COMPARATIVE STUDY OF AIR POLLUTION LEVELS IN RURAL AREA AND KIGALI CITY BASED ON AIR QUALITY INDEX.

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Declaration

I declare that this dissertation entitled **"Comparative study of air pollution levels in rural area and Kigali city based on Air Quality Index"** is my own research; the same work has never been submitted or presented anywhere for the same purpose. I further declare that this is a work presented as the best of my knowledge in partial fulfilment of the requirements for the degree of Master of Science in Atmospheric and Climate Science at University of Rwanda-College of Science and Technology during the Academic Year 2017-2018.

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Date…….

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ABSTRACT

Considering that the increase in road traