that was requested was received |
| Rwanda Transport Development Authority (RTDA) | Information related to traffic counts on key roads in Kigali | Traffic count data for paved and unpaved roads received |

# 2 Literature Review

## 2.1 Overview

This section provides an overview of the main principles behind why air quality is important and the impacts air pollution has on human health in Rwanda. Key pollutants that are responsible and have been assessed in this study are defined and an overview of pollutants is provided, including their sources and the key health impacts that they have. Finally, an overview of the existing air quality studies that have been undertaken in Rwanda is provided.

## 2.2 Why air quality is important

Poor air quality is considered the world's "largest single environmental health risk"[3]; in 2012, over three million premature deaths globally were attributed to poor ambient air quality. Approximately 87% of these deaths occurred in low and middle-income countries[4].

Exposure to poor air quality can cause a variety of health problems such as respiratory infections, cardiovascular disease, strokes and lung cancer [5]. To limit the risk of adverse health impacts from poor air quality, WHO has created air quality guidelines for key air pollutants. However, many people are exposed to pollutant concentrations which do not meet these guidelines. For example, approximately 92% of the world's population live in areas where the annual $PM_{2.5}$ guideline is exceeded[6].

Of the three million premature deaths from ambient air pollution in 2012, 211,000 (7%) occurred in Sub Saharan Africa. In Rwanda, in 2012, 2,227 deaths were attributed to ambient air pollution and resulted in a total of 108,622 years of life lost[7]. The main cause of death and years of life lost from poor air quality in Rwanda was acute lower respiratory disease or stroke (see Figure 1 and Figure 2). Long term health conditions associated with poor air quality can also put a strain on health services; in 2012 the top cause of morbidity in health centres in Rwanda was acute respiratory infections, accounting for 21.7% of all patients admitted to health centres (Figure 3) and 6.8% of patients admitted to hospitals (Figure 4). Respiratory infections are the largest cause of deaths in children under the age of five in Rwanda[8] (Figure 5).

[3] WHO (2014). WHO press release. http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

[4] WHO (2016). Ambient Air Pollution: A global assessment of exposure and burden of disease. http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf

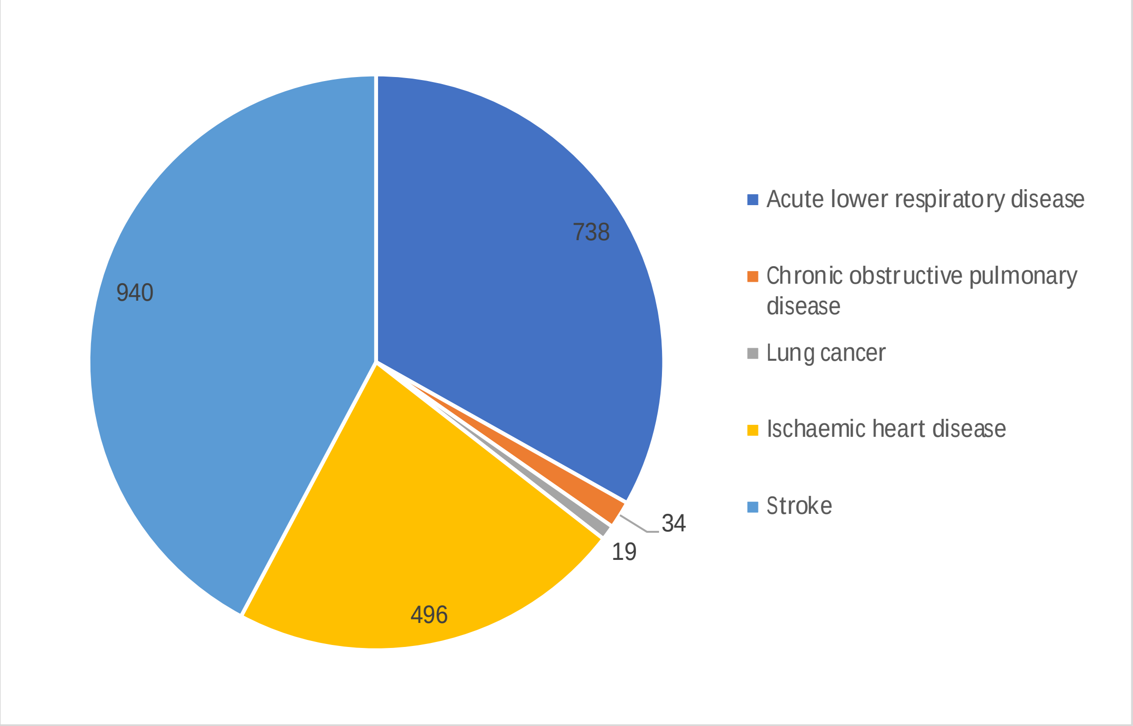
[5] Mannucci, P. M., & Franchini, M. (2017). Health Effects of Ambient Air Pollution in Developing Countries. International Journal of Environmental Research and Public Health, 14(9). https://doi.org/10.3390/ijerph14091048

[6] WHO (2016). Ambient Air Pollution: A global assessment of exposure and burden of disease. http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf

[7] WHO (2016). Ambient Air Pollution: A global assessment of exposure and burden of disease. http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf

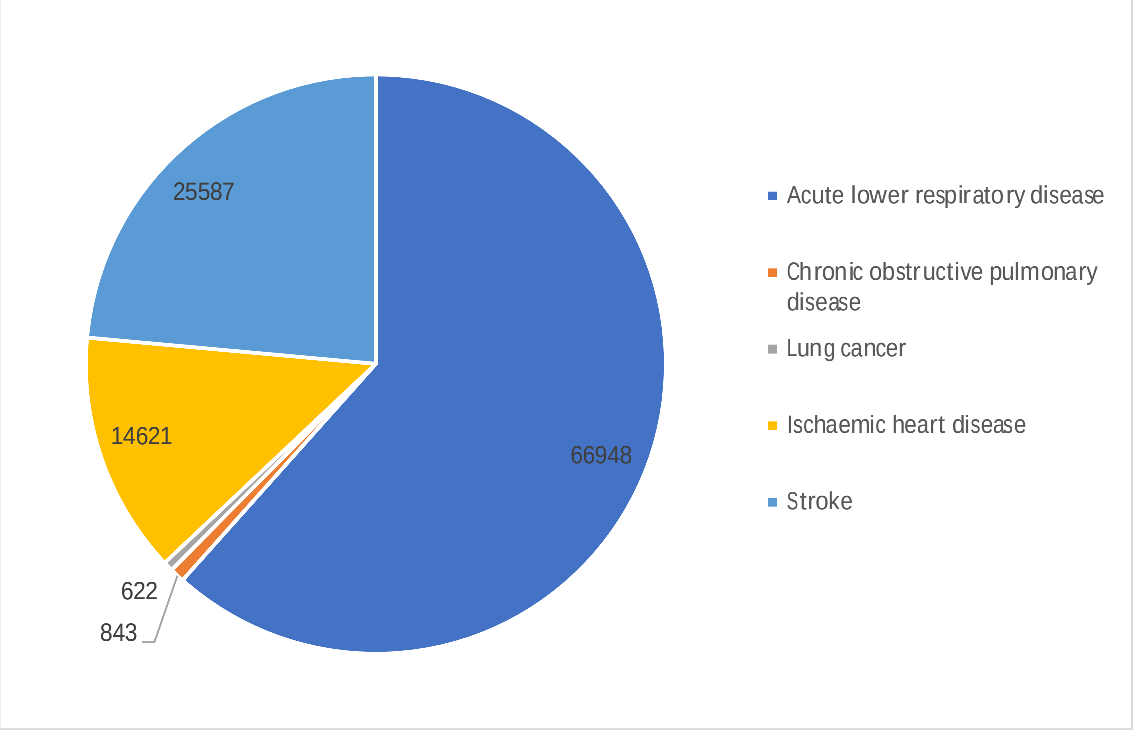
[8] Ministry of Health (2013). Annual Report: July 2012-June 2013. http://www.moh.gov.rw/fileadmin/templates/Press_release/MoH_Annual_Report_July_2012-June_2013.pdf

**Figure 1: Deaths in Rwanda, attributed to ambient air pollution (2012)**



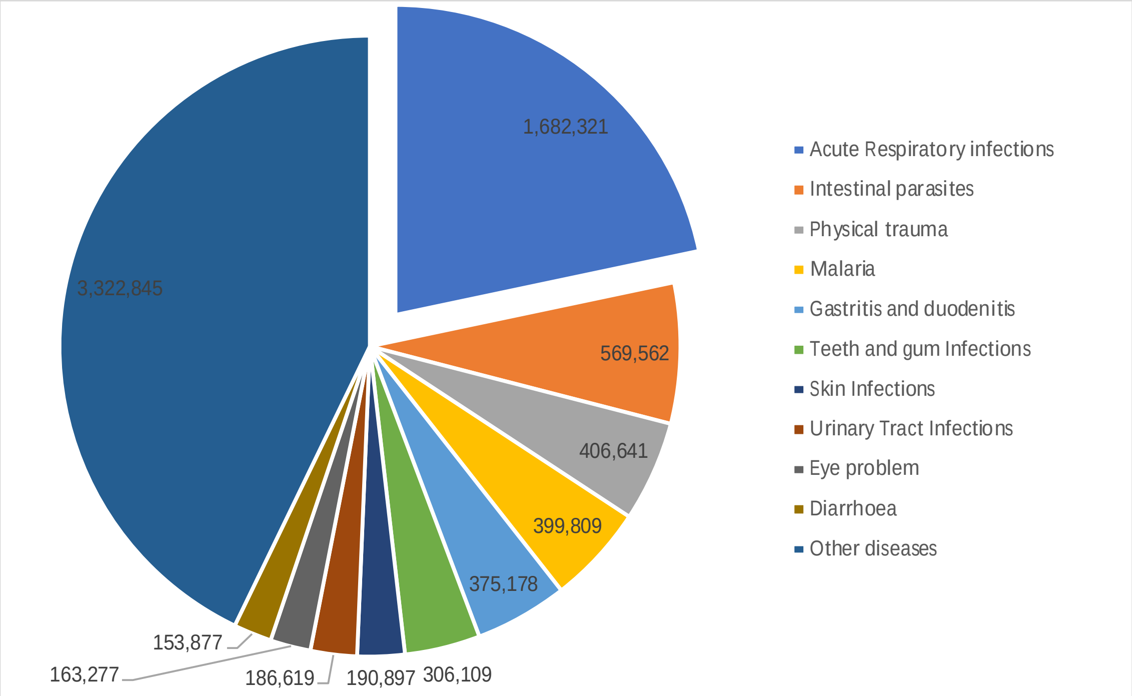

Source: WHO, 2016.

**Figure 2: Number of years of life lost in Rwanda, attributed to ambient air pollution (2012)**



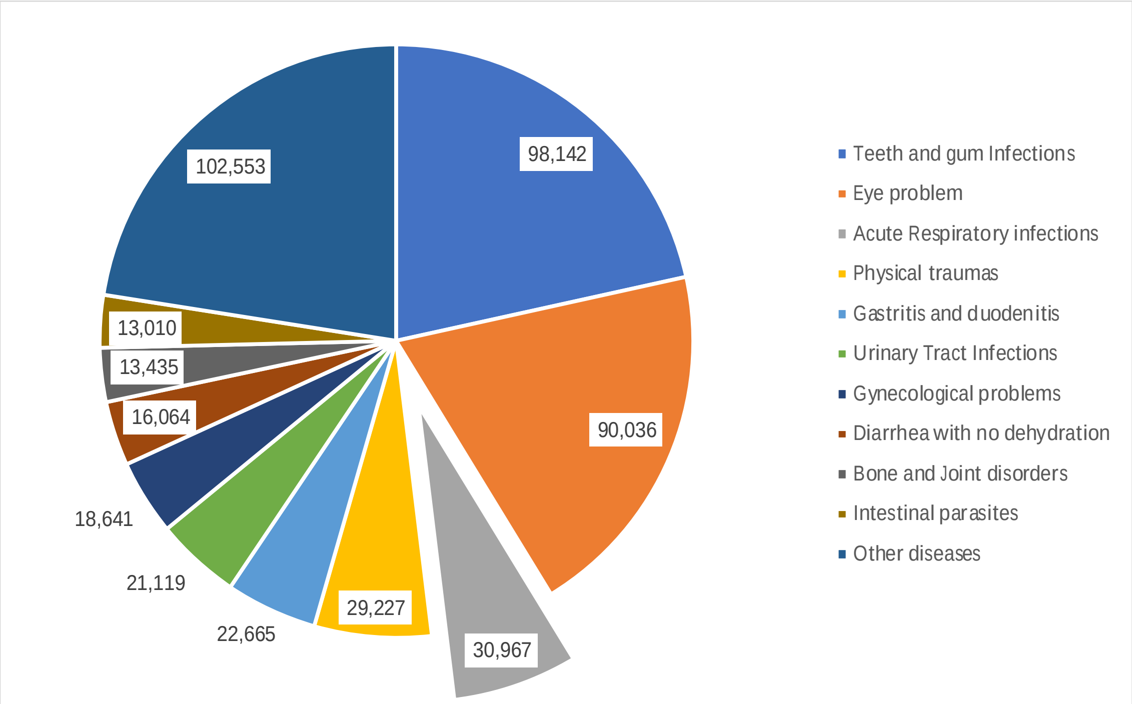

Source: WHO, 2016.

**Figure 3: Number and cause of patients admitted to health centres in Rwanda (2012)**



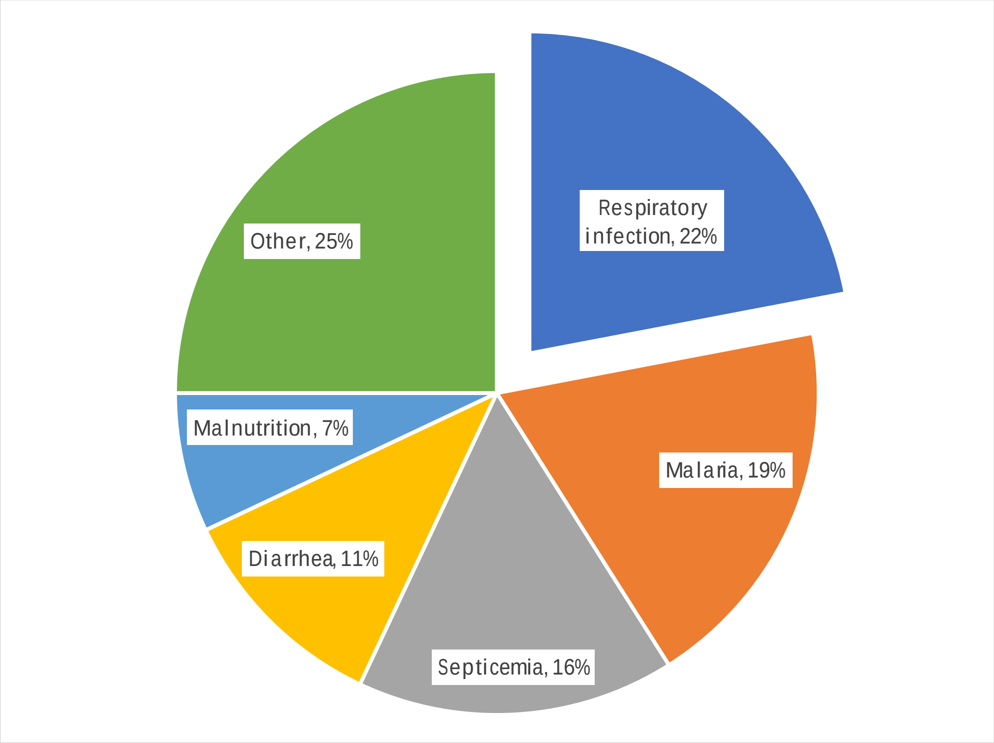

Source: Ministry of Health, 2013

**Figure 4: Number and cause of patients admitted to hospitals in Rwanda (2012)**




Source: Ministry of Health, 2013

**Figure 5: Cause of deaths of children under 5 in Rwanda (2012)**




Source: Ministry of Health, 2013

The large number of premature deaths and morbidity associated with poor air quality in Rwanda is largely attributed to high $PM_{10}$ and $PM_{2.5}$ concentrations from:

- High vehicle emissions (due to the heavy reliance on imported, used vehicles with poor or degraded emissions control technology)
- Use of biomass fuels (wood and other solid fuels)
- Emissions from industrial processes
- Seasonal burning of vegetation in the tropics[9]

Improving air quality in the most polluted areas of Rwanda could have a beneficial effect on human health by reducing the number of premature deaths from air quality and incidence of conditions such as acute lower respiratory disease. Reduced emissions of air pollutants could also have beneficial impacts on ecology, particularly vegetation in sensitive habitats, which are adversely affected by poor air quality. Consequently, Rwanda has recently introduced several policies and practices to improve air quality. For example, it has implemented new vehicular emission regulations and air quality standards and urban areas such as Kigali have installed modern vehicle testing centres[10].

[9] Henninger, S. M. (2009). Urban climate and air pollution in Kigali, Rwanda. The Seventh International Conference on Urban Climate, Yokohama, Japan, (July), 1038–1041.

[10] REMA (2015). State of the Environment and Outlook Report 2015.

## 2.3 Summary of key pollutants

### 2.3.1 Overview

Air pollutants can come from a variety of anthropogenic (man-made) and natural sources. In Rwanda, the main sources of anthropogenic air pollution are from industry, domestic fuel burning and road traffic.

Key pollutants of concern in Rwanda are:

- Nitrogen oxides (including oxides of nitrogen ($NO_x$) and nitrogen dioxide ($NO_2$))
- Sulphur dioxide ($SO_2$)
- Particulate matter (including particulate matter with an aerodynamic diameter of less than 10 microns ($PM_{10}$) and 2.5 microns ($PM_{2.5}$))
- Ozone ($O_3$)
- Carbon monoxide (CO)

The following sections provide a brief overview of each of these pollutants.

### 2.3.2 Nitrogen oxides

Nitrogen oxides is the term used to describe a mixture of nitric oxide (NO) and nitrogen dioxide ($NO_2$), referred to collectively as $NO_x$. NO is a colourless and tasteless gas whereas $NO_2$ is a yellowish-orange to reddish-brown gas with a pungent, irritating odour and is a strong oxidant. $NO_x$ is primarily formed as a result of high temperature combustion, when nitrogen in the atmosphere and in fuel is partially oxidised via a series of reactions to produce $NO_x$. In urban environments, the main anthropogenic sources are typically the combustion of fossil fuels in vehicles (predominantly road traffic) and power generation units. Naturally occurring processes associated with wildfires, lightning, and microbial activity in soils can also emit $NO_x$.

$NO_x$ emissions from elevated sources such as power plant stacks can be transported to the ground, depending on several factors including the time of day, abundance of oxidants and strength of vertical mixing. Elevated emissions can also be transported over long distances (up to a few hundred kilometres overnight depending on location[11]) and can therefore be distributed over a wider area than those emitted at the surface (e.g. from motor vehicles).

Most $NO_x$ exhausting from a combustion process is in the form of NO, with a smaller proportion directly emitted as $NO_2$ (referred to as 'primary' $NO_2$). The process, and hence the proportion of primary $NO_2$ produced, is dependent on the temperature, pressure, oxygen concentration and residence time of the combustion gases in the combustion zone. The proportion of primary $NO_2$ produced during combustion has been estimated to be around 5%[12] and 10%[13] and up to as much as 44% in the case of combustion products in vehicle exhausts[14],[15].

[11] Lee, H.-J., Kim, S.-W., Brioude, J. et al. (2014). Transport of NOx in East Asia identified by satellite and in situ measurements and Lagrangian particle dispersion model simulations, Journal of Geophysical Research, Volume 119, Issue 5, Pages 2574–2596.

[12] Defra (2004) Air Quality Expert Group (AQEG) – Nitrogen Dioxide in the United Kingdom. https://uk-air.defra.gov.uk/assets/documents/reports/aqeg/nd-summary.pdf

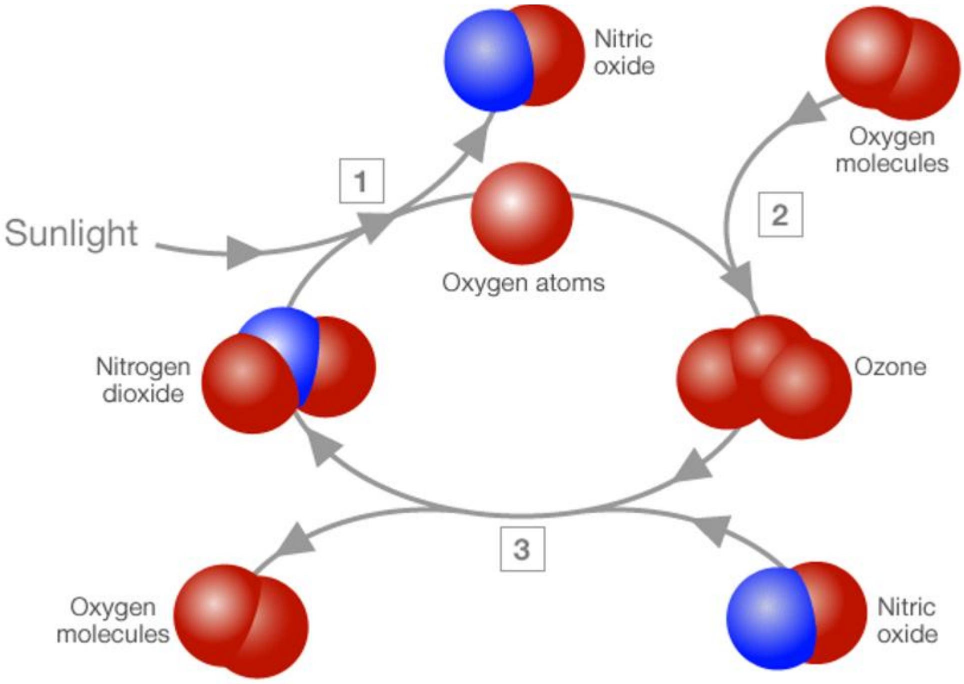
[13] USEPA (2016). Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

[14] Emissions Analytics (2016). Exhaust emissions of primary nitrogen dioxide (NO2). http://equaindex.com/wp-content/uploads/2016/09/Exhaust-emissions-of-primary-nitrogen-dioxide.pdf

[15] This study by Emissions Analytics measured the primary NOx emissions in the exhausts of diesel and petrol Euro 5 and Euro 6 vehicles, using a portable emissions measurement system (PEMS). For petrol vehicles, primary NO2 emissions made up 29% and 14% of NOx emissions for Euro 5 and Euro 6 respectively. For diesel vehicles, primary NO2 emissions were 40% for Euro 5 and 44% for Euro 6.

Emitted NO is readily oxidised to $NO_2$ in the atmosphere by chemical reactions with ozone and other chemicals in the atmosphere (known as secondary $NO_2$ formation). This reaction can occur rapidly; for example, an initial NO concentration of 30 parts per billion (ppb) and initial $O_3$ concentration of 40ppb (at 25°C) can form 10ppb $NO_2$ in just 20 seconds[16]. Higher temperatures and concentrations of reactants result in shorter reaction times, while dispersion and depletion of reactants increase the reaction time. The chemical interaction of NO, $NO_2$ and $O_3$ is shown in Figure 6.

**Figure 6: Summary of the sources and effects of tropospheric ozone**




Source: Source: Emissions Analytics (2016)

Further oxidation of $NO_2$ leads to the formation of other nitrogen species such as nitric acid, which can cause acid rain. $NO_2$ can also react with a variety of atmospheric species to produce organic and inorganic nitrates, which make substantial contributions to the mass of atmospheric particulate matter (PM) and the acidity of clouds, fog, and rainwater. $NO_2$ is an oxidant and can react to form other photochemical oxidants such as peroxyacyl nitrates (PANs) and toxic compounds such as nitro-substituted polycyclic aromatic hydrocarbons (nitro-PAHs). NO and $NO_2$, along with volatile organic compounds (VOCs), are also precursors in the formation of ozone ($O_3$) and photochemical smog. The major influences on $NO_2$ concentrations within and downwind of urban centres are the fraction of $NO_x$ emitted as primary $NO_2$, dispersion and the $NO/NO_2/O_3$ equilibrium.

$NO_2$ exposure has been shown to cause eye and lung irritation and respiratory illnesses in humans, with children and those with pre-existing respiratory conditions such as asthma being

[16] USEPA (2016). Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

the most susceptible[17]. However, it is complex to differentiate the health effects of $NO_2$ from those of other combustion-related pollutants that are typically found in elevated concentrations along with $NO_2$ (e.g. fine particles). Nevertheless, epidemiological studies have shown increases in bronchitic symptoms of asthmatic children and reduced lung function growth in children in association with long term exposure to $NO_2$[18].

Long term increases in $NO_x$ concentrations may also lead to an acceleration of freshwater eutrophication and acidification of soils and freshwater ecosystems, which can cause widespread damage to terrestrial and aquatic ecosystems.

### 2.3.3 Sulphur oxides

Sulphur oxides ($SO_x$) is a term used to refer to a range of gaseous sulphur-containing compounds, including sulphur dioxide ($SO_2$), sulphur trioxide ($SO_3$) and others. Of these compounds, $SO_2$ is found in the greatest concentrations in the lower atmosphere and is the pollutant of most concern; $SO_2$ is often used as an indicator for $SO_x$. $SO_2$ is a colourless, non-flammable gas, with an unpleasant, pungent odour. It reacts on the surface of a variety of airborne solid particles, is soluble in water and can be oxidised within airborne water droplets; $SO_2$ can be transformed by these reactions in the atmosphere to form, amongst others, sulphuric acid and sulphate particles. About 30% of the $SO_2$ in the atmosphere is converted to sulphate aerosol[19], which is removed through wet or dry deposition processes. Sulphate aerosol also contributes to particulate loading.

The most common anthropogenic sources of $SO_2$ include fossil fuel combustion for power generation, industry, shipping and road transport[20]. Coal burning is the single largest man-made source of $SO_2$. Natural sources of $SO_2$ (of which the most common source is volcanoes) account for 35 to 65% of global emissions[21]. In industrial countries such as those in Europe and North America, anthropogenic emissions can contribute as much as 95% of emissions, with natural sources contributing only 5%[22].

Human health impacts of exposure to $SO_2$ include adverse effects on the respiratory system and irritation of the eyes, nose, throat and airways. Asthmatics and those with respiratory conditions are more susceptible to adverse effects from $SO_2$ exposure. WHO (2006) reports changes in pulmonary function and respiratory symptoms in humans after short term exposure to $SO_2$, for periods as short as 10 minutes. As with other combustion-related pollutants, studies have found it difficult to isolate the health effects of long term (over 24 hours) $SO_2$ exposure from the health effects of exposure to other pollutants such as fine particulates. Although uncertainty still exists in this regard, WHO (2006) and other studies (e.g. Kan et al., 2010[23]) have found statistically significant associations between 24-hour $SO_2$ exposure and health effects including mortality, cardiac disease and childhood respiratory diseases.

[17] US EPA (2016) suggests this is in part because children and asthmatics tend to breath more through their mouths than through their noses, and nasal passages are better at scrubbing $NO_2$ from the inhaled air than the mouth.

[18] World Health Organization (WHO). 2006. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

[19] World Bank Group (1998). Pollution Prevention and Abatement Handbook. https://www.ifc.org/wps/wcm/connect/5cb16d8048855c248b24db6a6515bb18/HandbookSulfurOxides.pdf?MOD=AJPERES

[20] Klimont, Z., Smith, S.J., and Cofala, J. (2013). The last decade of global anthropogenic sulfur dioxide: 2000-2011 emissions, IOP Science. http://iopscience.iop.org/1748-9326/8/1/014003/media/erl441620suppdata.pdf

[21] World Bank Group (1998). Pollution Prevention and Abatement Handbook. https://www.ifc.org/wps/wcm/connect/5cb16d8048855c248b24db6a6515bb18/HandbookSulfurOxides.pdf?MOD=AJPERES

[22] National Science Foundation (2017). Website accessed at https://chem.libretexts.org/Exemplars_and_Case_Studies/Case_Studies/Acid_Rain/Sources_of_Sulfur_Oxides. Licensed under a Creative Commons Attribution-Noncommercial-Share Alike 3.0 United States License.

[23] Kan, H., Wong, C-M., Vichit-Vadakan, N., Qian, Z. et al. (2010). Short-term association between sulfur dioxide and daily mortality: the Public Health and Air Pollution in Asia (PAPA) study. Environmental Research. 2010 Apr; 110(3): 258–264.

Sulphur oxide emissions cause adverse impacts to vegetation, including forests and agricultural crops. Potential ecological impacts of increased $SO_2$ can include chronic injury from long-term exposure to lower concentrations of sulphur dioxide, loss of foliage, reduced growth, increased aging and premature death of vegetation. Some examples of $SO_2$-damaged vegetation are presented in Figure 7. Sensitivity to $SO_2$ varies amongst species, however plants in the immediate vicinity of emissions sources are more vulnerable. Sulphur deposition to soils and aquatic ecosystems contributes to acidification with associated adverse impacts on aquatic and terrestrial flora and fauna.

Sulphur dioxide emissions may also affect materials such as building stone and ferrous and nonferrous metals, through the formation of acidic rainwater than can corrode buildings and statues.

**Figure 7: $SO_2$ effects on blackberry (left) and pine needles (right)**


Source: Center for Invasive Species & Ecosystem Health, University of Georgia

### 2.3.4 Particulate matter

Particulate matter (PM) is a complex mixture of organic and inorganic substances present in the atmosphere. PM can be primary or secondary. Primary PM is emitted directly to the atmosphere by a variety of anthropogenic and natural sources. Secondary PM is formed in the atmosphere by physical and chemical transformations of other pollutants, which produces solid or liquid aerosols that can be transported long distances[24]. A dominant source of primary PM is from combustion, including vehicle engines, power generation, domestic heating and cooking[25]. Other significant man-made sources include mining, quarrying and fugitive dust emissions during construction[26]. Natural sources of PM, which can be significant contributors to the overall atmospheric loading of particulates, include erosion of natural materials, wind suspension of soils and, in coastal areas, the constituents of sea spray.

Combustion processes tend to emit fine particulates, which are commonly referred to in terms of their size: particles with an aerodynamic diameter less than 2.5µm ($PM_{2.5}$) and particles with an aerodynamic diameter less than 10µm ($PM_{10}$). Construction and mining activities typically emit larger particles, commonly referred to as 'dust'. 'Dust' is a generic term which usually refers to particulate matter in the size range 1-75 microns in diameter.

[24] Dall'Osto, M. and Harrison, R. M. (2012). Urban organic aerosols measured by single particle mass spectrometry in the megacity of London, Atmospheric Chemistry and Physics, 12, 9, 4127-4142.

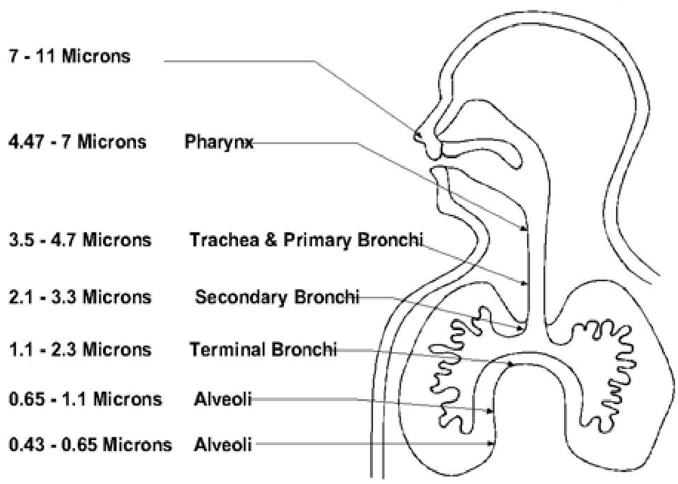
[25] Allan, J. D., Williams, P. I., Morgan, W. T. et al. (2010). Contributions from transport, solid fuel burning and cooking to primary organic aerosols in two UK cities, Atmospheric Chemistry and Physics, 10, 2, 647-668.

[26] Chen, B., Chen, J. S., Zhao, J. P. and Zhang, F. W. (2011). Particulate Air Pollution from Combustion and Construction in Coastal and Urban Areas of China, Journal of the Air & Waste Management Association, 61, 11, 1160-1165.

Nitrate ($NO_3^-$) and sulphate ($SO_4^{2-}$) particles are a major component of the total atmospheric particle load in industrial regions and research has shown that they can be a significant contributor to pollution episodes involving particulate matter (as $PM_{10}$). $NO_3^-$ is formed by the oxidation of $NO_X$ (via nitrite, $NO_2^-$) and chemical reactions involving ammonia and nitric acid; the concentration of $NO_3^-$ in the atmosphere therefore depends on the concentration of these precursor gases and the rate of reaction between them (which in turn is controlled by ambient conditions and the presence of other pollutants such as sulphates). Sulphate particles are produced by the oxidation of $SO_2$ in the atmosphere. Nitrate and sulphate particles are predominantly present in the atmosphere as ammonium salts, $NH_4NO_3$ and $(NH_4)_2SO_4$. As with most particles, deposition of $NO_3^-$ and $SO_4^{2-}$ occurs predominantly by wet deposition although dry deposition is also possible. Once deposited, nitrates and sulphates can contribute to acidification; nitrates can also contribute to eutrophication.

The human health and ecological effects of particulate matter are varied as they depend on the specific constituents of the particulate matter under consideration, for example nitrogen and sulphur containing particles can lead to acidification of soils and water courses. Human health impacts typically include respiratory and cardiovascular problems; finer particles (such as $PM_{2.5}$) can penetrate deeper into the respiratory system (as shown in Figure 8) than coarser particles and therefore are more of a concern with respect to human health impacts. Ultrafine particles ($PM_1$) can even cross through membranes in the alveoli and enter the blood stream, which is of particular concern as ultrafine particulates often have highly varied compositions and can contain carcinogenic substances.

**Figure 8: Deposition potential for particles of varying sizes**




Source: Government of British Columbia, Canada

The most common impacts from dust emissions are soiling and increased ambient $PM_{10}$ concentrations[27]. Dust is typically considered a nuisance effect and is not generally associated with human health concerns. High levels of dust deposition onto vegetation can affect plant health and reduce growth, through direct uptake by leaves of pollutants contained in the dust, blocking stomata in the leaves and reducing light penetration required for photosynthesis.

### 2.3.5 Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless gas produced by the incomplete or inefficient combustion of carbon-based fuels and by biological and industrial processes. Anthropogenic sources include fossil fuel combustion for power generation or transport, agricultural burning

[27] UK Government (2014). Mayor of London (July 2014). The Control of Dust and Emissions during Construction and Demolition, Supplementary Planning Guidance.

(e.g. of forests and savanna areas), and wood burning for heat and cooking fuel. Natural sources include forest fires, emissions from plants and oceans and the oxidation of methane and non-methane hydrocarbons. The major source of CO in urban areas is traffic (up to 75% of CO emissions in major cities according to US EPA[28]). The major natural source of CO is oxidation of non-methane hydrocarbons. In non-urban areas, WHO[29] estimates that human activities are responsible for approximately 60% of CO and natural processes account for the remaining 40%. NASA observations indicate that seasonal agricultural burning is a dominant CO source in Africa.

CO can be poisonous to humans. Exposure to elevated concentrations of CO can cause subtle effects on the human body and in sufficiently high concentrations, inhalation of CO can be fatal to humans. The health effects of CO largely arise from CO binding with haemoglobin in the blood to form carboxyhaemoglobin (COHb), which reduces the amount of haemoglobin available to bind to oxygen and thus impairs the oxygen carrying capacity of the blood[30]. People with several types of heart disease already have a reduced capacity for pumping oxygenated blood to the heart, which can cause them to experience myocardial ischemia (reduced oxygen to the heart), often accompanied by chest pain (angina), when exercising or under increased stress[31].

Health effects will begin to be seen when approximately 2.5% of haemoglobin is bound to CO as COHb. At fatal concentrations of CO, as much as 40% of haemoglobin can be bound to CO in this way[32]. WHO guidelines advise that “in order to protect non-smoking, middle-aged and elderly population groups with documented or latent coronary artery disease from acute ischaemic heart attacks and to protect the fetuses of non-smoking pregnant women from untoward hypoxic effects, a COHb level of 2.5% should not be exceeded.” Accordingly, the WHO guidelines for ‘safe’ concentrations of CO in ambient air are designed with this 2.5% level in mind[33].

In outdoor (ambient) air, CO is rapidly dispersed away from the source and is relatively inert over the timescales relevant for its dispersion; the atmospheric lifetime of CO is estimated to be between one to three months[34],[35]. Therefore, ambient concentrations are typically not a concern for human health in areas with good dispersion. For example, in the European Union, less than 2% of the population were estimated to have been exposed to CO levels above the WHO 8-hour guideline between 2009 and 2011[36]. Global trends in CO concentrations, measured by the NASA Measurements of Pollution in the Troposphere (MOPITT) instrument, indicate substantial reductions globally between 2000 and 2014, as shown in Figure 9. Seasonal biomass burning in Africa and Asia remains a noticeable source of CO.

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[28] USEPA (2010). Integrated science assessment for carbon monoxide. EPA/600/R-09/019F. Research Triangle Park, NC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.

[29] World Health Organization (WHO). 2004. Environmental Health Criteria for Carbon Monoxide (Second Edition). http://apps.who.int/iris/bitstream/10665/42180/1/WHO_EHC_213.pdf

[30] USEPA (2010). Integrated science assessment for carbon monoxide. EPA/600/R-09/019F. Research Triangle Park, NC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.

[31] USEPA (2010). Integrated science assessment for carbon monoxide. EPA/600/R-09/019F. Research Triangle Park, NC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.

[32] Australian Government, 2005 Department of the Environment and Heritage. Air quality fact sheet: Carbon Monoxide (CO). http://www.environment.gov.au/protection/publications/factsheet-carbon-monoxide-co

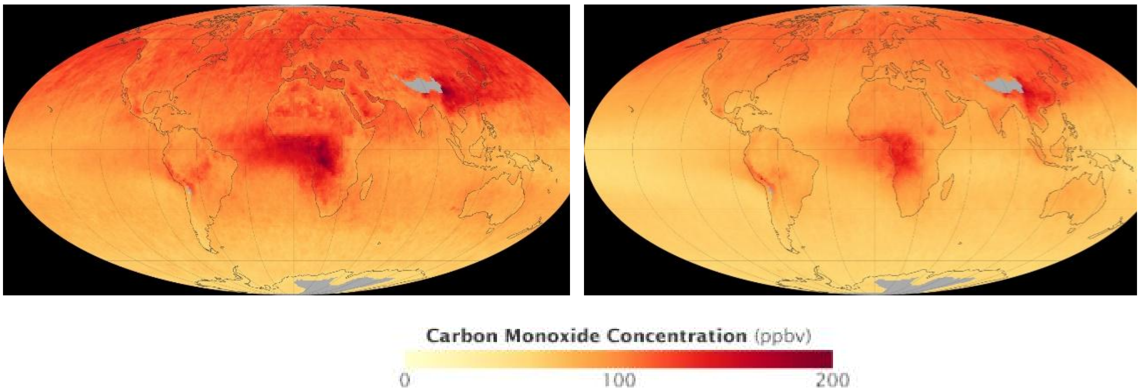
[33] World Health Organization (WHO). 2000 Air Quality Guidelines for Europe - Second Edition. http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf?ua=1

[34] NASA Earth Observatory (2015). Fourteen Years of Carbon Monoxide from MOPITT, June 2, 2015, https://earthobservatory.nasa.gov/IOTD//view.php?id=85967

[35] Guerreiro, C. B. B, Foltescu, V. and de Leeuw, F. (2014). Air quality status and trends in Europe, Atmospheric Environment, Volume 98, December 2014, Pages 376-384 http://www.sciencedirect.com/science/article/pii/S1352231014007109

[36] Guerreiro, C. B. B, Foltescu, V. and de Leeuw, F. (2014). Air quality status and trends in Europe, Atmospheric Environment, Volume 98, December 2014, Pages 376-384 http://www.sciencedirect.com/science/article/pii/S1352231014007109

**Figure 9: Global trend in CO concentrations between 2000 (left) and 2014 (right)**




Source: NASA Earth Observatory, 2015

Although ambient concentrations have improved, heavily congested traffic areas and enclosed spaces (such as inside vehicles, tunnels, underground or multistorey car parks) can experience elevated CO concentrations. CO is most often a pollutant associated with indoor air quality, particularly in countries where low quality fuels and inefficient stoves are used for cooking and heating in homes[37]. In addition, the relatively long atmospheric lifetime of CO allows it to slowly oxidise into carbon dioxide ($CO_2$)[38] and, in the presence of solar radiation, also react with other chemical compounds to form ground level $O_3$[39].

### 2.3.6 Ozone

Ozone ($O_3$) has different effects depending on whether it is present in the stratosphere or troposphere[40] of the atmosphere. Stratospheric ozone is a vital component of the atmosphere that prevents harmful UV radiation from reaching Earth's surface. Tropospheric ozone is found at Earth's surface and is created within the troposphere through a series of photochemical reactions involving $NO_x$, hydrocarbons and other compounds, many of which are emitted by fossil fuel combustion in vehicles and power plants. This section focusses on tropospheric ozone, which has the potential for harmful effects on human health and vegetation, as summarised in Figure 10.

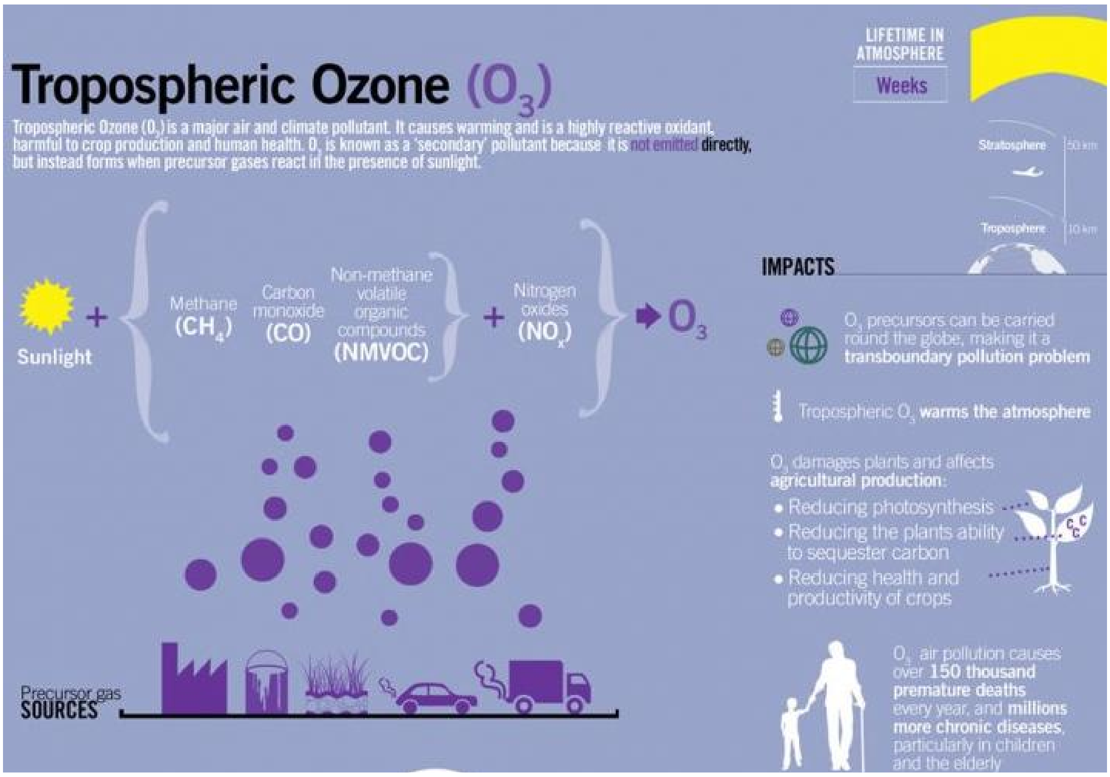
[37] WHO (2010). Guidelines for Indoor Air Quality: Selected Pollutants, Geneva: World Health Organization; 2010. ISBN-13: 978-92-890-0213-4 https://www.ncbi.nlm.nih.gov/books/NBK138705

[38] Guerreiro, C. B. B, Foltescu, V. and de Leeuw, F. (2014). Air quality status and trends in Europe, Atmospheric Environment, Volume 98, December 2014, Pages 376-384 http://www.sciencedirect.com/science/article/pii/S1352231014007109

[39] Indiana Department of Environmental Management (IDEM) April 2014. Criteria Pollutants: Carbon Monoxide (CO). Fact Sheet. https://www.in.gov/idem/files/factsheet_air_quality_co.pdf

[40] The troposphere is the first layer of atmosphere, extending from Earth's surface to approximately 10km above sea level. The troposphere contains around half of the Earth's atmosphere and nearly all weather occurs here. The stratosphere is the next layer, and it extends from the troposphere to approximately 50km above sea level.

**Figure 10: Summary of the sources and effects of tropospheric ozone**




Source: UNEP Climate and Clean Air Coalition (2017)

Tropospheric $O_3$ is a secondary pollutant, created in the atmosphere through reactions involving $NO_x$ and VOCs in the presence of sunlight[41]. Close to the source of these combustion emissions, ambient $O_3$ levels are likely to reduce as $O_3$ reacts with NO to produce $NO_2$, but over long distances concentrations of $O_3$ may increase. Management of $O_3$ concentrations has typically focussed on attempts to limit emissions of the ozone precursors ($NO_x$ and VOCs). However, as $O_3$ is also consumed by reaction with NO to produce $NO_2$, reductions in urban $NO_x$ emissions due to controls on vehicle emissions can result in increasing $O_3$ concentrations as there is less NO to consume $O_3$. Some countries, such as the UK, have seen an increase in $O_3$ concentrations in urban areas where $NO_x$ concentrations have been successfully reduced. High $O_3$ episodes are more common in summer, as higher solar intensity increases the rate of photochemical oxidation of VOCs. $O_3$ is also removed from the atmosphere through deposition to ground[42].

VOCs can also be emitted biogenically from trees and stratospheric ozone can intrude downwards into the troposphere; therefore WHO warns that elevated ozone concentrations (above the WHO guideline value) can sometimes occur naturally[43].

The human health impacts of ozone derive from its irritant properties and various studies have linked short term acute $O_3$ exposure to changes in lung function, lung inflammation, increased

[41] UNEP, 2017. Climate and Clean Air Coalition http://www.ccacoalition.org/en/slcps/tropospheric-ozone

[42] World Health Organization (WHO). 2006. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

[43] World Health Organization (WHO). 2006. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

incidence of respiratory symptoms (including cough and throat irritation) and increased daily mortality rates[44]. Available evidence suggests that both short term and long term $O_3$ exposure are linked to respiratory and cardiovascular health effects, although generally stronger causal relationships are observed for health effects with short term (acute) than long term exposure[45]. $O_3$ is a powerful oxidant and can react with biological and cellular components of the human body, affecting tissues of the respiratory tract and lungs[46]. Effects are more severe in individuals undertaking strenuous exercise or those with asthma. Epidemiological studies have found increased rates of asthma attacks, medication usage and hospital admissions for asthma on days with higher ozone concentrations[47]. Ozone is a common constituent of photochemical smog and therefore it can be difficult to separate the health effects of ozone from the health effects of other constituents of smog.

Ozone also has adverse effects on crop yields, on tree growth and on the composition of natural plant communities. Some species are more sensitive to ozone than others, for example certain tree species. Ozone affects plants by entering the leaves where it reduces photosynthesis, slows growth and increases susceptibility to disease, insect damage, effects of other pollutants and severe weather[48]. Visible foliar injury resulting from $O_3$ exposure is well documented in tree, shrub, herbaceous and crop species[49].

## 2.4 Air quality monitoring in Rwanda

There is limited air quality monitoring data available across Africa, particularly for particulate matter (Figure 11); the WHO Global Urban Ambient Air Pollution Database only has $PM_{10}$ data from 2012 for ten of the 47 cities in the sub-Saharan African region[50]. This is largely because many of these countries do not have air quality standards, or have only recently implemented air quality standards, so there has been little incentive in the past to undertake air quality monitoring, which can be costly to set up and maintain.

[44] World Health Organization (WHO). 2006. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

[45] USEPA (2013). Integrated Science Assessment (ISA) of Ozone and Related Photochemical Oxidants (Final Report, 2013). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

[46] European Environment Agency (1998). Tropospheric Ozone in EU - The consolidated report. Topic report No 8/1998. https://www.eea.europa.eu/publications/TOP08-98

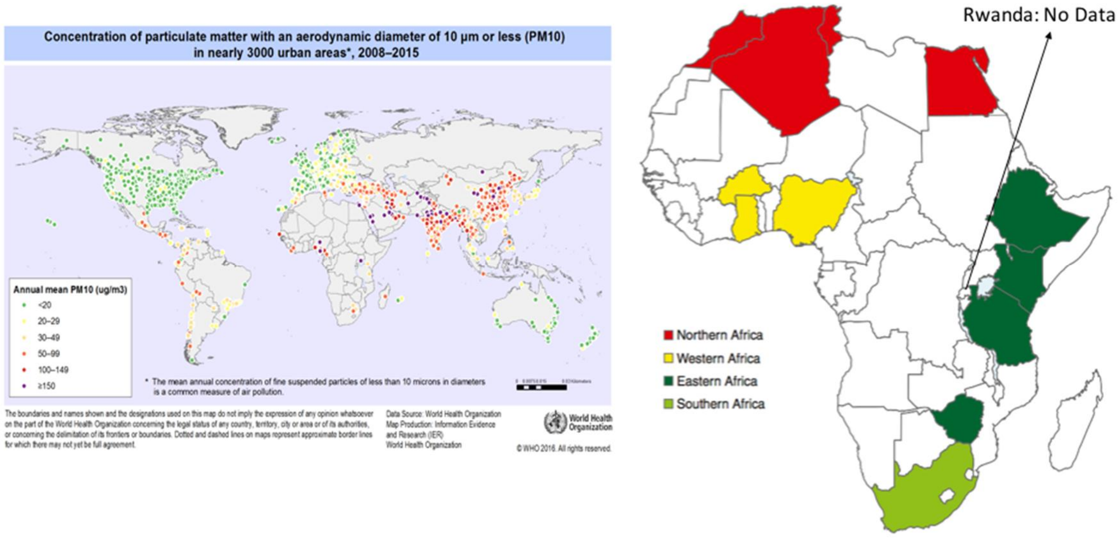
[47] COMEAP (2015). Quantification of Mortality and Hospital Admissions Associated with Ground-level Ozone https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/492949/COMEAP_Ozone_Report_2015__rev1_.pdf

[48] USEPA (2017). Website: “Ecosystem Effects of Ozone Pollution”. https://www.epa.gov/ozone-pollution/ecosystem-effects-ozone-pollution

[49] USEPA (2013). Integrated Science Assessment (ISA) of Ozone and Related Photochemical Oxidants (Final Report, 2013). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

[50] World Health Organization (WHO), 2015. World Health Organization: 2014 Air Pollution Ranking. Retrieved from http://aqicn.org/faq/2015-05-16/world-health-organization-2014-air-pollution-ranking/fr/

**Figure 11: Countries with PM monitoring studies**




Source: WHO, 2017[51]; Petkova et al., 2013[52]

To date, there are only a few studies available that have monitored air quality in Rwanda. The majority of these studies have been undertaken in Kigali, where there are high population densities and a large number of potential pollution sources. However, these studies have generally had short sampling durations using limited equipment. In 2016, REMA acknowledged this lack of air pollution data for Rwanda and enacted a new law governing the preservation of air quality in Rwanda which requires mandatory compliance with air quality standards. The National Climate Change and Environment Fund (FONERWA) has also funded the Rwanda Air Quality and Climate Change Monitoring Project[53]. This has installed climate change and air quality monitoring infrastructure and enabled data collection, training and processing of the data to inform decision-making and enforcement activities.

## 2.5 The state of air quality in Rwanda

A 3-month study in Kigali from 2017 found that $PM_{2.5}$ and $PM_{10}$ concentrations in the city greatly exceeded WHO guidelines. For example, mean 24 hour concentrations of $PM_{2.5}$ in Kigali were more than five times greater than the WHO guideline value of 25µg/m$^3$. The high concentrations of these pollutants were largely attributed to vehicle emissions as concentrations of particulates greatly reduced during holidays and car-free days[54],[55].

Earlier studies in Kigali from 2008 and 2009 also found $PM_{10}$ concentrations greatly exceeded WHO guidelines, with $PM_{10}$ emissions attributed to both vehicles and the burning of

[51] World Health Organisation (WHO). (2017). Global Health Observatory (GHO) data: Exposure to ambient air pollution. World Health Organization. Retrieved from http://www.who.int/gho/phe/outdoor_air_pollution/exposure/en/

[52] Petkova, E. P., Jack, D. W., Volavka-Close, N. H., & Kinney, P. L. (2013). Particulate matter pollution in African cities. Air Quality, Atmosphere & Health, 6(3), 603–614. https://doi.org/10.1007/s11869-013-0199-6

[53] Fonerwa. (2017). Rwanda Air Quality and Climate Change Monitoring Project. REMA. Retrieved from http://www.fonerwa.org/portfolio/rwanda-air-quality-and-climate-change-monitoring-project

[54] Kalisa, E., Nagato, E., et al., 2017. Spatial Temporal Variability of PM2.5 in Urban Areas in Rwanda. Kanazawa International Symposium. Noto Peninsula: Institute of Nature and Environmental Technology, pp. 1

[55] Kalisa, E., Sebashongore, D., et al., 2017. Temperature and Air Pollution Relationship in Kigali, Rwanda. In University of Rwanda (UR) Scientific Conference Week entitled: 'Rebranding Research for Sustainable development. Kigali: University of Rwanda, pp. 1–12. Available at: http://www.conference.ur.ac.rw/scw/index.php

biomass[56],[57],[58]. $PM_{10}$ concentrations in these earlier studies are much greater than in the 2017 study, suggesting that air quality in Kigali may have improved in recent years (although the studies were conducted using different methodologies in different locations).

Nonetheless, these studies demonstrate that particulate matter is a pollutant of concern in Kigali, more so than many other major African cities which have measured lower concentrations of particulate matter (see Table 3).

**Table 3: Sources and concentrations of PM in African cities**

| Location | Pollutant | Concentration ($\mu g/m^3$) | Source of PM | Reference |
|---|---|---|---|---|
| Kigali, Rwanda | $PM_{2.5}$<br>$PM_{10}$ | 133<br>156 | Vehicle emissions | Kalisa et.al., 2017[59] |
| Bamako, Mali | $PM_{2.5}$<br>$PM_{10}$ | 57<br>130 | Mineral dust | Val et al., 2013[60] |
| Dakar, Senegal | $PM_{2.5}$<br>$PM_{10}$ | 24<br>50.5 | Diesel vehicles | Val et al., 2013 |
| Abidjan, Ivory Cost | $PM_{2.5}$ | 88 | Vehicle | Kouassi et al., 2010 |
| South Africa | $PM_{2.5}$<br>$PM_{10}$ | 65<br>150 | coal combustion<br>vehicle | Engelbrecht et.al 2001[61] |
| Dar es Salaam, Tanzania | $PM_{2.5}$ | 100 | Soil derived dust | Boman et al., 2009[62] |
| Kampala, Uganda | $PM_{2.5}$ | 100 | Traffic, unpaved road dust | Kirenga et al., 2015[63] |
| Nairobi, Kenya | $PM_{2.5}$ | 128.7 | Motor Vehicles | Kinney et al., 2009[64] |
| Nouakchott, Mauritania | $PM_{10}$ | 108 | Dust | Ozer et al., 2007[65] |

A study by Nsengimana et al.[66] proposed that the high concentrations of particulates in Kigali are the result of:

- High densities of vehicles, particularly old vehicles
- Inadequate maintenance facilities

[56] Henninger, S. M. (2013). When Air Quality Becomes Deleterious—A Case Study for Kigali, Rwanda. Journal of Environmental Protection, 4(8), 1. https://doi.org/10.4236/jep.2013.48A1001

[57] Henninger, S. M. (2009). Urban climate and air pollution in kigali, rwanda. The Seventh International Conference on Urban Climate, Yokohama, Japan, (July), 1038–1041.

[58] Nsengimana, H., Bizimana, J. Pi. & Sezirahiga, Y. A (2011). Study on Air Pollution in Rwanda With Reference To Kigali City and Vehicular Emissions.

[59] Kalisa, E., Nagato, E., et al., 2017. Spatial Temporal Variability of PM2.5 in Urban Areas in Rwanda. Kanazawa International Symposium. Noto Peninsula: Institute of Nature and Environmental Technology, pp. 1

[60] Val, S. et al., 2013. Physico-chemical characterization of African urban aerosols (Bamako in Mali and Dakar in Senegal) and their toxic effects in human bronchial epithelial cells: description of a worrying situation. Particle and fibre toxicology, 10, p.10.

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[65] Ozer, P. et al., 2007. Estimation of air quality degradation due to Saharan dust at Nouakchott, Mauritania, from horizontal visibility data. Water, Air, and Soil Pollution, 178(1-4), pp.79–87.

[66] Nsengimana, H., Bizimana, J. Pi. & Sezirahiga, Y. A (2011). Study on Air Pollution in Rwanda With Reference To Kigali City and Vehicular Emissions.

- Poor traffic management systems and road conditions
- Lack of mass transport systems e.g. trains.

Heavy freight transport vehicles are also a major source of particulates in Rwanda; in 2012, despite only making up 3.4% of the national vehicle fleet, heavy trucks were estimated to contribute to 83.4% of all total suspended particulate (TSP) emissions[67].

Studies of $PM_{10}$ and $PM_{2.5}$ concentrations in other urban areas of Rwanda, such as Musanze, also found high concentrations of particulates which exceeded the WHO guidelines [68],[69],[70] suggesting this pollutant is of concern across several urban areas in Rwanda, not just in Kigali. These studies attributed the high pollutant concentrations to vehicles and the burning of biomass and diesel in both domestic and industrial settings[71],[72],[73].

Other studies in Kigali which monitored $NO_2$, $SO_2$ and CO found that concentrations of these pollutants were acceptable as they were generally below the WHO guidelines and the East African Standards, although there were some higher concentrations of $SO_2$ during the dry season [74],[75]. There were also high concentrations of ground-level $O_3$, resulting in some exceedances of the 8 hour WHO guidelines [76]. These studies are based on data which is more than four years old so more recent monitoring data is needed to assess whether concentrations of these pollutants are still acceptable from a human health perspective.

A summary of the findings from these studies is presented in Table 4

Overall, it can be concluded that no one sector is the biggest contributor to air pollution within Rwanda as the levels of air pollution in a specific area are dependent on its location in relation to pollution sources. For example, in locations adjacent to busy road, vehicle emissions are the biggest contributor to poor air quality whereas in areas away from busy roads in residential areas the biggest contributor is domestic stoves. Power plants may have higher emission rates of pollutants compared to domestic stoves but their effects on air quality in areas where there is high population density is low because the plants have stacks to aid dispersion and they not located in residential areas.

[67] REMA, 2015. Rwanda Sectoral Analysis

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[73] DeWitt, H. L. (2016). Air pollution in Rwanda, a growing East African country. Presented at the International Global Atmospheric Chemistry (IGAC) Project 2016 Science Conference, Breckenridge, CO, USA

[74] Nsengima et al. 2011. A Study on Air Pollution in Rwanda with Reference to Kigali City and Vehicular Emissions: Final Report. Kigali: Rwanda Environment Management Authority

[75] Nduwayezu, J. B., Ishimwe, T., Niyibizi, A., Ngirabakunzi, B., Nduwayezu, J. B., Ishimwe, T.Ngirabakunzi, B. (2015). Quantification of Air Pollution in Kigali City and Its Environmental and Socio-Economic Impact in Rwanda. American Journal of Environmental Engineering, 5(4), 106–119

[76] Nsengima et al. 2011. A Study on Air Pollution in Rwanda with Reference to Kigali City and Vehicular Emissions: Final Report. Kigali: Rwanda Environment Management Authority

**Table 4: Summary of recent studies on air pollution in Rwanda**

| Study | Location | Pollutant | Sampling period | Sampling method | Mean Concentration | Conclusion |
|---|---|---|---|---|---|---|
| Kalisa et al. 2017 | Kigali<br>Musanze | $PM_{2.5}$ and $PM_{10}$ | April –June 2017 | 3 month gravimetric sampling | 133µg/m$^3$ and 156µg/m$^3$<br>45µg/m$^3$ and 54µg/m$^3$ | $PM_{2.5}$ and $PM_{10}$ levels exceeded WHO guidelines in Rwanda. During public holidays and Kigali car-free days, air pollution reduces compared to normal working days as there are fewer cars on the road. The government should strongly consider implementing car free days as not just temporary events, but on a wider scale. |
| Kalisa et al. 2017 | Kigali | Ozone | 2009-2011 | 3 years of continuous monitoring | 58.3µg/m$^3$ | $O_3$ levels rose and the maximum temperature coincided with the peak of ozone during all three years studied. Public health programmes should be implemented to minimize elevated temperatures. |
| DeWitt, 2016 | Musanze Mt. Mugogo | BC | Continuous monitoring | Continuous monitoring | Black carbon levels were close to those in major US cities | Agricultural burning, cooking fires, charcoal making, kerosene lightning, brick kilns, and older diesel generators/vehicles were found to be major sources of air pollution in Rwanda. |
| WHO, 2016 | Urban areas Rwanda | $PM_{2.5}$ | Satellite sensing data 2014 | Satellite sensing/ modelling | 51µg/m$^3$ (annual median) | Air pollution continues to rise at an alarming rate and affects the economy and quality of life and is a public health emergency. |
| Nduwayezu et al., 2015 | Kigali-Nyamagabe | $O_3$, $NO_2$, $SO_2$, CO | 9 months (2012-2013) | 9 month Gray Wolf-Advanced Sense HVAC | $NO_2$ (0.119-0.050 ppm);<br>$SO_2$ (0.014-0.000ppm);<br>$O_3$ (0.033 – 0.009 ppm);<br>CO (3.148 – 0.000ppm) | Large amounts of air pollutants are released into the atmosphere of Kigali City by both petrol and diesel vehicles. Planting suitable tree species, frequent monitoring of imported fuel quality and the establishment of new fuel quality regulations and guidelines, national ambient air quality standards and national air quality emission standards are very crucial to ensure future generations of a quality life and living environment. |
| Henninger, 2013 | Kigali | $PM_{10}$ | Feb to March 2009 | 2 month gravimetric and SEM testing | 650µg/m$^3$ | The concentration of $PM_{10}$ in Kigali is considerably higher than the limits set by the WHO. The origins of the different airborne particles were from the combustion of biomass and from traffic. |
| Nsengima et al. 2011 | Kigali | PM, $NO_2$, $SO_2$, CO, $O_3$ | - | Literature review | $NO_2$ - 15-20µg/m$^3$ | The air quality in Kigali City is still at a favourable level compared to most countries in the world, but industrial activity and traffic density continue to grow. The resulting increase in air pollution is already a concern. |
| Henninger, 2009 | Kigali | $PM_{10}$ | Feb 2008 | 2 months of mobile measurement | 1,013µg/m$^3$ | The increasing rate of urbanization in Kigali is of great concern. The concentrations of $PM_{10}$ in Kigali have reached levels significantly greater than the limits set by the WHO and are a risk to the health of inhabitants. Transportation and dispersion of air pollutants causes the accumulation of airborne pollution in small valleys and residential areas. |

# 3 Current Legislative and Policy framework

## 3.1 Overview

This section provides an overview of the existing legislation and policy frameworks that are currently in place for air quality regulation in Rwanda.

The Republic of Rwanda adopted Law No. 18/2016 of 18 May 2016 governing the conservation of air quality and the prevention of air pollution in Rwanda which sets the framework for regulation and the protection of air quality.

The new law improves on previous versions which did not cover all aspects of air pollution, including:

- No requirements to undertake air quality monitoring
- It was not stated which government institution should regulate air quality
- The Regional air quality standards set by the East African Community (Standard EAS751:2001) where not enforced

The new law adopted in 2016 mandates REMA to regulate air quality in Rwanda by stating “inspection and monitoring of air quality shall be done by the Authority in charge of environment protection”. It also states that “The National Authority in charge of establishing quality standards must:

1. prescribe criteria and procedure for measuring air quality and air pollutants;
2. establish ambient air quality standards in order to curb the impact of air pollutants;
3. establish occupational air quality standards for various sources of air pollution which can cause harm to public health;
4. establish quality standards that regulate emissions of air pollutants from different sources contributing to air pollution;
5. establish specific quality standards that regulate industrial activities with a view to avoid or minimize environmental pollution that may result from such industries;
6. determine stack heights of chimneys for air emissions;
7. prescribe any matter in relation with or affecting air emission quality standards. “

The new law does not specify new ambient air quality standards or emission limits.  Therefore, the current East African Standards that have been adopted by Rwanda via the Rwanda Standards Board but were not previously enforced are still those that are applicable for air quality regulation.

## 3.2 Current ambient air quality and emissions to air standards

### 3.2.1 Emissions to air

The current East African Standards that have been adopted by the Republic of Rwanda with specific reference to emissions to air are:

- RS EAS 750 2010 – Emissions to the air by cement factories
- RS EAS 751 2010 – Air quality specification
- RS EAS 752 2010 – Tolerance limits of emissions discharged to the air by factories

Emissions standards relevant to the pollutants considered in this study are presented in Table 5 and Table 6.

### Table 5: Emission limits specified in EAS 751:2010

| Pollutant | Guideline | Limit level | Test method |
|---|---|---|---|
| Sulphur oxides ($SO_x$) | Large Combustion Plants (LCP) using solid fuel with thermal effect of: 50 to 100 MWth | Yearly average of 850 mg/Nm$^3$ | ISO 4221-and ISO 6767 |
| | 100 to 300 MWth | 200 mg/Nm$^3$ | |
| | > 300 MWth | 200 mg/Nm$^3$ | |
| | LCP using liquid fuel with thermal effect of: 50 to 100 MWth | 850 mg/Nm$^3$ | |
| | 100 to 300MWth | 400 to 200 mg/Nm$^3$ (linear decrease) | |
| | > 300 MWth | 200 mg/Nm$^3$ | |
| | LCP using gaseous fuels | 35 mg/Nm$^3$ | |
| | LCP using low calorific gases from gasification of refinery residues, coke oven gas, blast furnace gas | 800 mg/Nm$^3$ | |
| Carbon monoxide (CO) | Liquid fuel combustion with heat output exceeding 5MW | Not to exceed 175 mg/Nm$^3$ | ISO 4224 and ISO 8186 |
| | Solid fuel combustion with heat output of 50MW and above | Not to exceed the level of 250 mg/Nm$^3$ | |
| Dust | Inert dust, including cement | Not to exceed 250 mg/Nm$^3$ (24hr mean) | ISO |
| Nitrogen Oxides ($NO_x$) | LCP using solid fuel with thermal effect of 50 to 500 MWth | Yearly average of 600 mg/Nm$^3$ | ISO 7996 |
| | > 500 MWth | 500 mg/Nm$^3$ | |
| | LCP using liquid fuel with thermal effect of 50 to 500 MWth | 300 mg/Nm$^3$ | |
| | > 500 MWth | 200 > 500 MWth | |

Source: EAS 751:2010

Notes: emission limits are valid for concentration expressed for any dry gas under normal atmospheric conditions

### Table 6: Emissions limits for cement industry specified in EAS 752:2010

| Characteristic | Limit | | | Method of test |
|---|---|---|---|---|
| | Immediate | Optimal value | Time (yrs) | |
| Dust – for systems with | | | | |
| Mutlicyclone (MLTC) | 2000 | 50 | 5 | ISO 9096 |
| Fabric filter sheet type/mech. Rapping | 150 | 50 | 8 | |
| Electrostatic precipitators low efficiency | 500 | 50 | 8 | |

| Characteristic | Limit | | | Method of test |
|---|---|---|---|---|
| | Immediate | Optimal value | Time (yrs) | |
| Fabric filter sleeve type/jet pulse cleaning | 50 | 50 | N/A | |
| Electrostatic precipitator high efficiency | 50 | 50 | N/A | |
| NOx | 1800 | 1500 | 6 | ISO 11564 |
| SO2 | 800 | 500 | 8 | ISO 11632 |

Source: EAS 752:2010

Notes: All values are in mg/Nm$^3$, dry gas basis at 273 K, 101.3 KPa and 10% O2 (kiln stack only), limits are the values not to be exceeded during periodic measurements under normal conditions

In addition to the above standards for stationary sources, Prime minister instructions No 005/0. of 21/12/2013 preventing air pollution caused by vehicular emissions and machines using petroleum products in Rwanda has recently been adopted. This sets standards that are applicable for motorcycles, cars for personnel use, cars for commercial use and machines using petroleum products. It sets out requirements for emissions testing and gives powers to traffic officers to stop any vehicles that are suspected of not complying with the required standards. It also sets out the requirements that any cars imported into Rwanda should be fitted with a catalytic converter to reduced emissions of $NO_x$. A key requirement of this law was to limit the age of motorcycles in Rwanda and it stated that all motorcycles imported in Rwanda for sale shall be new and motorcycles imported into Rwanda for personal transport shall not exceed five years of age.

### 3.2.2 Ambient air quality

The current East African Standards that have been adopted by the Republic of Rwanda with specific reference to ambient air quality are:

- RS EAS 751 2010 Air quality specification

Ambient air quality standards are set out for the pollutants included within this study. The standards include values expressed as both parts per million (PPM) and micrograms per metre cubed (µg/m$^3$) as well as limits. The ambient air quality standards are presented in Table 7 and Table 8.

**Table 7: Ambient air quality tolerance limits included in EAS 751:2010**

| Pollutant | Time weighted average | Industrial area | Residential, rural & other | Controlled areas | Test methods |
|---|---|---|---|---|---|
| Sulphur oxides ($SO_x$) | Annual Average* | 80 µg/m$^3$ | 60 µg/m$^3$ | 15 µg/m$^3$ | ISO 4221-1980 |
| | 24 hours** | 125 µg/m$^3$ | 80 µg/m$^3$ | 30 µg/m$^3$ | |
| | Annual Average | | 0.019ppm/50 µg/m$^3$ | | |
| | 24 Hours | | 0.048ppm/125 µg/m$^3$ | | |
| | Instant Peak | | 500 µg/m$^3$ | | |
| | Instant Peak (10 min) | | 0.191 ppm | | |
| Oxides of nitrogen ($NO_x$) | Annual Average* | 80 µg/m$^3$ | 60 µg/m$^3$ | 15 µg/m$^3$ | ISO 7996: 1985 |
| | 24 hours** | 150 µg/m$^3$ | 80 µg/m$^3$ | 30 µg/m$^3$ | |

| Pollutant | Time weighted average | Industrial area | Residential, rural & other | Controlled areas | Test methods |
|---|---|---|---|---|---|
| | Annual average | | 0.2 ppm | | |
| | Month average | | 0.3 ppm | | |
| | 24 hours | | 0.4 ppm | | |
| | One hour | | 0.8 ppm | | |
| | Instant peak | | 1.4 ppm | | |
| Nitrogen dioxide | Annual average | 150 µg/m³ | 0.05 ppm | | ISO 6768: 1998 |
| | Month average | | 0.08 ppm | | |
| | 24 hours | 100 µg/m³ | 0.1 ppm | | |
| | One hour | | 0.2 ppm | | |
| | Instant peak | | 0.5 ppm | | |
| Suspended particulate matter (SPM) | Annual average* | 360 µg/m³ | 140 µg/m³ | 70 µg/m³ | ISO 9835: 1993 |
| | 24 hours** | 500 µg/m³ | 200 µg/m³ | 100 µg/m³ | |
| | Annual average**** | | 100 µg/m³ | | |
| | 24 hours*** | | 180 µg/m³ | | |
| Respirable particulate matter(<10µm) (RPM) | Annual average* | 70 µg/m³ | 50 µg/m³ | 50 µg/m³ | ISO 9835: 1993 |
| | 24 hours** | 150 µg/m³ | 100 µg/m³ | 75 µg/m³ | |
| $PM_{2.5}$ | Annual average | 35 µg/m³ | | | ISO 9835: 1993 |
| | 24 hours | 75 µg/m³ | | | |
| Carbon monoxide (CO) / carbon dioxide ($CO_2$) | 8 hours ** | 5.0 mg/m³ | 2.0 mg/m³ | 1.0 mg/m³ | ISO 4224: 2000 |
| | 1 hour | 10 mg/m³ | 4.0 mg/m³ | 2.0 mg/m³ | |
| Ozone | 1 hour | 200 µg/m³ | 0.12 ppm | | ISO 13964 |
| | 8 hour (instant peak) | 120 µg/m³ | 1.25 ppm | | |

Source: EAS 751:2010

* Annual Arithmetic mean of minimum *104* measurements in a year taken twice a week 24 hourly at uniform interval.

** 24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days

Whenever and wherever two consecutive values exceed the limit specified above for the respective category, it would be considered adequate reason to institute regular/continuous monitoring and further investigations

* the 24-hour limit may not be exceeded more than three times in one year

** 24-hour limit may not be exceeded more than three times in one year micrograms/m³

*** Not to be exceeded more than once per year average concentration

**Table 8: Ambient air quality at property boundary for general pollutants**

| Pollutant | Guideline | Limit Level |
|---|---|---|
| Particulate matter (PM) | Annual Average* | 50 µg/m$^3$ |
| | 24 hours** | 70 µg/m$^3$ |
| Oxides of nitrogen ($NO_x$) | Annual Average* | 80 µg/m$^3$ |
| | 24 hours** | 150 µg/m$^3$ |
| Sulphur oxides ($SO_x$) | Annual Average* | 50 µg/m$^3$ |
| | 24 hours** | 125 µg/m$^3$ |

Source: EAS 751:2010

For residential premises in designated industrial areas, the above standards do not apply

For industries in designated residential areas, standards for residential areas shall apply

## 3.3 Current approval process in Rwanda

There are a number of ministerial orders which set out how potentially polluting activities achieve permission to be constructed and operated, these are:

- Ministerial order No 003/2008 of 15/08/2008 relating to the requirements and procedure for environmental assessment sets the process for undertaking an environmental impacts study and confirms that the regulatory authority is REMA.
- Ministerial order No 004/2008 of 15/08/2008 Establishing the list of works, activities and projects that have to undertake an environmental impact assessment.
- Ministerial order No 005/2008 of 15/08/2008 Establishing modalities of inspecting companies or activities that pollute the environment sets the basis for inspections of industrial facilities. REMA are responsible for monitoring and for undertaking inspections.

## 3.4 Existing strategy documents

### 3.4.1 Rwanda Green City Toolkit

Rwanda has developed a Green City Toolkit for use in urban settlements, mainly secondary cities, districts towns and informal settlements. The toolkit will assist district technicians, local governments, technical institutes and professional training centres in identifying concrete and implementable solutions for Green Cities. The strategies to be implemented will ensure protection of the environment through various initiatives such as reducing carbon and other unwanted emissions, improving the rational use of natural resources, tackling climate change, securing access to clean energy and water, targeting poverty reduction, job creation and social inclusion. These strategies will be undertaken throughout Rwanda. Although this is not specific to air quality management many of the approaches will be mutually beneficial for air quality.

As part of the toolkit, Rwanda intends to develop secondary cities by 2050 in the following areas:

- Rubavu
- Musanze
- Nyagatare
- Muhanga
- Huye

KamembeThese secondary cities will be:

- Net zero carbon, resource efficient, maximize circular metabolism and sustain a diverse and inclusive green economy, offering full and high-quality employment and employing established and innovative green technologies
- Resilient infrastructure and land use will enable cities to adapt to a changing climate and economic conditions
- Cities will be compact and dense, walkable continuous grids enabling high levels of access for citizens supported by integrated public transport
- Urban layout and design (including public sphere) will promote healthy cities/citizenry and the development of social capital through strong social networks
- Structures of governance will enable citizens to live prosperous and engaged lives under an inclusive and participatory government.

Questionnaires were provided to various technicians from the following cities: Musanze, Muhanga and Rabavu and a vision of the green city regarding transport was outlined as shown below.

A Green City with regards to transport is:

- A walkable city, where the use of cars is limited
- A city that encourages the use of non-motorised transport such as bicycles
- A city with a reduced carbon footprint
- A city with adequate public transport options and systems.

The following challenges were outlined by the district technicians from these cities regarding transport

  - Inadequate public transport
  - Insufficient budget to improve the entire city road network, pedestrian ways and drainage on existing roads
  - Lack of guideline e.g. Kigali Transport Master Plan for other urban centres
  - Insufficient knowledge on Green Transport concepts
  - Insufficient intra-urban connectivity

The following were the recommendations provided:

  - Develop an efficient public transport system such as the Bus Rapid Transit system
  - District allocate budget to rehabilitate existing roads and construct and maintain new roads and pedestrian ways
  - Provide clear transportation development plans such as the City of Kigali Transport Master Plan for secondary cities
  - Educate stakeholders and the public on the Green Transport city vision
  - Expand the connectivity between urban centres through efficient public transport routes

A green city with regards to energy is:

- A city that uses electricity generated from renewable energy such as solar and hydro
- An energy efficient city
- A city where 100% of population has access to clean electricity.

District technicians from the secondary cities Musanzi, Muhanga and Rabavu highlighted the following as their challenges:

- Lack of awareness of other sources of energy and their benefits
- The perception that solar energy is for rural areas which are not yet connected to the national grid
- A large percentage of the population still use charcoal for cooking instead of gas
- Solar water heaters are still perceived as unaffordable only high-end hotels use them

To manage the above challenges, the following recommendations were made:

- Rwanda Energy Group and Ministry of Infrastructure (MININFRA) should organize an awareness campaign on renewable energy and other energy sources such as improved cooking stoves and gas
- Awareness campaigns to educate the population about the available solar energy options in urban areas
- Improved cooking stoves to be promoted and advertised. People to be educated about the benefits of using biogas and liquefied petroleum gas (LPG)
- The population to be educated about the pricing of solar water heaters and the long-term cost saving benefits

### 3.4.2 Smart City Rwanda Masterplan

"The Smart City Masterplan provides a framework to help Rwandan towns and cities manage the transition of the 21st century and help ensure the future prosperity of all Rwandans. It is intended as a guide to help Mayors and urban managers go through the process to develop their own smart city strategies and masterplans."[77]

The masterplan does not specifically include strategy measures to improve air quality but it does specify in initiative 16 that the sensor networks to collect environmental data is to provide data that can be shared with citizens to make better informed decisions on where to live and work.

## 3.5 Summary

Implementation of the new air quality law in 2016 set a new improved regulatory framework with clear responsibilities for air quality management.

The review of the current system has identified that:

- Existing East Africa Standards adopted in Rwanda are unsuitable for achieving effective regulation. The existing standards are unclear and in parts contradictory and therefore there is ambiguity over which ones apply at which locations.
- The emission standards also included are not tailored to Rwanda's need where there is more small-scale power generation rather than large combustion plants.

On the basis of the above, it is recommended that the air quality standards applicable in Rwanda are reviewed and updated to provide a clear and concise update that REMA can use to effectively regulate air quality.

Chapter 4 provides a review of emission limits and ambient air quality standards from a variety of countries across the world and Chapter 9 provides suggested standards for Rwanda to adopt going forward and who is responsible for actioning this recommendation.

[77] Goverbnent of Rwanda, 2017, Smart City Rwanda Masterplan

# 4 Review of air quality standards from other countries

## 4.1 Overview

This chapter provides an overview of air quality standards from other countries around the world. It focuses on countries located in Africa but also other countries such as the Singapore, USA, UAE and the UK to provide an overview of existing standards from a range of countries.

In countries where air quality does not meet national standards we have also undertaken a review of the policy interventions, focussing on developed countries where policy interventions have been established.

## 4.2 Identification air quality standards to be included in the review

In identifying which national ambient air quality standards and emission limits were suitable to be included for review, we used the following criteria:

- Countries which represent the most stringent and least stringent emissions limits and ambient standards (thereby identifying the upper and lower levels of the range in force internationally)
- Countries which are geographically close to Rwanda
- Countries which have a similar level of economic development (i.e. a similar gross domestic product (GDP)). We have identified both emission limits *and* ambient air quality standards for any given country where these were available. A summary of the countries from which international emission limits and ambient standards were reviewed is presented in Table 9.

Ambient standards and emission limits have also been taken from the World Bank/IFC[78] and WHO[79]. Ambient air quality standards and emission limits from EU countries have been presented as well as the values from the relevant directives themselves. This is because EU Member States have the option to enforce more stringent standards if necessary, and may interpret the application of the directives differently.

**Table 9: Sources of international standards**

| Country/Source | Ambient standards | Emission limits |
|---|---|---|
| Bosnia and Herzegovina | | ü |
| Botswana | ü | |
| Chile | ü | |
| China | ü | ü |
| European Union Directives | ü | ü |
| Finland (EU) | ü | |
| WB/IFC EHS Guidelines 2008 | | ü |
| WB Pollution Prevention and Abatement Handbook 1998 | | ü |
| World Health Organization | ü | |
| Israel | ü | |

[78] World Bank/IFC, 2008.Environmental, Health, and Safety (EHS) Guidelines for Thermal Power Plants

[79] World Health Organization (WHO), 2000. Air Quality Guidelines for Europe.

| Country/Source | Ambient standards | Emission limits |
|---|---|---|
| Japan | ü | ü |
| Jordan | ü | |
| Moldova | ü | |
| Mongolia | ü | ü |
| Pakistan | ü | |
| Philippines | ü | |
| Russia | ü | ü |
| Singapore | ü | ü |
| South Africa | ü | ü |
| Sri Lanka | ü | |
| Taiwan | ü | ü |
| Tanzania | ü | ü |
| Turkey | ü | ü |
| UAE | ü | ü |
| UK (EU) | ü | (as per EU) |
| USA | ü | |
| Zambia | ü | |

## 4.3 Review of ambient air quality standards

### 4.3.1 Principles of ambient air quality standards

**Overview**

An ‘ambient air quality standard’ can be defined as a concentration of pollutants in the atmosphere which achieve an acceptable level of environmental quality. The standards are based on assessment of the effects of each pollutant on human health including the effects on sensitive subgroups or on ecosystems. It should be noted that, in various publications, the word ‘objective’, ‘limit’ or ‘guideline’ is used instead of ‘standard’, often to denote the regulatory weight assigned. For the purposes of this report ‘standard’ has been used to refer to these in general, unless specified otherwise by the legislation in question.

There are other considerations that should be borne in mind when specifying or applying a limit:

- Averaging periods
- Locations where the standard applies (geographically and/or by receptor type).

A brief description of these principles is presented below.

**a) Averaging periods and allowances**

International ambient air quality standards are normally based on epidemiological studies which have assessed the health effects of a given pollutant over a specified averaging period. The resulting specified concentration is also accompanied by an averaging period over which that concentration should be applied.

Ambient standards may also be accompanied by an ‘allowance’ i.e. a specified number of times that the specified concentrations can be exceeded over a given period without incurring a breach of the standard. This allowance can reflect the epidemiological evidence upon which the standard is based but, more commonly, an allowance reflects the practicality of applying the standard in a regulatory context. For example, $PM_{10}$ concentrations may be found to be low over a year, with the exception of a small number of hours or days when, due to unusual circumstances, a 'spike' in concentrations occurred. Actions taken by a regulator in response to these unusual spikes could be considered unreasonable in the context of their potential health impacts.

An example of averaging periods and allowances applied to an ambient standard is presented in Figure 12.

**Figure 12: Averaging periods and allowances**

| Averaging Period | Limit value | Margin of tolerance | Date by which limit value is to be met |
|---|---|---|---|
| Lead | | | |
| Calendar year | 0,5 µg/m³ (3) | 100 % | — (3) |
| $PM_{10}$ | | | |
| One day | 50 µg/m³, not to be exceeded more than 35 times a calendar year | 50 % | — (1) |
| Calendar year | 40 µg/m³ | 20 % | — (1) |

Source: European Union Ambient Air Quality Directive (2008/50/EC)[80]

### b) Applicable locations

The application of the averaging period to a given standard, as described above, also relates to where a standard should be applied. As a general rule, standards should be applied where receptors are regularly present and are likely to be exposed for a period of time appropriate to the averaging period of the standard. It would not be appropriate to consider compliance of a standard at any location where relevant exposure would not be realistic. An example of this approach, as applied in the UK, is presented in Table 10. It should be noted that the range of national standards presented, and therefore the focus of this report, apply to locations of outdoor (ambient) public exposure, i.e. not indoor locations or locations where only occupational exposure exists.

**Table 10: Example of Where Ambient Air Quality Standards Apply – UK**

| Averaging period | Objectives should apply at: | Objectives should generally not apply at: |
|---|---|---|
| Annual mean | All locations where members of the public might be regularly exposed. Building façades of residential properties, schools, hospitals, care homes. | Building façades of offices or other places of work where members of the public do not have regular access.<br>Hotels, unless people live there as their permanent residence.<br>Gardens of residential properties.<br>Kerbside sites (as opposed to locations at the buildings façades), or any other location where public exposure is expected to be short-term. |
| 24-Hour mean and 8 hour mean | All locations where the annual mean objective would apply, together with hotels.<br>Gardens of residential properties. | Kerbside sites (as opposed to locations at the buildings façade), or any other location where public exposure is expected to be short-term. |
| 1-Hour Mean | All locations where the annual and 24 hour mean would apply. | Kerbside sites where the public would not be expected to have regular access. |

[80] European Commission (2008), Air Quality Directive, 2008/50/EC

| Averaging period | Objectives should apply at: | Objectives should generally not apply at: |
|---|---|---|
| | Kerbside sites (e.g. pavements of busy shopping streets).<br>Any outdoor locations to which the public might reasonably be expected to spend 1-hour or longer. | |

Source: Defra, 2016[81]

### 4.3.2 Analysis of selected ambient air quality standards

**Overview**

Appendix A presents details of the national ambient air quality standards which have been reviewed. The following sub-sections provide an analysis of the range of standards found for each pollutant (including WHO standards) and the most common single values applied for comparison against existing ambient air quality standards applicable in Rwanda. Unless explicitly stated, the Rwandan standards referred to below are those which apply to residential, rural and other locations as these standards apply to the majority of areas of Rwanda.

It is generally recognised that the WHO Air Quality Guidelines represent a reliable source of recommendations for ambient air quality standards as they are based on a robust review of epidemiological evidence. The WHO Air Quality Guidelines are referenced by the IFC/WB EHS Guidelines as a suitable source of ambient air quality standards, and they provide a basis upon which many national and international standards (such as the EU's) are set. Therefore, the WHO Guidelines and Interim Targets have been given considerable weight in the recommendations.

The review has identified that legislated standards focus on the pollutants listed below:

- Nitrogen dioxide ($NO_2$)
- Sulphur dioxide ($SO_2$)
- Carbon monoxide (CO)
- Ozone ($O_3$)
- Particulates

We recommend that ambient air quality standards in Rwanda are limited to these key pollutants and our review is made on that basis.

**Nitrogen dioxide ($NO_2$)**

A summary of $NO_2$ standards is presented in Table 11. Overall, a wide range of averaging periods exist, with annual standards being the most common.

Based on the limited data available[82], ambient $NO_2$ concentrations in Rwanda appear to meet the current Rwandan standards and more stringent international standards, even in urban areas such as Kigali where there are likely to be elevated concentrations of $NO_2$. As traffic levels increase in future years, ambient $NO_2$ concentrations are also likely to increase near to roads and in background locations if Rwandan air quality standards and emissions controls are not stringent.

[81] Department of Environment, Farming and Rural Affairs (Defra), 2016. Local Air Quality Management Technical Guidance (TG16)

[82] Nsengima et al. 2011. A Study on Air Pollution in Rwanda with Reference to Kigali City and Vehicular Emissions: Final Report. Kigali: Rwanda Environment Management Authority

The current 1 hour $NO_2$ standard in Rwanda, when converted from ppm into µg/m$^3$, is greater than the WHO guideline and the most common hourly $NO_2$ standard of 200µg/m$^3$. Therefore it is recommended this standard is reduced to 200µg/m$^3$ so it is in line with WHO guidelines and other national standards. The 24-hour Rwandan standard is also greater than 24 hour $NO_2$ standards in many other countries. This standard is considered to be unnecessary so can be removed as the 1 hour standard is sufficient to assess short-term concentrations of $NO_2$. It is also recommended that the 1 month Rwandan standard is removed as it is inconsistent with general international practice and the WHO Guidelines. Currently Botswana and South Africa also have standards that align with the WHO guidelines while Tanzania has standards that are broadly similar to the current Rwanda standards.

The annual Rwanda standard, when converted into µg/m$^3$, is almost twice the WHO Guideline of 40µg/m$^3$ (which is also the most common concentration for this standard used in other countries). It is recommended that the Rwandan annual $NO_2$ standard is reduced to be brought in line with this.

It is also recommended that all the Rwanda $NO_2$ standards are converted to µg/m$^3$ to better agree with standards used in other countries as well as other Rwandan air quality standards e.g. $PM_{10}$.

**Table 11: Summary of standards – $NO_2$ (µg/m$^3$)**

| Averaging period | Range of concentrations found | Most common concentration | WHO Guidelines and Interim Targets | Existing Rwandan standard |
|---|---|---|---|---|
| 20 minute | 85 – 200 | 85 | - | - |
| 30 minute | 940 | - | | |
| 1 hour | 150-660 | 200 | 200 (Guideline) | 0.2ppm (383) |
| 8 hour | 120-300 | - | - | - |
| 24 hour | 40-560 | 100 | - | 0.1ppm (192) |
| 1 month | - | - | - | 0.08ppm (153) |
| Annual | 30-100 | 40 | 40 (Guideline) | 0.05ppm (96) |

Source: Appendix A, Note: assumes ambient temperature of 20 degrees to convert ppm to µg/m$^3$

### Sulphur dioxide ($SO_2$)

A summary of $SO_2$ standards is presented in Table 12. Overall, a wide variation in averaging periods is found, although most countries focus on short term ambient standards. This is likely due to the nature of primary $SO_2$ emission sources (such as power generation) which often lead to short term elevated concentrations (whist long term concentrations remain low) and epidemiological evidence which indicates that health effects occur over short periods of exposure.

Previous studies in Rwanda have found annual concentrations of $SO_2$ to be low, which is likely due to the lack of emission sources (although concentrations of $SO_2$ have been found to increase in the dry season)[83],[84]. In areas close to emission sources, there are likely to be high short-term concentrations.

[83] Nsengima et al. 2011. A Study on Air Pollution in Rwanda with Reference to Kigali City and Vehicular Emissions: Final Report. Kigali: Rwanda Environment Management Authority

[84] Nduwayezu, J. B., Ishimwe, T., Niyibizi, A., Ngirabakunzi, B., Nduwayezu, J. B., Ishimwe, T.Ngirabakunzi, B. (2015). Quantification of Air Pollution in Kigali City and Its Environmental and Socio-Economic Impact in Rwanda. American Journal of Environmental Engineering, 5(4), 106–119

Rwanda's current standards cover 24 hour and annual averaging periods. The 24 hour standard of 80-125µg/m$^3$ is within the range found internationally and in line with the most common concentration used for this standard in other countries. It is also in line with WHO Interim Target 1. It is recommended that the 24 hour averaging period is retained, although clarification should be provided as to which standards should be used (multiple 24 hour standards exist within Rwandan legislation). Both Botswana and Tanzania have standards of 120 µg/m$^3$ and 100µg/m$^3$ respectively indicating that the Rwanda is aligned with these countries.

While a 10 minute guideline of 500µg/m$^3$ is identified by WHO, of the countries reviewed only Mongolia and South Africa have adopted a 10 minute standard. On the basis of the monitoring data currently available, it is unclear whether compliance with a concentration of 500µg/m$^3$ over a 10 minute period would be reasonably achievable in the vicinity of major emission sources. It is recommended that a 500µg/m$^3$ concentration over 10 minutes is applied, with a suitable allowance for exceedances.

The annual $SO_2$ Rwandan standard of 50µg/m$^3$ or 60µg/m$^3$ depending on which table is referred to in the current adopted standards is more stringent than the most common concentration used for this standard by other countries. It does align with those set in South Africa and Tanzania. On the basis of implementation of the short term standards above, the existing annual standard can be removed in line with the WHO guidelines as compliance with the short term objectives should protect against long term exposure.

**Table 12: Summary of standards – $SO_2$ (µg/m$^3$)**

| Averaging period | Range of concentrations Found | Most common concentration | WHO Guidelines and Interim Targets | Existing Rwanda standard |
|---|---|---|---|---|
| 10 minute | 500 | - | 500 (Guideline) | - |
| 20 minute | 200-500 | 500 | - | - |
| 30 minute | 500-1000 | - | - | - |
| 1 hour | 200-1000 (a) | 350 | - | - |
| 8 hour | 120 | - | - | - |
| 24 hour | 20-400 | 125 | 125 (Interim Target 1)<br>50 (Interim Target 2)<br>20 (Guideline) | 80-125 |
| 1 month | - | - | - | - |
| Annual | 10-150 | 80 | - | 50-60 |

Source: Appendix A

### Carbon monoxide (CO)

A summary of CO standards is presented in Table 13. Compared to other pollutants reviewed, CO standards had the least amount of variation across the different countries.

There is limited monitoring data on ambient CO concentrations in Rwanda, although one study found low long term CO concentrations in Kigali[85]. On the basis of this and the typical emission sources in Rwanda, it is considered unlikely that ambient CO concentrations in open, public areas would exceed the most stringent standards.

The existing Rwanda 1 hour CO standard is in line with the most common concentration for 1 hour standards found, although is slightly higher than the WHO guideline and countries such

[85] Nduwayezu, J. B., Ishimwe, T., Niyibizi, A., Ngirabakunzi, B., Nduwayezu, J. B., Ishimwe, T.Ngirabakunzi, B. (2015). Quantification of Air Pollution in Kigali City and Its Environmental and Socio-Economic Impact in Rwanda. American Journal of Environmental Engineering, 5(4), 106–119

as Botswana and Tanzania. It is recommended that the existing Rwanda 1 hour standard is reduced to meet the WHO guideline of 30,000 µg/m$^3$. The existing 8 hour Rwandan standard of 20,000µg/m$^3$ should also be reduced to meet with the WHO guideline so it is in line with other national standards such as those set in Botswana and Tanzania. This should be expressed as a maximum daily running 8 hour mean so that the standard is consistent with the typical daily exposure that it is expected to protect against adverse health impacts (see Section 4.3.1 for further details).

Although the WHO Guidelines also identify 15 minute and 30 minute averaging period standards, these have not been adopted by the countries reviewed. The 1 hour and 8 hour averaging periods should be sufficient to protect human health.

**Table 13: Summary of standards – CO (µg/m$^3$)**

| Averaging period | Range of concentrations found | Most common concentration | WHO Guidelines and Interim Targets | Existing Rwanda standard |
|---|---|---|---|---|
| 15 minutes | - | - | 100,000 (Guideline) | - |
| 30 minutes | - | - | 60,000 (Guideline) | - |
| 1 hour | 10,000-40,100 | 40,000 | 30,000 (Guideline) | 40,000 |
| 8 hour | 5,000 – 22,910 | 10,000 | 10,000 (Guideline) | 20,000 |
| 24 hour | 3,000 - 11,460 | 3,000 | - | - |

Source: Appendix A

### Ozone ($O_3$)

A summary of $O_3$ standards is presented in Table 14. Averaging periods found within the standards reviewed are limited to 1 hour and 8 hour only. The limited monitoring data that is available on ambient $O_3$ concentrations in Rwanda found some high concentrations of $O_3$ in Kigali, which resulted in some exceedances of the 8 hour WHO standard[86].

The 1 hour Rwandan standard is within the range of concentrations found in different countries, although it is slightly higher than the most common concentration for this standard. It is recommended the concentration is reduced to 200µg/m$^3$ so it is in line with other national standards. The 8 hour Rwandan standard is much higher than the WHO guidelines and the most common concentrations for the standard in other countries including in Botswana. It is recommended that the Rwandan 8 hour $O_3$ standard is reduced to 120µg/m$^3$ so that it is in line with standards in other countries and so it meets WHO Interim Target 1. It is also recommended that both the 1 hour and 8 hour standards are expressed in µg/m$^3$ for ease of use and to be in line with other national standards.

**Table 14: Summary of Standards – $O_3$ (µg/m$^3$)**

| Averaging period | Range of concentrations found | Most common concentration | WHO Guidelines and Interim Targets | Existing Rwandan standard |
|---|---|---|---|---|
| 1 hour | 130-300 | 200 | - | 0.12ppm(240) |
| 8 hour | 60 - 160 | 120, 160 | 160 (Interim Target 1)<br>100 (Guideline) | 1.25ppm(2496)* |

Source: Appendix A *instant peak, Note: assumes ambient temperature of 20 degrees to convert ppm to µg/m$^3$

[86] Nduwayezu, J. B., Ishimwe, T., Niyibizi, A., Ngirabakunzi, B., Nduwayezu, J. B., Ishimwe, T.Ngirabakunzi, B. (2015). Quantification of Air Pollution in Kigali City and Its Environmental and Socio-Economic Impact in Rwanda. American Journal of Environmental Engineering, 5(4), 106–119

### Particulates

A summary of particulate standards is presented in Table 15. Overall, standards were found to apply to a wide range of averaging periods as well as a range of particle sizes. The majority of countries focus on respirable particles (particles which are <10µg/m$^3$ that can enter the respiratory tract), particularly $PM_{10}$, as these are the more important fractions from a human health perspective.

$PM_{10}$ is the pollutant for which the most monitoring data is available in Rwanda (although this is still relatively limited), with very high concentrations of $PM_{10}$ found in urban areas, especially Kigali. Similar to $NO_2$, elevated $PM_{10}$ concentrations are more likely to be found in urban areas close to roads with higher traffic levels where there are regular exceedances of current Rwandan standards and the more stringent standards from other countries. As traffic levels increase in future years, ambient $PM_{10}$ concentrations are likely to increase even more near to roads and in urban areas, particularly over short term averaging periods if ambient standards and emission controls are not stringent.

Rwanda has existing standards for suspended particulate matter (SPM), $PM_{10}$ and $PM_{2.5}$, however the $PM_{2.5}$ standards only apply to industrial areas. The 24 hour and annual Rwandan $PM_{10}$ standards are in line with WHO Interim Target 2 and standards from other countries and are more stringent than those set out in other local countries such as Botswana and therefore should remain in place as they represent an appropriate level of protection. The $PM_{2.5}$ standards for industrial areas are much higher than WHO guidelines and standards found in other countries. It is recommended that the WHO Interim Target 1 concentrations for $PM_{2.5}$ are adopted, which have been identified by WHO on the basis that countries may find them helpful in gauging progress over time in the process of steadily reducing population exposures to particulates. They represent an appropriate level of protection and can be made more stringent at a later stage if appropriate.

While the Rwandan standards for SPM are in line with the range of concentrations found in different countries, it is recommended that these standards are removed in favour of the $PM_{10}$ and $PM_{2.5}$ standards. This is to help avoid confusion among the particulate standards and to focus on the particulate fractions which have a more important impact on human health.

**Table 15: Summary of Standards – Particulates (µg/m$^3$)**

| Pollutant | Averaging period | Range of concentrations found | Most common concentration | WHO Guidelines and Interim Targets | Existing Rwandan standard |
|---|---|---|---|---|---|
| Total suspended particulates | 30 minute | 500 | - | - | - |
| | 24 hour | 150-500 | 260 | - | 200 |
| | Monthly | | | - | - |
| | Annual | 50-360 | 90, 100 | - | 140 |
| Particulate matter ($PM_{10}$) | 1 hour | 200 | - | - | - |
| | 8 hour | 150 | - | - | - |
| | 24 hour | 50-340 | 150 | 150 (Interim Target 1)<br>100 (Interim Target 2)<br>75 (Interim Target 3)<br>50 (Guideline) | 100 |
| | Annual | 40-120 | 50 | 70 (Interim Target 1) | 50 |

| Pollutant | Averaging period | Range of concentrations found | Most common concentration | WHO Guidelines and Interim Targets | Existing Rwandan standard |
|---|---|---|---|---|---|
| | | | | 50 (Interim Target 2)<br>30 (Interim Target 3)<br>20 (Guideline) | |
| Particulate matter ($PM_{2.5}$) | 1 hour | 15 | - | - | - |
| | 24 hour | 35-65 | 35 | 75 (Interim Target 1)<br>50 (Interim Target 2)<br>37.5 (Interim Target 3)<br>25 (Guideline) | 150 (industrial) |
| | Annual | 15-25 | 15 | 35 (Interim Target 1)<br>25 (Interim Target 2)<br>15 (Interim Target 3)<br>10 (Guideline) | 70 (industrial) |

Source: Appendix A

Suggested revised ambient air quality standards for implementation in Rwanda based on the review above are proposed as part of the air quality strategy and presented in chapter 9.

## 4.4 Review of other national and international emission limits

### 4.4.1 Principles of emission limits

**Overview**

An ‘emission’ limit is a limit on pollutant emission concentrations from a defined, fixed source based on scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole and to be attained within a given period.

There are a number of principles that should or could be borne in mind when specifying or applying a limit:

- Reference conditions
- Averaging periods and allowances
- Applicability of the limit to particular plant
- Whether the specified limit can be deviated from in special circumstances.

A brief description of these principles is presented below.

**Reference conditions**

Where emission limits are specified as a mass of pollutant per volume of exhaust gas, for example milligrammes per cubic metre ($mg/m^3$) (the most commonly used units for emissions) ‘reference conditions’ refers to the specific oxygen content, water content, temperature and pressure of that volume of gas. Because all of these parameters can affect gas volume (and therefore the concentration of pollutant within it) they should be stated, or ‘normalised’ to allow a consistent method of measurement. If the ‘normalised’ conditions are not stated with the emission limit, the limit will be meaningless. An example of reference conditions is presented in Figure 13.

**Figure 13: Reference condition examples**

PART 2

*Emission limit values for combustion plants referred to in Article 30(3)*

1. All emission limit values shall be calculated at a temperature of 273,15 K, a pressure of 101,3 kPa and after correction for the water vapour content of the waste gases and at a standardised $O_2$ content of 6 % for solid fuels, 3 % for combustion plants other than gas turbines and gas engines using liquid and gaseous fuels and 15 % for gas turbines and gas engines.

Source: Industrial Emissions Directive[87]

### Averaging periods and allowances

Concentrations of pollutants within exhaust gas will inevitably fluctuate over time. Different emission limits therefore can be expressed over different averaging periods to control short term peaks (for example 1 hour) and longer term prevailing conditions (for example 24 hour). If stated, the applicable averaging period is often expressed within the specification for monitoring methods that can be used to demonstrate compliance with the emission limit (see Figure 14 ). Often, averaging periods are not stated and therefore it can usually be assumed that the emission limit should not be exceeded regardless of the averaging period over which it is measured. An allowance may also be made for a certain number of readings over a given period to be above the stated emission limit to allow for unusual, peak periods. This is often to allow for the inevitable variability in combustion conditions over very short periods which cannot be reasonably controlled (see Figure 14 for similar allowances for ‘abnormal’ operation such as start-up and shutdown).

[87] European Commission (2010), Industrial Emiissions Direcrtive 2010/75/EU

**Figure 14: Averaging periods and allowance examples**

PART 4

*Assessment of compliance with emission limit values*

1. In the case of continuous measurements, the emission limit values set out in Parts 1 and 2 shall be regarded as having been complied with if the evaluation of the measurement results indicates, for operating hours within a calendar year, that all of the following conditions have been met:

   (a) no validated monthly average value exceeds the relevant emission limit values set out in Parts 1 and 2;

   (b) no validated daily average value exceeds 110 % of the relevant emission limit values set out in Parts 1 and 2;

   (c) in cases of combustion plants composed only of boilers using coal with a total rated thermal input below 50 MW, no validated daily average value exceeds 150 % of the relevant emission limit values set out in Parts 1 and 2,

   (d) 95 % of all the validated hourly average values over the year do not exceed 200 % of the relevant emission limit values set out in Parts 1 and 2.

Source: Industrial Emissions Directive[88]

### Applicability of the limit to particular plant

Emission limits are usually specified for particular combustion technology types (e.g. engines, boilers, gas turbines), fuel types (gas, liquid, solid, waste-derived) and plant sizes (e.g. below 20MWth input, 20 to 50MWth input, above 50MWth input), amongst others. This reflects the specific characteristics of different combustion processes and the emission limits that can be realistically achieved by them. An example from the WB IFC EHS Guidelines is presented in Figure 15.

**Figure 15: Applicability of the limit example**

| Combustion Technology / Fuel | Particulate Matter (PM) | | Sulfur Dioxide ($SO_2$) | | Nitrogen Oxides (NOx) | | Dry Gas, Excess $O_2$ Content (%) |
|---|---|---|---|---|---|---|---|
| Boiler | NDA | DA | NDA | DA | NDA | DA | |
| Natural Gas | N/A | N/A | N/A | N/A | 240 | 240 | 3% |
| Other Gaseous Fuels | 50 | 30 | 400 | 400 | 240 | 240 | 3% |
| Liquid Fuels (Plant >50 MWth to <600 MWth) | 50 | 30 | 900 – 1,500[a] | 400 | 400 | 200 | 3% |
| Liquid Fuels (Plant >/=600 MWth) | 50 | 30 | 200 – 850[b] | 200 | 400 | 200 | 3% |
| Solid Fuels (Plant >50 MWth to <600 MWth) | 50 | 30 | 900 – 1,500[a] | 400 | 510[c] Or up to 1,100 if volatile matter of fuel < 10% | 200 | 6% |
| Solid Fuels (Plant >/=600 MWth) | 50 | 30 | 200 – 850[b] | 200 | | | 6% |

Source: World Bank/IFC Groups EHS Guidelines Thermal Power Plants[89] DA = degraded airshed, NDA = Non degraded airshed

### Whether the specified limit can be deviated from in special circumstances

In order to allow for special circumstances, some legislation allows for plants to be required to meet more stringent limits than those specified, or allowed to meet less stringent limits. More stringent limits can be required where existing ambient air quality concentrations are particularly

[88] European Commission (2010), Industrial Emiissions Direcrtive 2010/75/EU

[89] World Bank/IFC Group (2008) Environmental, Health and Safety Guidelines Thermal Power Plants

high; for example, the World Bank/IFC EHS Guidelines specify limits for 'degraded'[90] and 'non-degraded' airsheds, but also allow more or less stringent limits to be applied subject to the outcomes of the environmental assessment carried out for the plant in question.

Similarly, UK legislation assumes the application of European Union (EU) emission limits to combustion activities (which are considered to represent 'best available technique') but may require more stringent emission limits to be applied through the permitting process if EU ambient air quality standards are already being exceeded in the airshed.

Furthermore, it is common to include a caveat which notes that the limits should only apply during 'normal' operation; e.g. not during start-up or shutdown. This may be expressed as a percentage of full load output (often standards are only guaranteed by equipment manufacturers when the equipment is operating at 50% or 60% of full load or above).

### 4.4.2 Review of other national and international emission limits

**Overview**

Appendix B presents details of international emission limits which have been reviewed. The following sub-sections provide an analysis of the range of standards found for each pollutant and applies to new dedicated power generation plants only.

The majority of emission limits are only applicable to large combustion plants above 50MWth. The following sections and recommendations apply to plants of 50MWth input and above which may be built in the future as demand for electricity in Rwanda increases. Although many of Rwanda's existing thermal plants are less than 50MWth, emission limits for plants less than 50MWth are not common in other countries so are not considered necessary for Rwanda at this stage due to the high potential costs associated with meeting such limits. New plants less than 50MWth should have modelling undertaken to demonstrate that the plant does not result in significant impacts on ground level concentrations of pollutants.

Before the standards recommended here are implemented they should be subject to further scrutiny, including a cost benefit analysis. Recommendations made below are intended to allow for a range of potential primary and secondary abatement measures whilst still achieving a level of environmental protection, based on a review of international limits. It should also be noted that any new power plant would be subject to an EIA and modelling would have to be undertaken to demonstrate that the design of the plant is sufficient to not result in significant impacts on ground level pollutant concentrations.

**Sulphur dioxide ($SO_2$)**

$SO_2$ emission limits for new plants (or unspecified) range from 136mg/Nm$^3$ to 2000mg/Nm$^3$. Many of the limits for $SO_2$ do not differentiate between different plant capacities; those that do generally apply more stringent concentrations. Some countries apply a linear decrease with increasing plant capacity. The current WB/IFC guidelines provide a wide range of potential emission limits and note that the applicable limit for a given plant should be established on a case by case basis determined by individual environmental assessment considering the project's sustainability, development impact, and cost-benefit of the pollution control performance.

[90] 'Degraded Airsheds' are defined by the World Bank/IFC as those where nationally legislated standards are exceeded, or in their absence, if WHO Air Quality Guidelines are exceeded significantly

Differentiation is also made between some of the standards for emission limits applicable to certain combustion types, such as fluidised bed boilers, which is due to the different technical options available for desulphurisation.

The current Rwanda $SO_2$ standards specify different emission limits according to fuel types and thermal output. While some of these limits are lower than the WB/IFC limits for non-degraded airsheds, some are greater depending on the plant type. It is recommended that the Rwandan standards are brought in line with the WB/IFC limits for $SO_2$ for non-degraded airsheds, specifically with regard to differentiating emission limits between plant types. Relative to other international emission limits, the WB/IFC limit range is relatively high, allowing for achievable standards without entailing excessive cost. In addition, the majority of Rwanda is likely to be considered 'non-degraded' with respect to $SO_2$ concentrations.

**Nitrogen oxides ($NO_x$)**

$NO_x$ emission limits for new plants (or unspecified) range from 136mg/Nm$^3$ to 1500mg/Nm$^3$. Very few of the limits for $NO_x$ differentiate between different plant capacities.

The Rwandan NOx emission standards only provide standards for solid and liquid fuels. Again, there is no differentiation between plant type so the limits are much high than the WB/IFC emissions for boiler and turbine but lower for engines. It is recommended that the Rwandan standards are brought in line with the WB/IFC limits for non-degraded airsheds, which should allow for achievable standards without entailing excessive cost. In addition, the majority of Rwanda is likely to have relatively low NOx concentrations so non-degraded airshed limits are considered appropriate.

**Carbon monoxide (CO)**

Of the emission standards reviewed, only six contained emission limits relating to CO and, of those, most were directed toward older plants or were established in older legislation.

CO is a product of poor combustion efficiency and it is therefore in operators' interests to keep CO emissions to a minimum. In addition, ambient air quality standards for CO are generally very high compared to other pollutants reflecting the higher atmospheric levels that must be present before health effects are felt. It is likely that these are the reasons why CO emission limits are rare, particularly in new legislation or those standards which are applicable to new plants.

On the basis of the above, the current CO emission limit within Rwanda is considered unnecessary.

**Particulates**

Particulate emission limits for new plants (or unspecified) range widely from 10mg/Nm$^3$ to 250mg/Nm$^3$. Very few of the limits for particulates differentiate between different plant capacities.

Given the range of particulate limits found, and the uncertainty over abatement capabilities of future plants, we recommend that the WB/IFC approach is applied in Rwanda. The WB/IFC limits are in line with the particulate emission standards in other countries. As described in Section 2.5, monitored particulate concentrations in Rwanda can be very high, especially in urban areas. It is recommended that both the non-degraded and degraded emissions standards are used in Rwanda. Emission limits that a plant should comply with should be reviewed on a case by case basis in the EIA process, with plants that are in locations where ambient concentrations are above safe levels being required to comply with more stringent emission limits.

Suggested revised emissions limits for implementation in Rwanda based in the review above are proposed as part of the air quality strategy and presented in chapter 9.

## 4.5 Review of air quality strategy measures from other countries

### 4.5.1 United Kingdom

**Overview**

In the UK exceedance of air quality standards is predominantly experienced at locations close to busy roads in urban areas. The UK plan for tackling roadside nitrogen dioxide concentrations was released in July 2017[91]. The purpose of this plan is to reduce nitrogen dioxide ($NO_2$) levels to within statutory limits in the shortest time possible.

The plan sets out actions, the lead body responsible for action implementation, partners involved with the actions and timescales for achieving them. There are multiple measures proposed within the plan, however many can be grouped into similar overarching topics which are discussed in the following sections.

**Electric and hydrogen vehicles**

The UK government want to fund and increase the uptake of vehicles fuelled by alternative sources other than petrol and diesel, such as electricity and hydrogen. This increased funding has the aim of delivering the infrastructure required for the increased uptake of the vehicles, such as electric charging points and hydrogen refuelling stations. Uptake of electric vehicles is also to be encouraged for taxi drivers with grants to provide savings when switching to electric vehicles. There will also be new legislation passed in the form of the Automated and Electric Vehicles Bill to allow regulatory changes to encourage the uptake of electric and hydrogen vehicles. Regulatory changes are also sought to support the uptake of alternatively fuelled light commercial vehicles.

**Emissions testing**

Other regulatory changes include changes in emissions testing to reflect real driving conditions for light passenger and commercial vehicles as well as more stringent laboratory requirements for type approval of new vehicles. These changes are aimed at making sure new vehicles meet prescribed performance standards in real world driving conditions.

**Heavy duty vehicles**

There will be new funding to increase the uptake of low emission buses along with additional funding for retrofitting older buses with abatement technologies under a new accreditation scheme. There will be regulatory changes to support the uptake of alternatively fuelled light commercial vehicles and support has been pledged for the development and deployment of low emission freight vehicles.

**Taxes and levies**

The government has started to look into taxes and levies on diesel vehicles and heavy goods vehicles in the hope of encouraging road users to move to vehicles with improved environmental performances. There have also been calls for evidence to investigate a new

[91] Department for Environment, Food and Rural Affairs & Department for Transport (2017) 'UK plan for tackling roadside nitrogen dioxide concentrations – Detailed plan'

aviation strategy and the use of red diesel (red diesel used in agricultural and off-road construction plant has a lower level of duty applied than standard road diesel (Derv)).

**Local government and low emission zones**

Central government has passed the responsibility for deciding what specific actions to take to improve air quality to local government. Local government are encouraged to consider a wide range of options but are told their plans to combat roadside $NO_2$ concentrations could include:

a. Changing road layouts at congestion and air pollution pinch points.
b. Encouraging public and private uptake of ultra-low emission vehicles.
c. Using innovative retrofitting technologies and new fuels.
d. Encouraging use of public transport.

Local government can implement clean air zones to address air quality issues, these can either be non-charging where a geographical area is used to focus actions to improve air quality or charging where, in addition to the above, vehicles that do not meet certain emission limits are charged to enter. The Mayor of London is looking to launch an ultra-low emission zone (ULEZ) by April 2019 and extend it London wide to limit HGVs, buses and coaches that do not adhere to certain emission standards in the future.

**Raising awareness**

Along with specific regulatory changes and funding, the UK government wants to raise public awareness relating to air pollution. The use of social and other media to communicate real time and forecast air pollution data is one method to be employed. Text messaging services are also being employed to inform vulnerable people about air pollution levels within their area.

### 4.5.2 France

**Overview**

The National Plan for Reduction of Emissions of Air Pollutants (PREPA)[92] was adopted on 10 May 2017[93], this plan is to ensure there are no exceedances of limit values and mobilise and engage regional and local authorities.

The main aims of French policies to improve air quality are to:

- Promote research in the area and assess and understand problems
- Act from the international level down to local
- Promote an integrated approach through actions in all emitting sectors (greenhouse gases and atmospheric pollutants)
- Reduce frequency and intensity of air pollution episodes as well as reducing background pollution
- Engage the public along with regional and local authorities

France is looking to engage national, regional and local authorities to combat air pollution. National policies and regulations for a number of sectors are to be put in place. The plan is said to have an important role in territorial planning, urban planning and clean mobility. The plan promotes emissions reductions and public exposure to pollutants. Policies within PREPA are

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[92] Ministry of Ecological and Solidarity Transition (2017) 'National Plan for reduction of Emissions of Air Pollutants (PREPA)'

[93] Ministry of Ecological and Solidarity Transition (2017) 'Public policies to reduce air pollution', available at: https://www.ecologique-solidaire.gouv.fr/politiques-publiques-reduire-pollution-lair

split by industry, the following sections discuss measures relating to road and other transport in detail before briefly looking at other sectors[94].

**PREPA: Road and other transport**

PREPA aims to promote and support behaviour changes. Travel plans have been made mandatory for all enterprises and public administrations with more than 100 employees. The government has provided grants for bicycle schemes and is encouraging car sharing and public transport.

The plan also promotes emissions reductions and the promotion of low emission vehicles; policies to achieve this are:

- Speed reductions on large roads in urban areas.
- Grants for conversion of old vehicles to cleaner fuels and for purchasing electric vehicles.
- Grants for electric charging points.
- Developing a CRIT'AIR label system for cars that characterises a car on its emissions and is mandatory for some areas. These labels are to be used to limit movements of polluting vehicles during episodes of air pollution and for use in low emission zones.
- Promote further implementation of low emission zones.

The plan also includes measures for the reduction of emissions from trains, aeroplanes and boats. These include development of electric charging at ports and the use of natural gas for inland water way and maritime transport. The plan also looks to assess the feasibility of a low emission zone for $NO_x$ and $SO_2$ in the Mediterranean Sea.

**PREPA: Housing, industry and agriculture**

The main aim of PREPA on housing is to reduce emissions from combustion of wood and green wastes, this is to be done through replacing old appliances, increasing awareness and better communication with the public.

For emissions from industry, compliance with the European Industrial Emission Directive (2010/75/EU) through implementation of best available techniques (BATs) is prescribed with a focus on regular plant inspections and financial support.

PREPA aims to promote changes in practice within agriculture to limit emissions and ensure farmers are compliant with European regulation.

**Regional and local levels**

As with the UK, regional and local measures will be produced by the areas local authorities, plans to be produced will look to monitor regional mobility, urban development and traffic management.

[94] Information taken from presentation by Nadine Allemand, deputy director of the Interproffesional Technical Centre for Air Pollution Studies (CITEPA) given at Route to Clean Air Conference in Birmingham, UK in November 2017.

### 4.5.3 China

**Overview**

In China the Action Plan for Air Pollution Prevention and Control (2013)[95] [96] set out the plan to reduce levels of pollution in the in the air between 2013 – 2017 and specifically focused on $PM_{10}$ and $PM_{2.5}$. The following sections set out objectives and policy proposals set out within the plan.

**Plan objectives**

The plan included a number of objectives to reduce the concentrations of pollutants by 2017. The objectives of the plan were to:

- Guarantee public health
- Combine government control and market regulation
- Promote cross-area cooperation and local management
- Improved industrial strategies
- Reduction and improvements
- Conduct tailored and phased management
- Achieve environmental, economic and social benefits

**Policies to achieve objectives**

In order to achieve the planned objectives ten policy areas where identified and these are set out within the action plan. These were:

1. Increase the effort of comprehensive control and reduce emissions of air pollutants
2. Optimise the industrial structure and promote industrial restructure
3. Accelerate the technology transformation and improve innovation capability
4. Increase clean energy supply
5. Strengthen the environmental thresholds and optimise industrial layout
6. Better play the role of market mechanism and improve environmental economic policies
7. Improve law and regulation system. Carry out monitoring based on regulations
8. Create regional environmental management and coordination mechanisms
9. Create air pollution monitoring and warning systems to better cope with air pollution episodes
10. Increase public participation along with clarifying responsibilities of society, government and business

The plan included laws that were to be introduced to set out and revise the air emission standards for vehicles and industry and set new fuel quality standards. The plan set out that a national air quality monitoring system would be introduced consisting of city stations, regional stations and background stations which would monitoring air quality.

One of the main areas included was overall policy and tightening of environmental requirements within industry. As a result, taxes and levies were introduced with a shift towards the polluter pays principle.

Specific policies to reduce emissions were set out within the plan. A shift from small scale coal fired boilers, replacing them with gas and electricity as well as widescale introduction of

[95] Chinese State Council (2013) 'Action Plan for Air Pollution Prevention and Control'. English translation available at: http://www.sustainabletransport.org/wp-content/uploads/2017/08/National-Action-Plan-of-Air-Pollution-Control.pdf

[96] Jin, Y. Andersson, H. Zhang, S. (2016) 'Air pollution control policies in China: A retrospective and prospects' *International Journal of Environmental Research and Public Health*, 13.

abatement policies for desulphurisation, denitrification and dust control was promoted. A policy to move away from large scale coal power generation was also included.

The plan also introduced a requirement for environmental impact assessment (EIA) to be mandatory for new projects within some industries. The plan specified that areas of China identified with high pollution levels required new projects to deliver energy savings and increased environmental performance than would be required elsewhere in the country with lower pollution levels.

The plan also included the requirement for stronger collaboration between government departments, between central and local governments and between government and non-government bodies. The plan clearly sets out that air pollution was a problem of society and not just central government. Local government were assigned targets and responsibilities for air quality so they were aware of what was required of them. The plan is also to encourage and increase public participation with air quality.

Many policies set out within the plan included environmental aspects beyond air quality.

# 5 Identification of the main sources of pollution In Kigali

## 5.1 Overview

This section provides analysis on the main contributors to air pollution within Rwanda with a focus on Kigali, and summarises the main types of pollutants emitted from each sector. Analysis has been undertaken on the following sectors:

- Emissions from road traffic
- Emissions from power generation
- Emissions from industrial sources
- Emissions from domestic sources

### 5.1.1 Limitations

This study does not provide details of mass emissions of each pollutant from the four sectors named above because the necessary data was not available. However, where possible the study has quantified emissions from the power generation sector based on reasoned assumptions and internationally recognised emission factors. In addition, emission calculations related to road traffic have been presented based on percentage contributions of the types and the age of vehicles to demonstrate which ones have the biggest impact on air quality, and to demonstrated how policy interventions could reduce the mass emissions of pollutants released. The report provides a qualitative commentary on emissions related to industrial and domestic sources based on existing literature that is available.

To establish more detailed mass emissions for each of the sectors, information required includes: miles travelled by the national vehicle fleet broken down according to engine and fuel types; operating philosophy, hours of operation and loading of thermal power plants; fuel type, combustion process details and hours of operation of industrial processes; and domestic fuel types and quantities consumed.

Recommendations are made in chapter 10 about improving the detail of the emissions inventory by future detailed data gathering.

## 5.2 Road traffic emissions

### 5.2.1 Overview

Emissions to air from road traffic is a major contributor to poor air quality across many urban environments across the globe.

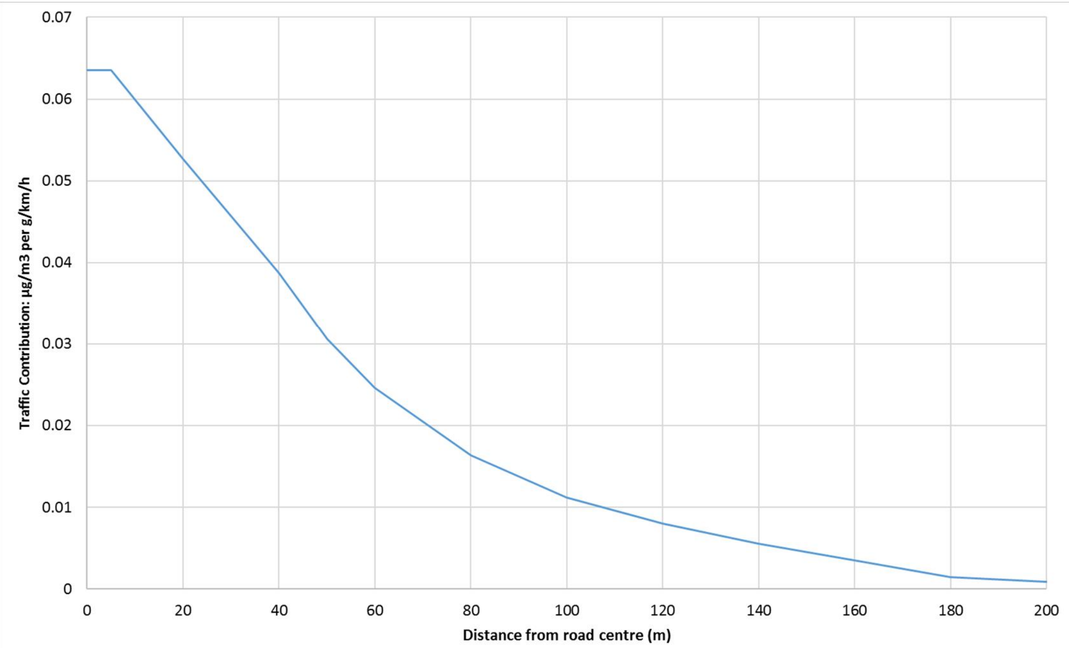
Emissions from cars that affect local air quality include:

- $NO_x$
- $PM_{10}$ and $PM_{2.5}$
- CO
- Unburnt hydrocarbons

### 5.2.2 Distance from the road

Roadside receptors near busy roads are those that can often experience the highest ambient pollutant concentrations. Guidance produced for assessing impacts of road scheme developments In the UK provides advice on how pollutant concentrations are likely to be affected by traffic sources and the distance to the road. Figure 16 presents a graph which shows the calculated falloff of emissions from road traffic and distance from the road. The graph illustrates that the highest concentrations are experienced very close to the road and drop off rapidly in the first 30 metres where they are approximately half of the roadside concentration. Beyond 100 metres from the roadside the traffic contribution to pollutant levels is minimal and there is a negligible contribution at distances beyond 200 metres from the road. The same changes in concentrations would also be expected in Rwanda and impacts from road traffic on air quality mainly affect receptors located in close proximity to roads.

**Figure 16: Traffic contribution to concentration at difference distances from the road centre line**




Source: Mott MacDonald produced from Highways Agency, 2007, Design Manual for Roads and Bridges, Volume 11, Section 3

### 5.2.3 Fleet breakdown

Table 16 presents the current number of registered vehicles in Rwanda and is split by period of registration. The data was provided during consultation with the Rwanda Revenue Authority in September 2017. Figure 17 shows that the majority of registered vehicles in the 'Up to 1999' range are cars and that in subsequent registered periods the number of cars registered reduces.

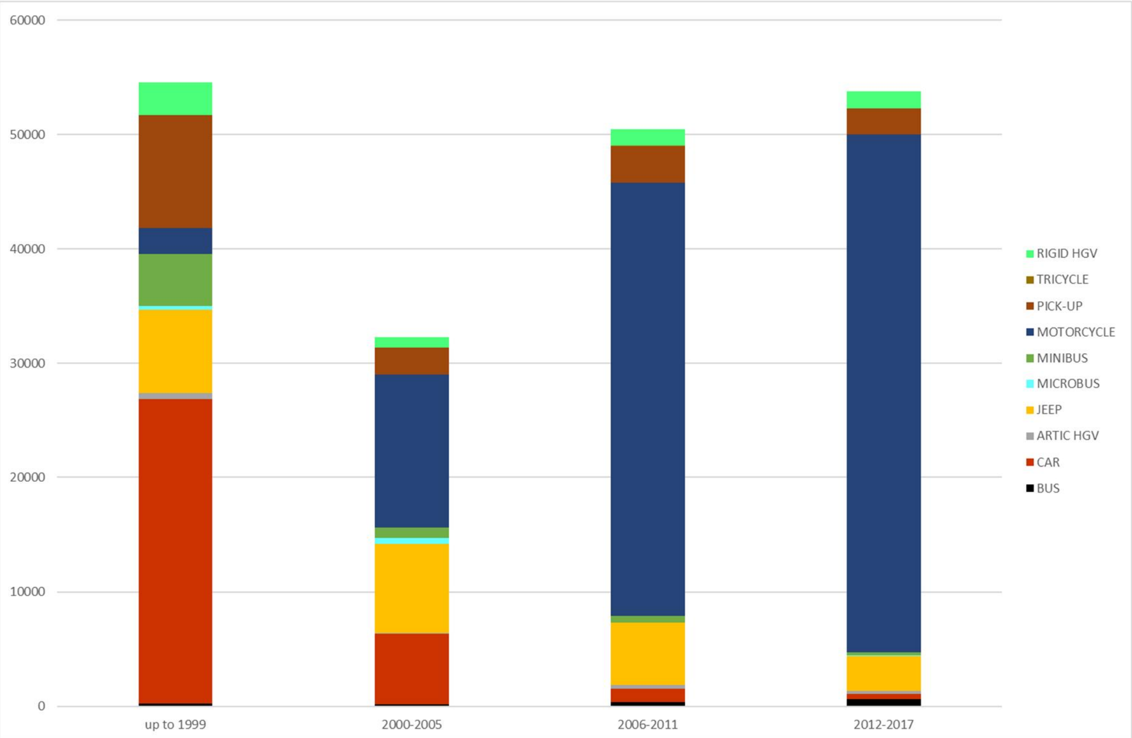
The data illustrates that the fleet of registered motorcycles is becoming more modern with the highest number of registered motorcycles being in the 2012-2017 period. The data shows that the Rwanda policy related to the import of motorcycles had a positive effect on the age of the fleet and provides direct evidence that policy interventions such as this have a positive effect on air quality.

**Table 16: Number and year of registration of vehicles in Rwanda**

| Vehicle type | Up to 1999 | 2000-2005 | 2006-2011 | 2012-2017 | Total |
|---|---|---|---|---|---|
| Bus | 232 | 155 | 398 | 623 | 1,408 |
| Car | 26,590 | 6,165 | 1,130 | 493 | 34,378 |
| Artic HGV | 516 | 107 | 343 | 204 | 1,170 |
| Jeep | 7,365 | 7,780 | 5,439 | 3,089 | 23,673 |
| Microbus | 297 | 512 | 36 | 22 | 867 |
| Minibus | 4,572 | 906 | 562 | 285 | 6,325 |
| Motorcycle | 2,284 | 13,357 | 37,905 | 45,261 | 98,807 |
| Pick-up | 9,858 | 2,411 | 3,152 | 2,282 | 17,703 |
| Tricycle | 0 | 0 | 60 | 13 | 73 |
| Rigid HGV | 2,853 | 872 | 1,404 | 1,482 | 6,611 |
| Total | 54,567 | 32,265 | 50,429 | 53,754 | 191,015 |
| Percentage | 28.6% | 16.9% | 26.4% | 28.1% | |

Source: Rwanda Revenue Authority, Notes: HGV = Heavy Goods Vehicle, Artic HGV = articulated Heavy Goods Vehicle and is equivalent to a 'half-trailer' and 'trailer'. Rigid HGV is equivalent to a 'truck'.

**Figure 17: Number of vehicles by period of registration**



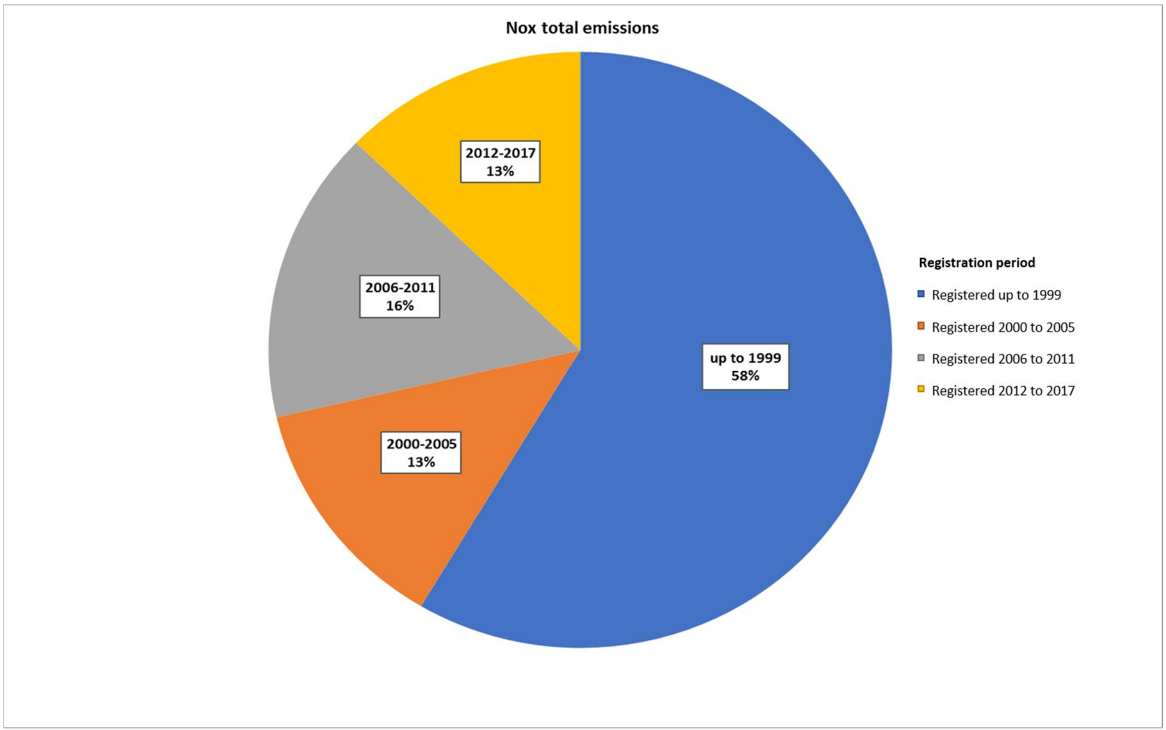

Source: Mott MacDonald based on data from Rwanda Revenue Authority, Note: Tricycles do not appear as numbers are too few

Figure 18 presents the percentage of total $NO_x$ emissions by period of vehicle registration. The data shows that based on the assumptions which are presented below, more than half of the $NO_x$ emission are as a result of vehicles registered before 1999 which account for only 28.6% of total registered vehicles.

The United Kingdom's Department for Environment, Food and Rural Affairs Emission Factor Toolkit (EFT version 7) was used to calculate $NO_x$ and $PM_{10}$ emissions rates associated with the Rwandan vehicle fleet. The EFT uses the European Vehicle Emission Limits to calculate emission rates from different types of vehicle and for different ages. Although not designed for use specifically in Rwanda, the analysis using the toolkit has been undertaken on percentage difference rather than absolute emissions and therefore it is considered appropriate as it demonstrates the improvements in emissions that newer vehicles achieve.

Table 17 and Table 18 present the assumptions used within the EFT to calculate total vehicle emissions in Rwanda. Appendix C presented the emission factors used within the calculations for the different types of vehicles.

**Figure 18: Percentage of total NOx emissions by period of registration**




Source: Mott MacDonald based on data from Rwanda Revenue Authority

**Table 17: Comparison between Rwandan fleet breakdown and EFT vehicle types**

| Rwandan fleet vehicle type | EFT vehicle type |
|---|---|
| Bus | Bus and Coach |
| Car | Car (petrol and diesel combined) |
| Half Trailer / Trailer | Articulated HGV |
| Jeep | Car (petrol only for pre-2005 vehicles, petrol and diesel combined for 2006 onwards) |
| Microbus | Diesel Car |
| Minibus | Diesel Car |
| Motorcycle | Motorcycle |
| Pick-up | LGV |

| Rwandan fleet vehicle type | EFT vehicle type |
|---|---|
| Tricycle | Motorcycle |
| Truck | Rigid HGV |

**Table 18: Euro vehicle emissions standard applied to age range of Rwanda vehicles**

| Vehicle Age | Euro Standard applied |
|---|---|
| Up to 1999 | Pre Euro 1 / I |
| 2000-2005 | Average of Euro 1/I, Euro 2/II and Euro 3 / III |
| 2006-2011 | Euro 4 / IV |
| 2012-2017 | Euro 5 / V |

Note: Arabic numerals (e.g. 1, 2, 3) represent light duty vehicles such as cars and motorcycles. Roman numerals represent (e.g. I, II, III) heavy duty vehicles (e.g. articulated HGVs)

Figure 19 presents the percentage of $NO_x$ emissions for each vehicle type by period of registration. It also provides the number of vehicles registered in each period to show which vehicles are having the greatest contribution to total emissions from road traffic.

The data shows that the oldest registered cars, articulated (artic) HGV's, Jeeps, minibus, pick-ups and rigid HGVs contributed more than 50% of the total emissions from these classifications. Only emissions for motorcycles and tricycles have the smallest percentage of emissions contributions from vehicles registered before 1999 which is a reflection of low numbers of older motorcycles being registered due to current legislation.

The same emissions profile is also present when looking at emissions of particulate matter. Graphs for particulate matter are presented in Appendix D.

Older vehicles emit higher levels of $NO_x$ and $PM_{10}$ compared to new more modern vehicles. As newer vehicles are imported into Rwanda they meet tighter emission controls depending on where they have been imported from. For example, in the EU there are European Emission Standards for cars, light commercial vehicles and HGVs. This ensures newer vehicles meet more stringent emission performance. Table 19 and Table 20 present the applicable emission standards and the year they became applicable for reference showing the improvements over time for each specific vehicle category.

**Table 19: Euro emission standards for passenger cars and light commercial vehicles**

| | | Emission limits (g/km) | | | | | |
|---|---|---|---|---|---|---|---|
| Euro standard | Date | Carbon monoxide (CO) | Hydrocarbon (THC) | Non-methane hydrocarbon (NMHC) | Nitrogen oxides (NOx) | Hydrocarbon + nitrogen oxides (HC+NOx) | Particulate Matter (PM) |
| **Diesel passenger car** | | | | | | | |
| Euro 1 | July 1992 | 2.72 | | | | 0.97 | 0.14 |
| Euro 2 | January 1996 | 1.00 | | | | 0.7 | |
| Euro 3 | January 2000 | 0.66 | | | 0.50 | 0.56 | |
| Euro 4 | January 2005 | 0.50 | | | 0.25 | 0.30 | |
| Euro 5 | January 2011 | 0.50 | | | 0.18 | 0.230 | |

| | | | | Emission limits (g/km) | | | |
|---|---|---|---|---|---|---|---|
| Euro 6 | September 2014 | 0.50 | | | 0.08 | 0.170 | |
| **Petrol passenger car** | | | | | | | |
| Euro 1 | July 1992 | 2.72 | | | | 0.97 | |
| Euro 2 | January 1996 | 2.20 | | | | 0.50 | |
| Euro 3 | January 2000 | 2.30 | 0.20 | | 0.15 | | |
| Euro 4 | January 2005 | 1.00 | 0.10 | | 0.08 | | |
| Euro 5 | January 2011 | 1.00 | 0.10 | 0.07 | 0.06 | | 0.01[a] |
| Euro 6 | September 2014 | 1.00 | 0.10 | 0.07 | 0.06 | | 0.01[a] |
| **Diesel light commercial vehicle ⩽ 1305kg** | | | | | | | |
| Euro 1 | October 1994 | 2.72 | | | | 0.97 | 0.14 |
| Euro 2 | January 1998 | 1.00 | | | | 0.70 | 0.08 |
| Euro 3 | January 2000 | 0.64 | | | 0.50 | 0.56 | 0.05 |
| Euro 4 | January 2005 | 0.50 | | | 0.25 | 0.30 | 0.03 |
| Euro 5 | September 2011 | 0.50 | | | 0.18 | 0.23 | 0.01 |
| Euro 6 | September 2014 | 0.50 | | | 0.08 | 0.17 | 0.01 |
| **Petrol light commercial vehicle ⩽ 1305kg** | | | | | | | |
| Euro 1 | October 1994 | 2.72 | | | | | |
| Euro 2 | January 1998 | 2.20 | | | | | |
| Euro 3 | January 2000 | 2.30 | 0.20 | | 0.15 | | |
| Euro 4 | January 2005 | 1.00 | 0.10 | | 0.08 | | |
| Euro 5 | September 2011 | 1.00 | 0.10 | 0.07 | 0.06 | 0.01[a] | |
| Euro 6 | September 2014 | 1.00 | 0.10 | 0.07 | 0.06 | 0.01[a] | |
| **Diesel light commercial vehicle 1305 - 1760kg** | | | | | | | |
| Euro 1 | October 1994 | 5.17 | | | | 1.40 | 0.19 |
| Euro 2 | January 1998 | 1.25 | | | | 1.00 | 0.12 |
| Euro 3 | January 2001 | 0.80 | | | 0.65 | 0.72 | 0.07 |
| Euro 4 | January 2006 | 0.63 | | | 0.33 | 0.39 | 0.04 |
| Euro 5 | September 2011 | 0.63 | | | 0.24 | 0.30 | 0.01 |
| Euro 6 | September 2015 | 0.63 | | | 0.11 | 0.20 | 0.01 |
| **Petrol light commercial vehicle 1305 - 1760kg** | | | | | | | |

| | | | | Emission limits (g/km) | | | |
|---|---|---|---|---|---|---|---|
| Euro 1 | October 1994 | 5.17 | | | | 1.40 | |
| Euro 2 | January 1998 | 4.00 | | | | 0.60 | |
| Euro 3 | January 2001 | 4.17 | 0.25 | | 0.18 | | |
| Euro 4 | January 2006 | 1.81 | 0.13 | | 0.10 | | |
| Euro 5 | September 2011 | 1.81 | 0.13 | 0.09 | 0.08 | | 0.01[(a)] |
| Euro 6 | September 2015 | 1.81 | 0.13 | 0.09 | 0.08 | | 0.01[(a)] |
| **Diesel light commercial vehicle 1760 - 3500kg** | | | | | | | |
| Euro 1 | October 1994 | 6.90 | | | | 1.70 | 0.25 |
| Euro 2 | January 1998 | 1.50 | | | | 1.20 | 0.17 |
| Euro 3 | January 2001 | 0.95 | | | 0.78 | 0.86 | 0.10 |
| Euro 4 | January 2006 | 0.74 | | | 0.39 | 0.46 | 0.06 |
| Euro 5 | September 2011 | 0.74 | | | 0.28 | 0.35 | 0.01 |
| Euro 6 | September 2015 | 0.74 | | | 0.13 | 0.22 | 0.01 |
| **Diesel light commercial vehicle 1760 - 3500kg** | | | | | | | |
| Euro 1 | October 1994 | 6.90 | | | | 1.7 | |
| Euro 2 | January 1998 | 5.00 | | | | 0.7 | |
| Euro 3 | January 2001 | 5.22 | 0.29 | | 0.21 | | |
| Euro 4 | January 2006 | 2.27 | 0.16 | | 0.11 | | |
| Euro 5 | September 2011 | 2.27 | 0.16 | 0.11 | 0.08 | | 0.01[(a)] |
| Euro 6 | September 2015 | 2.27 | 0.16 | 0.11 | 0.08 | | 0.01[(a)] |

Source: EU Directives: 91/441/EEC[97], 94/12/EC[98], 96/69/EC[99], 98/69/EC[100], 2002/80/EC[101], 715/2007/EC[102], 459/2012/EC[103].
[(a)]Applies only to vehicles with direct injection engines.

97 European Union (1991) 'Council Directive 91/441/EEC of 26 June 1991 amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles'.

98 European Union (1994) 'Directive 94/12/EC of the European Parliament and the Council of 23 March 1994 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Directive 70/220/EEC'.

99 European Union (1996) 'Directive 96/69/EC of the European Parliament and of the Council of 8 October 1996 amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles'

100 European Union (1998) 'Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC'.

101 European Union (2002) 'Commission Directive 2002/80/EC of 3 October 2002 adapting to technical progress Council Directive 70/220/EEC relating to measures to be taken against air pollution by emissions from motor vehicles'.

102 European Union (2007) 'Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information'.

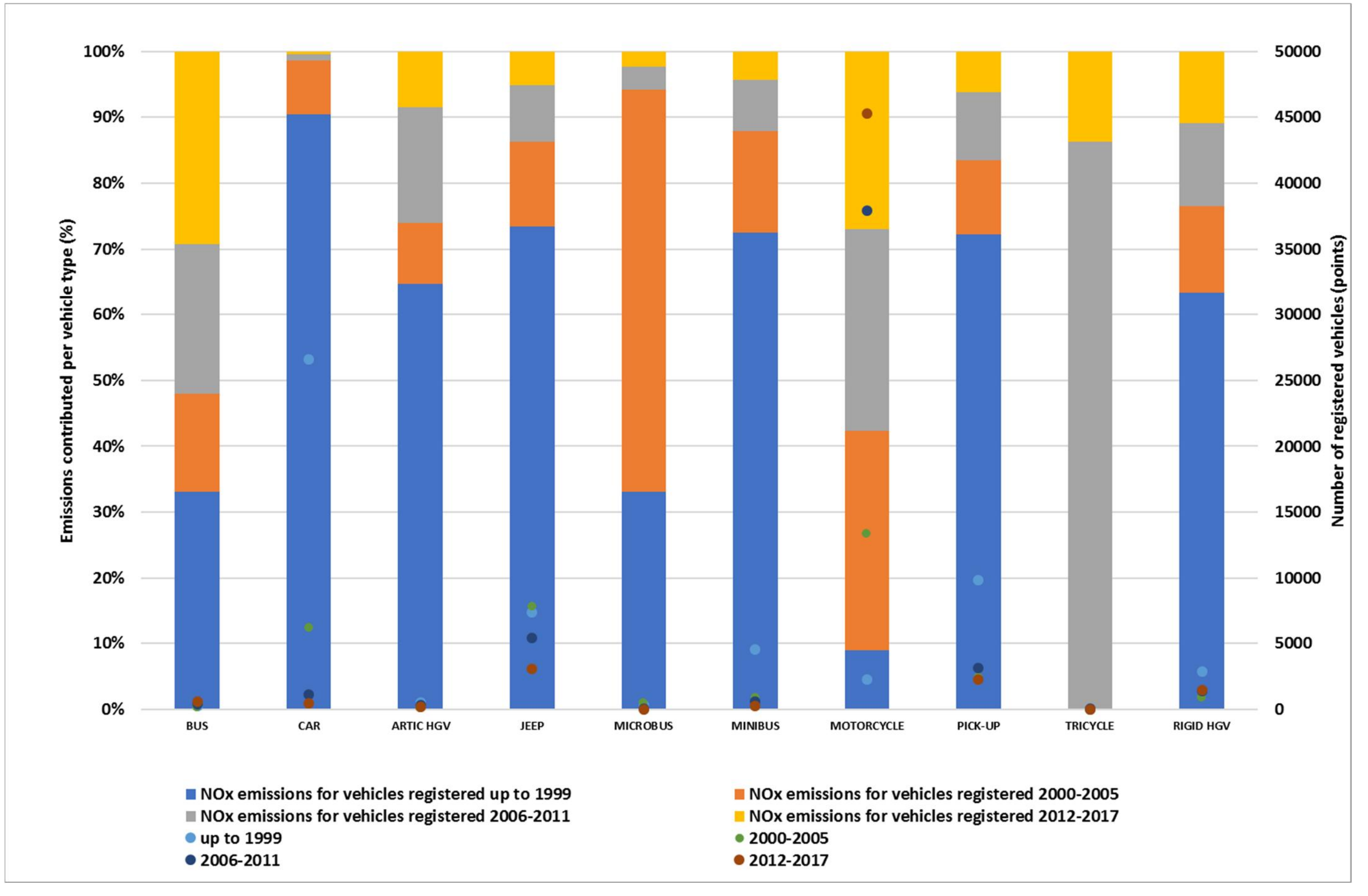
103 European Union (2012) 'Commission Regulation (EU) No 459/2012 of 29 May 2012 amending Regulation (EC) No 715/2007 of the European Parliament and of the Council and Commission Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)'.

Absence of value means no value prescribed under euro standard.

**Table 20: Euro emission standards for trucks, buses and large goods vehicles.**

| Euro standard | Date | Emission Limits (g/kWh) (smoke in $m^{-1}$) | | | | |
|---|---|---|---|---|---|---|
| | | Carbon monoxide (CO) | Hydrocarbon (HC) | Nitrogen oxides ($NO_x$) | Particulate matter (PM) | Smoke |
| **Trucks and buses – HD diesel engines** | | | | | | |
| Euro I | 1992 | 4.50 | 1.10 | 8.00 | 0.36 | |
| Euro II | October 1998 | 4.00 | 1.10 | 7.00 | 0.15 | |
| Euro III | October 2000 | 2.10 | 0.66 | 5.00 | 0.10 | 0.80 |
| Euro IV | October 2005 | 1.50 | 0.46 | 3.50 | 0.02 | 0.50 |
| Euro V | October 2008 | 1.50 | 0.46 | 2.00 | 0.02 | 0.50 |
| Euro VI | December 2013 | 1.50 | 0.13 | 0.40 | 0.01 | |
| **Large goods vehicles –category N3 (2000 and up)** | | | | | | |
| Euro 0 | 1988-1992 | 12.30 | 2.60 | 15.80 | | |
| Euro I | 1992-1995 | 4.90 | 1.23 | 9.00 | 0.40 | |
| Euro II | 1995-1999 | 4.00 | 1.10 | 7.00 | 0.15 | |
| Euro III | 1999-2005 | 2.10 | 0.66 | 5.00 | 0.10 | |
| Euro IV | 2005-2008 | 1.50 | 0.46 | 3.50 | 0.02 | |
| Euro V | 2008-2012 | 1.50 | 0.46 | 2.00 | 0.02 | |
| **Large goods vehicles – older ECE R49 cycle** | | | | | | |
| Euro 0 | 1988-1992 | 11.20 | 2.40 | 14.40 | | |
| Euro I | 1992-1995 | 4.50 | 1.10 | 8.00 | 0.36 | |
| Euro II | 1995-1999 | 4.00 | 1.10 | 7.00 | 0.15 | |

**Figure 19: Percentage of NOx emissions for each vehicle type by period of registration**

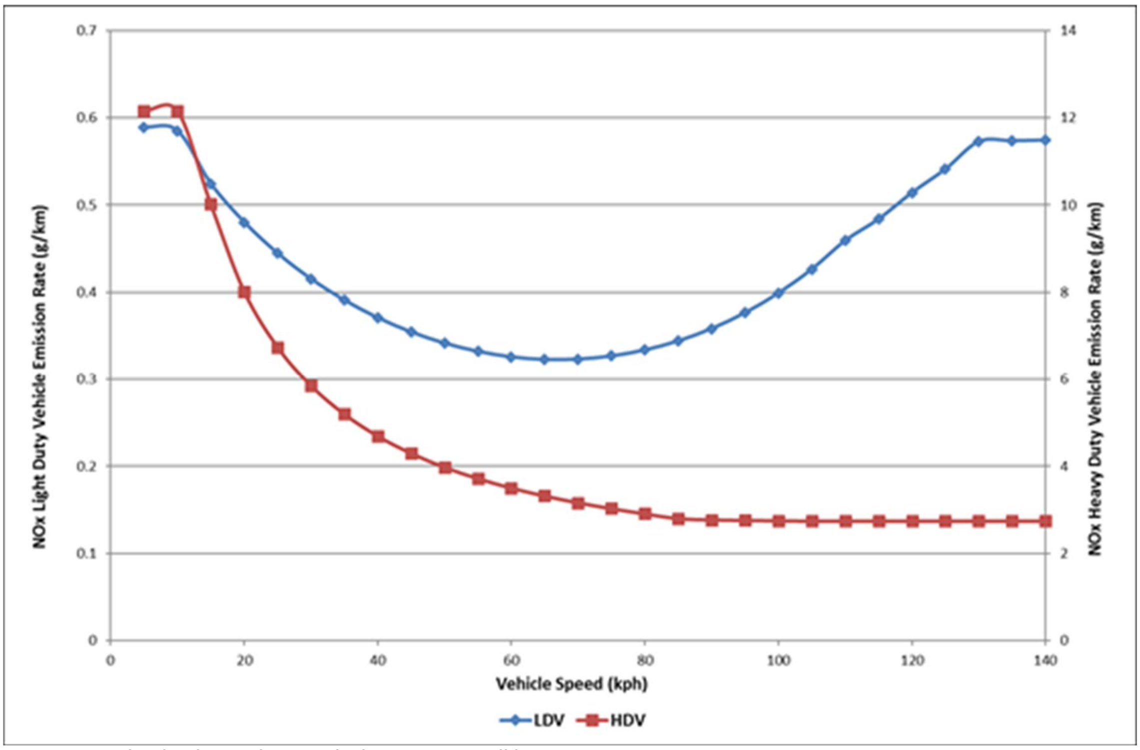



Source: Mott MacDonald based on data from Rwanda Revenue Authority

### 5.2.4 Effect of speed on emissions

Congestion within cities and the speed vehicles travel has a significant effect on emissions rates of NOx and PM. Considering the data presented in Figure 20 light duty vehicles (cars and vans less than 3.5 tonnes) (LDV) produce the least emissions at around 60 kph. Heavy duty vehicles (lorries, busses and vans above 3.5 tonnes) (HDV) produce lower emissions when travelling above 80 kph. HDV's emissions are greatest at slow speeds below 10 kph and for LDVs emissions from slow speeds are the same as high as speeds above 130 kph.

**Figure 20: Speed flow curve**

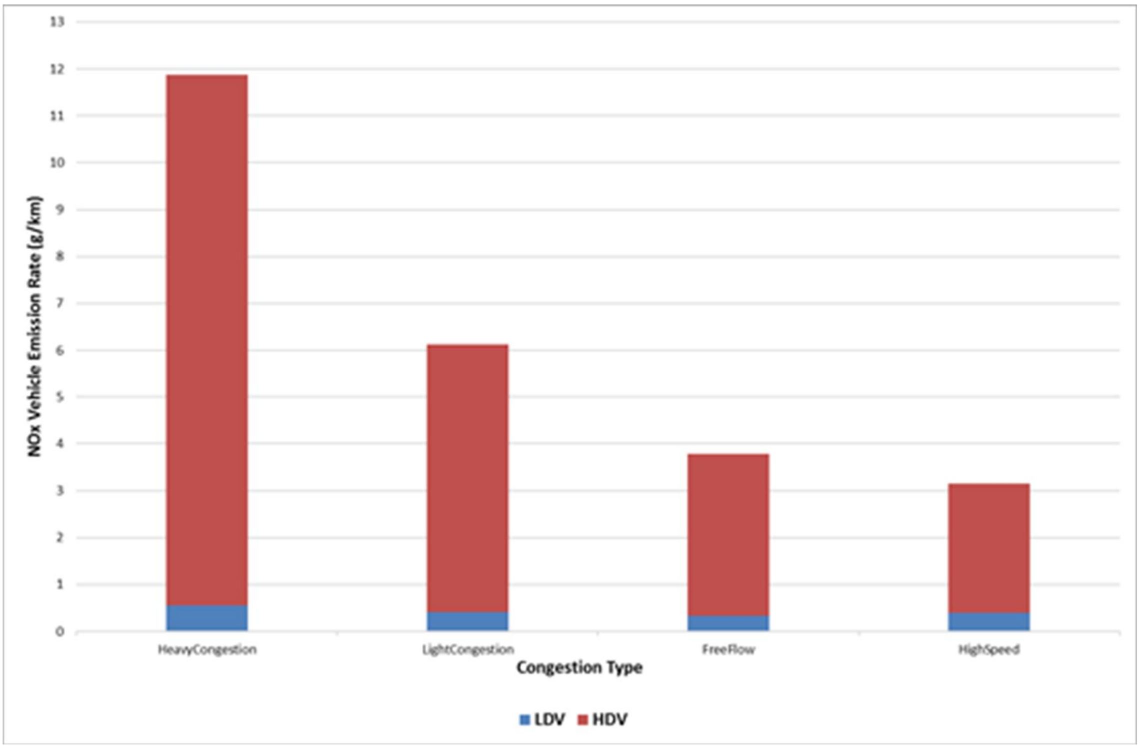



Source: Derived using Defra's Emission Factor Toolkit.

Notes: please note different scales on Light Duty and Heavy Vehicle Emission axis

Figure 21 presents emissions from vehicles when considering the level of congestion on an urban road and demonstrates that in heavily congested areas emissions are significantly higher from both LDV's and HDV's compared to non-congested areas. Although data has only been presented for emissions of NOx the same trends occur for emissions of $PM_{10}$.

**Figure 21: Congestion emissions**




Source: Highways England

## 5.3 Emissions from power generation

### 5.3.1 Overview

Data was obtained from Rwanda Energy Group for existing power plants currently in operation or under commissioning in Rwanda. The following provides an overview of the number of power stations, their locations and an estimation of emissions.

A breakdown of the overall installed capacity by technology is presented in Table 21 while an overview of the existing operational thermal power plants is presented in Table 22. The locations of the thermal power plants are presented in Appendix E. There are no power plants located within Kigali close to residential receptors. Considering the sizes of the existing power plants it can assumed that air quality impacts would he localised do not have a significant impact on regional air quality or air quality within Kigali.

**Table 21: Split of installed capacity by technology type**

| Technology | Installed capacity (megawatts) |
|---|---|
| Thermal | 99.27 |
| Hydro | 102.59 |
| Solar | 12.08 |

Source: Rwanda Energy Group

**Table 22: Operational thermal power plants in Rwanda**

| Power plant | Fuel type | Location | Installed capacity (megawatts) | Operational mode |
|---|---|---|---|---|
| Jabana 1 | Fuel oil / Heavy fuel oil | Gasabo | 20 | Peak |
| Jabana 2 | Fuel oil / Light fuel oil | Gasabo | 7.8 | Peak |
| Mukungwa SoEnergy | Light fuel oil | Mukungwa SS | 10 | Peak |
| Ndera SoEnergy | Light fuel oil | KEZ free zone | 10 | Peak |
| Birembo SoEnergy | Light fuel oil | Birembo SS | 10 | Peak |
| KP1 | Methane gas | Rubavu | -[a] | Base |
| Kivuwatt | Methane gas | Karongi | 26.4 | Base |
| Biomass | Biomass (rice husks) | Nyagare | 0.07 | Base |
| Gishoma | Peat | Rusizi | 15 | Base |

Source: Rwanda Energy Group.
[a] Under liquidation process.

It should be noted that Rwanda also currently imports a small proportion of its electrical energy from Uganda.

### 5.3.2 Estimated emissions from thermal power plant

**Methodology - European Environment Agency Air Pollutant Emission Inventory Guidebook 2016**

The European Environment Agency (EEA) Air Pollutant Emission Inventory Guidebook (2016)[104] has been used to quantify emissions from thermal power stations within Rwanda. This document provides guidance on compiling national atmospheric emissions inventories and has been used as it is considered best practice and is referred to by the Intergovernmental Panel on Climate Change. General information on basic principles of producing emissions inventories are provided along with emissions factors and methods of how to produce one.

*Fuel emission factors*

Fuel emission factors are provided for use in compiling emissions inventories in Part B: sectoral guidance chapters, 1. Energy, 1.A Combustion, 1.A.1 Energy Industries[105] of the EEA Air Pollutant Emission Inventory Guidebook. This chapter describes the methods and provides the data required to estimate emissions in combustion and other processes involved in the conversion of fuels to produce energy.

Emissions factors are provided for different fuel types. As presented in Table 22, the types of fuels currently used in Rwanda are heavy fuel oil, light fuel oil (gas oil), methane gas (gaseous fuels), biomass and peat which has been assumed to be brown coal for the purpose of the inventory. The specific emission factors for $NO_x$, $PM_{10}$, $PM_{2.5}$, $SO_x$ and CO for these fuel types are presented in Table 27. The upper 95% confidence interval of the fuel emission factor has been selected as information on the makeup and quality of fuel being combusted in Rwanda is unknown and this provides a precautionary approach to the assessment.

104 European Environment Agency (2016) 'EMEP/EEA Air pollutant emission inventory guidebook 2016 – Technical guidance to prepare national emission inventories'.

105 European Environment Agency (2016) 'EMEP/EEA Air pollutant emission inventory guidebook 2016 – Technical guidance to prepare national emission inventories – 1.A.1 Energy Industries'.

### Table 23: Fuel emission factors

| Type of Fuel | Fuel emission factors — Pollutant (Upper 95% confidence Interval) | | | | |
|---|---|---|---|---|---|
| | $NO_2$ (g/GJ) | $PM_{10}$ (g/GJ) | $PM_{2.5}$ (g/GJ) | $SO_x$ (g/GJ) | CO (g/GJ) |
| Heavy fuel oil | 300 | 150 | 90 | 1700[a] | 21.1 |
| Gas oil | 195 | 10 | 2.5 | 465[a] | 65 |
| Gaseous fuels | 185 | 1.34 | 1.34 | 0.393 | 60 |
| Biomass | 160 | 310 | 266 | 15.1 | 180 |
| Brown coal | 571 | 79 | 32 | 5000[a] | 60.5 |

Source: Collated by European Environment Agency (2016)[105]

Notes: Upper 95% confidence limit used to give worst case scenario as fuel makeup and quality is unknown.

[a]Factor for $SO_x$ assumes no $SO_2$ abatement is installed and is based on a 1% mass sulphur content.

### Calculated emissions

Emissions for each pollutant at each thermal power station have been calculated using fuel emission factors for the specified fuel, the installed capacity at the site and the estimated hours of operation. Conservative assumptions have been made regarding the emissions factors used and hours of operation. The equation below has been used to calculate pollutant emissions which assumes that average or typical technology and abatement mechanisms are in place[105].

$E_{\text{(pollutant)}} = AR_{\text{(fuel consumption)}} \times EF_{\text{(pollutant)}}$[105].

E = Annual emission of pollutant.

AR = Activity rate by fuel consumption.

EF = Emission factor of pollutant.

Emissions for $NO_x$, $PM_{10}$, $PM_{2.5}$, $SO_x$ and CO for each thermal power station are presented in Table 24. Data is presented in tonnes of pollutant emitted. It should be noted that the emissions of $SO_x$ for heavy fuel oil, light fuel oil and peat assumes no $SO_2$ abatement is installed and is based on fuel with a 1% mass sulphur content as discussed in Table 23. The emissions have been calculated on the assumption that the baseload plant as defined in Table 22 operate for 8,000 hours per year and the peak load plants operate for 4,000 per year.

### Table 24: Thermal power generation station by station emissions

| Power plant | Fuel type | Installed capacity (megawatts) | $NO_x$ (tonnes) | $PM_{10}$ (tonnes) | $PM_{2.5}$ (tonnes) | $SO_x$ (tonnes) | CO (tonnes) |
|---|---|---|---|---|---|---|---|
| Jabana 1 | Light Fuel Oil (LFO) | 7.8 | 21.73 | 1.11 | 0.28 | 51.81 | 7.24 |
| Jabana 2 | Heavy Fuel Oil (HFO) | 20 | 85.71 | 42.86 | 25.71 | 485.71 | 6.03 |
| Mukungwa SoEnergy | LFO | 10 | 27.86 | 1.43 | 0.36 | 66.43 | 9.29 |
| Ndera SoEnergy | LFO | 10 | 27.86 | 1.43 | 0.36 | 66.43 | 9.29 |
| Birembo SoEnergy | LFO | 10 | 27.86 | 1.43 | 0.36 | 66.43 | 9.29 |
| Kivuwatt Phase I | Methane gas | 26.4 | 152.80 | 1.11 | 1.11 | 0.32 | 49.56 |

| Power plant | Fuel type | Installed capacity (megawatts) | $NO_x$ (tonnes) | $PM_{10}$ (tonnes) | $PM_{2.5}$ (tonnes) | $SO_x$ (tonnes) | CO (tonnes) |
|---|---|---|---|---|---|---|---|
| Biomass | Biomass (Rice Husks) | 0.07 | 0.03 | 0.05 | 0.05 | 0.00 | 0.03 |
| Gishoma | Peat | 15 | 267.96 | 37.07 | 15.02 | 2346.43 | 28.39 |

Source: Based on data supplied by Rwanda Energy Group and calculated using methodologies and fuel emissions factors within EMEP/EEA Air pollutant emission inventory guidebook 2016[105].

The overall estimated emissions of $NO_x$, $PM_{10}$, $PM_{2.5}$, $SO_x$ and CO for all thermal power stations are presented in Table 25. $SO_x$ has the largest proportion of overall emissions followed by $NO_x$.

**Table 25: Thermal power generation overall station emissions**

| | Thermal power plant emissions | | | | |
|---|---|---|---|---|---|
| | $NO_x$ (tonnes) | $PM_{10}$ (tonnes) | $PM_{2.5}$ (tonnes) | $SO_x$ (tonnes) | CO (tonnes) |
| Total emissions | 611.80 | 86.49 | 43.23 | 3083.57 | 119.11 |

Table 26, Figure 22 and Figure 23 present a breakdown of the estimated emissions of $NO_x$, $PM_{10}$, $PM_{2.5}$, $SO_x$ and CO on a per MW and per fuel basis. Emissions of $SO_x$ are the highest on a per MW basis and are mainly emitted by the combustion of peat. Methane gas is the cleanest fuel. The breakdown of emissions was based on the data calculated emissions presented in Table 24 and installed capacity of each of the power plants.

**Table 26: Thermal power generation overall station emissions per MW of installed capacity**

| | Thermal power plant emissions | | | | |
|---|---|---|---|---|---|
| | $NO_x$ (tonnes per MW) | $PM_{10}$ (tonnes per MW) | $PM_{2.5}$ (tonnes per MW) | $SO_x$ (tonnes per MW) | CO (tonnes per MW) |
| Total installed capacity | 6.16 | 0.87 | 0.44 | 31.06 | 1.20 |
| LFO | 2.79 | 0.14 | 0.04 | 6.64 | 0.93 |
| HFO | 4.29 | 2.14 | 1.29 | 24.29 | 0.30 |
| Methane gas | 5.79 | 0.04 | 0.04 | 0.01 | 1.88 |
| Biomass | 0.39 | 0.76 | 0.65 | 0.04 | 0.44 |
| Peat | 17.86 | 2.47 | 1.00 | 156.43 | 1.89 |

**Figure 22: Total thermal power generation station emissions per MW of installed capacity**

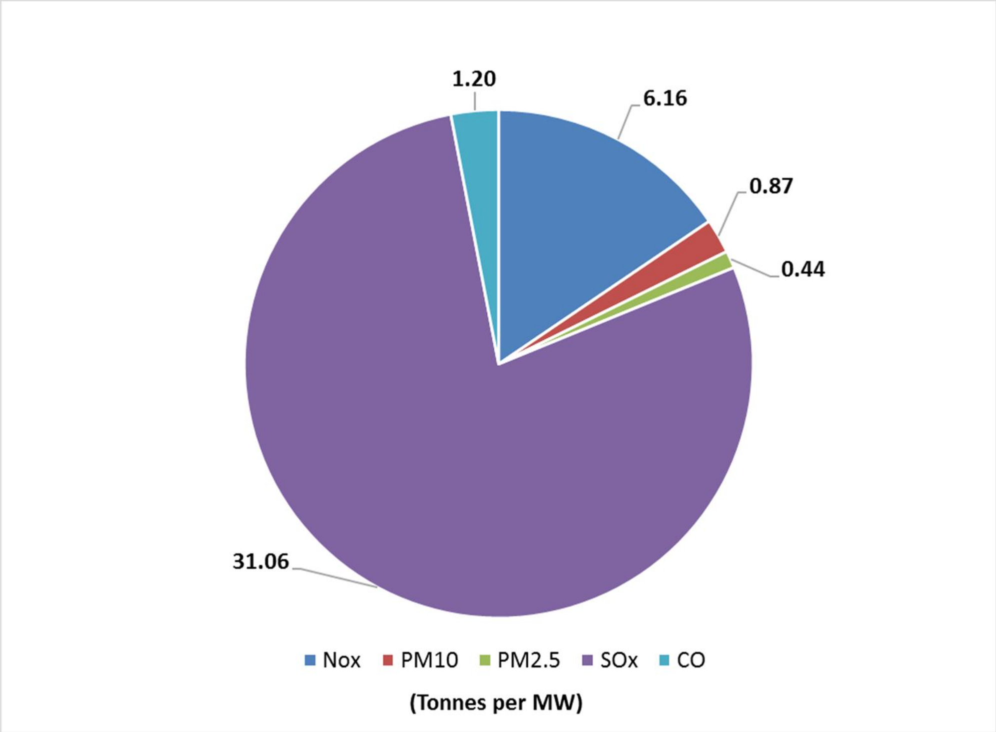
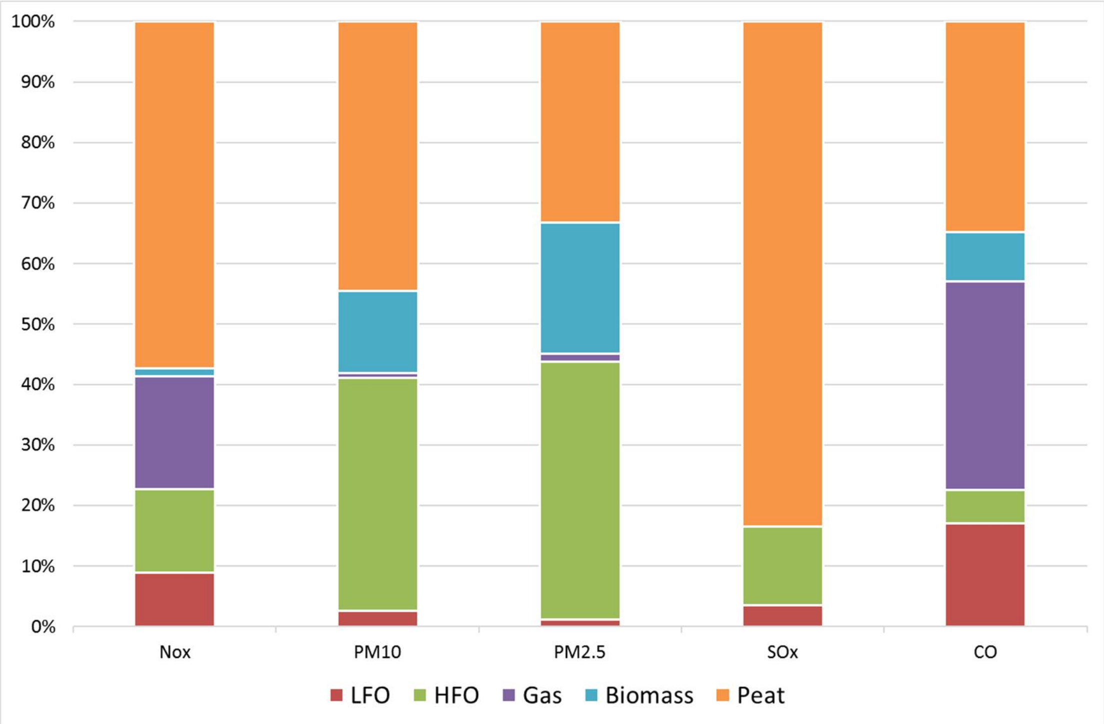



**Figure 23: Percentage of thermal power generation emissions from different fuel types**



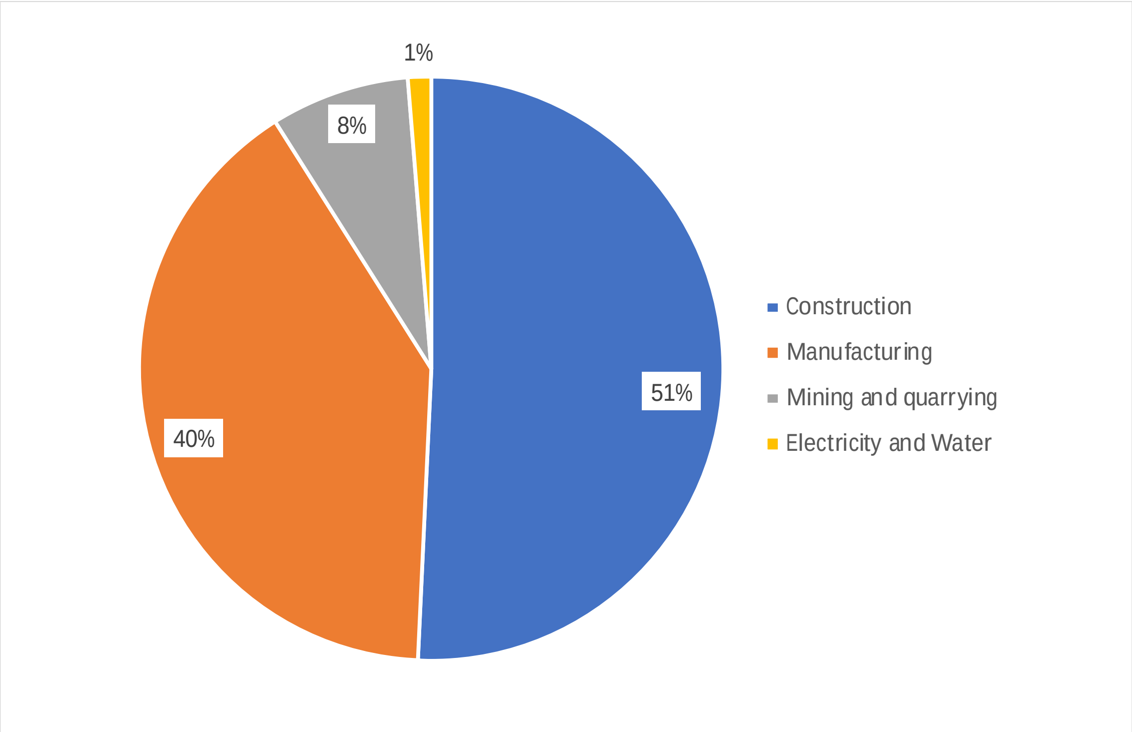
## 5.4 Emissions from industrial sources

### 5.4.1 Overview

The industrial sector in Rwanda is relatively small, only contributing 14% of total GDP in 2011[106]. This sector is expected to grow to 20% by 2018 and 26% by 2020 as a result of government policies such as EDPRS 2 and Vision 2020, which aims to increase domestic production and boost exports of key products[107]. Approximately 63% of all industry in Rwanda is located in and around Kigali[108].

Of the 14% of total GDP that the industrial sector makes up in Rwanda the contribution from industry is dominated by the construction (51%) and manufacturing industries (40%) (see Figure 24)[109], and therefore the majority of air pollutant emissions from industry would be from these sources consisting of numerous facilities. Mining and quarrying, such as of tin, tungsten, tantalite, columbite, beryl and gold, can also generate high emissions, especially dust and $PM_{10}$ from practices such as blasting[110]. However, mining and quarrying only makes up a small proportion of the industrial sector contribution to the overall 14% of GDP so would be a relatively small source of industrial emissions and likely to be limited to a small number sites with localised impacts.

**Figure 24: Composition of the industrial sector in Rwanda (2011)**




Source: Ministry of Trade and Industry, 2011 (Table B.1)

[106] Ministry of Trade et al. (2011). Rwanda Industrial Survey 2011. http://www.minicom.gov.rw/fileadmin/minicom_publications/Reports/minicomIndustrialSurveyUpdated_opt1.pdf

[107] Rwanda Association of Manufacturers (2015). Overview of Rwandan Manufacturing Industry. http://www.ram.org.rw/?page_id=253

[108] REMA, 2009. Industry and mining. http://www.rema.gov.rw/soe/chap4.php

[109] Ministry of Trade et al. (2011). Rwanda Industrial Survey 2011. http://www.minicom.gov.rw/fileadmin/minicom_publications/Reports/minicomIndustrialSurveyUpdated_opt1.pdf

[110] http://www.our-africa.org/rwanda/economy-industry

Note: The percentages above represent the contribution of different industries to the overall GDP attributed to the industrial sector.

### 5.4.2 Construction industry

Emissions from the construction industry are primarily associated with dust and particulate matter ($PM_{10}$ and $PM_{2.5}$) from activities such as demolition and earthworks. There are also emissions of pollutants such as $NO_2$ and $PM_{10}$ associated with energy usage; 73% of energy consumed by the construction industry in Rwanda is from furnaces/heavy oils, which are high polluting fuels[111]. However, these energy sources would have highly localised impacts and would have relatively small emissions compared to those from power generation.

A potential key source of emissions in the construction industry is from cement plants. Cement demand in 2015 was approximately 450,000 tons per year, the majority of which was supplied by Ciments du Rwanda Limited (CIMERWA), which is Rwanda's only integrated cement producer (mines the raw materials and produces cement)[112], [113]. CIMERWA currently produces 100,000 tons of cement per year and is currently expanding its capacity by building an additional plant in Bugarama which will be able to produce up to 600,000 tons of cement per year[114],[115].

There are also some smaller scale plants in Rwanda that produce cement from clinker which is imported from neighbouring countries[116]. For example, the Kigali Cement Company/ ARM Cement plant in Gitikinyami has the capacity to produce approximately 100,000 tons of cement per year[117].

There are also numerous small-scale brick kilns located within the country although emissions from these are localised.

Overall, emissions associated with the construction industry would only have a localised impact on ambient air quality and would not contribute significantly to background pollutant concentrations in Rwanda.

### 5.4.3 Manufacturing industry

The manufacturing industry in Rwanda is dominated by the manufacture of food products (43%), followed by the manufacture of beverages and tobacco (26%) (see Figure 25). Approximately 45% of energy consumption within the manufacturing industry is from furnace/heavy oils and 3% from wood, both of which have relatively high pollutant emissions, such as particulate matter, associated with them. However, these emission sources are relatively small so will only have a highly localised impact on ambient air quality.

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[111] Ministry of Trade et al. (2011). Rwanda Industrial Survey 2011. http://www.minicom.gov.rw/fileadmin/minicom_publications/Reports/minicomIndustrialSurveyUpdated_opt1.pdf

[112] Global Cement, 2015. CIMERWA inaugyrates new cement plant in Rwanda. http://www.globalcement.com/news/itemlist/tag/Rwanda?start=10

[113] CIMERWA (2017). About CIMERWA. http://www.cimerwa.rw/cimerwa.php

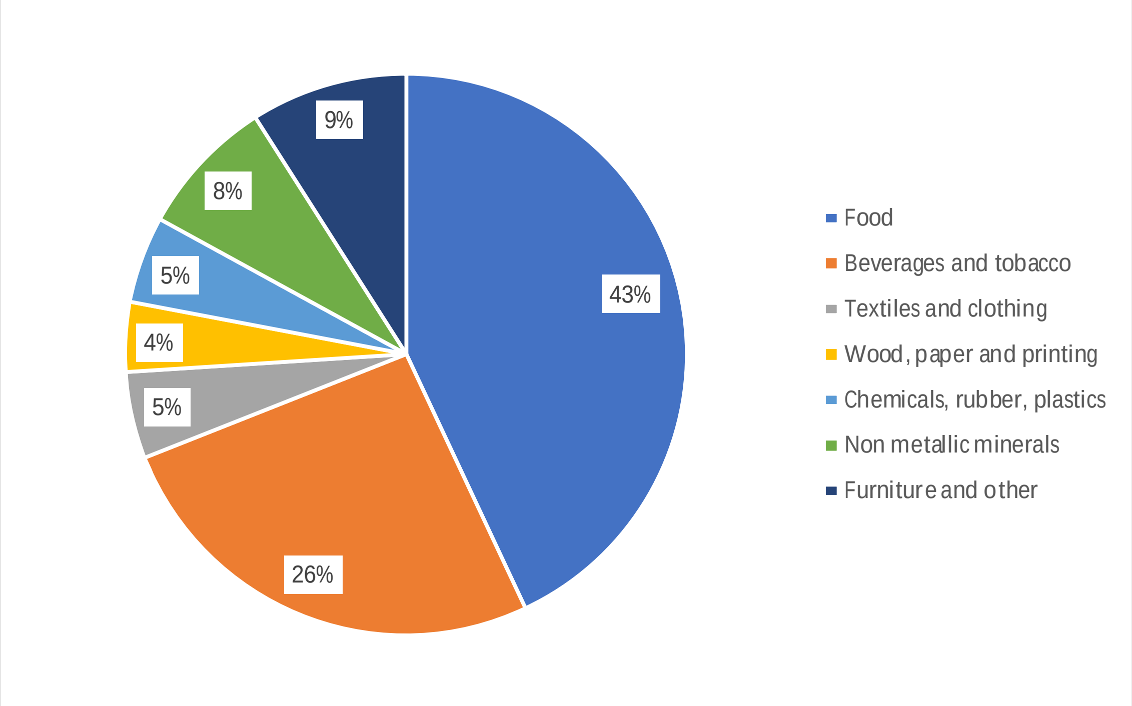
[114] Kumaran, G. S., Msinjili, N. S., Schmidt, W., Florea, M. V. A. & Nibasumba (). A study on sustainable energy for cement industries in Rwanda.

[115] CIMERWA (2017). About CIMERWA. http://www.cimerwa.rw/cimerwa.php

[116] Kumaran, G. S., Msinjili, N. S., Schmidt, W., Florea, M. V. A. & Nibasumba (). A study on sustainable energy for cement industries in Rwanda.

[117] Global Cement, 2014. ARM Cement acquires Kigali Cement http://www.globalcement.com/news/item/2651-arm-cement-acquires-kigali-cement

**Figure 25: Components of the manufacturing industry (2011)**




Source: Ministry of Trade and Industry, 2011 (Table B.1)

Notes: The graph provides a breakdown of the manufacturing sector GDP contribution which makes up 40% of the overall industrial contribution to GDP as shown in Figure 24.

## 5.5 Emissions from domestic sources

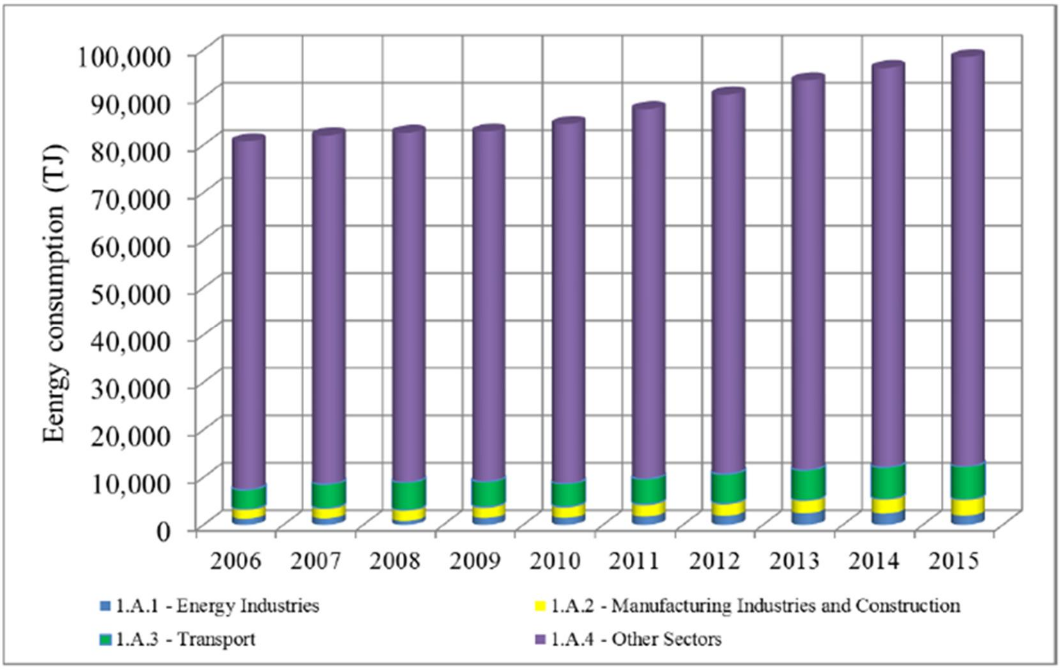
One of the main characteristics influencing pollutant emissions from cooking stoves is fuel type and quality. The choice of fuel will impact upon the peak temperatures achieved within combustion which will consequentially influence the make-up and volume of emissions. Solid fuels such as biomass, peat, coke and coal which are commonly used in Rwanda can vary substantially in make-up and quality. Biomass can cover a wide range of materials and therefore contaminants in biomass can differ, for example herbaceous biomass such as grasses and corn stover can contain high levels of ash, sulphur and nitrogen similar to coal, where woody biomass tends to contain lower levels of these contaminants[118]. Other variables such as moisture content can affect the efficiency of combustion and affect makeup and quantity of emissions. Products of incomplete combustion are predominantly made up of CO along with a variety of particulates. $NO_x$ is typically produced when combustion is conducted at higher temperatures. Poor fuel quality can lead to a range of other emissions, contaminants within fuel can lead to emissions such as sulphur, particulates, mineral fibres and gaseous mercury[119].

[118] Edwards, R. Karnani, S. Fisher, E.M. Johnson, M. Naeher, L. Smith, K.R. Morawska, L. (2014) 'WHO Indoor Air Quality Guidelines: Household fuel Combustion. Review 2: Emissions of Health-Damaging Pollutants from Household Stoves' Available at: http://www.who.int/indoorair/guidelines/hhfc/Review_2.pdf

[119] Edwards, R. Karnani, S. Fisher, E.M. Johnson, M. Naeher, L. Smith, K.R. Morawska, L. (2014) 'WHO Indoor Air Quality Guidelines: Household fuel Combustion. Review 2: Emissions of Health-Damaging Pollutants from Household Stoves' Available at: http://www.who.int/indoorair/guidelines/hhfc/Review_2.pdf

A report summarising greenhouse gas emissions [120] provides analysis on the fuel consumption for energy production Rwanda. The data for 2015 shows that approximately 88% of fuel used in Rwanda is biomass which is used in domestic stoves. This provides an indication of the level of contribution that domestic sources have on air pollution.

**Figure 26: Energy consumption from different sectors between 2006 and 2015**




Source: Final inventory report for Third National Communication reports [121]

A study in China was conducted in 2017 to compare emissions from coal and wood stoves, it was concluded that coal combustion produced higher levels of $CO_2$, $CH_4$ and $SO_2$ in comparison to wood, however wood combustion produced higher levels of $PM_{2.5}$[122].

PM concentrations can be heavily influenced by emissions from cooking stoves. In 2013 a study was undertaken in rural Ghana, this study measured mean 24-hour $PM_{2.5}$ concentrations in kitchens that cooked on traditional fires and stoves and used biomass and coal as their primary fuel source. The mean 24-hour concentration within kitchens was measured to be 446.8µg/m$^3$[123]. Concentrations this high are not only extremely dangerous to people living inside with them, but would also be a substantial contributor to outdoor ambient PM concentrations, especially if similar cooking stoves were the primary source of cooking for the majority of the

[120] Innocent Nkurikiyimfura, Telesphore Mugwiza and Theoneste, 2017, Energy Greenhouse Gas emission in Rwanda (2006/2015), Final inventory report for Third National Communication Reports

[121] Innocent Nkurikiyimfura, Telesphore Mugwiza and Theoneste, 2017, Energy Greenhouse Gas emission in Rwanda (2006/2015), Final inventory report for Third National Communication Reports

[122] Du, W. Shen, G. Chen, Y. Zhu, X. Zhuo, S. Zhong, Q. Qi, M. Xue, C. Lie, G. Zeng, E. Xing, B. Tao, S. (2017) 'Comparison of air pollutant emissions and household air quality in rural homes using improved wood and coal stoves' *Atmospheric Environment*, 166, pp. 215-223.

[123] Van Vliet, E.D.S. Asante, K. Jack, D.W. Kinney, P.L. Whyatt, R.M. Chillrud, S.N. Aboyki, L. Zandoh, C. Owusu-Agyei, S. (2013) 'Personal exposures to fine particulate matter and black carbon in households cooking with biomass fuels in rural Ghana' *Environmental Research,* 127, pp. 40-48.

population. As PM concentrations in ambient air in Rwanda are high it can be concluded that it is highly likely that cooking stoves contribute significantly to these high concentrations.

# 6 Monitoring data used in the study

## 6.1 Monitoring network established for the study

### 6.1.1 Overview

This chapter provides a summary of the study specific monitoring that was undertaken including the methodology and the locations selected. It also provides a summary of the existing data provided by Egide Kalisa our local sub consultant which was collected as part of his PhD study and data obtained by the Carnegie Mellon University (CMU) which was also analysed.

### 6.1.2 Objectives of monitoring

The ambient monitoring undertaken specifically for the study has two main objectives, firstly to identify the existing air quality baseline within Kigali and to compare it to rural locations and to determine appropriate air quality standards. Secondly, to provide evidence of the likely major contributors to pollutant concentrations to guide policy recommendations aimed at managing air quality with future development within Rwanda; this aspect is of particular importance given the lack of mass emission data, discussed in section 5.1.1, that would have allowed a quantitative analysis of the sector contributions.

The overall approach to the monitoring survey has been developed to provide data for the types of locations presented in Table 27. This is to understand where the greatest pollutant concentrations are and how the spatial distribution of pollution changes across Kigali depending on the site type.

**Table 27: Monitoring site classifications**

| Site type | Description |
|---|---|
| Urban background / Residential | An urban location distanced from sources and therefore broadly representative of city-wide background conditions, e.g. urban residential areas |
| Roadside | A site sampling typically within one to five metres of the kerb of a busy road (although distance can be up to 15m from the kerb in some cases) |
| Industrial | An area where industrial sources make an important contribution to the total pollution burden |
| Rural | An open countryside location, in an area of low population density distanced as far as possible from roads, populated and industrial areas |

Source: Defra LAQM TG16

### 6.1.3 Continuous air quality monitoring

**Overview**

Real time continuous air quality monitoring is being undertaken at four locations. The four AQMesh monitors were installed between Monday the 23 and Wednesday the 25 of October 2017.

The AQMesh monitors have been programmed to collect data at 15 minute intervals to provide a high frequency of data to allow longer term averages to be calculated and presented in the study.

The AQMesh monitors have been built to contain several sensors to monitor different pollutants. The monitors measure:

- Oxides of nitrogen ($NO_x$)
- Nitrogen dioxide ($NO_2$)
- Sulphur dioxide ($SO_2$)
- Ozone ($O_3$)
- Carbon monoxide (CO)
- Particulate matter with an aerodynamic diameter of less than 10 microns ($PM_{10}$)
- Particulate matter with an aerodynamic diameter of less than 2.5 microns ($PM_{2.5}$)

The range and limit of detection for each pollutant monitored by the AQMesh monitors is presented in Table 28.

**Table 28: Monitoring range and limit of detection**

| Parameter | Range | Limit of detection |
|---|---|---|
| $NO_x$ | 0-800 ppb | <10 ppb |
| $NO_2$ | 0-400 ppb | <10 ppb |
| $SO_2$ | 0-10,000 ppb | <10 ppb |
| $O_3$ | 0-1,800 ppb | <5 ppb |
| CO | 0-6,000 ppb | <5 ppb |
| $PM_{10}$ | 0-200 µg/m$^3$ | -[(a)] |
| $PM_{2.5}$ | 0-500 µg/m$^3$ | -[(a)] |

Source: www.aqmesh.com

Notes: (a) As AQMesh uses an optical particle counter for particle mass estimation, each individual particle within the sample taken is counted and sized. As such there is no limit of detection for PM measured by AQMesh

The AQMesh monitors relay results in real time via GPRS communication to an online data web page. The data provided is calibrated based on the optimisation process that the monitors went through prior to being supplied for the project. The optimisation process involved the concentrations monitored by the AQMesh's being compared to monitored concentrations obtained from a co-located reference station. The data calibration process is undertaken by Air Monitors who are the manufacturers of the monitoring equipment.

An overview of the continuous monitoring sites is presented in Table 29 and details of the locations of the continuous monitoring sites are provided in Appendix F. The locations have been selected to coincide with existing meteorological stations that will provide historical data representative of the monitoring locations.

**Table 29: Continuous air quality monitoring sites**

| ID | Monitoring location | Coordinates | | Site type | Date installed | Serial number |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | | | |
| CM-1 | In Kigali at Nyabugogo bus terminal | 01°56.391' | 030°02.609' | Roadside | 23 October 2017 | 1828150 |
| CM-2 | In Kigali at the Meteo Rwanda headquarters | 01°57.372' | 030°03.465' | Urban background | 23 October 2017 | 1827150 |
| CM-3 | Kawangire meteorological station in Kayonza district in the Eastern province | 01°49.452' | 030°26.857' | Rural | 24 October 2017 | 1826150 |

| ID | Monitoring location | Coordinates | | Site type | Date installed | Serial number |
|---|---|---|---|---|---|---|
| | | Latitude | Longitude | | | |
| CM-4 | Gasaka meteorological station in Nyamagabe district in the Southern province | 02°28.025' | 029°34.658' | Rural | 25 October 2017 | 1829150 |

### Nyabugogo bus terminal

The AQMesh was installed at Engen petrol station at Nyabugogo bus terminal in Kigali. For security purposes, the AQMesh was installed over two metres from the ground with the help of the Energy Utility Corporation Limited (EUCL). Appendix F present the location. The main sources of pollution at this location are petrol and diesel fuelled heavy vehicles, buses and moto taxis travelling in Kigali. The AQMesh is located approximately two metres from the main road to Uganda which is one of the main import routes into the country. The closest residential community is Gatsata- rubonono located approximately 200m from where the AQMesh is installed; wood and charcoal are the predominant source of domestic fuel in this area. As such there is no immediate residential receptors at this location but the site was chosen as it represents one of the worst potential air quality hotspots within Kigali.

### Gitega Meteorological site

The AQMesh was installed at Gitega at the Meteo Rwanda headquarters in Kigali. TheAQMesh was located on the site boundary. Gitega and Kimisagara are the closest communities to this urban background location. The main potential sources of pollution are charcoal and wood used as fuel by these residential communities. Other potential sources of pollution are an incinerator and a diesel generator located within the Meteo premises Meteo informed Mott MacDonald that the incinerator is only used every Saturday to dispose of waste generated onsite and the generator is used approximately once a week for less than one hour when there is a power cut. The distance to the closest main road is approximately 100m and therefore road traffic emissions will have minimal impact at this location.

### Kawangire meteorological station

The AQMesh was installed at the Kawangire meteorological station in Gatsibo district in the Eastern province. It is located within the Kawangire community at the Kawangire cell headquarters. Its location is presented in Appendix F. This AQMesh was collocated with two sets of passive diffusion tubes monitoring nitrogen dioxide ($NO_2$) and sulphur dioxide ($SO_2$). The main potential source of pollution is wood used as fuel by the surrounding communities. The closest residential houses are located approximately 10m from the AQMesh. Kawangire High School is approximately 600m away. There are no major roads located within 200 metres of the monitoring site.

### Gasaka meteorological station

The AQMesh was installed at the Gasaka meteorological station in Nyamagabe district in the Southern province. Its location is presented in Appendix F. This AQMesh was collocated with two sets of passive diffusion tubes monitoring $NO_2$ and $SO_2$. It is located adjacent to the District Police Unit (DPU), Nyamagabe. Surrounding the meteorological station is the SACCO Bank offices and a honey making industry, MIGE. The main potential source of pollution is traffic on the main road to Rusizi town from Huye town approximately 200m from where the AQMesh is located.

### 6.1.4 Passive air quality monitoring

**Overview**

Passive air quality monitoring was undertaken at 32 locations using diffusion tubes. The first set of diffusion tubes where installed on Thursday 12 and Friday 13 of October 2017. These were collected and replaced by the second set on Thursday 26 and Friday 27 of October 2017. The second set of tubes were collected on the 16 and 17 of November 2017.

Diffusion tubes have been installed to monitor for:

- $NO_2$
- $SO_2$

The diffusion tubes were analysed at SOCOTEC an accredited laboratory in the United Kingdom which holds the highest rank of accreditation in accordance with the United Kingdom Accreditation Service which is responsible for determining, in the public interest, the technical competence and integrity of organisations such as those offering testing, calibration and certification services in accordance with ISO/IEC 17025. Diffusion tubes are not considered as accurate as continuous monitoring methods (particularly reference methods) and because the monitoring duration is relatively short, the data is not suitable for deriving long term trends. However, the monitored concentrations from the diffusion tubes do provide indicative concentrations and provide a useful tool for gathering data to show the change in concentrations between locations and monitoring site types.

**Passive monitoring sites**

30 monitoring sites were located as presented in Table 30 and in Appendix G. In addition, diffusion tubes were co-located with the AQMesh monitors located at the Kawangire and Gasaka meteorological sites.

**Table 30: Passive air quality monitoring sites**

| Site ID | Coordinates | | Site type | Description |
|---|---|---|---|---|
| | Latitude | Longitude | | |
| 1 | 1° 54.937'S | 30° 4.254'E | Roadside | Located approximately one metre from KG14 Avenue at the corner of KG14 Avenue and KG77 Street in Gisozi residential area. Site relocated after previous tubes were stolen. |
| 2 | 1° 55.594'S | 30° 6.627'E | Roadside | Situated in Kibagabaga residential area approximately two metres from a busy road KG19 Avenue. |
| 3 | 1° 55.927'S | 30° 5.950'E | Roadside | Situated about two metres along a busy road KG9 Avenue. |
| 4 | 1° 57.697'S | 30° 7.313'E | Roadside | Situated one metre from the busy road KN5 Road to Kigali International Airport. |
| 5 | 1° 59.061'S | 30° 6.198'E | Roadside | Located next to offices and the School of Governance National Council of Nurses and Midwives, one metre from a busy road KK15 Road. |
| 6 | 1° 58.158'S | 30° 3.545'E | Roadside | Located in a residential area, one metre from a busy road KN123 Street. |
| 7 | 1° 57.145'S | 30° 3.264'E | Roadside | Located about a metre from a bus stop along KN112 Street. |
| 8 | 1° 56.927'S | 30° 4.143'E | Roadside | Located at the entrance of Restoration Church approximately one metre from a busy road KN51 Street. |
| 9 | 1° 58.129'S | 30° 3.129'E | Roadside | Located one metre from a busy road KK4 Avenue in Gikondo residential area. |
| 10 | 1° 56.678'S | 30° 3.687'E | Roadside | Located one metre from the KN1 roundabout at KN6 Avenue adjacent to the Union Trade Centre. |
| 11 | 1° 56.342'S | 30° 3.695'E | Roadside | Located in the city centre about one metre from KN1 Road adjacent to Safari Plaza. |
| 12 | 1° 55.161'S | 30° 4.319'E | Residential | Located in Gisozi residential area along a dirt road at the corner of KG727 Street and KG 754 Street one metre from KG727 Street. |
| 13 | 1° 55.593'S | 30° 6.761'E | Residential | Located in a residential area one metre from a dirt road KG366 Street. |
| 14 | 1° 56.073'S | 30° 6.237'E | Residential | Located in an informal settlement, households use charcoal stoves and firewood. |
| 15 | 1° 57.485'S | 30° 8.261'E | Residential | Located one metre from a dirt road in Kanombwe residential area approximately two kilometres from Kigali International Airport. |
| 16 | 1° 59.051'S | 30° 6.191'E | Residential | Located one metre from a dirt road in the Kicukiro residential area. |
| 17 | 1° 59.660'S | 30° 4.021'E | Residential | Located one metre from a dirt road in Rebero residential area, there are some construction activities using heavy vehicles in the community approximately one kilometre from the site. |
| 18 | 1° 58.232'S | 30° 4.417'E | Residential | Located in a residential community about one metre from the community dirt road. Tubes stolen so relocated. |
| 19 | 1° 58.333'S | 30° 3.388'E | Residential | Located one metre from a dirt road at the corner of KK704 Street and KK701 Street in Gikondo residential area. |
| 20 | 1° 57.145'S | 30° 3.266'E | Residential | Located one metre from KN11 Street in the Cyahafi residential area. |
| 21 | 1° 57.061'S | 30° 4.842'E | Residential | Site located at a guest lodge one metre from the road in Kimihurura. Tubes stolen so relocated |
| 22 | 1° 55.293'S | 30° 3.266'E | Residential | Located one metre from KN1 Street on a dirt road. Tubes stolen and relocated. |
| 23 | 1° 55.881'S | 30° 3.664'E | Urban background | Located at the Kigali Genocide Memorial. |

| Site ID | Coordinates | | Site type | Description |
|---|---|---|---|---|
| | Latitude | Longitude | | |
| 24 | 1° 57.398'S | 30° 7.008'E | Urban background | Located at Kukiri 2 behind Amahoro Stadium adjacent to Centre Christus one metre from a busy road KG180 Street. |
| 25 | 1° 57.062'S | 30° 3.784'E | Urban background | Urban City Blue Hotel in Kiyovu located four metres from KN67 Street. |
| 26 | 1° 58.200'S | 30° 4.384'E | Urban background | Located one metre from KK500 Street behind the National Agriculture Exports Development Board (NAEB) opposite Rwacof Exports. |
| 27 | 1° 57.204'S | 30° 9.204'E | Industrial | Located at Imasoro Industrial Park prime economic zone gateway to East and Central Africa. |
| 28 | 1° 58.182'S | 30° 5.581'E | Industrial | Industrial area, Bralirwa Limited, Kicukiro community beer and soda, a soap and cosmetic industry and Anik Rwanda. |
| 29 | 1° 53.510'S | 30° 4.210'E | Industrial | Located 600m from the Kigali Gatuna Road adjacent to Kabuye Sugar factory, Enterprise Rwandaise de Petrole (ERP) and rice pads are in the vicinity. |
| 30 | 1° 56.956'S | 30° 3.675'E | Roadside | Could not get a car free zone location so used a roadside next to the construction area and I&M Bank which is one metre from KN2 Avenue. |

## 6.2 Historical particulate matter monitoring

From the 01 April 2017 to 30 June 2017 a particulate matter monitoring programme was undertaken by Egide Kalisa, a local air quality specialist and PHD student, and local sub consultant for this study at three locations. The monitoring programme investigated $PM_{10}$ and $PM_{2.5}$ concentrations at one urban background, one roadside and one rural location over a period of three months.

### 6.2.1 Methodology

$PM_{10}$ and $PM_{2.5}$ concentrations were collected using a high volume air sampler (SIBATA Electric Company Limited, Japan, and VHS-RW-1000F) equipped with a $PM_{2.5}$ and $PM_{10}$ size selected inlet, operating at a flow rate of 1000 litres per minute. Substrates were collected on pre-weighed sterilized glass fibre filters. Each sterilized filter was packaged in sterilized aluminium foil and stored in a sealed bag until loaded into the filter cartridge. The samplers (filter holder) was sterilized with 70% ethanol before each sampling set. All inside surfaces of the two stages of the high volume sampler was maintained in a sterile condition until sampling.

$PM_{2.5}$ and $PM_{10}$ concentrations were then obtained through gravimetric analysis of the sampled filters following procedures prescribed by the US Environmental Protection Agency's Compendium Method IO-2.1 sampling of ambient air for total suspended particulate matter and $PM_{10}$ using high volume sampler[124]. In order to minimize the influence of water adsorption, PM filters were pre–conditioned for 24 hours in a desiccator at a temperature of 15–30°C and a humidity less than 40% prior to weighing. Before and after exposure, the filters were weighed using a five digit semi micro analytical balance (Model KERN, RS-232 ACJ). The 24-hour average $PM_{2.5}$ and $PM_{10}$ levels were calculated from the ratio of the mass of particulates retained on the filter paper to the total volume of air sampled.

### 6.2.2 Sampling

There were three locations sampled within the particulate matter monitoring programme, these were at an urban background, rural and urban roadside location. The following sections describe each of these locations and the sampling undertaken in further detail.

**Urban background (Kigali)**

Monitoring was undertaken at an urban background location in the capital Kigali. The College of Science and Technology campus at the University of Rwanda (coordinates: 1°57'32.5"S, 30°03'53.2"E) was selected as it was located away from emission sources and broadly representative of city-wide background conditions. It was also stated to be chosen as measurements could be collected reliably over time. This monitor was placed on the rooftop of a building. The height of the rooftop is approximately 10 meters above the ground.

Sampling was undertaken in the wet season and dry season[125] at the Kigali urban background site. Wet season monitoring was undertaken from 01 April 2017 to 21 April 2017 with dry season monitoring being undertaken from 15 June 2017 to 30 June 2017. It should be noted that the week of commemoration of genocide against Tutsi was from 07 April 2017 to 13 April 2017 and activities in Kigali are substantially reduced during this time.

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[124] US Environment Protection Agency (1999), 'Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air; Compendium Method IO-2.1; EPA/625/R-96/010a. Sampling of Ambient Air for Total Suspended Particulate Matter (SPM) and PM10 Using High Volume (HV) Sampler'

[125] Rwandan dry season is June to September and December to February, the wet season is March to May and October to November.

**Urban roadside (Kigali)**

An urban roadside location was selected in Kigali for monitoring. The rooftop of the Nyarugenge Pension Plaza building was used (coordinates: 1°95'17.1"S, 30°07'18.4"E). The monitor was located 15m away from a main road (KN3 Road). This road experiences high traffic volumes. The height of the rooftop is approximately 10 metres above the ground. Although not at ground level the rooftop was selected for security reasons and still allows for an effective comparison between the urban background location as both sites were located on rooftops.

Sampling was again undertaken in the wet and dry seasons for the urban roadside location, the wet season monitoring ran from the 15 May 2017 to 31 May 2017 and the dry season monitoring ran from 01 June 2017 to 14 June 2017.

**Rural (Mukungwa, Musanze District)**

Monitoring was undertaken at the rural location of Musanze in north western Rwanda (coordinates: -1°32’16” S, 29°41’31” E) located approximately 100km north of Kigali. The site is away from major pollution sources and representative of regional background concentrations. The nearest tree cover to the monitoring station are 200 – 300m away and the surrounding area is generally open with agricultural fields and residential areas.

Sampling at the rural site was conducted during the wet season only, the monitoring ran from 23 April 2017 to 14 May 2017.

### 6.2.3 Meteorological data

Meteorological data from two monitoring stations in close proximity to sampling sites was also obtained for temperature, wind speed, wind direction and relative humidity. These monitoring stations were located in Kigali at the Kanombe International Airport and the weather station of Ruhengeri located in the Musanze district.

## 6.3 Data provided by Carnegie Mellon University (CMU)

Data was provided by CMU for analysis within the study. This monitoring data covered CO, $SO_2$, $NO_2$, $O_3$ and $CO_2$ as well as temperature and relative humidity at three locations between the 05 July 2017 and 10 October 2017.

### 6.3.1 Methodology

Monitoring was undertaken using Real Time Affordable Multi-Pollutant (RAMP) Monitors. The RAMP monitor uses electrochemical sensors to measure CO, $NO_2$, $SO_2$ and $O_3$ and utilises a non-dispersive infrared (NDIR) sensor to record $CO_2$. A scientific paper describing the approach to the monitoring method was also reviewed[126].

The following sections describe the locations and sampling undertaken in further detail; it should be noted that this is based on Mott MacDonald analysis as exact details were not provided with the data.

[126] Zimmerman, N. Presto, A.A. Kumar, S.P.N. Gu, J. Hauryliuk, A. Robinson, E.S. Robinson, A.L. Subramanian, R. (2017) ‘Closing the gap on lower cost air quality monitoring: machine learning calibration methods to improve low-cost sensor performance’ *Atmospheric Measurement Techniques Discussions*.

**CMU Africa Campus (Telecom House, Kacyiru)**

The CMU Africa Campus at Telecom House is located in north west Kigali, the building is set away from KG7 Ave which is a busy road. There are a number of national embassies located on KG7 Ave. Sampling was undertaken from 10 July 2017 to 26 July 2017

**Gacuriro (Belle Vue Estate)**

The Belle Vue Estate in Gacuriro is a residential area in northern Kigali. Sampling ran from 06 July 2017 to 09 October 2017.

**University of Rwanda, college of Science and Technology (UR CST Campus)**

The UR CST campus is located in western Kigali, the campus is set away from major roads and other major emission sources. Sampling ran from 05 July 2017 to 06 October 2017.

### 6.3.2 Data uncertainty

The data provided by CMU had only undergone initial validation and was not considered a final set of data. As some of the data had not been calibrated and as contained some uncertainties and irregularities which the university had not had an opportunity to investigate further it could not all be used in the analysis.

There were no units of measurement provided for the data. Units were assumed from the scientific paper provided[126]. Units were converted from parts per billion (ppb) to µg/m$^3$ for presentation within the report.

No data supplied from the UR CST campus monitoring site could be interpreted for analysis.

# 7 Analysis of air quality

## 7.1 Overview

This chapter provides analysis for the air quality monitoring data that has been collected as part of this study along with the data provided by our local sub consultant and CMU. The data was analysed in order to use it to help characterise the main sources of air pollution in Kigali and to establish the existing baseline within Kigali and at rural locations. A qualitative assessment of the likely level of pollution in Bugarama, a city at low altitude, and Rubavu, a city at high altitude, which are both located in the Western province of Rwanda has also been undertaken and presented in this chapter.

Finally, the chapter provides a summary of the existing air quality baseline for the key pollutants assessed and compares them against existing air quality standards.

## 7.2 Data collected for the study

### 7.2.1 Overview

The following sections present data collected during the study and includes data collected from the AQMesh monitors and data collected using the diffusion tubes. The chapter should be read in conjunction with the figures of the monitoring locations which are presented in Appendix F and Appendix G.

### 7.2.2 Data collected using AQMesh monitors

The continuous monitoring data analysed in the draft report was undertaken between 25 October 2017 and 26 November 2017. The monitored mean 24-hour concentrations for $NO_2$, $O_3$, $SO_2$, $PM_{10}$, $PM_{2.5}$ and CO at each site during this time are presented in the following sections.

**Overall average 24-hour concentrations**

Mean concentrations during the monitoring periods are presented in Table 31. Highest $NO_2$, $SO_2$ and CO concentrations were measured at the Nyabugogo roadside location. Due to the sites close proximity to major roads and a bus station, it would be expected to have the highest pollutant concentrations. Highest mean $PM_{10}$ and $PM_{2.5}$ concentrations were measured at the Kawangire rural location. Period mean concentrations of $PM_{10}$ are below the annual mean standards for rural and residential areas, which is 50µg/m$^3$, at Nyabugogo, Gitega and Gasaka but they are above the standard at Kawangire. Monitored concentrations are below the $PM_{2.5}$ annual mean standard of 35µg/m$^3$ at all four sites.

The data illustrates that monitored concentrations of $NO_2$ at the rural sites are low. Although the concentrations at Nyabugogo are the highest monitored they remain below the Rwanda annual mean ambient standards of 0.05ppm (96µg/m$^3$).

The period mean of $SO_2$ concentrations is very low and below the existing Rwanda annual mean standard at all monitoring locations.

**Table 31: Average pollutant concentrations at four monitoring sites.**

| Pollutant | Current Rwanda annual mean ambient air quality standards | Monitoring site monitored mean concentration (µg/m³) | | | |
|---|---|---|---|---|---|
| | | Nyabugogo (roadside) | Gitega – Meteo (urban background) | Kawangire (rural) | Gasaka (rural) |
| $NO_2$ | 0.05ppm (96µg/m³) | 35.0 | 20.7 | 9.6 | 8.7 |
| $O_3$ | - | 58.9 | 42.4 | 33.0 | 149.0 |
| $SO_2$ | 60µg/m³ | 11.9 | 6.9 | 2.0 | 2.0 |
| $PM_{10}$ | 50µg/m³ | 36.7 | 19.5 | 101.9 | 17.5 |
| $PM_{2.5}$ | 35µg/m³ | 10.0 | 8.5 | 31.1 | 6.4 |
| CO | - | 973.7 | 714.4 | 144.3 | 178.9 |

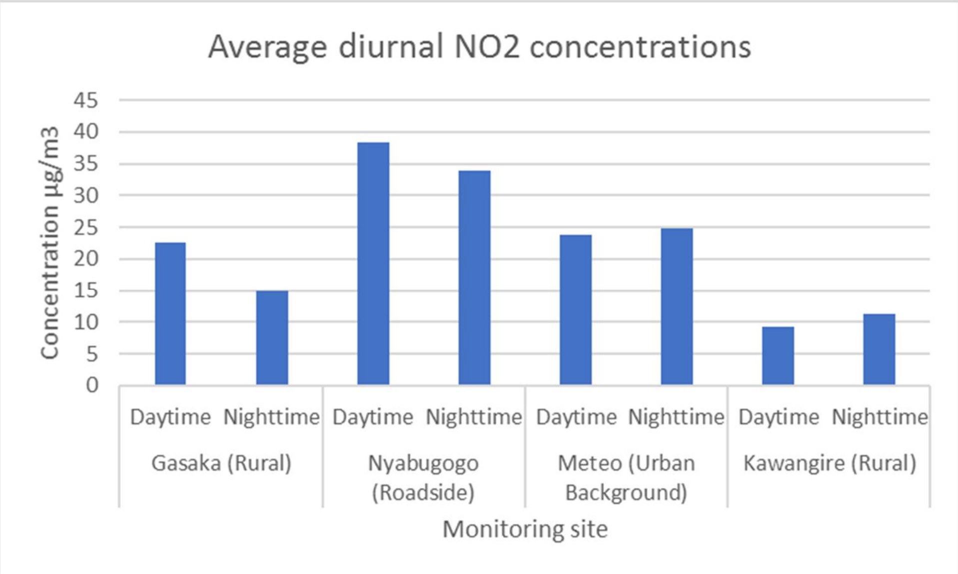
**Diurnal concentrations**

Average concentrations at the four AQMesh monitoring sites have been averaged between for day and night time periods. The average concentrations are presented in Figure 27 and show that concentrations are higher in the daytime at the roadside location.  It should be noted that the change in concentrations at this location may be less pronounced between day and night compared to other roadside locations because its location close to the busy bus station and the petrol station there would be greater activity through the night compared to other locations.

The urban background locations show little difference between day and night indicating that average background concentrations away from major sources in Kigali remain consistent between day and night.

The Gasaka rural location shows higher concentrations in the day compared to nigh time while the Kawangire site shows little difference.

**Figure 27: Average diurnal concentration**

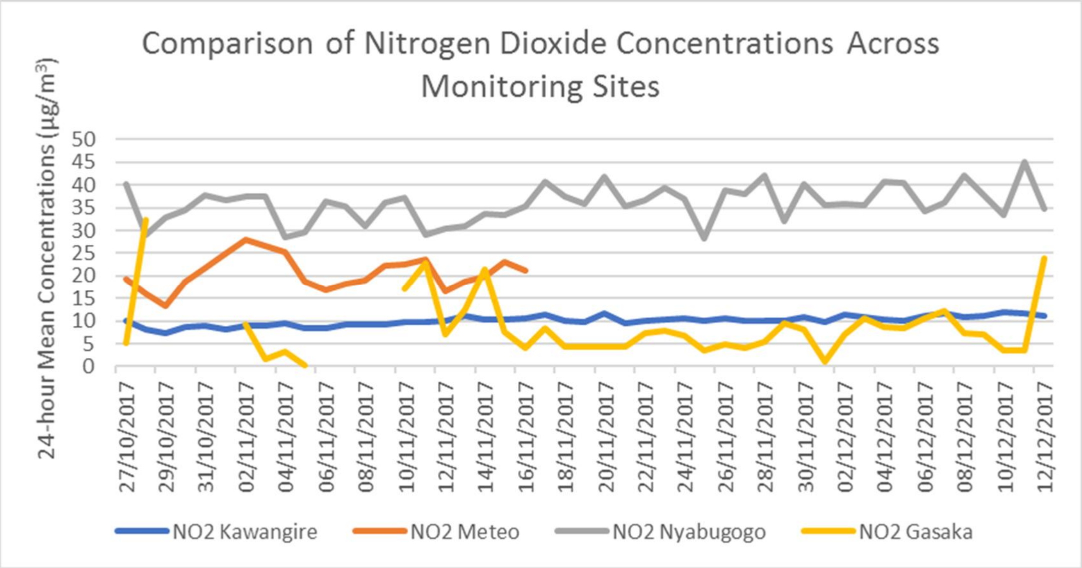



Notes: Daytime assumed to be 06.00 to 20.00 and night time 20.00 to 06.00

## Nitrogen dioxide

The highest measured concentrations of $NO_2$ were recorded at the Nyabugogo roadside site, this is expected due to the monitor location being next to the bus terminal and busy roads. The urban background site in Kigali located at the Meteo Headquarters in Gitega on average had the second highest $NO_2$ concentrations. The concentrations recorded at the two rural sites (Kawangire and Gasaka) were lower than both sites in Kigali. Nitrogen dioxide concentrations for the four sites are presented in Figure 28.

**Figure 28: Comparison of $NO_2$ concentrations**

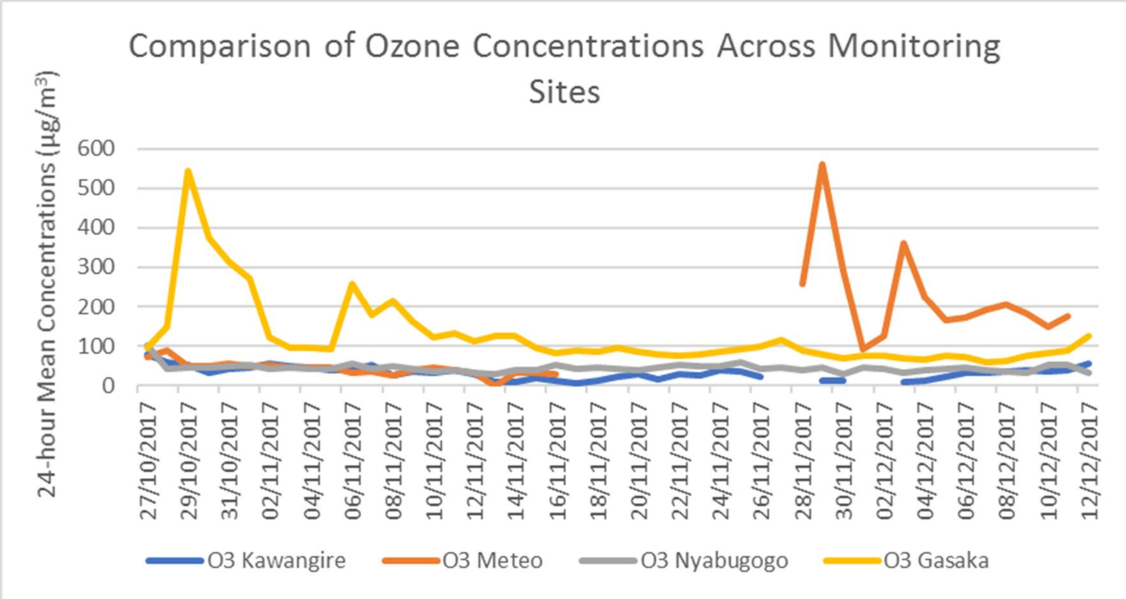



Note: Site data removed where data irregularities not considered representative.

## Ozone

The highest $O_3$ concentration was measured at the Gasaka rural site that consistently measured higher than the other three monitoring sites. $O_3$ concentrations at the Kawangire, Meteo and Nyabugogo site were similar, Nyabugogo roadside site had slightly higher concentrations out of the three sites. $O_3$ concentrations for the four monitoring sites are presented in Figure 29.

**Figure 29: Comparison of $O_3$ concentrations**

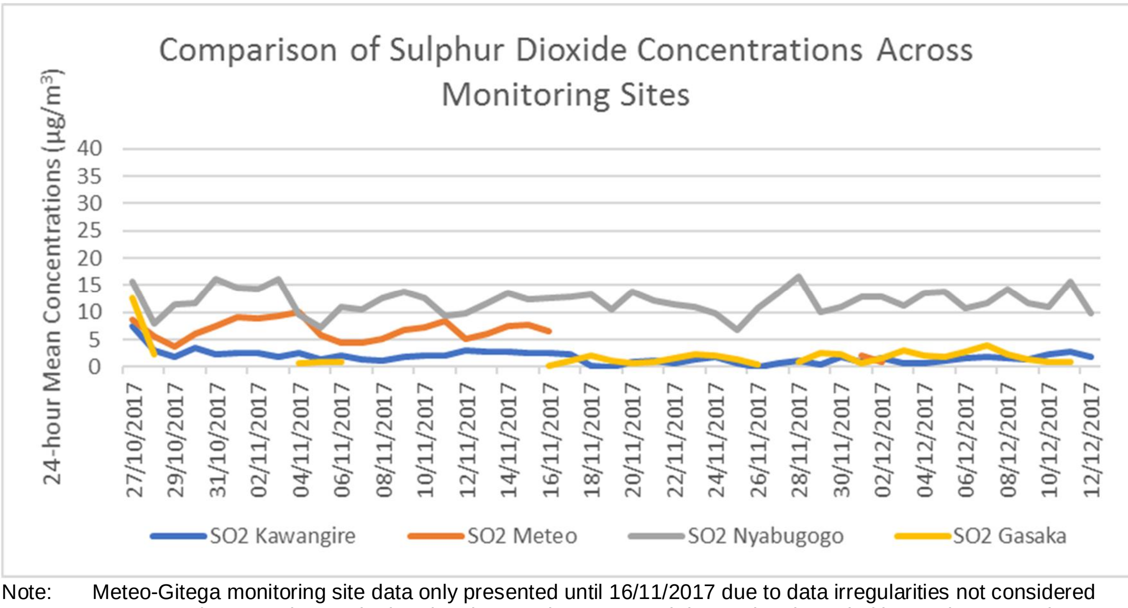



Note: Site data removed where data irregularities not considered representative.

### Sulphur dioxide

Measured $SO_2$ concentrations across all monitoring sites were low. Highest concentrations were measured at the roadside Nyabugogo site. $SO_2$ concentrations for all sites are presented in Figure 30.

**Figure 30: Comparison of $SO_2$ concentrations**




Note: Meteo-Gitega monitoring site data only presented until 16/11/2017 due to data irregularities not considered representative. Gasaka monitoring data has 14 days removed due to data irregularities such as negative concentrations that are attributed to concentrations being very low.

**Particulate matter$_{10}$**

Highest $PM_{10}$ concentrations were measured at the Kawangire rural site. This result is unexpected as there are no major roads within 200m of the monitor. High concentrations are most likely be due to the close proximity of wood burning stoves to the monitor with residences located approximately 10m away and windblown dust from regional sources. The levels of $PM_{10}$ at the Kawangire site are presented in Figure 31.

At the other three sites the highest $PM_{10}$ concentrations were measured at the Nyabugogo roadside site, this would be expected due to the sites proximity to major roads. $PM_{10}$ concentrations for the Gasaka, Meteo-Gitega and Nyabugogo sites are presented in Figure 32.

**Figure 31: Kawangire measured $PM_{10}$ concentrations**

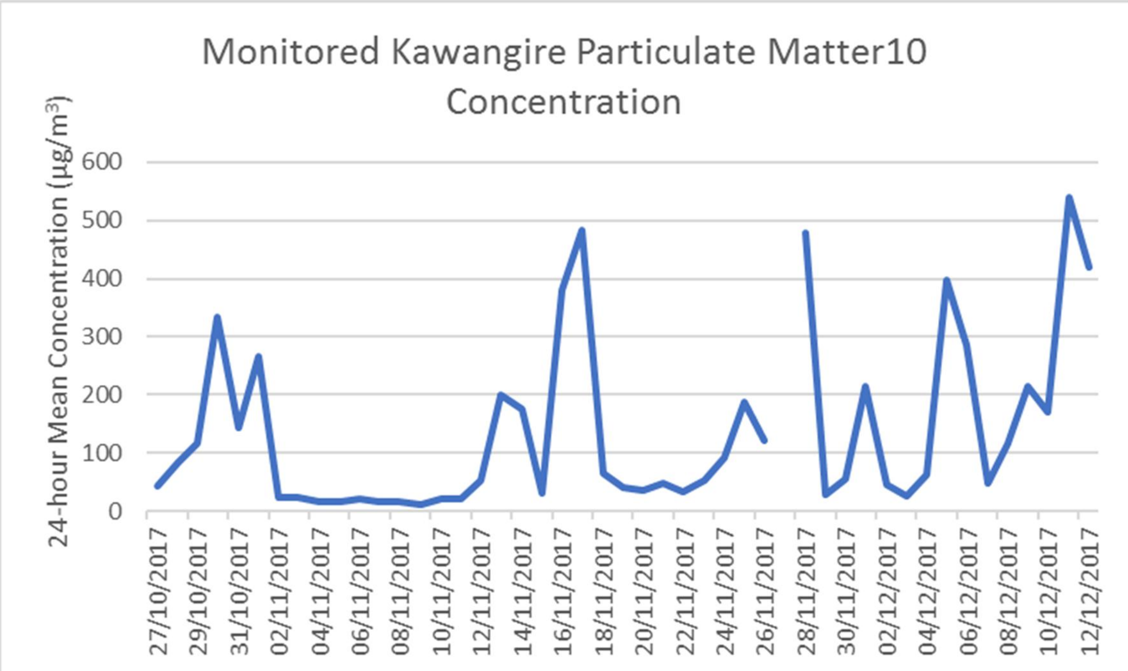
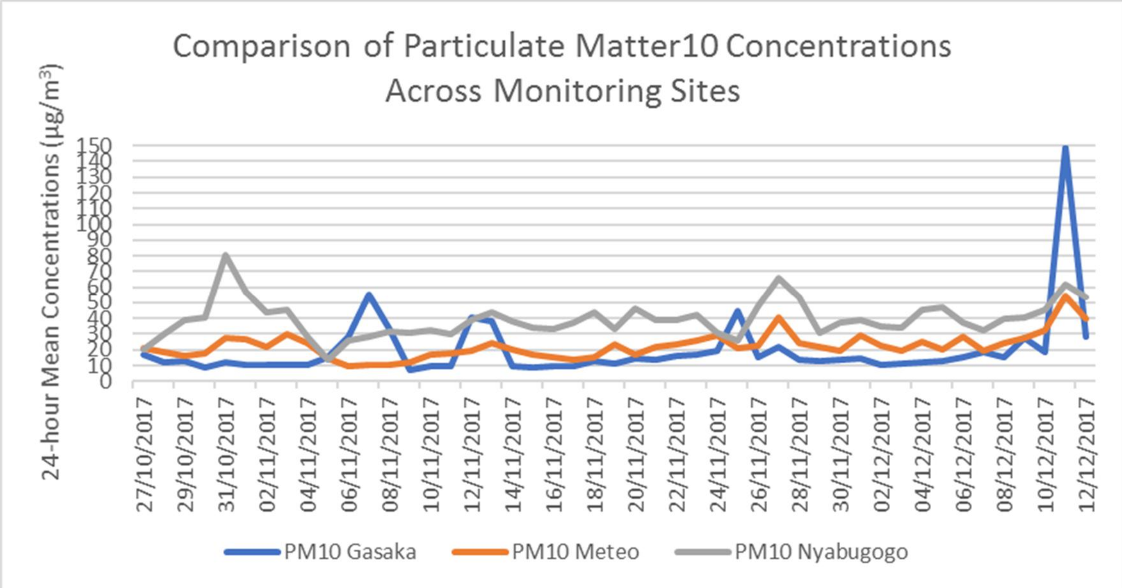


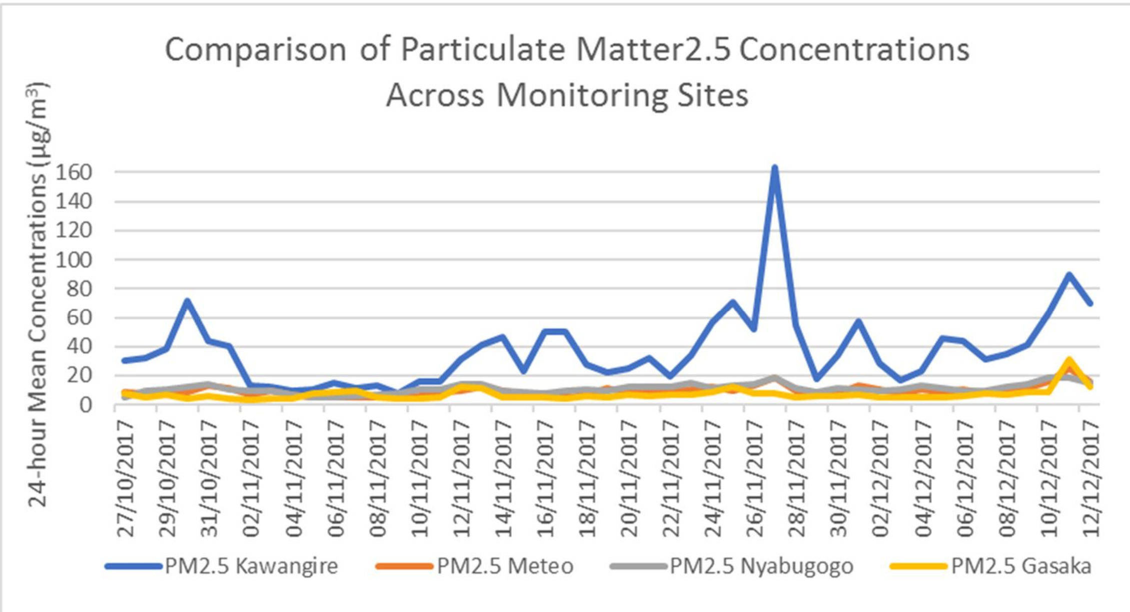
**Figure 32: Gasaka, Meteo-Gitega and Nyabugogo measured $PM_{10}$ concentrations.**




### Particulate matter$_{2.5}$

As with $PM_{10}$, the highest $PM_{2.5}$ 24-hour mean concentrations were measured at the Kawangire rural site; at this location the $PM_{2.5}$ peak corresponds with the $PM_{10}$ peak. At the other locations the PM2.5 concentrations email much more consistent and dint have major peaks. $PM_{2.5}$ concentrations at the Meteo-Gitega, Nyabugogo and Gasaka sites were similar. $PM_{2.5}$ concentrations for all sites are presented on Figure 33.

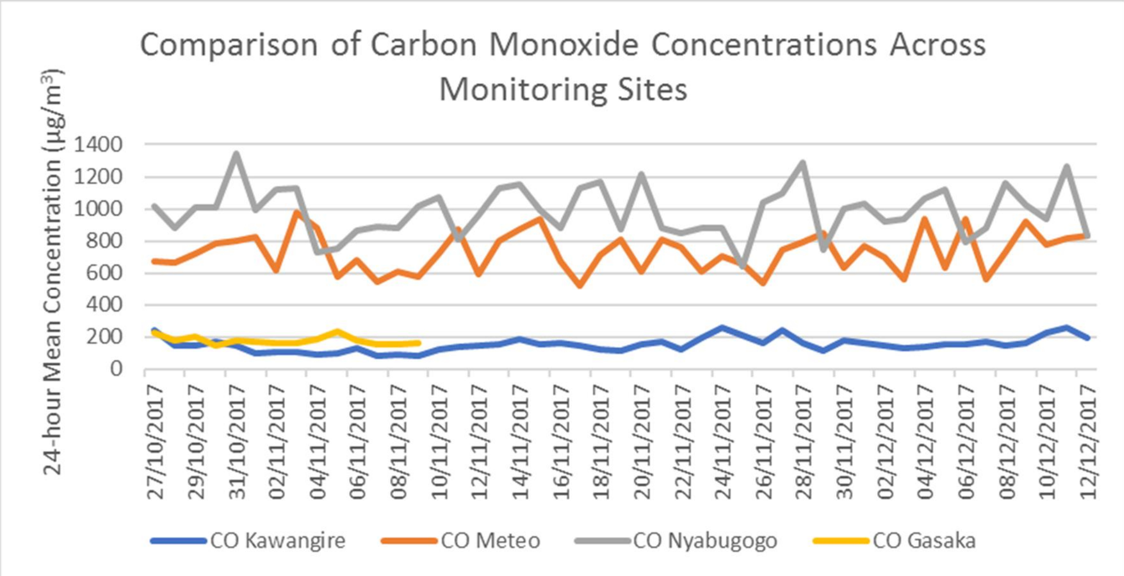
**Figure 33: Comparison of $PM_{2.5}$ concentrations**



**Carbon monoxide**

CO concentrations at the Nyabugogo roadside and Meteo – Gitega urban background sites were substantially higher than the concentrations recorded at the Kawangire and Gasaka rural sites. This would be expected as there are more sources of CO pollution in the urban environment. Nyabugogo had the highest measured concentrations of CO. CO concentrations are presented on Figure 34.

**Figure 34: Comparison of CO concentrations**




Note: Gasaka data only presented until 09/11/2017 due to data irregularities not considered representative.

### 7.2.3 Data collected using diffusion tubes

Raw data from diffusion tube monitoring is presented in Table 33 and a summary of the $NO_2$ results is presented in Table 32 and Figure 35. The raw data for $SO_2$ indicates that concentrations at all monitoring sites is low and below 5.4µg/m$^3$. These monitoring results indicate that existing concentrations of $SO_2$ are very low and below current air quality standards and that there is no significant difference between site classifications in Kigali. On this basis, no further analysis of $SO_2$ has been undertaken on the diffusion tube results.

Overall, the diffusion tube monitoring shows that concentrations of $NO_2$ are high but are not likely to be above the existing annual mean Rwanda air quality standards for $NO_2$ which are 0.05ppm,equivalent to 96µg/m$^3$. If the proposed updates to the existing air quality standards in chapter 9 are adopted the monitored concentrations would exceed the standard.

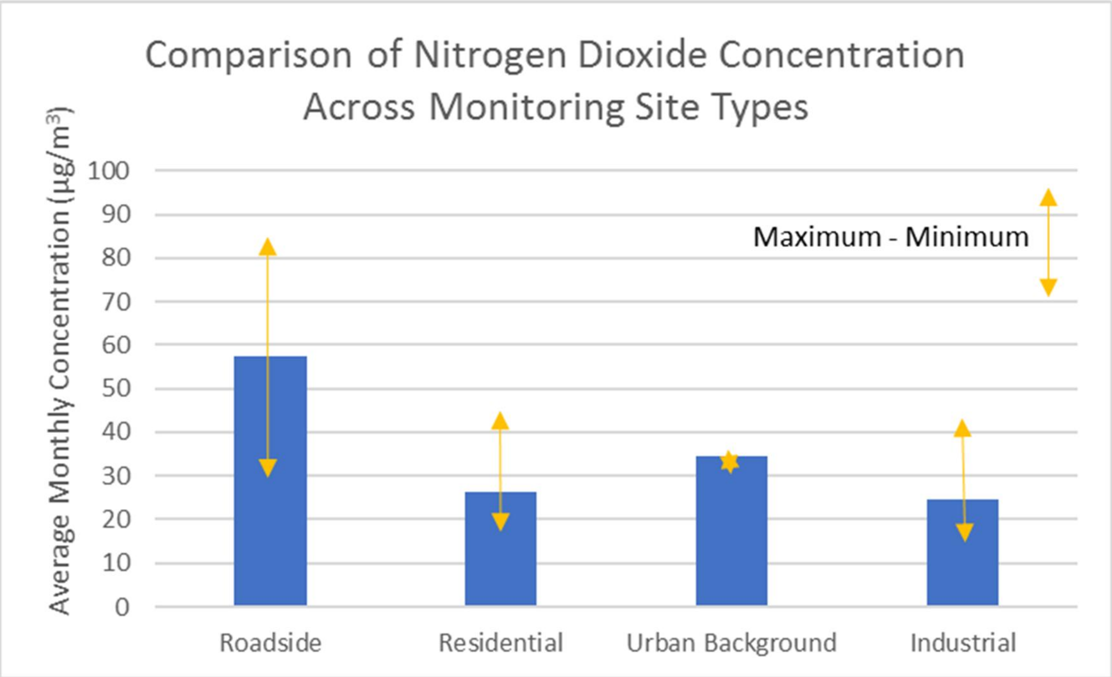
Passive monitoring for $NO_2$ indicates that average monitored concentration at roadside locations are significantly higher (more than double) than residential locations. Monitored concentrations at residential areas, urban background locations and industrial areas are similar indicating that concentrations monitored are likely to be representative of background city wide $NO_2$ concentrations.

Monitoring data collected at the industrial areas in Kigali is not significantly different to other urban background and residential areas. This indicates that industry does not appear to have a significant localised impact on air quality compared to industry contributions to city wide background concentrations.

**Table 32: Summary of passive air quality monitoring results for $NO_2$**

| Site type | Average (µg/m$^3$) | Minimum (µg/m$^3$) | Maximum (µg/m$^3$) |
|---|---|---|---|
| Roadside | 57 | 30 | 84 |
| Residential | 26 | 16 | 44 |
| Urban background | 35 | 31 | 35 |
| Industrial | 24 | 18 | 42 |

**Figure 35: Summary of passive air quality monitoring results for $NO_2$**




The roadside location with the highest recorded concentration was at site number 4 which is located on KN-5, the main road to Kigali international airport and is reporting a concentration of 84µg/m$^3$ across the two monitoring periods. Monitoring site 15, which is located in a residential area in the same area but set away from the road only recorded a concentration of 24µg/m$^3$. This demonstrates that the high concentration is only located within close proximity to the road, clearly demonstrating that vehicles are one of the main sources of pollution in Kigali and that the airport itself is not having a significant impact on $NO_2$ concentrations.

Generally, all monitored $NO_2$ concentrations are high where data has been collected next to roadside locations and there is a drop off in concentrations with distance from the road. This is demonstrated at monitoring sites 2 and 13 where the roadside site recorded concentrations of 39.2µg/m$^3$ and the nearby residential site is only recorded 18.5µg/m$^3$.

Monitoring site 17 which is representative of a residential area, and is located on the southern edge of the city recorded the lowest concentration of 16µg/m$^3$ from all the diffusion tube sites. Residential site 13 on the north-east edge of the city also recorded a low concentration of 18.5µg/m$^3$ while site 12 in the north of the city recorded concentrations of 25.3µg/m$^3$. These results show that in addition to air quality being better away from roads it also improves as you move away from the main city centre and the areas with the highest population density. This is further confirmed by the data monitored at some for the residential sites (site 8) and the urban background sites (site 23, 24 and 25) located more centrally where $NO_2$ concentrations were 10 to 15µg/$m^3$ higher than the sites on the edge of the city.

**Table 33: Passive air quality monitoring results**

| Site ID | Coordinates | | Site Type | $NO_2$ | | | $SO_2$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Period 1 | Period 2 | Average | Period 1 | Period 2 | Average |
| 1 | 1° 54.937'S | 30° 4.254'E | Roadside | No data | 29.5 | 29.5 | No data | <4.2 | <4.2 |
| 2 | 1° 55.594'S | 30° 6.627'E | Roadside | 45.8 | 32.6 | 39.2 | <5.3 | <3.8 | <4.6 |
| 3 | 1° 55.927'S | 30° 5.950'E | Roadside | No data | 40.2 | 40.2 | No data | <3.8 | <3.8 |
| 4 | 1° 57.697'S | 30° 7.313'E | Roadside | 92.9 | 75.8 | 84.4 | <5.3 | <4.2 | <4.8 |
| 5 | 1° 59.061'S | 30° 6.198'E | Roadside | 58.6 | 48.2 | 53.4 | <5.3 | <4.2 | <4.8 |
| 6 | 1° 58.158'S | 30° 3.545'E | Roadside | 71.5 | 51.4 | 61.5 | <5.1 | <4.2 | <4.7 |
| 7 | 1° 57.145'S | 30° 3.264'E | Roadside | 80.7 | 51.1 | 65.9 | <5.4 | <4.3 | <4.9 |
| 8 | 1° 56.927'S | 30° 4.143'E | Roadside | 55 | No data | 55 | <5.4 | No data | <5.4 |
| 9 | 1° 58.129'S | 30° 3.129'E | Roadside | 62.2 | No data | 62.2 | <5.1 | No data | <5.1 |
| 10 | 1° 56.678'S | 30° 3.687'E | Roadside | 58.3 | 46.2 | 52.3 | <5.4 | <4.2 | <4.8 |
| 11 | 1° 56.342'S | 30° 3.695'E | Roadside | 78.5 | 62.5 | 70.5 | <5.4 | <4.2 | <4.8 |
| 12 | 1° 55.161'S | 30° 4.319'E | Residential | 28.8 | 21.8 | 25.3 | <5.4 | <4.2 | <4.8 |
| 13 | 1° 55.593'S | 30° 6.761'E | Residential | 20.6 | 16.3 | 18.5 | <5.3 | <3.8 | <4.6 |
| 14 | 1° 56.073'S | 30° 6.237'E | Residential | No data | No data | No data | No data | No data | No data |
| 15 | 1° 57.485'S | 30° 8.261'E | Residential | 26.9 | 21 | 24.0 | <5.3 | <4.2 | <4.8 |
| 16 | 1° 59.051'S | 30° 6.191'E | Residential | 31.1 | 26.5 | 28.8 | <5.3 | <4.2 | <4.8 |
| 17 | 1° 59.660'S | 30° 4.021'E | Residential | 18.3 | 13.7 | 16 | <5.1 | <4.2 | <4.7 |
| 18 | 1° 58.232'S | 30° 4.417'E | Residential | No data | 27.5 | 27.5 | No data | <4.2 | <4.2 |
| 19 | 1° 58.333'S | 30° 3.388'E | Residential | No data | 43.6 | 43.6 | No data | <4.2 | <4.2 |
| 20 | 1° 57.145'S | 30° 3.266'E | Residential | 43.3 | No data | 43.3 | No data | No data | No data |
| 21 | 1° 57.061'S | 30° 4.842'E | Residential | No data | No data | No data | No data | No data | No data |
| 22 | 1° 55.293'S | 30° 3.266'E | Residential | No data | 28.1 | 28.1 | No data | <3.8 | <3.8 |
| 23 | 1° 55.881'S | 30° 3.664'E | Urban background | 37.3 | 24.9 | 31.1 | <5.4 | <3.8 | <4.6 |
| 24 | 1° 57.398'S | 30° 7.008'E | Urban background | 46.8 | 35 | 40.9 | <5.3 | <4.2 | <4.8 |
| 25 | 1° 57.062'S | 30° 3.784'E | Urban background | 38.7 | 30.9 | 34.8 | <5.3 | <4.3 | <4.8 |
| 26 | 1° 58.200'S | 30° 4.384'E | Urban background | 34.4 | 28.5 | 31.5 | <5.1 | <4.2 | <4.7 |

| Site ID | Coordinates | | Site Type | $NO_2$ | | | $SO_2$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | Latitude | Longitude | | Period 1 | Period 2 | Average | Period 1 | Period 2 | Average |
| 27 | 1° 57.204'S | 30° 9.204'E | Industrial | 26.7 | 18.3 | 22.5 | <5.3 | <3.8 | <4.6 |
| 28 | 1° 58.182'S | 30° 5.581'E | Industrial | 42.2 | No data | 42.2 | <5.1 | No data | <5.1 |
| 29 | 1° 53.510'S | 30° 4.210'E | Industrial | 20.5 | 14.6 | 17.6 | <5.4 | <4.2 | <4.8 |
| 30 | 1° 56.956'S | 30° 3.675'E | Roadside | 64.8 | 42.8 | 53.8 | <5.4 | <4.2 | <4.8 |

Notes: No data is where diffusion tubes were missing following the monitoring period. $SO_2$ data shown as < as below the limit of detection

## 7.3 Analysis of historical particulate matter monitoring

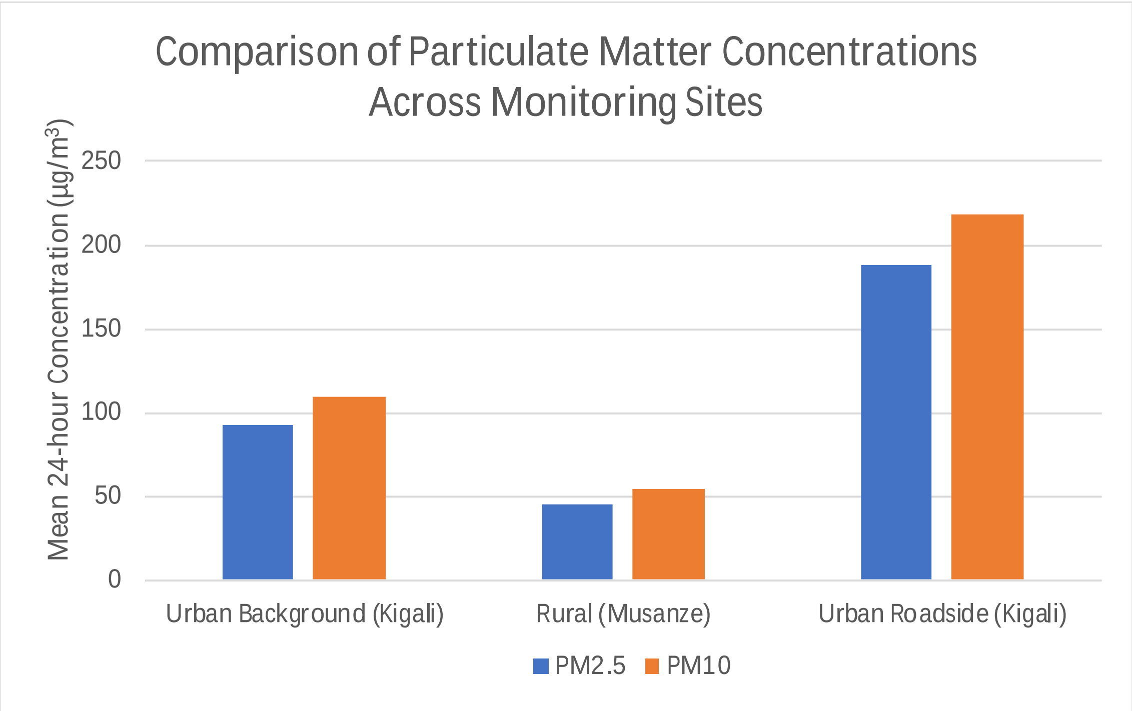
### 7.3.1 Overview

The following sections provide an analysis of the PM monitoring undertaken at urban background and urban roadside sites in Kigali and the rural site in Mukungwa between 01 April 2017 and 30 June 2017.

### 7.3.2 General particulate matter concentrations

The mean measured 24-hour $PM_{2.5}$ and $PM_{10}$ concentrations were highest at the urban roadside location in Kigali, followed by the urban background location in Kigali with the lowest concentrations being measured at the rural site in Musanze district. The $PM_{2.5}$ and $PM_{10}$ concentrations were over four times higher at the urban roadside location in Kigali compared to the rural site in Musanze. These results are expected due to the proximity of the monitoring sites to emission sources. The results are presented in Figure 36.

**Figure 36: Comparison of mean measured 24-hour PM concentrations across monitoring sites**

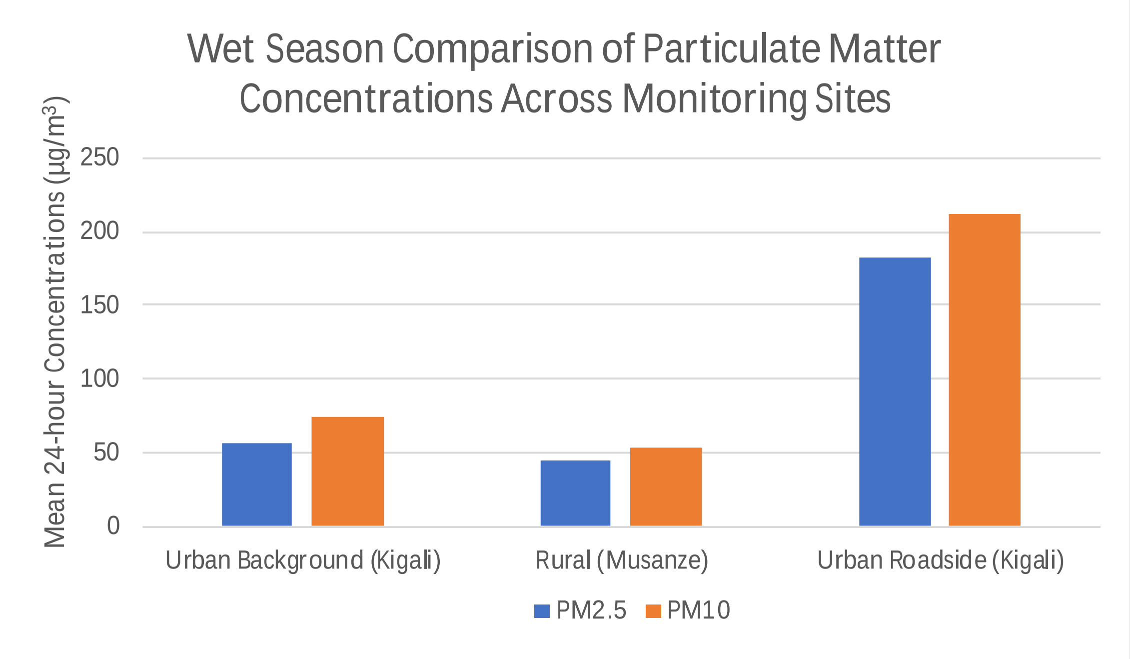



Source: Mott MacDonald .Notes: Urban background and urban roadside means contain data from both wet and dry seasons, rural monitoring was undertaken during the wet season only. A week of data was removed from the urban background site due to it coinciding with Tutsi Genocide Commemoration Week that notably reduces activity within the city and impacts upon average concentrations. Urban background mean contains 29 days of monitoring data, rural contains 21 days and urban roadside 31. A car free day was excluded from the urban roadside concentrations.

### 7.3.3 Wet season

A comparison of the monitoring undertaken at the three sites during the wet season only showed a similar pattern to the overall monitoring results with concentrations highest at the roadside location, followed by the urban background and the rural. The wet season mean 24-hour PM concentrations are presented in Figure 37.

**Figure 37: Comparison of wet season mean measured 24-hour PM concentrations across monitoring sites**

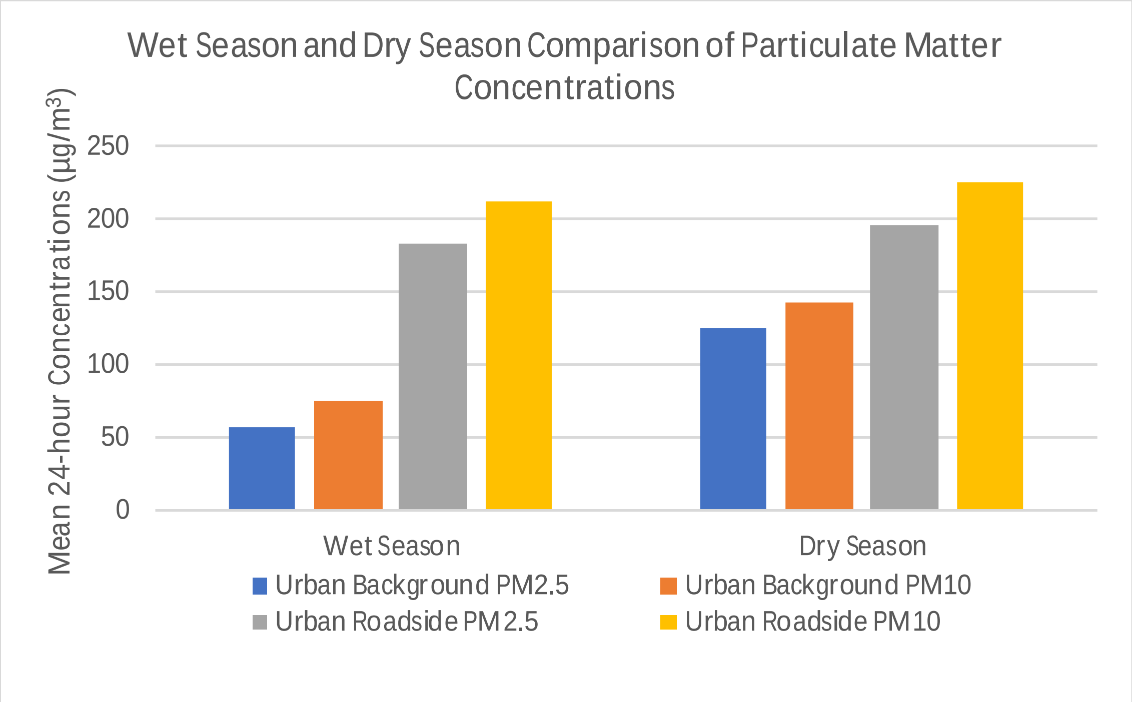



Source: Mott MacDonald . Notes: A week of data was removed from the urban background site due to it coinciding with the week of commemoration of genocide against Tutsi that notably reduces activity within the city and therefore impacts upon concentrations. Urban background mean contains 14 days of monitoring data, rural contains 21 days and urban roadside contains 17 days.

### 7.3.4 Wet season vs dry season

Monitoring was undertaken during the wet and dry seasons at the urban background and urban roadside locations in Kigali. Mean 24-hour $PM_{2.5}$ and $PM_{10}$ concentrations were lower at both sites in the wet season compared to the dry season. The roadside location only showed a slight reduction in PM concentrations from the dry season to the wet season, however at the urban background location a reduction of approximately 50% was measured. This indicates that there may be quite substantial seasonal variances in background PM concentrations in areas with lower volumes of road traffic. The seasonal variance at the urban background and urban roadside sites are presented in Figure 38.

**Figure 38: Comparison of seasonal variation in mean measured 24-hour PM concentrations**

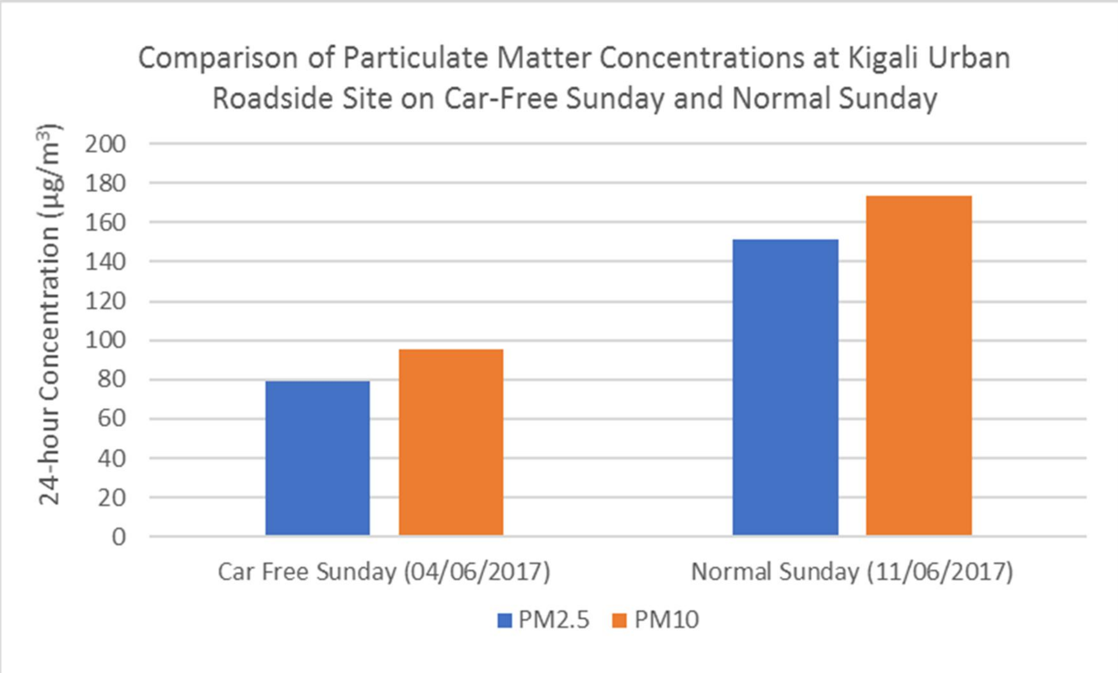



Source: Mott MacDonald . Notes: A week of data was removed from the urban background site due to it coinciding with Tutsi Genocide Commemoration Week that notably reduces activity within the city and therefore impacts upon concentrations. A day of data was removed from the urban roadside dry season due to it being a car free day. Urban background wet season means contain 14 days of monitoring data with the dry season 15 days. Urban roadside wet season mean concentrations contain 17 days of monitoring data with the dry season 13 days.

### 7.3.5 Car free day monitoring

During the monitoring undertaken at the urban roadside location in Kigali, there was a car free day. The 24-hour mean concentration for this day has been compared to mean of the 24-hour mean concentrations of the dry season for the urban roadside site. $PM_{2.5}$ and $PM_{10}$ concentrations reduced by approximately 50% on the car free day. It should also be noted that the car free day was on a Sunday where concentrations may already be lower than usual due to reduced overall city activity. The results from this monitoring are presented in Figure 39.

**Figure 39: Comparison of dry season Sunday to car free Sunday in the mean measured 24-hour PM concentrations**

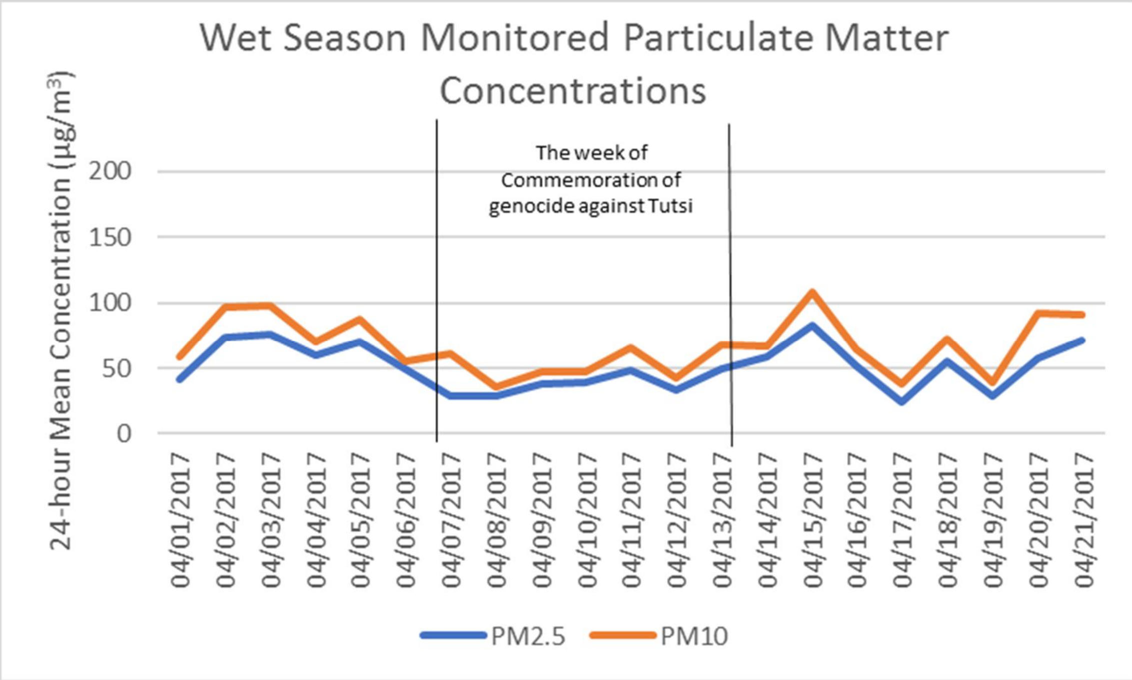



Source: Mott MacDonald.

### 7.3.6 Urban background (Kigali)

Figure 40 presents the $PM_{2.5}$ and $PM_{10}$ concentrations measured during the wet season monitoring for the urban background site in Kigali. The week of Commemoration of genocide against Tutsi was from 07 April 2017 to 13 April 2017, this event notably reduces activity in the city and this is demonstrated in the measured PM concentrations.

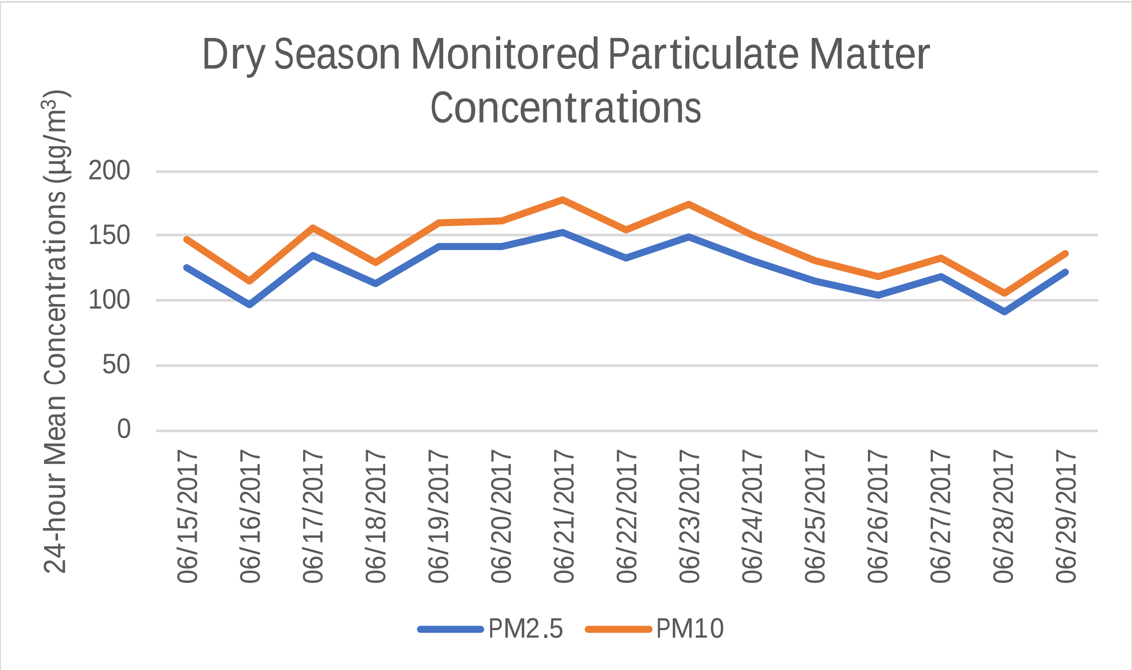
**Figure 40: Wet season measured urban background PM concentrations.**




Source: Mott MacDonald.

Figure 41 below presents the $PM_{2.5}$ and $PM_{10}$ concentrations measured during the dry season monitoring for the urban background site in Kigali.

**Figure 41: Dry season measured urban background PM concentrations.**

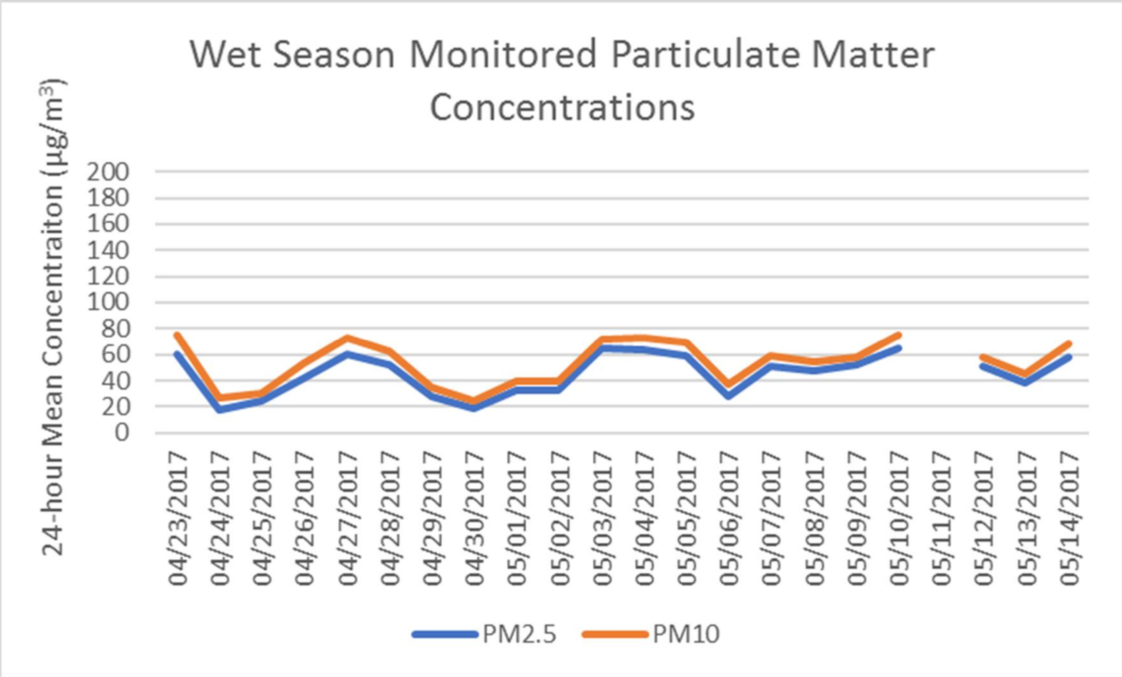



Source: Mott MacDonald. .

### 7.3.7 Rural (Mukungwa, Musanze district)

Figure 42 presents the $PM_{2.5}$ and $PM_{10}$ concentrations measured during the wet season monitoring for the urban background site in Kigali. When compared to data collected at the urban background site presented in Figure 43 it can be concluded that rural concentrations are significantly lower.

**Figure 42: Wet season measured rural PM concentrations.**

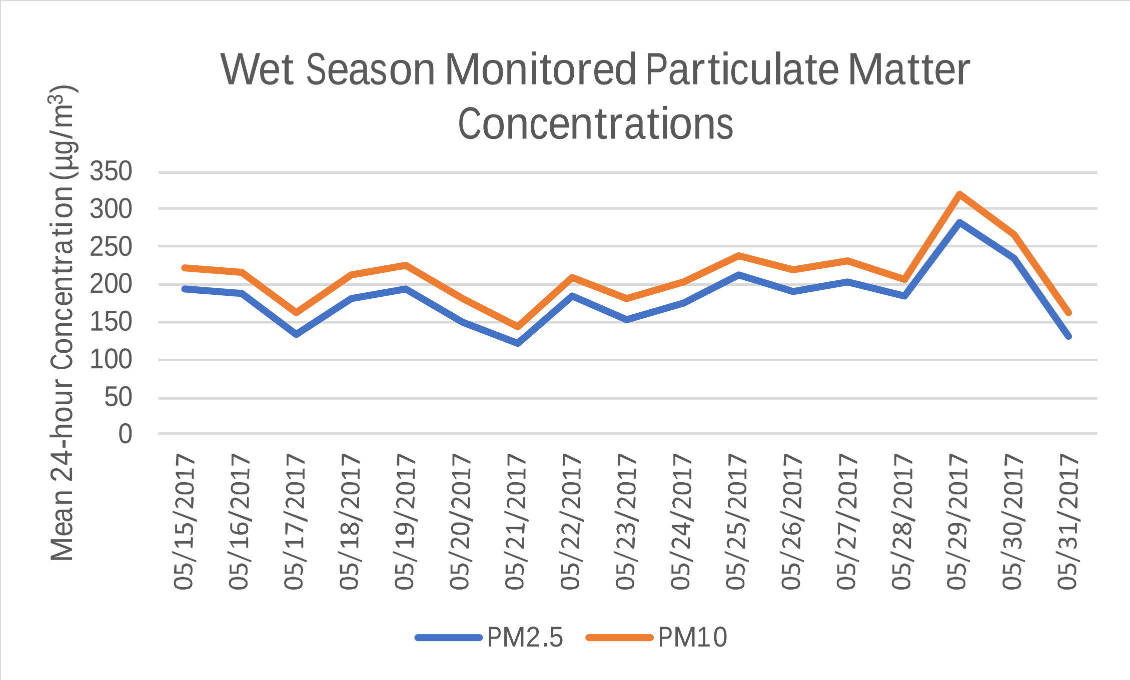



Source: Mott MacDonald. Notes: data from the 11/05/2017 missing due to monitor being affected by strong winds.

### 7.3.8 Urban roadside (Kigali)

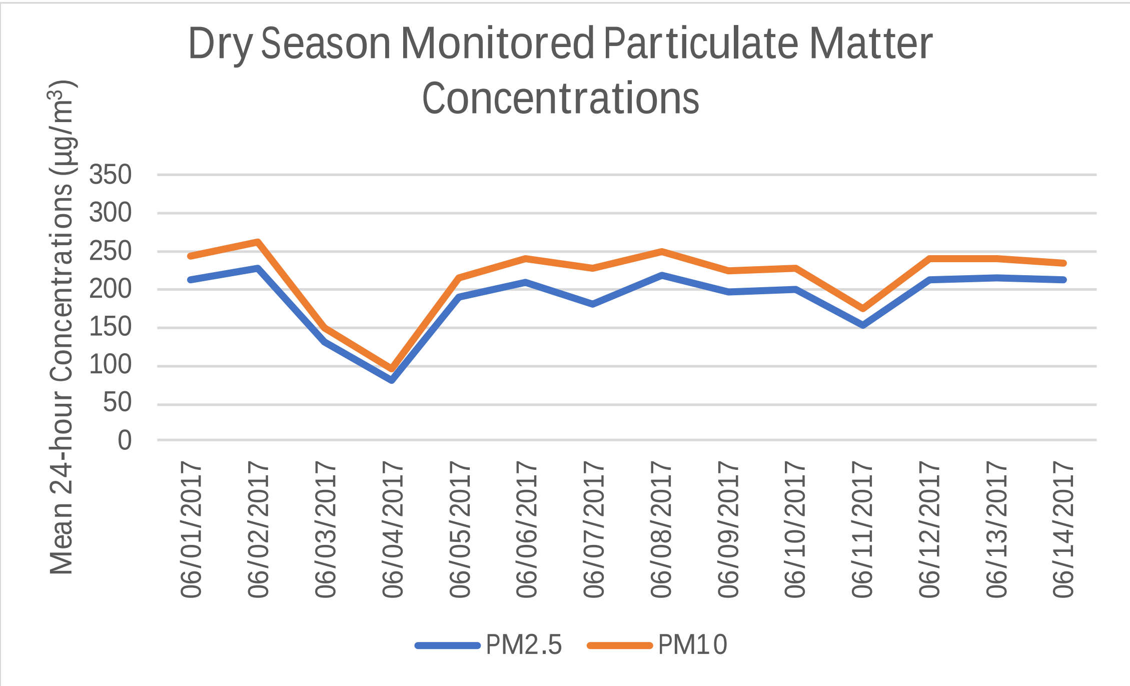
Figure 43 presents the $PM_{2.5}$ and $PM_{10}$ concentrations measured during the wet season monitoring for the urban roadside site in Kigali. Figure 44 presents $PM_{2.5}$ and $PM_{10}$ concentrations measured during the dry season monitoring for the urban roadside site in Kigali. The data shows that the wet season does not significantly reduce particulate concentrations compared to the dry season at urban roadside locations. Monitored concentrations are high and in excess of current Rwandan and best practice international air quality standards for particulate matter.

**Figure 43: Wet season measured urban roadside PM concentrations.**




Source: Mott MacDonald.

**Figure 44: Dry season measured urban roadside PM concentrations.**




Source: Mott MacDonald..

### 7.3.9 Meteorological Data

Meteorological data from stations around the monitoring sites at the time of sampling was interrogated to identify any correlations. Temperatures were slightly higher in the dry season over the wet season during the monitoring periods. There were no great variations in wind direction or speeds between seasons leading to the conclusions that the additional rainfall in the wet season reduces particulate concentrations comparted to the dry season.

## 7.4 Analysis of data provided by CMU

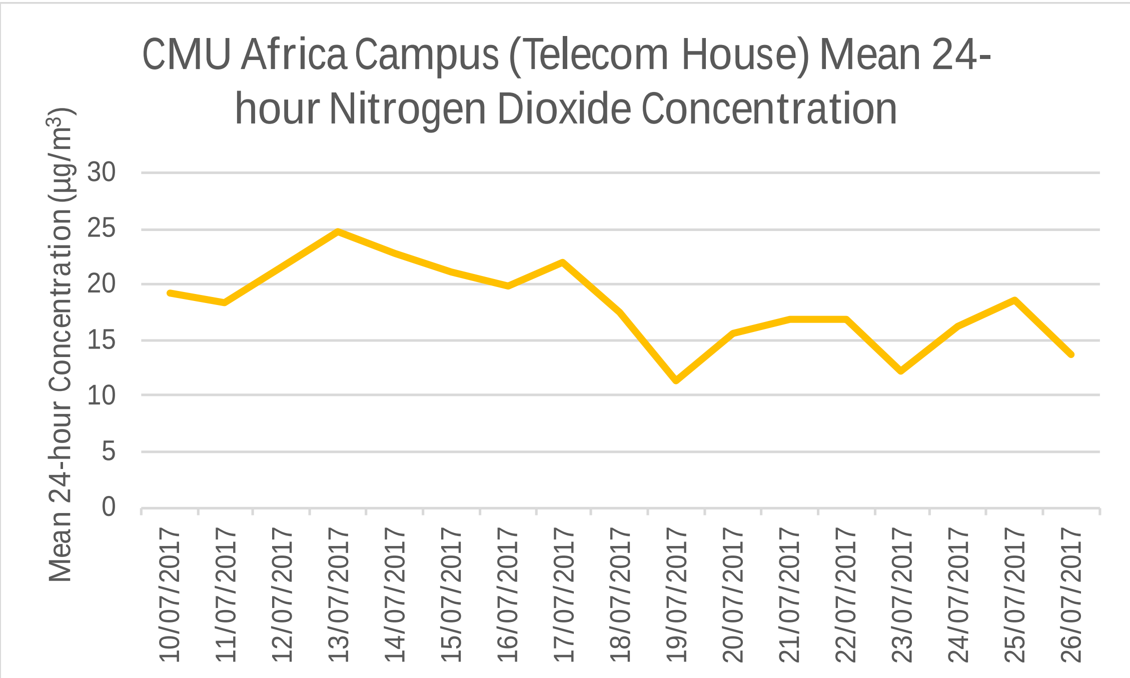
### 7.4.1 Overview

As discussed in Section 6.3.2, the data supplied by CMU contained various uncertainties and irregularities that limited the level of analysis that could be completed. The following sections present the analysis that could be drawn from $NO_2$ and $O_3$ concentrations. Mean 24-hour concentrations were produced for these pollutants where possible.

### 7.4.2 CMU Africa Campus (Telecom House)

During the monitoring undertaken at Telecom House, $NO_2$ concentration ranged from approximately 11µg/m$^3$ to 25µg/m$^3$. These concentrations are considered low and are below current Rwanda standards and best practice international standards. They are presented in Figure 45.

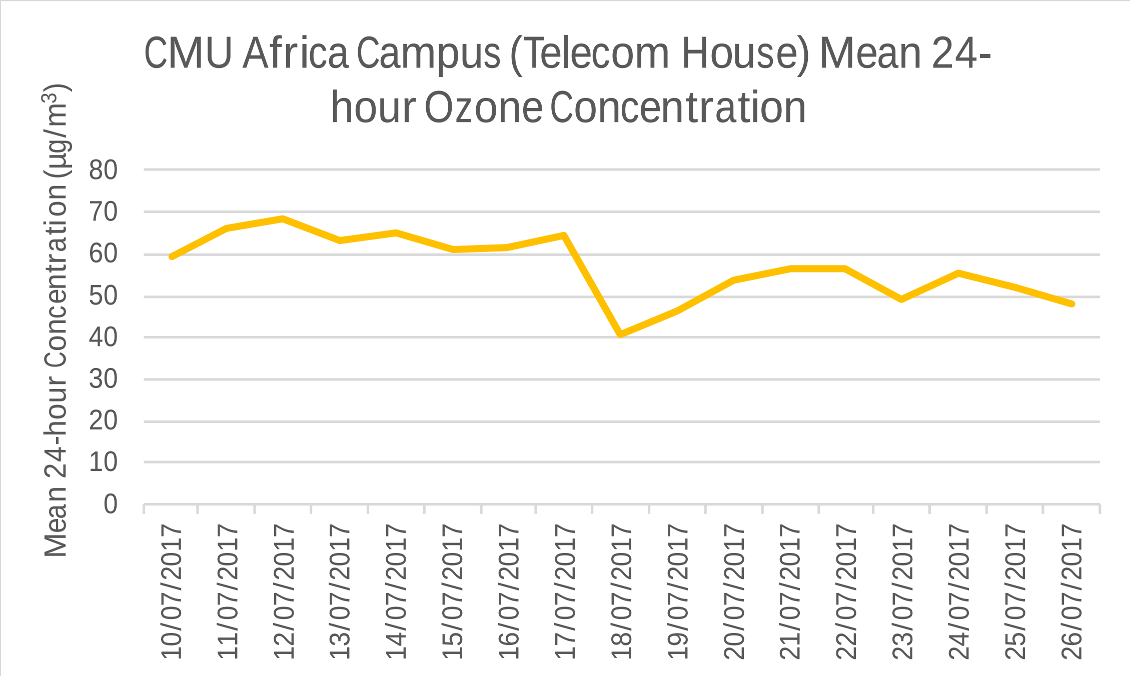
**Figure 45: CMU Africa Campus (Telecom House) measured nitrogen dioxide concentrations**




Source: CMU Data converted from parts per billion (ppb) to µg/m$^3$ using equation: Concentration (µg/m$^3$) = Concentration (ppb) x Molecular Weight (g) / Molar Volume (at given temperature).

Measured $O_3$ levels during the sampling period ranged from approximately 40µg/m$^3$ to 68µg/m$^3$, these concentrations, which are considered low and to be below the existing Rwanda standards, are presented in Figure 46.

**Figure 46: CMU Africa Campus (Telecom House) measured ozone concentrations**

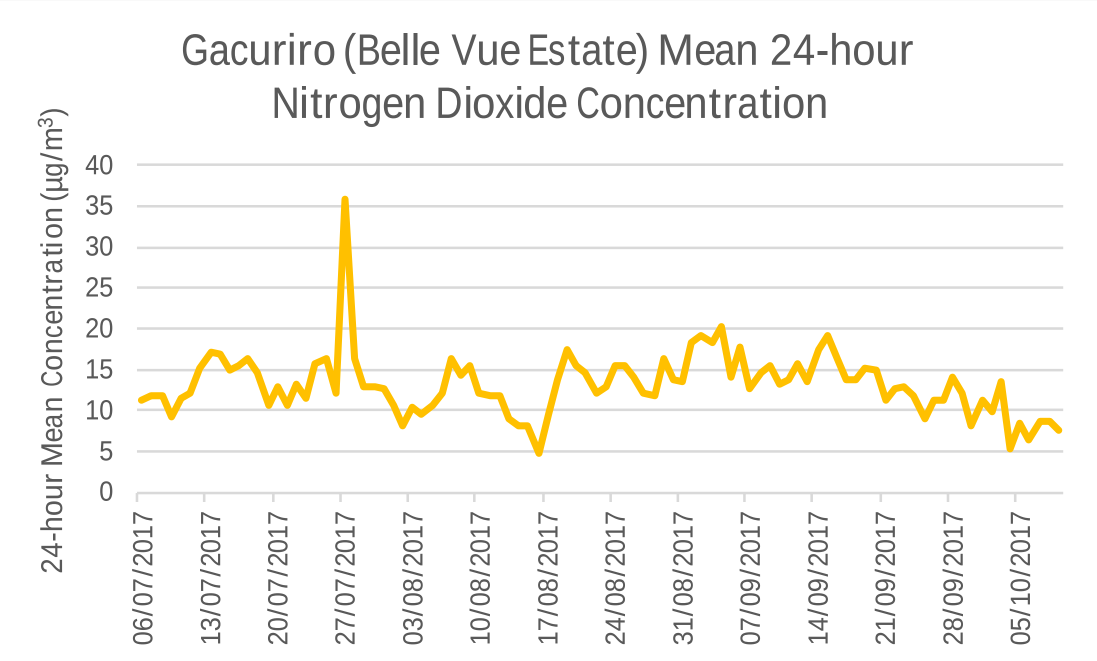



Source: CMU. Data converted from parts per billion (ppb) to µg/m$^3$ using equation: Concentration (µg/m$^3$) = Concentration (ppb) x Molecular Weight (g) / Molar Volume (at given temperature).

### 7.4.3 Gacuriro (Belle Vue Estate)

Measured $NO_2$ levels at the Belle Vue Estate were low across the monitoring undertaken between July and October 2017 supporting the conclusion that ambient $NO_2$ concentrations are not a material concern currently in Rwanda. The concentrations are presented in Figure 47.

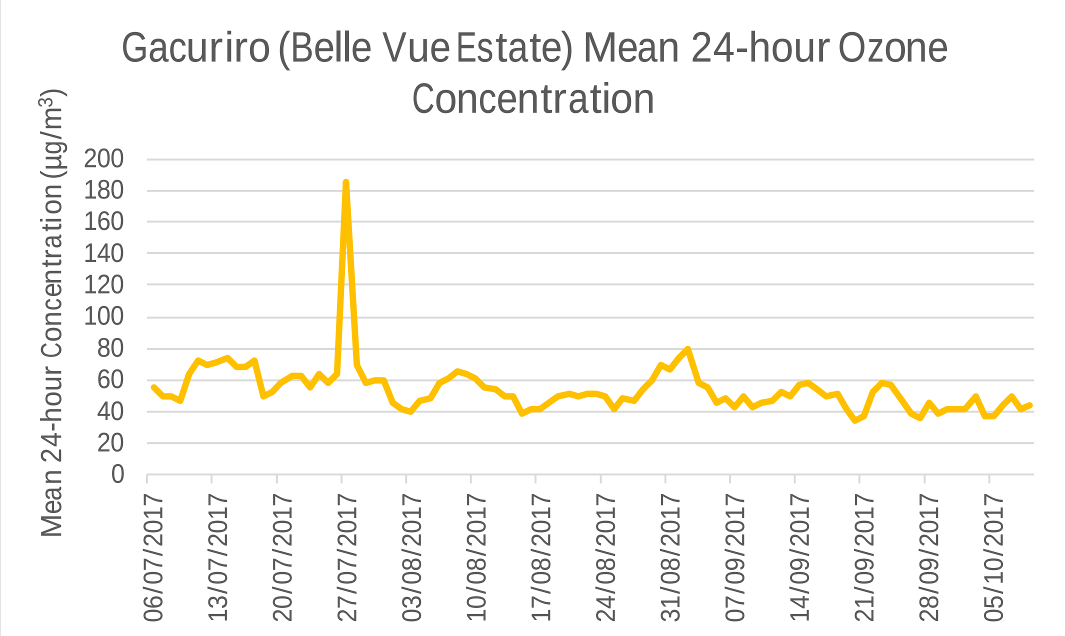
**Figure 47: Gacuriro (Belle Vue Estate) measured nitrogen dioxide concentrations**




Source: CMU Data converted from parts per billion (ppb) to µg/m³ using equation: Concentration (µg/m³) = Concentration (ppb) x Molecular Weight (g) / Molar Volume (at given temperature).

Measured $O_3$ levels were generally low at the Belle Vue Estate across the monitoring period. There was one spike in concentration across the three months. Concentrations of $O_3$ are presented in Figure 48.

**Figure 48: Gacuriro (Belle Vue Estate) measured ozone concentrations**




Source: CMU. Data converted from parts per billion (ppb) to µg/m³ using equation: Concentration (µg/m³) = Concentration (ppb) x Molecular Weight (g) / Molar Volume (at given temperature).

## 7.5 Qualitative analysis of air quality in two further cities

### 7.5.1 Overview

This section includes qualitative analysis of air quality in two cities one located at high altitude and one located at low altitude. Altitude can have an important role to play in ambient air quality as cities at higher altitudes have lower atmospheric pressure. This means mobile emission sources designed to operate at normal atmospheric pressure operate less efficiently and can emit higher concentrations of hydrocarbons and carbon monoxide.

### 7.5.2 Bugarama – located at low altitude

Bugarama is located in the Rusizi District of the Western Province and is adjacent to borders with Burundi to the east and the Democratic Republic of the Congo to the west (2°41′50″S 29°00′30″E). Bugarama is located in the lowlands of the south-west which are the lowest parts of Rwanda at an altitude of 900m approximately 300 kilometres from Kigali. The climate is tropical continental and humid with an average temperature of 25°C.

Total population of Bugarama is estimated to be approximately 30,000. Due to the size of the city it would be expected that air quality would be better compared to Kigali as there would be less emissions from vehicles and a much lower housing density resulting in fewer emissions per square kilometre from domestic stoves.

Air pollution in this city is likely to be dominated by sources such as:

- Burning as a result of agriculture in the region
- Transboundary pollution from nearby Burundi and the DRC
- Nearby mining activities in the area

- The cement factory owned and operated by CIMERWA which is located approximately 10 kilometres to the north.

As the city is located at a lower altitude than Kigali it is anticipated that this would also contribute to air quality being better overall compared to Kigali.

### 7.5.3 Rubavu – located at high altitude

The Rubavu district is located at an altitude of 2158m and is located in the Western Province. It is approximately 145 kilometres from Kigali (1.69865S &29.37149 E). The main city in the district is Gisenyi which is located on the shores of Lake Kivu. There are several hotels and sandy beaches. Rubavu is located to the east of Gisenyi and is part of the strategic masterplan plan to develop second cities away from Kigali.

Air quality in Rubavu is likely to be better than in Kigali as there is limited industry and the population density is lower than in Kigali. Air pollution levels are likely to be heavily influenced by transboundary pollution from the adjacent city of Goma which lies adjacent to the border with the DRC and is understood to experience poor air quality. In addition, existing air quality will be influenced by natural sources such as the active volcano on Mount Nyiragongo.

Although located at a high altitude, and a higher altitude than Kigali, the altitude is not anticipated to significantly affect the existing ambient air quality to an extent that air quality would be worse than in Kigali. This is because the number of emissions sources are sufficiently lower than in Kigali for it not to make a significant difference in ambient pollutant concentrations.

### 7.5.4 Summary

Generally, it is expected that Kigali is likely to experience the highest baseline pollutant concentrations of the major cities within Rwanda due to its size and range of emission sources present. However, air quality strategy measures outlined in chapter 9 are considered to be beneficial countrywide particularly those related to reducing emissions from domestic stove use and pollution hotspots in all cities are expected where there are traffic congestion hotspots and a high density of domestic stoves.

## 7.6 Summary of existing baseline

A review of data collected for the study and existing air quality data indicates that the main pollutants of concern are:

- $PM_{10}$ and $PM_{2.5}$
- $NO_2$

Monitoring data has shown that the main areas where $NO_2$ concentrations are high and above international standards is along busy roads within Kigali. Monitoring data for $NO_2$ has indicated that there are not significantly elevated pollutant concentrations across the whole country.

The data has indicated that background concentrations of $PM_{10}$ and $PM_{2.5}$ in Kigali are elevated and are likely to be well above standards used in other countries. A review of the data and the main emissions sources indicates that domestic stoves are likely to be heavily influencing background concentrations but road traffic also is a large contributor to high PM concentrations near busy roads.

PM concentrations in Rural areas although not generally as high as in Kigali are still elevated and for some periods can be above international standards for protection of health. This indicates that there are lots of regional sources and existing practices such as agriculture and localised burning of biomass in domestic stoves raising the baseline to high levels which is added to and elevated further by localised naturally occurring sources.

Although not all monitoring data used in the study indicates the same conclusion, data has been collected using multiple methods. Therefore, a precautionary approach has been adopted and strategy measures have been produced based on the worst case monitoring results and are aimed at improving concentrations of $PM_{10}$, $PM_{2.5}$ and $NO_2$.

# 8 Likely future trends

## 8.1 Overview

This chapter provides a qualitative analysis of what the likely future air quality trends are in Rwanda and is split between a business as usual approach and following the implementation of the air quality strategy outline in chapter 9. The analysis has been undertaken up to 2030.

## 8.2 Business as usual approach

Emissions within Rwanda are predicted to increase year on year as the population grows and the country becomes more developed. Emissions would increase from all of the main sectors including energy generation, industry, domestic sources and transportation.

The increase in transport related emissions has the potential to lead to the greatest impact on local air quality as the study has demonstrated that emissions from transport has significant effects on air quality in close proximity to roads.

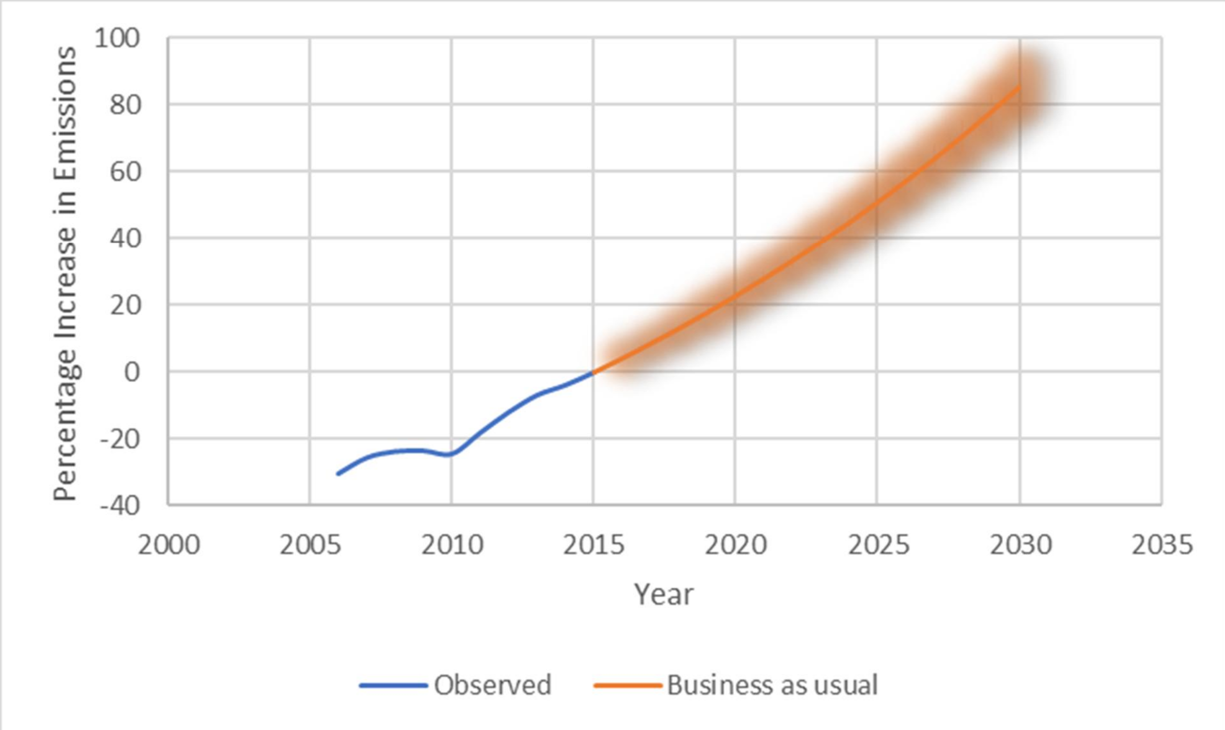
Increases in emissions from stoves, due to increased population and urbanisation are likely to increase background concentrations of pollutants, particularly $PM_{10}$, across the whole of Kigali and other urban areas as the distribution of these emissions sources is widespread.

Emissions from the energy sector are likely to increase as a greater number of thermal power plants are required to supplement existing supplies and future generation supplied by renewable sources. However, there is already good provision of renewable sources and plans to develop renewable generation meaning that emissions from the energy sector will not increase as much as would be expected if all future power needs were met through thermal generation.

Emissions from industry will increase as Rwanda develops its manufacturing sectors and increased manufacturing of cement and bricks is required to meet the demands off future population growth.

Figure 49 presents the potential increase in emissions up to 2030. Percentage increase compared to a base year of 2015 has been derived based on the annual increases in observed emissions of greenhouse gases between 2006 and 2015. The average increase across this period indicated a 4.2% annual increase in emissions. Based in these estimates emissions would increase by approximately 85% by 2030 compared to 2015 levels.

**Figure 49: Rwanda emissions assuming business as usual**




Source: Mott MacDonald based on observed emissions presented in Final inventory report for Third National Communication Reports[127]

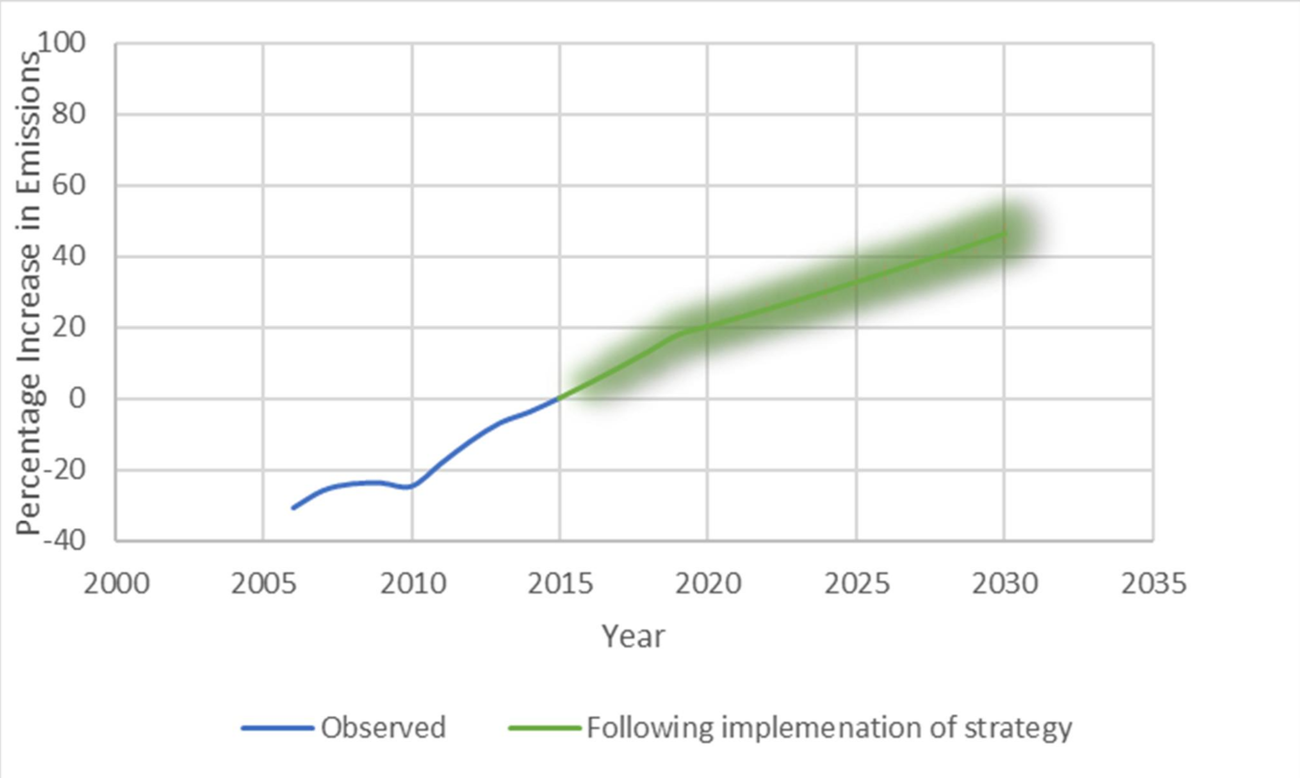
Notes: Shaded area represents uncertainty of 10 percent

## 8.3 Following implementation of air quality strategy

Figure 50 presents an estimated projection for the increase in emissions following the implementation of measures identified in the air quality strategy. It has been assumed that the increase in emissions would follow the same projection as in the business as usual case up to 2020, after which the effects of the strategy measures would take effect as they are implemented. The projection has assumed a 2.1% annual increase in emissions rather than a 4.2 percent annual increase. Based on these estimates the emissions would increase by approximately 50% compared to 2015 levels in 2030.

[127] Innocent Nkurikiyimfura, Telesphore Mugwiza and Theoneste, 2017, Energy Greenhouse Gas emission in Rwanda (2006/2015), Final inventory report for Third National Communication Reports

**Figure 50: Rwanda emissions following implementation of strategy**




Source: Mott MacDonald based on observed emissions presented in Final inventory report for Third National Communication Reports [128]

Notes: Shaded area represents uncertainty of 10 percent

[128] Innocent Nkurikiyimfura, Telesphore Mugwiza and Theoneste, 2017, Energy Greenhouse Gas emission in Rwanda (2006/2015), Final inventory report for Third National Communication Reports

# 9 Air quality control strategy

## 9.1 Overview

The review of existing literature, applicable standards and monitoring data undertaken in the preceding chapters has been completed with a view to recommending realistic and implementable strategies that can be used to manage air quality alongside future urbanisation and development in Rwanda.

## 9.2 Strategy recommendations

### 9.2.1 Overarching framework

Our suggested strategy recommendations are presented in Table 34 in conjunction with a summary of the evidence base for the policy need. Where appropriate we have identified the government department who should take ownership of the policy recommendation and provided an indicative timeframe.

**Table 34: Strategy recommendations**

| Policy number | Policy recommendation | Description | Evidence base | Responsibility | Timeframe |
|---|---|---|---|---|---|
| AQ-1 | Refresh existing air quality standards | Develop Rwanda's own set of ambient air quality and emissions to air standards that are tailored to the specific needs of Rwanda | Review of existing standards identified some inconsistencies and confusion in standards which are based on EAC standards that are common across the EAC area and not specific to Rwanda. See evidence in chapter 3, chapter 4 and section 9.2.2. | REMA and the RSB | 12 months |
| AQ-2 | Apply strict import regulations on vehicles | Restrict the age of imported cars, buses, Jeeps, articulated and rigid HGV's so that only newer less polluting vehicles enter the fleet. | Analysis of emissions from existing vehicle fleet identified older cars, buses, Jeeps, articulated and rigid HGV's to be the largest contributors to poor air quality. See analysis in chapter 5. | REMA and RRA | 2 years |
| AQ-3 | Smooth traffic flows around traffic hotspots | Review traffic congestion in Kigali, identify the most heavily congested areas where there is relevant human health exposure and investigate options to smooth the flow through road improvements | Analysis identified that emissions are greatest when traffic is moving at slow speeds in heavily congested areas leading to high pollutant concentrations near these areas. See analysis in chapter 5. | RTDA | 2 years |
| AQ-4 | Reduce emissions from bus fleet | Promote incentives to renew the bus fleet and include new hybrid vehicles | Analysis of emissions indicates emissions from buses are proportionally high considering the total number of buses in operation. See analysis in chapter 5. | RTDA | 3 years |
| AQ-5 | Invest in public transport systems | Identify major transport corridors and investigate the potential to develop additional public transport systems in Kigali. This could involve a tram system that shares the existing highway alignment | Analysis shows congested roads lead to poor air quality. By reducing the traffic flows congestion eases increasing speeds and reducing emissions. See analysis in chapter 5. | RTDA | 5 years |
| AQ-6 | Reduce emissions from domestic stoves | Promote through subsidy increased uptake of newer less polluting domestic stoves and alternative fuels such as gas. | Review of emissions sources and monitoring data indicates that domestic emissions from stoves are a significant contributor to poor air quality. | REMA | 3 years |

| Policy number | Policy recommendation | Description | Evidence base | Responsibility | Timeframe |
|---|---|---|---|---|---|
| | | | See analysis in chapter 5 and below in section 9.2.7. | | |
| AQ-7 | Develop renewable energy generation | Meet increasing energy demand through Increasing the installed capacity of renewable energy. This would also help facilitate the update of electric stoves | Analysis indicates additional generating capacity is required to facilitate electrification across Rwanda. See chapter 5 and section 9.2.8. | REG | 5 years |
| AQ-8 | Manage freight movements across Kigali | Develop a freight management plan to reduce the number of heavy good vehicles travelling within Kigali city centre | Analysis in Section 5 shows HGVs and congestion contribute significantly to poor air quality within Kigali | RTDA | 3 years |

### 9.2.2 AQ-1 – Refresh existing air quality standards

Based on the analysis presented in chapter 3 and chapter 4 and recommendations made, suggested ambient air quality standards for Rwanda are summarised in Table 35. Suggested emission limits for plants over 50MWth are suggested in Table 36 which are based on the current World Bank/IFC emission guidelines for Thermal Power Plants. Suggested emission limits for plants below 50MWth are based on current World Bank/IFC General Environmental Guidelines; they are presented in Table 37 .

The air quality standards should be supported by provision of an air quality monitoring network to be managed by REMA to monitor compliance with the proposed ambient air quality standards.

It is recommended that any new standard that are adopted are periodically reviewed every five years against the current World Bank/IFC General Environmental Guidelines.

**Table 35: Recommended ambient air quality standards for Rwanda**

| Pollutant | Averaging Period | National standard (µg/m$^3$) | Justification |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 10 minute | 500 | In line with WHO guideline |
| | 24 hour | 125 | In line with WHO Interim Target 1 and the most common national standards |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 | In line with WHO guideline and the most common national standards |
| | Annual | 40 | |
| $PM_{10}$ | 24 hour | 100 | In line with WHO Interim Target 2, the existing Rwandan standards and other national standards |
| | Annual | 50 | |
| $PM_{2.5}$ | 24 hour | 75 | In line with WHO Interim Target 1 |
| | Annual | 35 | |
| Ozone $O_3$ | 1 hour | 200 | In line with the most common national standards |
| | 8-hour daily maximum | 120 | In line with WHO Interim Target 1 and the most common national standards |
| Carbon monoxide CO | 1 hour | 30,000 | In line with WHO guideline and the most common national standards |
| | 8 hours | 10,000 | |

**Table 36: Recommended emission limits for Rwanda for plants above 50MWth**

| Pollutant | Airshed status | Plant type | Fuel, thermal capacity | mg/Nm$^3$ under reference conditions of 15% $O_2$, 273 Kelvin and 101.3kPa |
|---|---|---|---|---|
| Sulphur dioxide $SO_2$ | All | Engine | Liquid fuel, 50-300MWth | 1,170 or use 2% or less S fuel |
| | | | Liquid fuel, >=300MWth | 585 or use 1% or less S fuel |
| | | Turbine | Fuel other than natural gas, >50MWth | <1% S fuel |
| | | Boiler | Gas fuel other than natural gas | 400 |
| | | | Liquid fuel, 50-600MWth | 900-1,500 |
| | | | Liquid fuel, >=600MWth | 200-850 |
| | | | Solid fuel, 50-600MWth | 900-1,500 |
| | | | Solid fuel, >=600MWth | 200-850 |
| Nitrogen oxides | All | Engine | Natural gas | 400 (dual fuel)<br>200 (spark ignition) |

| Pollutant | Airshed status | Plant type | Fuel, thermal capacity | mg/Nm³ under reference conditions of 15% $O_2$, 273 Kelvin and 101.3kPa |
|---|---|---|---|---|
| $NO_x$ | | | Liquid fuel, 50-300MWth | 2000 (dual fuel)<br>1,850 (compression ignition) |
| | | | Liquid fuel, >=300MWth | 740 |
| | | | Biofuels/ gaseous fuels other than natural gas | 30% higher than value above (according to fuel type and thermal capacity) |
| | | Turbine | Natural gas, >50MWth | 51 |
| | | | Fuel other than natural gas, >50MWth | 152 |
| | | Boiler | Gaseous fuels, >50MWth | 240 |
| | | | Liquid fuel, >50MWth | 400 |
| | | | Solid fuel, >50MWth | 510 |
| Particulate Matter PM | Non-degraded | All | All fuel | 50 |
| | Degraded | All | All fuel | 30 |

Source: IFC Environmental, Health and Safety Guidelines. Thermal Power Plants, 2008.

Notes: Reference conditions of 15% $O_2$, 273 Kelvin and 101.3kPa for all plant and fuel types except for boilers (3% $O_2$ for gaseous and liquid fuels, 6% for solid fuels)

### Table 37: Recommended emission limits for Rwanda for plants below 50MWth

| Technology | Fuel | Particulate matter | Sulphur dioxide | Nitrogen dioxide | Dry gas, excess $O_2$ content (%) |
|---|---|---|---|---|---|
| Engine | Gas | N/A | N/A | 200 (spark ignition) mg/Nm³<br>400 (dual fuel) mg/Nm³<br>1,600 (compression ignition) mg/Nm³ | 15 |
| | Liquids | 50 or up to 100 mg/Nm³ if justified by project specific considerations | 1.5 % sulphur (in fuel) | 1,850 mg/Nm³ | 15 |
| Turbine | Natural gas (<15MWth | N/A | N/A | 42 ppm (electrical generation) (86mg/Nm³)<br>100 ppm (mechanical drive) (205 mg/m³) | 15 |
| | Natural gas (15-50 MWth) | N/A | N/A | 25 ppm<br>(51mg/Nm³) | 15 |
| | Fuels other than natural gas (<15MWth) | N/A | 0.5% sulphur | 96 ppm (electrical generation)<br>(197 mg/Nm³<br>150 ppm (mechanical drive)<br>(308 mg/Nm³) | 15 |
| | Fuels other than natural gas (15-50 MWth) | N/A | 0.5% sulphur | 74 ppm<br>(152 mg/Nm³) | 15 |
| Boiler | Gas | N/A | N/A | 320 mg/Nm³ | 3 |
| | Liquid | 50 or up to 150 mg/Nm³ if justified by project specific considerations | 2,000 mg/Nm³ | 460 mg/Nm³ | 3 |

| Technology | Fuel | Particulate matter | Sulphur dioxide | Nitrogen dioxide | Dry gas, excess $O_2$ content (%) |
|---|---|---|---|---|---|
| | Solid | 50 or up to 150 mg/Nm$^3$ if justified by project specific considerations | 2,000 mg/Nm$^3$ | 650 mg/Nm$^3$ | 6 |

Source: IFC General Environmental, Health and Safety Guidelines. Air Emissions and Ambient Air quality, 2007.

Notes: Reference conditions of 273 Kelvin, dry gas 101.3kPa with $O_2$ content stated in table above

### 9.2.3 AQ 2 – Apply strict import regulations on vehicles

Evidence has indicated that the new laws relating to the import of motorbikes led to significant changes in the age of the motorcycle fleet. Similar changes re other vehicles would help promote the renewal of the existing fleet and lead to significant reductions in emissions.

New compulsory vehicle emission testing established under Prime Minister instructions No. 005/03 of 27/12/2013 preventing air pollution caused by vehicular emissions and machines using petroleum products in Rwanda provides a regulatory system to manage and monitor implementation to assist with the phasing out of old vehicles.

### 9.2.4 AQ -3 Smooth traffic flows around traffic hotspots

Traffic congestion hotspots which are located close to residential receptors in Kigali should be identified and a set of options to alleviate congestion investigated. Options should include but not be limited to:

- Change in signalling timing and phasing at busy junctions to favour routes through a junction that require additional time, with priority to reduce overall queuing
- Changes in junction design to include roundabouts or priority lanes
- Increasing capacity of road by adding lanes
- Changing road design in other areas to make the busiest areas less attractive to reduce the flow of vehicles traveling through them; the aim is to introduce road layouts/design that encourage drivers to take alternative routes, thus avoiding areas of high traffic congestion - e.g. restricting left turning traffic at busy junctions where there is no priority for them
- Limit some areas to bus/taxi only

### 9.2.5 AQ – 4 Reduce emissions from bus fleet

In the short terms a new policy to require all old buses to meet the most stringent international emission standards through retrofitting of abatement techniques such as selective catalytic reduction to the exhaust systems by a set date should be developed. This policy would only be applicable to buses that currently do not have catalytic convertors as specified by Prime Minsters instructions No005/03 of 27/12/2013 preventing air pollution caused by vehicular emissions and machines using petroleum products in Rwanda. It is likely that bus operators would replace alder buses with new buses sooner due to the cost of retrofitting catalytic converters to old vehicles, thus improving emissions of the bus fleet.

A longer-term aspiration should be to encourage all new buses to be hybrid vehicles that operate off electric batteries when travelling at slow speeds.

### 9.2.6 AQ – 5 Invest in public transport systems

Improved public transport system through provision of train, train or bus rapid systems through the busiest transport corridors will promote increased accessibility and modal shift across Kigali.

Improved public transport links reduce reliance on personal vehicles as well as having other wide economic and social benefits.

Existing measures set out in the Rwanda Green City Toolkit state that Rwanda aims to increase public transport to private transport participation rate to 70:30.

Other measures include the introduction of non-motorised means of transport such as walking and cycling though the development of bicycle lanes and footpaths. These can be linked with public transport. A bicycle rental programme would provide free or affordable access to bicycles for short trips in cities as an alternative to using motorized transport systems.

A hub and spoke transport system can be developed which is an efficient distribution system that allows people or goods to converge in a ring, and radiate from a central hub.

### 9.2.7 AQ – 6 Reduce emissions from domestic stoves

Emissions from cooking stoves are well studied within literature. Vicente and Alves, 2018,concluded that effective measures to reduce emissions include improving combustion technology, implementation of air staged combustion through pre heating of primary combustion air, increased fuel efficiency or through increasing the mechanism of feeding fuel[129].

In Rwanda, improvements in combustion technology and increases in fuel efficiency are primarily recommended. A modal shift towards natural gas from biomass and coal would help to reduce PM concentrations. If this is not feasible, the quality of biomasses and coal being burnt should be improved along with the combustion technology within stoves.

Cutz *et al*, 2017, concluded that a shift from old biomass technologies to modern biomass such as improved stoves and more efficient fuels decreases local environmental pollution in the form of particulates and $CO_2$ emissions, avoids harmful indoor pollution, reduces energy poverty and could also boost local economies through the creation of a biomass industry and infrastructure[130].

Promotion of cleaner fuels and improved technologies should be achieved through government subsidy but should be considered an interim measure only.

Promotion of electric stoves through provision of reliable electricity to all homes should be the long-term goal.

### 9.2.8 AQ – 7 Develop renewable energy generation

Rwanda currently has set ambitious targets for achieving rapid electrification across the country with the Rwanda Development Board setting a target to achieve 512MW installed power generation by 2023/2024 with universal access achieved by this date with 52% on grid connection and 48% off grid connection[131]. According to the Rwanda Energy Group Rwanda has achieved 40.5% access rate with on-grid representing 29.5% and off-grid 11%[132]. Links to existing policies in place for improved energy generation should be linked with air quality benefits to help demonstrate the importance of implementation.

[129] Vicente, E.D. Alves, C.A. (2018) 'An overview of particulate emissions from residential biomass combustion' *Atmospheric Research*, 199, pp. 159-185.

[130] Cutz, L. Masera, O. Santana, D. Faaij, A.P.C. (2017) 'Switching to efficient technologies in traditional biomass intensive countries: The resultant change in emissions' *Energy*, 126, pp. 513-526

[131] Rwnada Development Board, http://www.rdb.rw/rdb/energy.html

[132] Rwanda Energy Group Report, August 2017

### 9.2.9 AQ – 8 Manage freight movements across Kigali

A hub and spoke transport system can be developed which is an efficient distribution system that allows goods to converge in a ring, and radiate from a central hub. In addition, a longer-term goal would be to develop new roads that can carry cross border traffic that do not pass through main city centres.

# 10 Recommendations

This study has been undertaken over a limited timeframe and with limited budget. This chapter identifies significant gaps in data collection and recommends actions for REMA to progress in the future to improve data availability and stakeholder engagement/collaboration to assist in development and implementation of the strategy.

1. The air quality monitoring data collected during the study which forms part of the background information for developing the strategy has only been undertaken for a limited period. It is recommended that the length of the study is extended for a period of at least one year so that all seasonal and regional changes in ambient pollution can be monitored, reviewed and analysed to produce additional evidence to support the need for the air quality strategy.
2. A national air quality monitoring network should be established and maintained with data from the monitoring survey published on a specific Rwanda air quality website. The network should monitor pollutants at a variety of urban and rural locations across the country and include reference method monitors for $NO_2$ and particulate matter as well as sensor monitors such as AQMeshes (or similar) and passive methods such as diffusion tubes. Not only will the network allow for additional information gathering to understand where there is poor air quality it will allow REMA to track how air quality changes over time and assess the success of the implementation of future strategy measures.
3. Appoint specialist traffic consultants to undertake studies related to the traffic related measures
4. Set up a cross department air quality working group to help with the implementation of the strategy measures identified in section 9.
5. Improve data availability in all sectors which impact on ambient air quality with the aim of establishing mass emissions of key pollutants by sector. It is recommended that systems are established to gather the following data, as a minimum:
    - Miles travelled by the national vehicle fleet broken down according to engine type (emissions management) and fuel types
    - Operating philosophy, hours of operation and loading of thermal power plants
    - Fuel type, combustion process details, operating philosophy and hours of operation of industrial processes
    - Domestic fuel types and quantities consumed nationally

    The data listed here should be expanded as necessary to achieve the required aim of a detailed emissions inventory.

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# A. International and national ambient air quality standards

**Table 38: National Ambient Air Quality Standards for Relevant Pollutants: Botswana**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur Dioxide ($SO_2$) | 1 hour | 350 | In force |
| | 24 hour | 120 | In force |
| Nitrogen dioxide $NO_2$ | 1 Hour | 200 | In force |
| | Annual | 40 | In force |
| Carbon monoxide | 1 Hour | 30,000 | In force |
| | 8 Hour | 10,000 | In force |
| Ozone | 8 Hour | 120 | In force |
| Lead (Pb) | Annual | 0.5 | In force |
| Benzene ($C_6H_6$) | Annual | 5 | In force |
| Particulate Matter ($PM_{10}$) | Monthly | 200 | In force |
| | Annual | 100 | In force |

Source: Botswana Bureau of Standards, 2012 (BOS 498:2012)

**Table 39: National Ambient Air Quality Standards for Relevant Pollutants: Chile**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 1000 (North) | In force |
| | 1 hour | 700 (South) | In force |
| | 24 hour | 365 (North) | In force |
| | 24 hour | 260 (South) | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 470 | In force |
| | 8 hour | 300 | In force |
| | 24 hour | 100 | In force |
| Carbon monoxide CO | 1 hour | 40,000 | In force |
| | 8 hour | 10,000 | In force |
| Ozone $O_3$ | 1 hour | 160 | In force |
| TSP | 24 hour | 260 | In force |
| Respirable particles | 8 hour | 150 | In force |
| | 24 hour | 50 | In force |

Source: CEDRM, 1992, Solari, 1993a (original reference)
http://www2.gtz.de/dokumente/bib/96-0342.pdf
402/94-6 e PVI Division 402. Environmental Protection, Conservation of Natural Resources, Dissemination of Appropriate Technologies (GAPE). “The Use of Economic Instruments in the Environmental Policy of Chile” (1994)

Notes: For sulphur dioxide air quality standards, the country is divided into two sections, the dividing line being drawn from the mouth of the Rio Maipo south of the Metropolitan Region to the Andean mountains. The Northern Region is drier with most of the copper smelters, whereas the Southern Region is humid with a higher importance of agriculture and forestry.

**Table 40: National Ambient Air Quality Standards for Relevant Pollutants: China**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 500 or 150([a]) | 01.01.2016 |
| | 24 hour | 150 or 50([a]) | 01.01.2016 |
| | Annual | 60 or 20([a]) | 01.01.2016 |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 | 01.01.2016 |
| | 24 hour | 80 | 01.01.2016 |
| | Annual | 40 | 01.01.2016 |
| Carbon monoxide CO | 1 hour | 10,000 | 01.01.2016 |
| | 24 hour | 4,000 | 01.01.2016 |
| Ozone $O_3$ | 1 hour | 200 or 160([a]) | 01.01.2016 |
| | 8 hour | 160 or 100([a]) | 01.01.2016 |
| $PM_{10}$ | 24 hour | 150 or 50([a]) | 01.01.2016 |
| | Annual | 70 or 40([a]) | 01.01.2016 |
| $PM_{2.5}$ | 24 hour | 75 or 35([a]) | 01.01.2016 |
| | Annual | 35 or 15([a]) | 01.01.2016 |

Source: GB 3095-2012
PRC National Standard. Emission Standard of Air Pollutants for Thermal Power Plants. Published on 29th July 2011. Ministry of Environmental Protection. National Quality Supervision, Inspection and Quarantine Agency.

Notes: The Ambient Air Quality Standards (GB 3095-2012) prescribes the first-ever limits for PM2.5 and has modified the previous area classifications by combining Class III (special industrial areas) with Class II (residential, mixed use areas). The new standards are comparable to the interim targets set by the World Health Organization (WHO). Specifically, PM2.5, PM10 and O3 (8-hour) standards are same as WHO IT-1. The new standards will be implemented on 1 January 2016 for whole China. In accordance with the Guidance of Promoting Joint Prevention and Control of Air Pollution and Improving the Regional Air Quality, the Ministry of Environmental Protection (MEP) may require some cities to implement the new standards before the 2016 implementation schedule. At the same time, provinces are also encouraged to implement the new standards even before 2016, as soon as the cities under their jurisdiction are ready.
[(a)] The standard for Natural Protection Areas and other areas which need special protection. Where no (a) is given, the other value applied, which is a standard set for residential, commercial, industrial and rural areas.

**Table 41: EU Ambient Air Quality Directive Standards**

| Pollutant | Averaging Period | National Standard (allowable exceedences) (µg/m$^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 350 (24 times/yr) | In force |
| | 24 hour | 125 (3 times/yr) | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 (18 times/yr) | In force |
| | Annual | 40 | In force |
| Carbon monoxide CO | Maximum daily running 8 hour mean | 10,000 | In force |
| Ozone $O_3$ | 8 hour | 120 (25 days/yr over 3 years) | In force |
| $PM_{10}$ | 24 hour | 50 (35 times/yr) | In force |
| | Annual | 40 | In force |
| $PM_{2.5}$ exposure reduction | Annual | 25 | In force (target) |
| | Annual | Target of 20% reduction in concentrations at urban background between 2010 and 2020 | In force (target) |
| Lead | Annual | 0.5 | In force |
| Arsenic | Annual | 0.006 (within $PM_{10}$ fraction) | In force (target) |
| Cadmium | Annual | 0.005 (within $PM_{10}$ fraction) | In force (target) |
| Nickel | Annual | 0.02 (within $PM_{10}$ fraction) | In force (target) |
| Polycyclic aromatic hydrocarbons | Annual | 0.001 B[a]P (within $PM_{10}$ fraction) | In force (target) |
| Benzene | Annual | 5 | In force |
| **For the protection of vegetation and ecosystems** | | | |
| Nitrogen oxides NOx | Annual | 30 | In force |
| Sulphur dioxide $SO_2$ | Annual | 20 | In force |
| | Winter average | 20 | In force |
| Ozone $O_3$ | 8 hour mean | 120 (<25 days a year averaged over 3 years) | In force |
| | Average over 5 years | Target value of 18,000 µg/m$^3$ based on AOT40 to be calculated from 1 hour values from May to July | In force |

Source: EU Air Quality Framework Directive 96/62/EEC

### Table 42: National Ambient Air Quality Standards for Relevant Pollutants: Finland

| Pollutant | Averaging Period | National Standard (allowable exceedences/percentiles) ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 250 (99th percentile of hourly means in a month) | In force |
| | 24 hour | 80 (second highest daily mean in a month) | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 150 (99th percentile of hourly means in a month) | In force |
| | 24 hour | 70 (second highest daily mean in a month) | In force |
| Carbon monoxide CO | 1 hour | 20,000 (hourly mean) | In force |
| | 8 hour | 8,000 (rolling average) | In force |
| $PM_{10}$ | 24 hour | 70 (second highest daily mean in a month) | In force |
| TSP | 24 hour | 120 (98th percentile of daily means in a year) | In force |
| | Annual | 50 (annual average) | In force |
| Malodorous sulphur compounds (TRS) | 24 hour | 10 (second highest daily mean in a month TRS given as sulphur) | In force |

Source: Helsinki Region Environmental Services Authority.
http://www.hsy.fi/en/regionalinfo/airquality/information/Pages/Limitvalues.aspx

Notes: The limit values prescribed by the European Union define the maximum acceptable concentrations, issued to protect human health. Threshold values specify the levels at which the public must be informed or warned of elevated pollutant concentrations. Target values stipulate the concentration or critical load that should not be exceeded within a given period of time if possible. Critical levels refer to concentrations above which direct adverse effects may occur on trees, other plants or natural ecosystems but not on humans. Finland also has national guidelines that express air quality objectives and the goals of air pollution control (as above). These are primarily intended to guide public authorities. The guidelines are applied in land use planning, city and traffic planning, in construction, and in environmental permits. They are characteristically not as binding as limit values, but they are intended to guide planning and efforts should be made to avoid exceeding them. Information and alert thresholds specify the levels at which the public must be informed or warned of elevated air pollution concentrations.

**Table 43: National Ambient Air Quality Standards for Relevant Pollutants: Israel**

| Pollutant | Averaging Period | National Standard (µg/m³) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 0.5 hour (*absolute) | 1000 | In force |
| | 0.5 hour (**statistical) | 500 | In force |
| | 24 hour | 280 | In force |
| | Annual | 60 | In force |
| Nitrogen dioxide $NO_2$ | 0.5 hour | 940 (500 ppb) | In force |
| | 24 hour | 560 (300 ppb) | In force |
| Carbon monoxide CO | 0.5 hour | 60,000 (52 ppm) | In force |
| | 8 hour | 11,000 (0.6 ppm) | In force |
| Ozone $O_3$ | 0.5 hour | 230 | In force |
| | 8 hour | 160 | In force |
| $PM_{10}$ | 24 hour | 150 | In force |
| | Annual | 60 | In force |

Source: State of Israel Ministry of Environmental Protection
http://old.sviva.gov.il/bin/en.jsp?enPage=e_BlankPage&enDisplay=view&enDispWhat=Zone&enDispWho=Israeli_Ambient&enZone=Israeli_Ambient

### Table 44: National Ambient Air Quality Standards for Relevant Pollutants: Japan

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 260 (0.1 ppm) | In force |
| | 24 hour (the daily average for hourly values) | 100 (0.04 ppm) | In force |
| Nitrogen dioxide $NO_2$ | 24 hour | 80-100 (0.04-0.06 ppm) | In force |
| $PM_{10}$ | 1 hour | 200 | In force |
| | 24 hour | 100 | In force |
| $PM_{2.5}$ | 24 hour | 35 | In force |
| | Annual | 15 | In force |
| Carbon monoxide CO | 8 hour (average of hourly values for any consecutive 8 hour period) | 2,2910 (20 ppm) | In force |
| | 24 hour | 11,460 (10 ppm) | In force |
| Benzene | Annual | 3 | In force |
| Trichloroethylene | Annual | 200 | In force |
| Dichloromethane | Annual | 150 | In force |
| Photochemical oxidants | 1 hour | 0.06 ppm | In force |

Source: Ministry of the Environment. Government of Japan. http://www.hsy.fi/en/regionalinfo/airquality/information/Pages/Limitvalues.aspx

Notes: Photochemical oxidants are oxidizing substances such as ozone and peroxiacetyl nitrate produced by photochemical reactions (only those capable of isolating iodine from neutral potassium iodide, excluding nitrogen dioxide.) An air temperature of $25^0$C was assumed when converting ppm to $\mu g/m^3$

**Table 45: National Ambient Air Quality Standards for Relevant Pollutants: Jordan**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 786 (0.3ppm) ([a]) | In force |
| | 24 hour | 370 (0.14ppm) ([b]) | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 400 (0.21ppm) ([a]) | In force |
| | 24 hour | 150 (0.08ppm) ([a]) | In force |
| Carbon monoxide CO | 1 hour | 30,279 (26ppm) ([a]) | In force |
| | 8 hour | 10,481 (9ppm) ([a]) | In force |
| $PM_{10}$ | 24 hour | 120 ([a]) | In force |
| $PM_{2.5}$ | 24 hour | 65 ([a]) | In force |
| TSP | 24 hour | 260 ([a]) | In force |
| $H_2S$ | 1 hour | 42 (0.030ppm) ([a]) | In force |
| | 24 hour | 14 (0.010ppm) ([a]) | In force |

Source: Jordanian emission standards for ambient air quality (1140/2006). AES Baltic Holding B.V. & Mitsui & Company Limited. AES Levant Holding BV Jordan PSC IPP4. Al-Manakher Power Project. Prepared by Parsons Brinckerhoff in association with the Royal Scientific Society, Amman, Jordan. May 2012.

Notes: ([a]) 3 times during any consecutive 3 months
([b]) Once during any consecutive 3 months

**Table 46: National Ambient Air Quality Standards for Relevant Pollutants: Moldova**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 20 minute | 500 | In force |
| | 24 hour | 50 | In force |
| Carbon monoxide CO | 20 minute | 5,000 | In force |
| | 24 hour | 3,000 | In force |
| Ozone $O_3$ | 20 minute | 160 | In force |
| | 24 hour | 30 | In force |
| Lead | 20 minute | 1 | In force |
| | 24 hour | 0.3 | In force |
| Mercury | 24 hour | 3 | In force |
| Cadmium | 24 hour | 0.3 (compounds) | In force |
| Formaldehyde | 20 minute | 35 | In force |
| | 24 hour | 3 | In force |
| Styrene | 20 minute | 200 | In force |
| Tetrachloroethylene | 20 minute | 500 | In force |
| | 24 hour | 60 | In force |
| Toluene | 20 minute | 600 | In force |
| | 24 hour | 600 | In force |
| Trichloroethylene | 20 minute | 4000 | In force |
| | 24 hour | 1000 | In force |
| Arsenic | 24 hour | 3 | In force |
| Manganese (compounds) | 20 minute | 400 | In force |
| | 24 hour | 50 | In force |

Source: http://www.unece.org/fileadmin/DAM/env/epr/epr_studies/moldova.pdf
Economic Commission for Europe. Committee on Environmental Policy. Environmental Performance Reviews. Republic of Moldova. United Nations. New York and Geneva, 1998

**Table 47: National Ambient Air Quality Standards for Relevant Pollutants: Mongolia**

| Pollutant | Averaging Period | National Standard (µg/m³) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 10 minute | 500 | In force |
| | 20 minute | 450 | In force |
| | 24 hour | 20 | In force |
| | Annual | 10 | In force |
| Nitrogen dioxide $NO_2$ | 20 minute | 85 | In force |
| | 24 hour | 40 | In force |
| | Annual | 30 | In force |
| Carbon monoxide CO | 30 minute | 60,000 | In force |
| | 1 hour | 30,000 | In force |
| | 8 hour | 10,000 | In force |
| Ozone $O_3$ | 8 hour | 100 | In force |
| $PM_{10}$ | 24 hour | 100 | In force |
| | Annual | 50 | In force |
| $PM_{2.5}$ | 24 hour | 50 | In force |
| | Annual | 25 | In force |
| TSP | 30 minute | 500 | In force |
| | 24 hour | 150 | In force |
| | Annual | 100 | In force |
| Lead | 24 hour | 1 | In force |
| | Annual | 0.5 | In force |
| $C_{20}H_{12}$ | 24 hour | 0.001 | In force |

Source: MNS 4585:2007.http://www.ub-air.info/ub-air/en/about/air-quality-standard.html

**Table 48: National Ambient Air Quality Standards for Relevant Pollutants: Pakistan**

| Pollutant | Averaging Period | National Standard (allowable exceedences) ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 24 hour | 120 | In force |
| | Annual | 80 | In force |
| Nitrogen dioxide $NO_2$ | 24 hour | 80 | In force |
| | Annual | 40 | In force |
| NO | 24 hour | 40 | In force |
| | Annual | 40 | In force |
| Carbon monoxide CO | 1 hour | 10,000 | In force |
| | 8 hour | 5,000 | In force |
| Ozone $O_3$ | 1 hour | 130 | In force |
| $PM_{10}$ | 24 hour | 150 | In force |
| | Annual | 120 | In force |
| $PM_{2.5}$ | 1 hour | 15 | In force |
| | 24 hour | 35 | In force |
| | Annual | 15 | In force |
| SPM | 24 hour | 500 | In force |
| | Annual | 360 | In force |
| Lead | 24 hour | 1.5 | In force |
| | Annual | 1 | In force |

Source: http://www.environment.gov.pk/act-rules/NEQS%20for%20Ambient%20Air.pdf
Government of Pakistan. Pakistan Environmental Protection Agency.

Notes: 24 hourly / 8 hourly values should be met 98% of the time in a year. 2% of the time, it may exceed but not on two consecutive days. Annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval

**Table 49: National Ambient Air Quality Standards for Relevant Pollutants: Philippines**

| Pollutant | Averaging Period | National Standard (allowable exceedences) (µg/m$^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 24 hour | 180 | In force |
| | Annual | 80 | In force |
| Nitrogen dioxide $NO_2$ | 24 hour | 150 | In force |
| Carbon monoxide CO | 1 hour | 35,000 | In force |
| | 8 hour | 10,000 | In force |
| Ozone $O_3$ | 1 hour | 140 | In force |
| | 8 hour | 60 | In force |
| $PM_{10}$ | 24 hour | 150 | In force |
| | Annual | 60 | In force |
| TSP | 24 hour | 230 | In force |
| | Annual | 90 | In force |
| Lead | 3 month | 1.5 | In force |
| | Annual | 1.0 | In force |

Source: NAAQGV. Philippines: Air Quality Profile. 2010 Edition. Clean Air Iniative for Asian Cities (CAI-Asia) Center. Country Synthesis Report on Urban Air Quality Management. Philippines Discussion Draft, December 2006. ADB & CAIniative

Notes: 24 hourly / 8 hourly values should be met 98% of the time in a year. 2% of the time, it may exceed but not on two consecutive days

**Table 50: National Ambient Air Quality Standards for Relevant Pollutants: Russia**

| Pollutant | Averaging Period | National Standard (allowable exceedences) (µg/m$^3$) | Compliance Date |
|---|---|---|---|
| Nitrogen dioxide $NO_2$ | 20 minute ([a]) | 200 ([b]) | In force |
| | Annual ([a]) | 40 ([b]) | In force |
| Carbon monoxide CO | 20 minute ([a]) | 5,000 | In force |
| | Annual ([a]) | 3,000 | In force |
| TSP | 20 minute ([a]) | 500 | In force |
| | Annual ([a]) | 150 | In force |

Source: Air Quality Draft_EC (JGP) for EIA. Nizhnevartovsk Unit 3. Air Quality Assessment. April 2009. Second Issue (MM)

Notes: [(a)] Hygiene norms GN 2.1.6.1338-03. Maximum Admissable Concentrations (MAC) of pollutants in ambient air
[(b)] Hygiene norms GN 2.1.6.1983-05. Maximum Admissible Concentrations (MAC) of pollutants in ambient air. Addition No. 2 to GN 2.1.6.1338-03. (RF)

**Table 51: National Ambient Air Quality Standards for Relevant Pollutants: Singapore**

| Pollutant | Averaging Period | National Standard (allowable exceedences) (µg/m$^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 24 hour | 50 | 2020 |
| | Annual | 15 | 2020 |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 | 2020 |
| | Annual | 40 | 2020 |
| Carbon monoxide CO | 1 hour | 30,000 | 2020 |
| | 8 hour | 10,000 | 2020 |
| Ozone $O_3$ | 8 hour | 100 | 2020 |
| $PM_{10}$ | 24 hour | 50 | 2020 |
| | Annual | 20 | 2020 |
| $PM_{2.5}$ | 24 hour | 37.5 | 2020 |
| | Annual | 12 | 2020 |

Source: http://www.nea.gov.sg/anti-pollution-radiation-protection
Executive Summary Report of the Advisory Committee on Ambient Air Quality

**Table 52: National Ambient Air Quality Standards for Relevant Pollutants: South Africa**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 10 minute | 500 (526[(a)]) | Immediate |
| | 1 hour | 350 (88[(a)]) | Immediate |
| | 24 hour | 125 (4[(b)]) | Immediate |
| | Annual | 50 (0) | Immediate |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 (88[(a)]) | Immediate |
| | Annual | 40 (0) | Immediate |
| $PM_{10}$ | 24 hour | 120 (4[(b)]) | Immediate – 31 December 2014 |
| | 24 hour | 75 (4[(b)]) | 1 January 2015 |
| | Annual | 50 (0) | Immediate – 31 December 2014 |
| | Annual | 40 (0) | 1 January 2015 |

Source: Government Notice No. 515
[(a)] Can be expressed as the 99th percentile
[(b)] Can be expressed as the 98.9th percentile

Notes: December 2009, National Ambient Air Quality Standards (NAAQS) were established (in terms of Section 9(1) of the AQA)

**Table 53: National Ambient Air Quality Standards for Relevant Pollutants: Sri Lanka**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 200 | In force |
| | 8 hour | 120 | In force |
| | 24 hour | 80 | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 250 | In force |
| | 8 hour | 150 | In force |
| | 24 hour | 100 | In force |
| Carbon monoxide CO | 1 hour | 30,000 | In force |
| | 8 hour | 10,000 | In force |
| | Any time | 58,000 | In force |
| Ozone $O_3$ | 1 hour | 200 | In force |
| $PM_{10}$ | 24 hour | 100 | In force |
| | Annual | 50 | In force |
| $PM_{2.5}$ | 24 hour | 50 | In force |
| | Annual | 25 | In force |

Source: www.indiaenvironmentportal.org.in/files/SriLanka.pdf
Gazette No. 1562/22, 2008. National Environmental (Ambient Air Quality) Regulations – Sri Lanka. Clean Air in Sri Lanka: Summary of progression improving air quality. Country Network Sri Lanka & Clean Air Sri Lanka. November 2008
ADB & CAI.

Notes: Sri Lanka reviewed the NAAQS and incorporated $PM_{10}$ and $PM_{2.5}$.

**Table 54: National Ambient Air Quality Standards for Relevant Pollutants: Taiwan**

| Pollutant | Averaging Period | National Standard (µg/m³) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 660 (0.25ppm) | In force |
| | 24 hour | 260 (0.1ppm) | In force |
| | Annual | 80 (0.03ppm) | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 470 (0.25ppm) | In force |
| | Annual | 90 (0.05ppm) | In force |
| Carbon monoxide CO | 1 hour | 40100 (35ppm) | In force |
| | 8 hour | 10310 (9ppm) | In force |
| Ozone $O_3$ | 1 hour | 240 (0.12ppm) | In force |
| | 8 hour | 120 (0.06ppm) | In force |
| $PM_{10}$ | 24 hour | 125 | In force |
| | Annual | 65 | In force |
| TSP | 24 hour | 250 | In force |
| Lead | 1 Month | 1 | In force |

Source: http://taqm.epa.gov.tw/taqm/en/b0206.aspx
Environmental Protection Administration. Executive Yuan R.O.C. (Taiwan)

Notes: An air temperature of $25^0$C was assumed in the calculations converting ppm to µg/m³

**Table 55: National Ambient Air Quality Standards for Relevant Pollutants: Tanzania**

| Pollutant | Averaging Period | National Standard (µg/m³) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 24 hour | 100 (a) | In force |
| | Annual | 40-60 (a) | In force |
| Nitrogen dioxide $NO_2$ | 24 hour | 150 | In force |
| | 8 hour | 120 | In force |
| | Annual | 100 | In force |
| Carbon monoxide CO | 15 minutes | 100,000 (b) | In force |
| | 30 minutes | 60,000 (b) | In force |
| | 1 hour | 30,000 (b) | In force |
| | 8 hour | 10,000 (b) | In force |
| Black smoke and SPM | Black smoke | 40-60 (c) | In force |
| | Total SPM | 60-90 (c) | In force |
| Lead Pb | 24 hour | 1.5 | In force |
| | Annual | 0.5-1.0 | In force |

Source: Preparation Of The East African Transport Facilitation Strategy
Bureau For Industrial Cooperation Working Paper 2.2. Thematic Area 2
Environmental Regulations And Standards. Working Paper 2.2. Harmonisation Of Environmental Regulations And Standards

Notes: (a) Daily average of hourly values shall not exceed 0.5 mg/Nm³ for 10 minutes
(b) Daily average of hourly values shall not exceed 10mg/kg and average of hourly values in eight consecutive hours shall not exceed 20mg/kg
(c) Daily average of hourly values shall not exceed 0.01 mg/kg and hourly values shall not exceed 20 mg/kg

**Table 56: National Ambient Air Quality Standards for Relevant Pollutants: Turkey**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 1 hour | 900 | From 1.1.2014. will be 500 and it will decrease 30 $\mu g/m^3$ each year down to 350 till 1.1.2019 |
| | 24 hour (95th percentile) | 400 | Will decrease 30 $\mu g/m^3$ each year down to 250 till 1.1.2014. From 1.1.2014, will decrease 25 ug/m3 each year down to 125 till 1.1.2019 |
| | Winter season average (1 Oct-31 March) | 250 | Will decrease 25 $\mu g/m^3$ each year down to 125 $\mu g/m^3$ till 1.1.2014 |
| | Target limit value winter season average (1 Oct-31 March) | 120 | In force |
| | Annual | 150 | In force |
| | Annual – to protect vulnerable animals, plants and entities | 60 | Will decrease 8$\mu g/m^3$ each year down to 20$\mu g/m^3$ till 1.1.2014 |
| | Target limit value Annual | 60 | In force |
| Nitrogen dioxide $NO_2$ | 24 hour (95th percentile) | 300 | Will decrease 10$\mu g/m^3$ each year down to 200 starting from 1.1.2014 till 1.1.2024 |
| | Annual | 100 | Will decrease 8 $\mu g/m^3$ each year down to 60 till 1.1.2014. From 1.1.2014, will decrease 2 $\mu g/m^3$ each year down to 40 $\mu g/m^3$ till 1.1.2024 |
| NOx | Annual – to protect vegetation | 30 | The limit value will be valid after 1.1.2014 |
| Carbon monoxide CO | 24 hour (95th percentile) | 30 | Will decrease 4$\mu g/m^3$ each year down to 10 till 1.1.2014 |
| | Annual | 10 | In force |
| $PM_{10}$ | 24 hour (95th percentile) | 300 | Will decrease 40 $\mu g/m^3$ each year down to 100 till 1.1.2014. From 1.1.2014, will decrease 10µg/m3 each year down to 50 till 1.1.2019 |
| | Winter season average (1 Oct-13 March) | 200 | Will decrease 22 $\mu g/m^3$ each year down to 90 till 1.1.2014 |
| | Annual | 150 | Will decrease 18$\mu g/m^3$ each year down to 60 till 1.1.2014. From 1.1.2014, will decrease 4$\mu g/m^3$ each year down to 40 till 1.1.2019 |

Source: Environmental and social impact assessment for Ic Anadblu Natural Gas Combined Cycle Power Plant. AECOM Turkey. TR-R400-03 21 July 2011.

Notes: Regulation on Assessment and Management of Air Quality (RAMAQ) defines ambient air quality limits for two regulatory periods. The first period is transitional period which is until January 1 2014. The transitional period ambient air quality standards are given in Annex-IA of RAMAQ. Limit values for ambient air quality standards after transitional period are given in Annex I of RAMAQ.

**Table 57: National Ambient Air Quality Standards for Relevant Pollutants: UAE**

| Pollutant | Averaging Period | National Standard (allowable exceedences) ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Nitrogen dioxide $NO_2$ | 1 hour | 400 | In force |
| | 24 hour | 150 | In force |
| | Annual | - | In force |
| Sulphur Dioxide $SO_2$ | 10 minute | - | In force |
| | 1 hour | 350 | In force |
| | 24 hour | 150 | In force |
| | Annual | 60 | In force |
| $PM_{10}$ | 24 hour | 150 | In force |
| TSP | 24 Hour | 230 | In force |
| | Annual | 90 | In force |
| Carbon monoxide CO | 1 hour | 30,000 | In force |
| Polycyclic aromatic hydrocarbons | 8 hour | 10,000 | In force |

Source: Federal Law No. (12) of 2006 on Air Quality

Notes: PM 24-hour value is the 99$^{th}$ percentile.

**Table 58: National Ambient Air Quality Standards for Relevant Pollutants: UK**

| Pollutant | Averaging Period | National Standard (allowable exceedences) ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 15 minute | 266 (35 times/yr) | In force |
| | 1 hour | 350 (24 times/yr) | In force |
| | 24 hour | 125 (3 times/yr) | In force |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 (18 times/yr) | In force |
| | Annual | 40 | In force |
| Carbon monoxide CO | Maximum daily running 8 hour mean/in Scotland as running 8 hour mean | 10,000 | In force |
| Ozone $O_3$ | 8 hour | 100 (10 times/yr) | In force |
| $PM_{10}$ | UK 24 hour | 50 (35 times/yr) | In force |
| | UK Annual | 40 | In force |
| | Scotland 24 hour | 50 (7 times/yr) | In force |
| | Scotland Annual | 18 | In force |
| $PM_{2.5}$ exposure reduction | UK (except Scotland) Annual | 25 | In force |
| | Scotland Annual | 12 | In force |
| | UK urban areas Annual | Target of 15% reduction in concentrations at urban background | In force |
| Lead | Annual | 0.25 | In force |
| Arsenic | Annual | 0.006 | In force |
| Cadmium | Annual | 0.005 | In force |
| Nickel | Annual | 0.02 | In force |
| Polycyclic aromatic hydrocarbons | Annual | 0.25 $ng/m^3$ B[a]P | In force |
| Benzene | UK Running annual mean | 16.25 | In force |
| | England and Wales Annual | 5 | In force |
| | Scotland and Northern Ireland Running annual mean | 3.25 | In force |
| 1,3-butadiene | Running annual mean | 2.25 | In force |
| **For the protection of vegetation and ecosystems** | | | |
| Nitrogen oxides NOx | Annual | 30 | In force |
| Sulphur dioxide $SO_2$ | Annual | 20 | In force |
| | Winter average | 20 | In force |
| Ozone $O_3$ | Average over 5 years | Target value of 18,000 $\mu g/m^3$ based on AOT40 to be calculated from 1 hour values from May to July | In force |

Source: http://uk-air.defra.gov.uk/documents/National_air_quality_objectives.pdf Department for Environment, Food and Rural Affairs.

Notes: Whilst some of these standards reflect EU Directives and set within legislation (see EU Table), others are considered Policy targets which Government bodies are required to work towards.

**Table 59: National Ambient Air Quality Standards for Relevant Pollutants: USA**

| Pollutant | Averaging Period | National Standard (µg/m3) | Compliance Date |
|---|---|---|---|
| Sulphur Dioxide $SO_2$ | 1 hour | 75 ppb | In force |
| | 3 hour | 0.5 ppm (not to be exceeded more than once/yr) | In force |
| Nitrogen Dioxide $NO_2$ | 1 hour | 100 ppb (98th percentile, averaged over 3 years) | In force |
| | Annual | 53 ppb | In force |
| Carbon monoxide CO | 1 hour | 40100 (35ppm) | In force |
| | 8 hour | 10310 (9ppm) | In force |
| Ozone $O_3$ | 8 hour | 0.075 ppm | In force |
| $PM_{2.5}$ | 24 hour | 35 | In force |
| | Annual | 15 | In force |
| $PM_{10}$ | 24 hour | 150 | In force |
| Lead | Rolling 3 month average | 0.15 | In force |

Source: http://www.epa.gov/air/criteria.html
US Environmental Protection Agency

Notes: An air temperature of 250C was assumed in the calculations converting ppm to µg/m3

**Table 60: World Health Organization Ambient Air Quality Standards**

| Pollutant | Averaging Period | National Standard (allowable exceedences) (µg/m³) | Compliance Date |
|---|---|---|---|
| Sulphur dioxide $SO_2$ | 10 minute | 500 | Guideline |
| | 24 hour | 125<br>50<br>20 | Interim target 1<br>Interim target 2<br>Guideline |
| Nitrogen dioxide $NO_2$ | 1 hour | 200 | Guideline |
| | Annual | 40 | Guideline |
| $PM_{10}$ | 24 hour | 150<br>100<br>75<br>50 | Interim target 1<br>Interim target 2<br>Interim target 3<br>Guideline |
| | Annual | 70<br>50<br>30<br>20 | Interim target 1<br>Interim target 2<br>Interim target 3<br>Guideline |
| $PM_{2.5}$ | 24 hour | 75<br>50<br>37.5<br>25 | Interim target 1<br>Interim target 2<br>Interim target 3<br>Guideline |
| | Annual | 35<br>25<br>15<br>10 | Interim target 1<br>Interim target 2<br>Interim target 3<br>Guideline |
| Ozone $O_3$ | 8-hour daily maximum | 160<br>100 | Interim target 1<br>Guideline |
| Carbon monoxide | 15 minutes | 100,000 | Guideline |
| | 30 minutes | 60,000 | Guideline |
| | 1 hour | 30,000 | Guideline |
| | 8 hours | 10,000 | Guideline |
| Cadmium | Annual | 0.005 | Guideline |
| Lead | Annual | 0.5 | Guideline |
| Manganese | Annual | 0.15 | Guideline |
| Mercury | Annual | 1 | Guideline |

Source: Air Quality Guidelines for Europe, 2nd Edition, WHO Regional Publications, European Series, No. 91, 2000. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005, WHO 2006

**Table 61: National Ambient Air Quality Standards for Relevant Pollutants: Zambia**

| Pollutant | Averaging Period | National Standard ($\mu g/m^3$) | Compliance Date |
|---|---|---|---|
| Sulphur Dioxide $SO_2$ | 10 minute | 500 | In force |
| | 1 hour | 350 | In force |
| Oxide of nitrogen as nitrogen dioxide $NO_2$ | 1 hour | 400 | In force |
| | 24 hour | 150 | In force |
| Carbon monoxide CO | 15 minute | 100,000 | In force |
| | 30 minute | 60,000 | In force |
| | 1 hour | 30,000 | In force |
| | 8 hour | 10,000 | In force |
| Sulphur dioxide in combination with total suspended particles (TSP) and $PM_{10}$ | $SO_2$ 24 hours | 125 | In force |
| | $SO_2$ 5 months | 50 | In force |
| | TSP 24 hours | 120 | In force |
| | TSP 6 months | 50 | In force |
| | $PM_{10}$ 24 hours | 70 | In force |
| $PM_{10}$ | 24 hour | 70 | In force |
| Dust fall | 30 days | 7.5 tonnes/$km^2$ | In force |
| Lead | 3 month | 1.5 | In force |
| | 12 month | 1 | In force |

Source: Air Pollution Control (Licensing and Emission Standards) Regulations of 1996, made under the EPPCA of 1990, Cap 204

# B. International and national emission limits

### Table 62: National Emission Limit Values for Relevant Pollutants: Bosnia and Herzegovina

| Substance or mixture substances | | Plant status | Thermal capacity (MWt) | $mg/Nm^3$ under reference conditions of 6%$O_2$, 273 Kelvin and 101.3kPa. |
|---|---|---|---|---|
| Common name | Chemical symbol | | | |
| Sulphur dioxide | $SO_2$ | New | <50 | 2000 |
| | | | 50-300 | 2000-400 (linear decrease) |
| | | | >300 | 400 |
| Oxides of nitrogen | $NO_x$ | New & existing | 0.35-10 | 400 |
| | | | 10-50 | 350 |
| | | New | >50 | 650* |
| Particles | N/A | New & existing | 0.35-2 | 150 |
| | | | 2-50 | 50 |
| | | New | 50-500 | 100 |
| | | | >500 | 50 |
| Carbon monoxide | CO | New & existing | 0.35-1 | 1000 |
| | | | 1-50 | 150 |

Source: http://www.eihp.hr/bh-study/files/final_e/m13_fr.pdf
ESSBIH Third Electric Power Reconstruction Project (BHP3-ESS-TEPRP-Q-04/05 WB)
Energy Sector Study BIH Final Report. Module 13 – Environment
Project implemented by the consortium of Energy Institute Hrvoje Pozar, Croatia; Soluziona, Spain; Economics Institute Banjaluka, BIH, Mining Institute Tuzia, BIH. Funded by The World Bank. March 31st 2008

Notes: * for solid fuels with less than 10% of volatile compounds: 1300 mg $NOx/m^3$
The air emissions are limited for all new plants and for existing plants with thermal input below $50MW_t$. Thus, the existing large combustion plants (over $50MW_t$) are exempted from the limits when air emissions are concerned.

### Table 63: National Emission Limit Values for Relevant Pollutants: China

| Substance or mixture substances | | Plant status | mg/Nm$^3$ under reference conditions of 6%$O_2$, 273 Kelvin and 101.325kPa. | mg/Nm$^3$ under reference conditions of 10%$O_2$, 273 Kelvin and 101.325kPa. |
|---|---|---|---|---|
| Common name | Chemical symbol | | | |
| Sulphur dioxide | $SO_2$ | New | 136 or 273(1) | 100 or 200(1) |
| | | Existing | 273 or 545(1) | 200 or 400(1) |
| | | All (key) | 68 | 50 |
| Oxides of nitrogen | NOx | All | 136 or 273(2) | 100 or 200(2) |
| | | All (key) | 136 | 100 |
| Particulates | N/A | All | 41 | 30 |
| | | All (key) | 27 | 20 |
| Mercury and its compound | N/A | All | 0 | 0.03 |
| | | All (key) | 0 | 0.03 |

Source: GB 3095-2012
PRC National Standard. Emission Standard of Air Pollutants for Thermal Power Plants. Published on 29th July 2011. Ministry of Environmental Protection. National Quality Supervision, Inspection and Quarantine Agency

Notes: For fuel and heat transfer type: Coal Fired Boiler

(1) Applies to boilers in Guang'xi Province, Chongqing city, Si'chuan Province, and Gui'zhou province.

(2) Applies to all downshot boilers, existing CFB boilers, and units achieved COD or whose EIA approved before 31st December 2003.

(key): Key Region: The region that needs strict air pollution control due to higher density of land development, environmental carrying capacity, or smaller capacity of atmospheric environment, the fragile ecological environment , and prone to serious air pollution.

With effect from 1st July 2014, all existing power plants will comply with emission limits of particulate, $SO_2$, $NO_x$, and flue gas blackness as per table above.

With effect from 1st January 2012, all new plants will comply with emission limits of particulate, $SO_2$, $NO_x$, and flue gas blackness as per table above.

With effect from 1st January 2015, all coal-fired boilers will comply with emission limits of mercury and its compounds as per table above.

All units in the key regions will comply with the emission limits in Table 2. The implementation date and area will be decided by Environmental Protection Administration Department under the State Council.

### Table 64: National Emission Limit Values for Relevant Pollutants: European Union

| Substance or mixture substances | | Plant Type | Thermal capacity | $mg/Nm^3$ under reference conditions of 6% $O_2$, 273 Kelvin and 101.3kPa |
|---|---|---|---|---|
| Common name | Chemical symbol | | | |
| Sulphur dioxide | $SO_2$ | Part 1 Annex V[(a)] | 50 to 100 | 400 |
| | | | 100-300 | 250 |
| | | | > 300 | 200 |
| | | Part 2 Annex V[(b)] | 50 to 100 | 400 |
| | | | 100-300 | 200 |
| | | | > 300 | 150 (200 in case of circulating or pressurised fluidised bed combustion) |
| Nitrogen oxides | $NO_x$ | Part 1 Annex V[(a)] | 50 to 100 | 300 (450 for pulverised lignite) |
| | | | 100-300 | 200 |
| | | | > 300 | 200 |
| | | Part 2 Annex V[(b)] | 50 to 100 | 300 (400 for pulverised lignite) |
| | | | 100-300 | 200 |
| | | | > 300 | 150 (200 for pulverised lignite) |
| Dust | N/A | Part 1 Annex V[(a)] | 50 to 100 | 30 |
| | | | 100-300 | 25 |
| | | | > 300 | 20 |
| | | Part 2 Annex V[(b)] | 50 to 300 | 20 |
| | | | > 300 | 10 |

Source: Directive 2010/75/EU of The European Parliament and of The Council Of 24 November 2010 On Industrial Emissions (Integrated Pollution Prevention And Control) (Recast)

Notes: (a) Plants which have applied for/ been granted a permit before 7/1/13, provided operation before 7/1/14
(b) Plants granted an exemption under Directive 2001/80/EC and which are in operation after 1/12/16, or plants not covered under (a)All units in the key regions will comply with the emission limits in Table 2. The implementation date and area will be decided by Environmental Protection Administration Department under the State Council.

**Table 65: IFC Limit Values for Relevant Pollutants**

| Substance or mixture substances | | Airshed status | Thermal capacity | mg/Nm³ under reference conditions of 6% $O_2$, 273 Kelvin and 101.3kPa |
|---|---|---|---|---|
| Common name | Chemical symbol | | | |
| Sulphur dioxide | $SO_2$ | Non-degraded | 50 to 600 | 900-1500 ([a]) |
| | | | >600 | 200 to 850 ([b]) |
| | | Degraded | 50 to 600 | 400 |
| | | | >600 | 200 |
| Nitrogen oxides | $NO_x$ | Non-degraded | All | 510 ([c]) ([d]) |
| | | Degraded | All | 200 |
| Particulate Matter (PM) | N/A | Non-degraded | All | 50 |
| | | Degraded | All | 30 |

Source: IFC Environmental, Health and Safety Guidelines. Thermal Power Plants.2008.

Notes: [(a)] Targeting the lower guidelines values and recognising issues related to quality of available fuel, cost effectiveness of controls on smaller units, and the potential for higher energy conversion efficiencies.
[(b)] Targeting the lower guidelines values and recognising variability in approaches to the management of SO2 emissions and the potential for higher energy conversion efficiencies. Larger plants are expected to have additional emission control measures. Selection of the emission level in the range is to be determined by EA considering the project's sustainability, development impact, and cost-benefit of the pollution control performance.
[(c)] Stoker boilers may require different emissions values which should be evaluated on a case-by-case basis through the EA process.
[(d)] Or up to 1,100 if volatile matter of fuel <10%

**Table 66: National Emission Limit Values for Relevant Pollutants: Japan**

| Substance or mixture substances | | Type | Specification | Capactity ($Nm^3/h$) | General standard ($mg/Nm^3$) | Special Standard ($mg/Nm^3$) |
|---|---|---|---|---|---|---|
| Common name | Chemical Symbol | | | | | |
| Particulate Matter | N/A | Coal Boiler | Heating area: $10m^2$ or above | >200,000 | 100 | 50 |
| | | | | >40,000 and <200,000 | 200 | 100 |
| | | | | < 40,000 | 300 | 150 |
| | | Gasifier | Coal consumption ; 20 t/day or above | | 50 | 30 |
| Oxides of nitrogen | $NO_x$ (as $NO_2$) | Coal Boiler | Heating area: $10m^2$ or above | > 700, 000 | 410 | N/A |
| | | | | >40,000and < 700,000 | 512.5 | |
| | | | | <40,000 | 615 | |
| | | Gasifier | Coal consumption ; 20 t/day or above | | 307.5 | |

Source: http://www.iea-coal.org.uk/documents/82549/7839/Japan
Ministry of the Environment, Government of Japan. Regulatory measures against air pollutants emitted from factories and business sites and the outline of the regulation.

Notes: 1. General standards are national standards applying to existing plants. Special standards apply to new plants in the defined areas. The same emission limit values for NOx apply to both existing and new plants.
2. Normalised volume Nm3 is expressed at 0 ºC and 101.3 kPa.
3. Japan has a formula for determining SOx emissions limits which includes effective stack height and a constant value according to the region the plant is located in and is therefore not representative.

### Table 67: National Emission Limit Values for Relevant Pollutants: Mongolia

| Substance or mixture substances | | Plant status | mg/Nm³ under reference conditions of 6%$O_2$, 273 Kelvin and 101.3kPa. |
|---|---|---|---|
| Common name | Chemical symbol | | |
| Sulphur dioxide | $SO_2$ | Coal burning | 400 |
| Oxides of nitrogen | $NO_x$ expressed as $NO_2$ | Coal burning | 1100 ([a]) |
| | | | 650 ([b]) |
| | | | 450 ([c]) |
| Carbon monoxide | CO | Coal burning | 180 |

Source: Mongolian Standard MNS 6298:2011.
ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT. Project Number: TA 7502-MON July 2012.
Ulaanbaatar Low Carbon Energy Supply Project Using Public-Private Partnership Model (CHP5 Project)

Notes: (a) if Vdaf <10%
(b) if 10% <Vdaf <20%
(c) if Vdaf > 20%
Vdaf – Volatile compound concentration in coal ash and flammable objects.
No N given, so reference conditions are assumed

### Table 68: National Emission Limit Values for Relevant Pollutants: Russia

| Substance or mixture substances | | Plant status | mg/Nm³ under reference conditions of 15%$O_2$, 273 Kelvin and 101.3kPa. |
|---|---|---|---|
| Common name | Chemical symbol | | |
| Oxides of nitrogen | $NO_x$ | | 125 |

Source: GOST 29328-92 “Stationary gas turbines for turbo-generators. General Technical requirements.
(a) Unit: milligrams per normal cubic metre (mg/Nm3) at reference conditions: Dry, 0OC, 1 atmosphere, 15% O2

### Table 69: National Emission Limit Values for Relevant Pollutants: Singapore

| Substance or mixture substances | | $mg/Nm^3$ under reference conditions of 273 Kelvin and 101.3kPa. |
|---|---|---|
| **Common name** | **Chemical symbol** | |
| Sulphur dioxide | $SO_2$ | 1,700; or<br>Where there is more than on flue, duct or chimney in any scheduled premises, the total mass of the sulphur dioxide emissions from all of such flue, duct or chimney divided by the total volume of such emissions shall not exceed 1,700 $mg/Nm^3$ on a daily basis. |
| Oxides of nitrogen | $NO_x$ expressed as $NO_2$ | 400 |
| Particulate matter | N/A | 50; or<br>Where there is more than one flue, duct or chimney in any scheduled premises, the total mass of the particulate emissions from all of such flue, duct or chimney divided by the total volume of such emissions shall not exceed 50 $mg/Nm^3$ and the particulate emissions from each of such flue, duct or chimney shall not exceed 100 $mg/Nm^3$ at any point in time. |
| Carbon monoxide | CO | 250 |
| Mercury and its compounds | Hg | 0.05 |
| Cadmium and its compounds | Cd | 0.05 |
| Lead and its compounds | Pb | 0.5 |
| Ammonia and ammonium compounds | $NH_3$ | 30 |
| Fluorine, hydrofluoric acid and inorganic fluorine compounds | Fl | 10 |

Source: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/nea-announces-tighter-industrial-emissions-standards-for-better-air-quality
Environmental Protection and Management (Air Impurities) Regulations

**Table 70: National Emission Limit Values for Relevant Pollutants: South Africa**

| Substance or mixture substances | | Plant status | $mg/Nm^3$ under reference conditions of $10\%O_2$, 273 Kelvin and 101.3kPa. | $mg/Nm^3$ under reference conditions of 6% $O_2$, 273 Kelvin and 101.3kPa |
|---|---|---|---|---|
| Common name | Chemical symbol | | | |
| Sulphur dioxide | $SO_2$ | New | 500 | 682 |
| | | Existing | 3500 | 4773 |
| Oxides of nitrogen | $NO_x$ expressed as $NO_2$ | New | 750 | 1023 |
| | | Existing | 1100 | 1500 |
| Particulate matter | N/A | New | 50 | 68 |
| | | Existing | 100 | 136 |

Source: Government Notice No. 30284
Stack Height Calculation – Sasol No. 3 Power Station. October 2011. Africana Finance and Investments (MM)

Notes: Description: Solid fuels (excluding biomass) combustion installations used primarily for steam raising or electricity generation
Application: All installations with design capacity equal to or greater than 50 MW heat input per unit, based on the lower calorific value of the fuel used.
Section 21 of the AQA allows for the setting of Emission Limit Values (ELVs) for specific activities which are likely to cause air quality impacts. These were published under Notice No. 30284 of March 2010.

**Table 71: National Emission Limit Values for Relevant Pollutants: Taiwan**

| Substance or mixture substances | | $mg/Nm^3$ under reference conditions of 6%$O_2$, 273 Kelvin and 101.3kPa. | Compliance Date |
|---|---|---|---|
| Common name | Chemical symbol | | |
| Sulphur oxides | ($SO_x$ expressed as $SO_2$) | 858 | Date of promulgation |
| Nitrogen oxides | ($NO_x$ expressed as $NO_2$) | 1000(1)<br>720(2) | Date of promulgation |
| Carbon monoxide | CO | 4112 | Date of promulgation |

| Particulates | | |
|---|---|---|
| Emissions Displacement Q ($Nm^3$/min) | Concentration C ($mg/Nm^3$) Standard 1 | Concentration C ($mg/Nm^3$) Standard 2 |
| 30 or less | 500 | 500 |
| 50 | 430 | 411 |
| 100 | 350 | 314 |
| 200 | 285 | 241 |
| 300 | 252 | 206 |
| 500 | 217 | 169 |
| 800 | 189 | 141 |
| 1000 | 176 | 129 |
| 2000 | 144 | 99 |
| 3000 | 127 | 85 |
| 5000 | 109 | 70 |
| 8000 | 95 | 58 |
| 10000 | 89 | 53 |
| 20000 | 73 | 41 |
| 30000 | 64 | 35 |
| 50000 | 55 | 29 |
| 70,000 and higher | 50 | 25 |

Source: http://law.epa.gov.tw/en/laws/631743675.html
R.O.C. Taiwan Environmental Law Library. Stationary Pollution Source Air Pollution Emissions Standards

Notes: Particulates: Standard (1) shall take effect Nationwide on the date of Promulgation
Standard (2) takes effect of the date of promulgation in Taipei County, Kaohsiung County, Pingtung County, Taitung County, Taipei City, and Kaohsiung City.Other areas shall be subject to Standard (1).
(1) Boilers over 4 tons and other combustion equipment with thermal input of 2.64 x 10 6 kcal/hr or higher.
(2) Mixed fuels shall use the following formulas to calculate emissions values:
Emissions Limit = Ax+By+Cz
Emissions using dry calculations
A: Gas fuel of NOx emissions standards.
A: Liquid fuel of NOx emissions standards.
A: Solid fuel of NOx emissions standards.
x: Gas fuel as a percentage of total thermal input volume.
y: Liquid fuel as a percentage of total thermal input volume.
y: Solid fuel as a percentage of total thermal input volume..

### Table 72: National Emission Limit Values for Relevant Pollutants: Tanzania

| Substance or mixture substances | | Plant status | $mg/Nm^3$ under reference conditions of 273 Kelvin and 101.3kPa. |
|---|---|---|---|
| Common name | Chemical symbol | | |
| Sulphur dioxide | $SO_2$ | 50-100MWth | Yearly average 850 $mg/Nm^3$ |
| | | 100-300 | 200 |
| | | >300 | 200 |
| Oxides of nitrogen | NOx as NO2 | 50-500 | 450 |
| | | >500 | 400 |
| Dust | N/A | Inert dust including cement | 250 |
| Carbon monoxide | CO | >50 | 250 |

Source: PREPARATION OF THE EAST AFRICAN TRANSPORT FACILITATION STRATEGY BUREAU FOR INDUSTRIAL COOPERATION WORKING PAPER 2.2. Thematic Area 2 Environmental Regulations and Standards. WORKING PAPER 2.2. HARMONISATION OF ENVIRONMENTAL REGULATIONS AND STANDARDS

Notes: No reference conditions given, so N assumed.

### Table 73: National Emission Limit Values for Relevant Pollutants: Turkey

| Substance or mixture substances | | Plant status | $mg/Nm^3$ under reference conditions of 6% $O_2$, 273 Kelvin and 101.3kPa. (calculated) |
|---|---|---|---|
| Common name | Chemical symbol | | |
| Sulphur dioxide | $SO_2$ | <100 | 2000 |
| | | >100 - 300 | 1300 |
| | | >300 | 1000 |
| Particulates | - | >50 | 100 |
| Oxides of nitrogen | NOx | - | 800 |

Source: http://www.iea-coal.org.uk/documents/82571/7864/Turkey

Notes: When SO2 emissions exceed above ELVs, measures to capture sulphur before, during or after combustion shall be applied to minimised SO2 emissions. If the above ELVs still cannot be met after sulphur reduction measures are taken, the SO2 emissions should be limited to a maximum 10% of the potential combustion concentration (90% reduction) for a combustion plant with a thermal capacity equal to or smaller than 300 MWth, or to a maximum 5% of the potential combustion concentration (95% reduction) for a combustion plant greater than 300 MWth.

**Table 74: National Emission Limit Values for Relevant Pollutants: UAE**

| Substance or mixture substances: Common name | Substance or mixture substances: Chemical symbol | Plant status | $g/Nm^3$ under reference conditions of 15% O2, dry gas.[(a)] | $mg/Nm^3$ under reference conditions of 15% O2, dry gas [(b)] |
|---|---|---|---|---|
| Oxides of nitrogen | NOx as NO2 | Gas turbines for power generation | 0.07 | - |
| | | Power generation by other fuels | 0.15 | - |
| | | Turbine units:<br>- gas fuel<br>- liquid fuel | - | <br>70<br>150 |
| Sulphur dioxide | $SO_2$ | All fuel burning sources | 0.50 | 500 |
| Total particulate matter | N/A | All combustion sources | 0.25 | 250 |
| | | Large sources | 0.1 | - |
| | | Fuels other than natural gas | - | - |
| Carbon monoxide | CO | All stationary sources | 1.5 | 500 |

Source: (a) DM Information Bulletin – Environmental Standards and Allowable Limits of Pollutants on Land, Water and Air Environment (2003)
(b) Federal Law No. (12) of 2006 on Air Quality

**Table 75: WB Pollution Prevention and Abatement Handbook 1998 Emission Limits**

| Substance or mixture substances: Common name | Substance or mixture substances: Chemical symbol | Plant status | Capacity | Limits |
|---|---|---|---|---|
| Sulphur dioxide | $SO_2$ | N/A | 50 to 500MWe | 0.2 tpd per MWe |
| | | | >500MWe | 0.2 tpd per MWe up to 500MWe, plus 0.1tpd for each additional MWe |
| | | | Any | 2000 $mg/Nm^3$ (500 tpd) |
| Nitrogen oxides | $NO_x$ | N/A | >50MWe | 750 $mg/Nm^3$[(a)]<br>1500 $mg/Nm^3$[(b)] |
| Particulate Matter (PM) | N/A | N/A | >50MWe | 50 $mg/Nm^3$ |

Notes: (a) Plants using coal with volatile matter <10%
(b) Plants using coal with volatile matter >10%
mg/Nm3 under reference conditions of 6% O2, 273 Kelvin and 101.3kPa

# C. Vehicle emission factors used in calculations

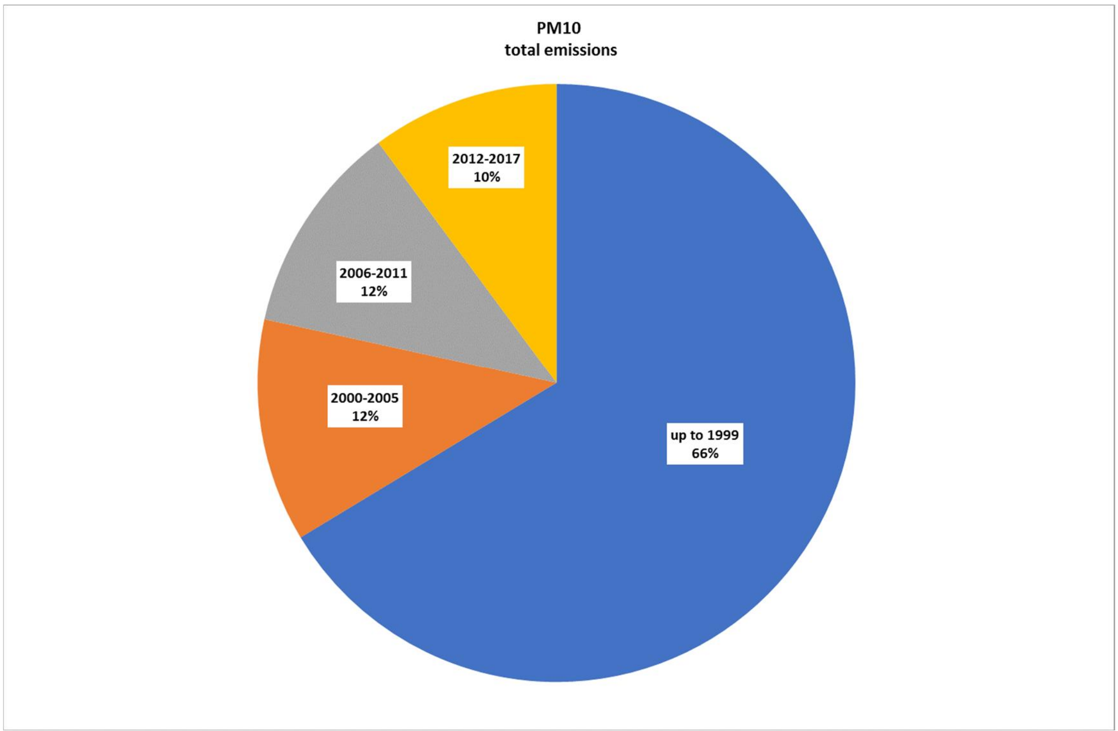
**Table 76: Vehicle emission factors**

| Vehicle type (as provided) | NOx | | | | PM | | | |
|---|---|---|---|---|---|---|---|---|
| | Up to 1999 | 2000-2005 | 2006-2011 | 2012-2017 | Up to 1999 | 2000-2005 | 2006-2011 | 2012-2017 |
| Bus | 11.645 | 7.768 | 4.671 | 3.831 | 0.586 | 0.300 | 0.149 | 0.154 |
| Car | 1.250 | 0.489 | 0.299 | 0.311 | 0.108 | 0.047 | 0.042 | 0.030 |
| Artic HGV | 15.548 | 10.616 | 6.358 | 5.143 | 0.631 | 0.399 | 0.181 | 0.185 |
| Jeep | 1.250 | 0.489 | 0.299 | 0.311 | 0.108 | 0.047 | 0.042 | 0.030 |
| Microbus | 0.619 | 0.663 | 0.539 | 0.593 | 0.185 | 0.063 | 0.055 | 0.030 |
| Minibus | 0.619 | 0.663 | 0.539 | 0.593 | 0.185 | 0.063 | 0.055 | 0.030 |
| Motorcycle | 0.206 | 0.132 | 0.043 | 0.031 | 0.042 | 0.023 | 0.017 | 0.016 |
| Pick-up | 1.649 | 1.042 | 0.737 | 0.615 | 0.254 | 0.087 | 0.062 | 0.041 |
| Motorcycle | 0.206 | 0.132 | 0.043 | 0.031 | 0.042 | 0.023 | 0.017 | 0.016 |
| Tricycle | 9.169 | 6.167 | 3.700 | 3.050 | 0.477 | 0.268 | 0.139 | 0.144 |
| Rigid HGV | 11.645 | 7.768 | 4.671 | 3.831 | 0.586 | 0.300 | 0.149 | 0.154 |

Source: Mott MacDonald calculation based on data provided by Defra Emission Factor Toolkit

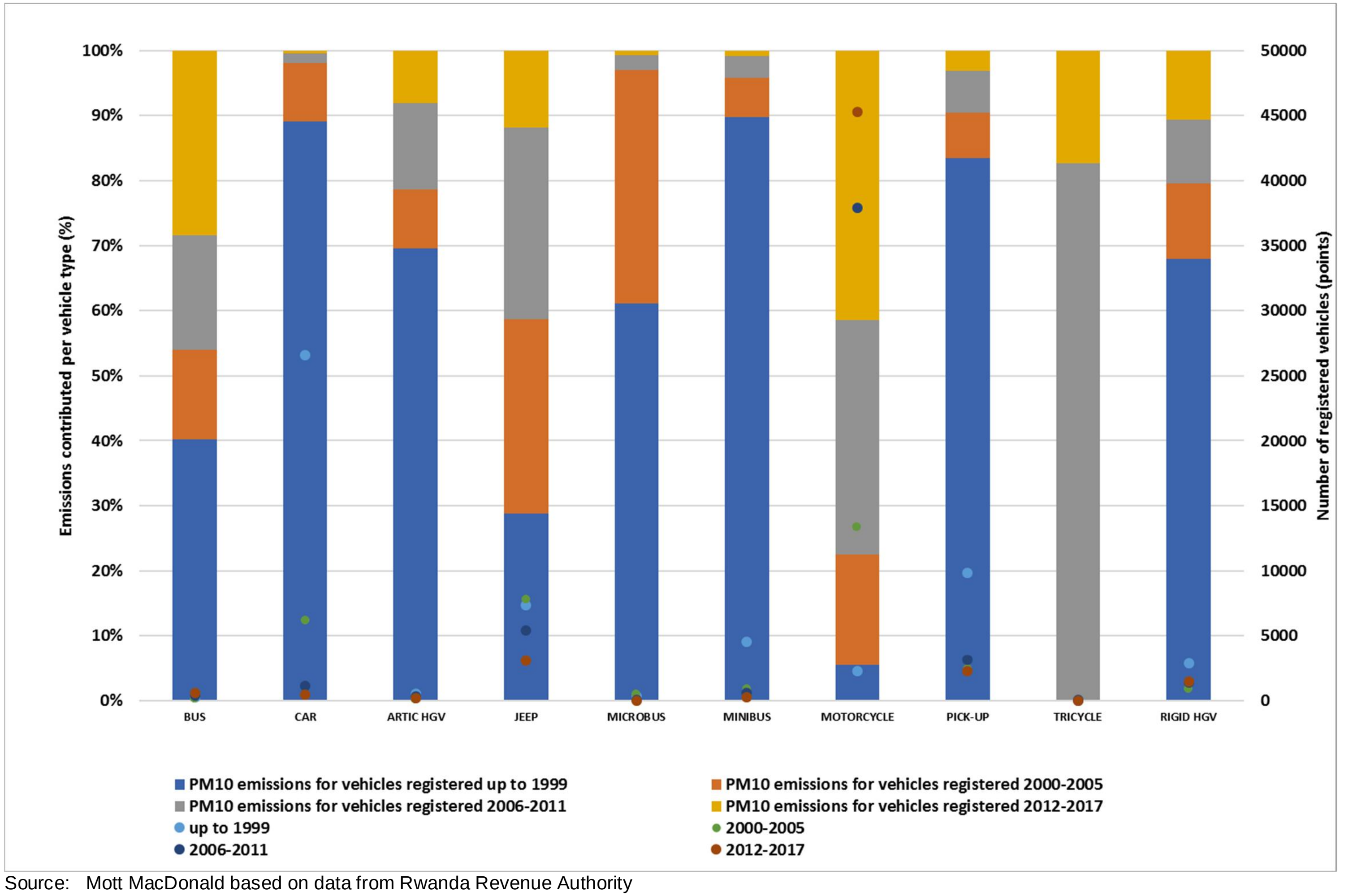
# D. Emissions of particulates from road vehicles

**Figure 51: Percentage of total $PM_{10}$ emissions by period of registration**



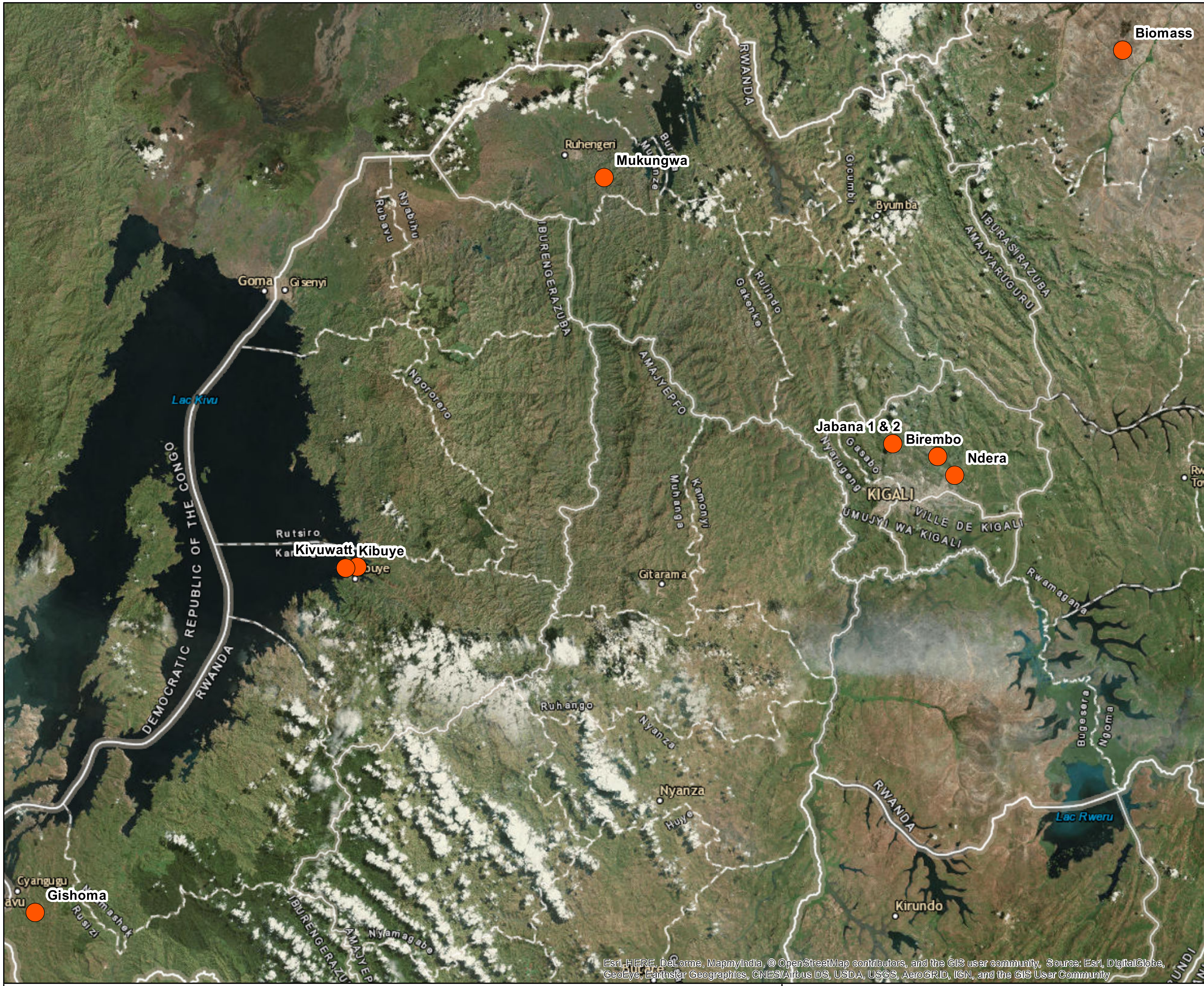

Source: Mott MacDonald based on data from Rwanda Revenue Authority

**Figure 52: Percentage of $PM_{10}$ emissions for each vehicle type by period of registration**




Source: Mott MacDonald based on data from Rwanda Revenue Authority

# E. Existing thermal power plant locations




Key to Symbols

Thermal power plants

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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Title

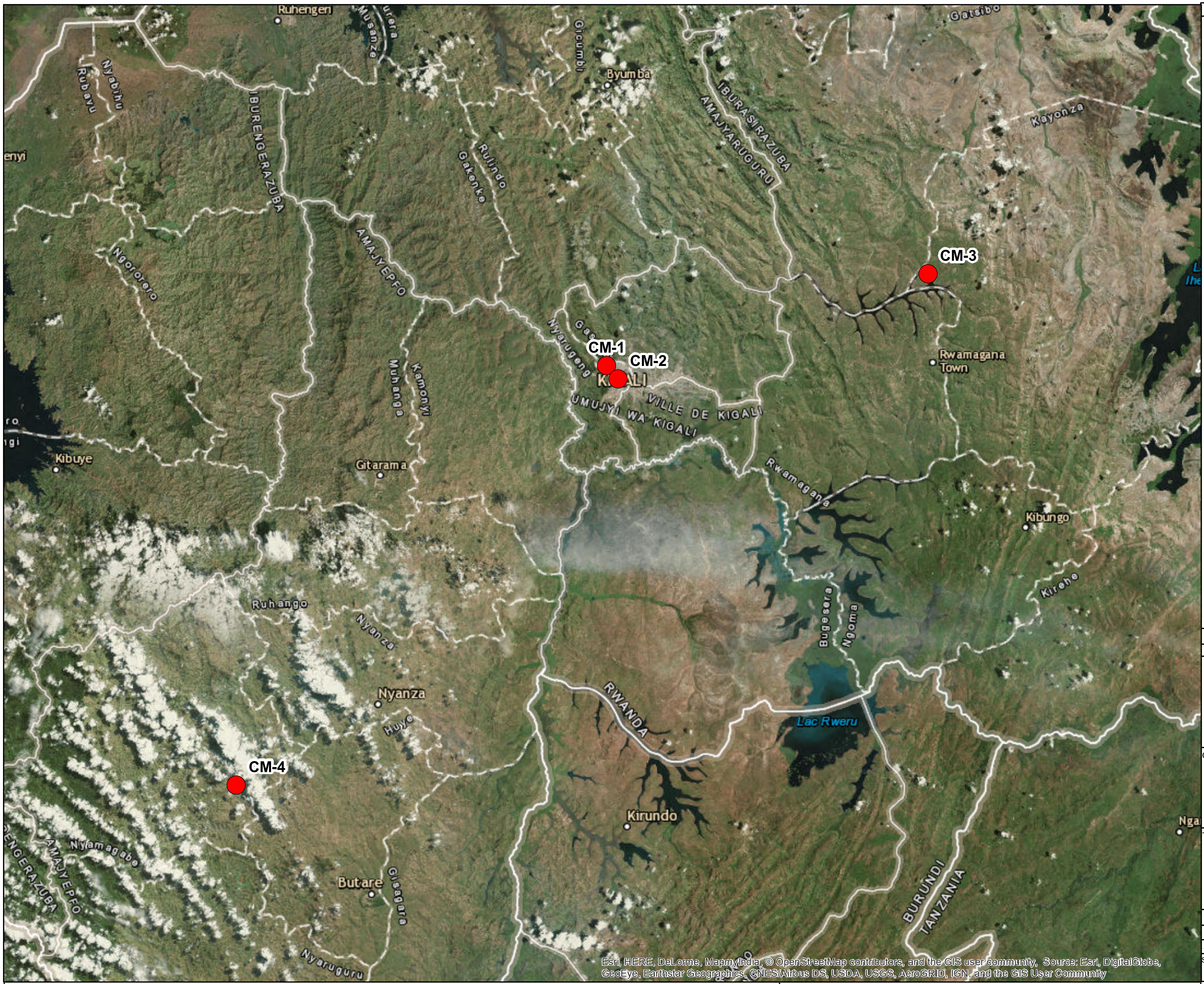
Thermal power plants in Rwanda

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:530,000 | PRE | P1 | STD |

0 15 30 45 Kilometres

# F. Continuous air quality monitoring locations




Key to Symbols

Continuous monitoring sites

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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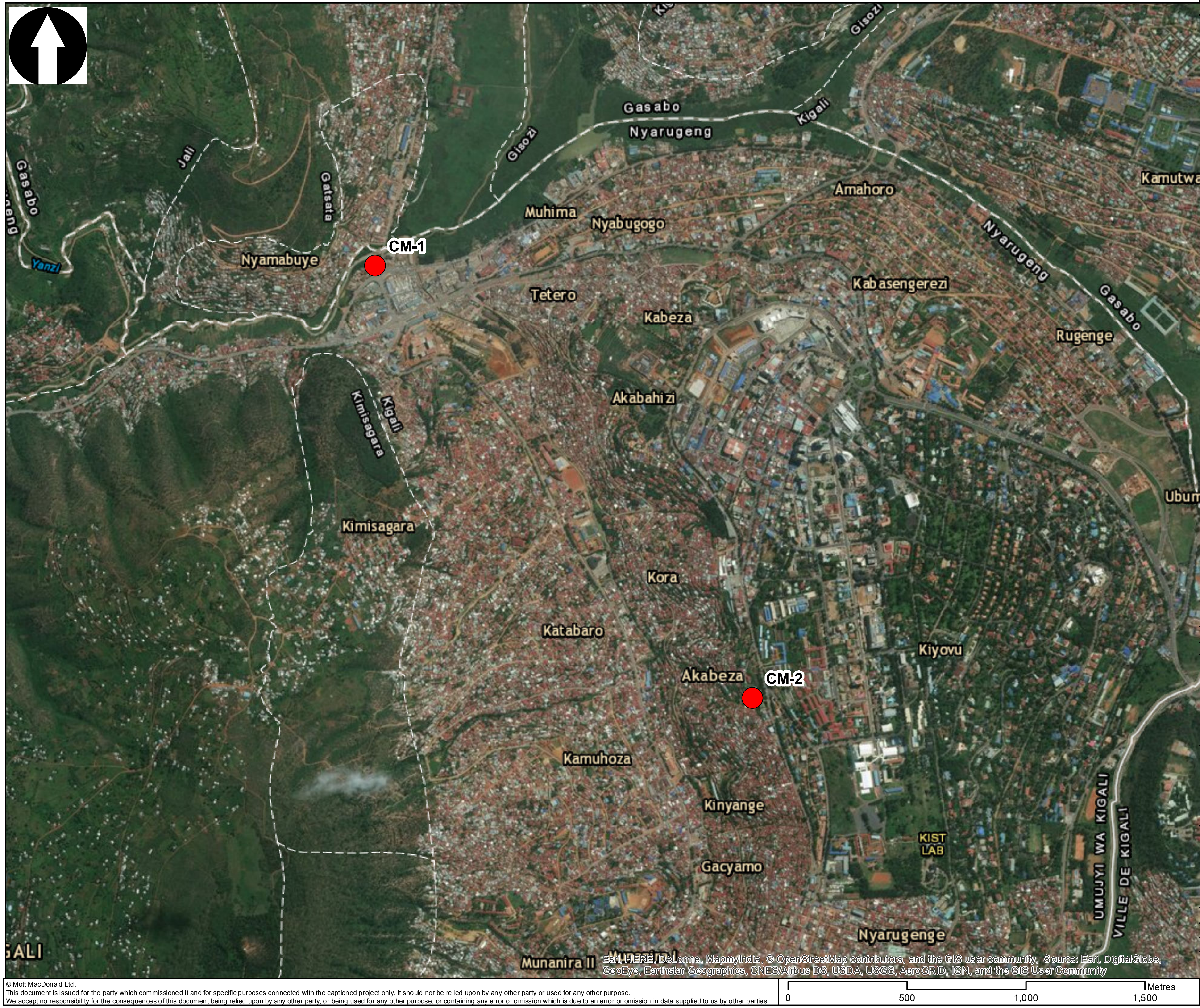
Continuous air quality monitoring sites overview

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:500,000 | PRE | P1 | STD |

0 5 10 20 30 Kilometers




Key to Symbols

Continuous monitoring sites

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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Continuous air quality monitoring sites Kigali

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:15,000 | PRE | P1 | STD |


Key to Symbols

Continuous monitoring sites

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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Title

Continuous air quality monitoring sites Kawangire

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:6,000 | PRE | P1 | STD |

0 180 360 540 Metres


Key to Symbols

Continuous monitoring sites

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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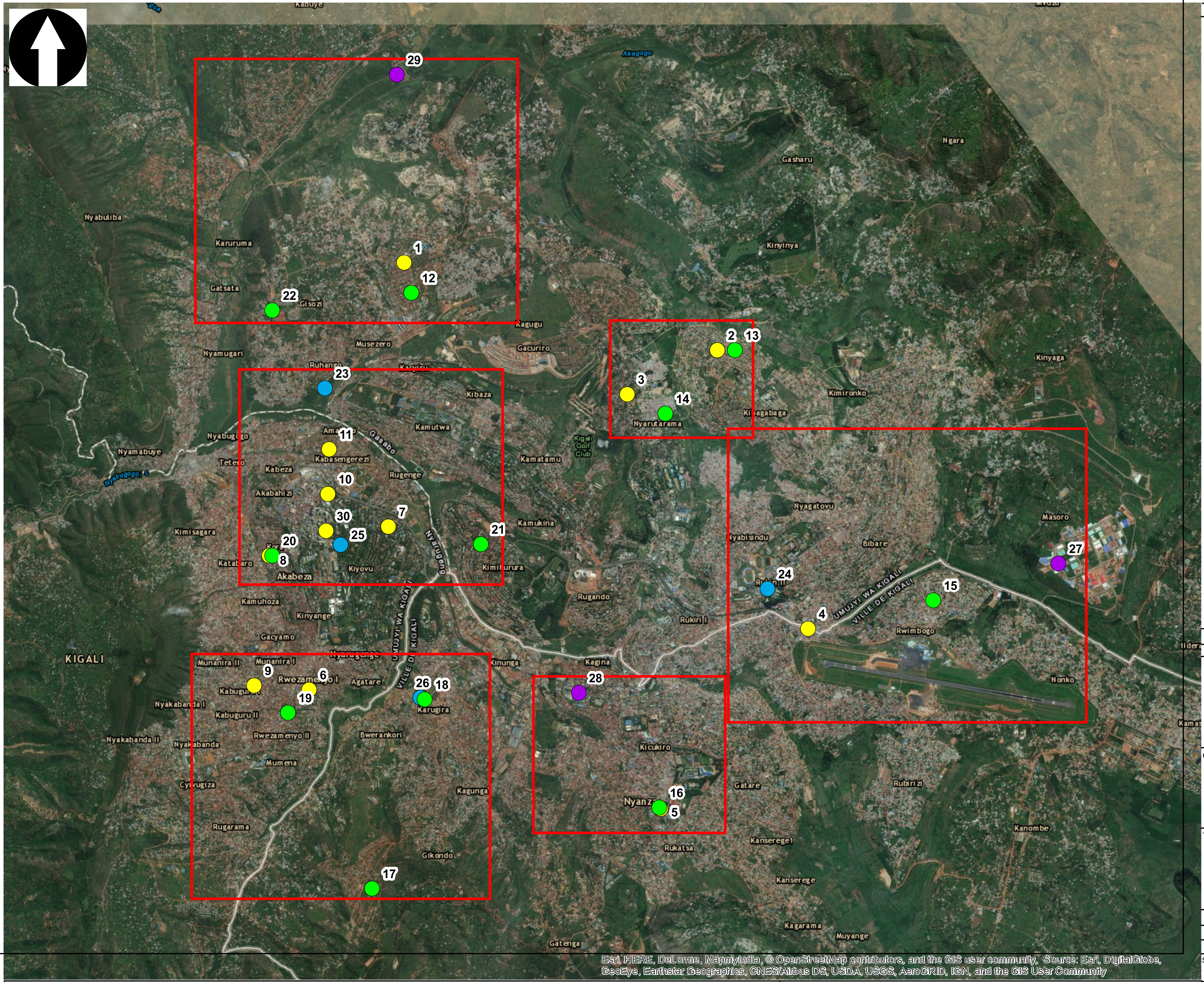
Title

Continuous air quality monitoring sites Gasaka

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:6,000 | PRE | P1 | STD |

# G. Passive air quality monitoring locations




Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |
|---|---|---|---|---|---|
| Rev | Date | Drawn | Description | Ch'k'd | App'd |

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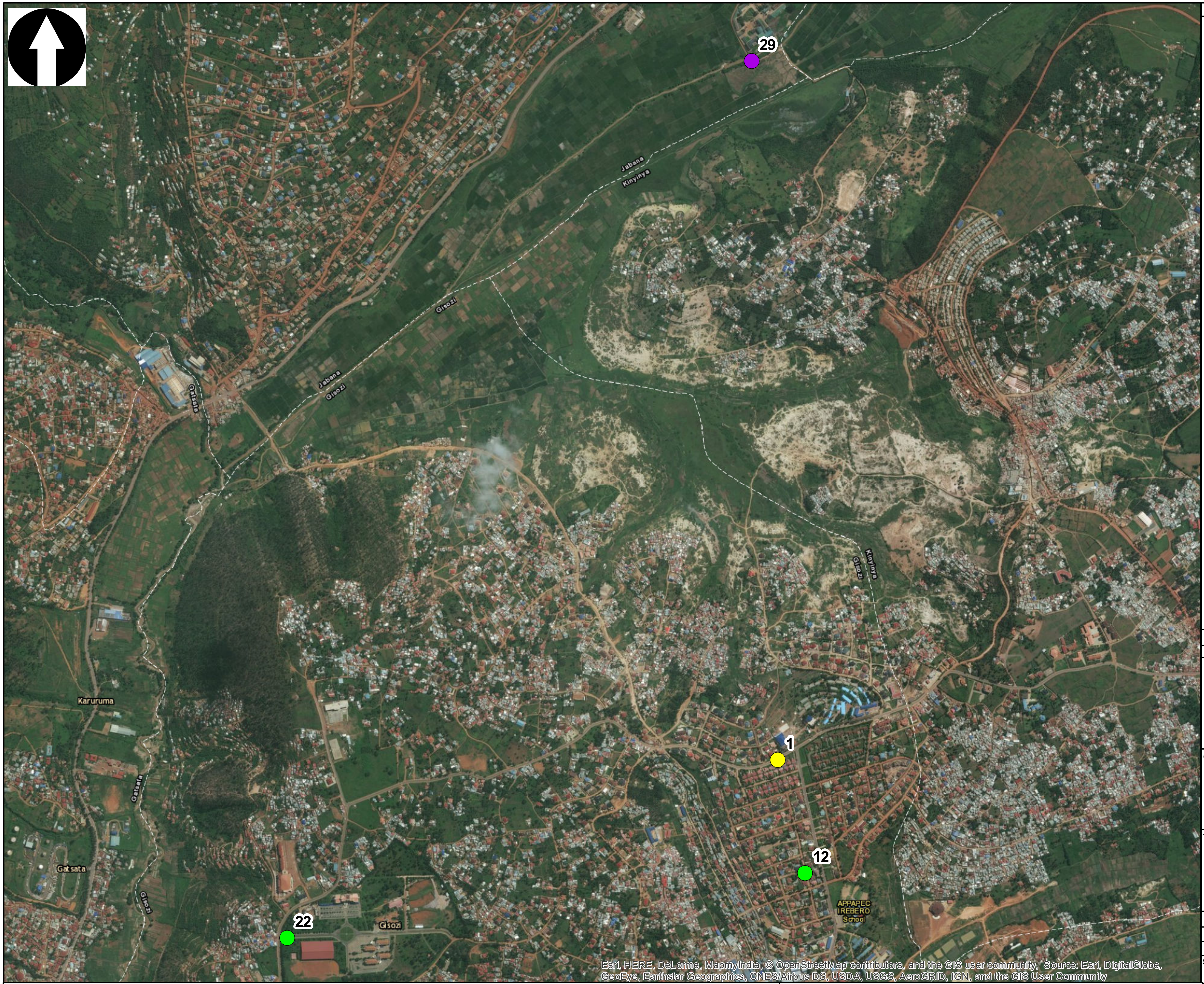
Title

Diffusion tube monitoring locations overview

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:50,000 | PRE | P1 | STD |




Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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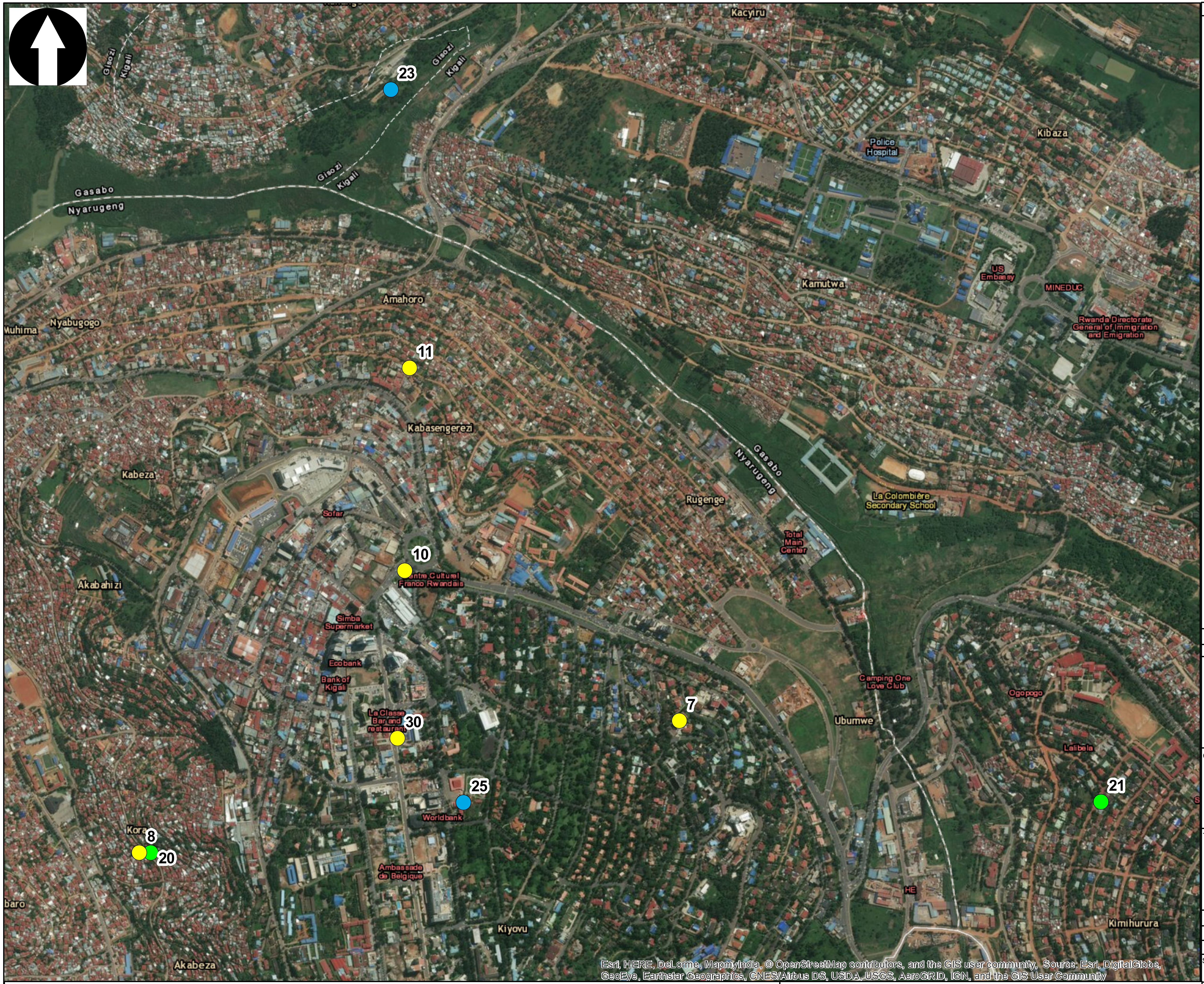
Title

# Diffusion tube monitoring locations

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:11,000 | PRE | P1 | STD |

Metres: 0, 300, 600, 900




Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |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Diffusion tube monitoring locations

| | |
|---|---|
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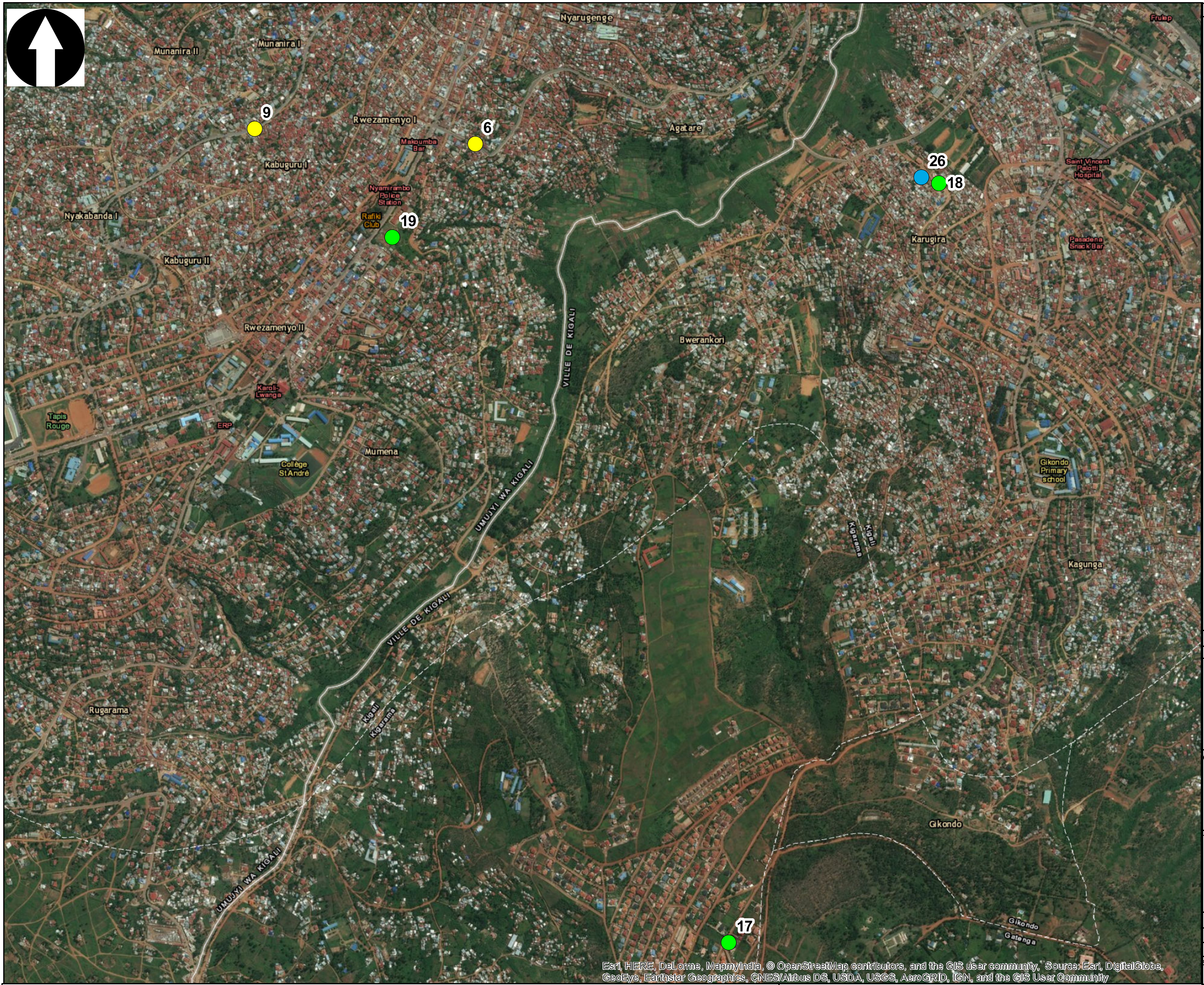
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:11,000 | PRE | P1 | STD |

0 300 600 900 Meters




Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |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| | |
|---|---|
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| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:12,500 | PRE | P1 | STD |

0 300 600 900 Metres


Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |


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Diffusion tube monitoring locations

| | |
|---|---|
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| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:8,000 | PRE | P1 | STD |

0 200 400 600 Metres


Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |

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| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:15,000 | PRE | P1 | STD |


Key to Symbols

- Residential
- Roadside
- Urban background
- Industrial

| Rev | Date | Drawn | Description | Ch'k'd | App'd |
|---|---|---|---|---|---|
| A1 | Nov 2017 | JAB | Monitor locations | CM | CM |


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Title

Diffusion tube monitoring locations

| | |
|---|---|
| Drawn | J Burnell |
| Check | C Mills |
| Approve | C Mills |

| Scale at A3 | Status | Rev | Security |
|---|---|---|---|
| 1:6,000 | PRE | P1 | STD |

0 150 300 450 Metres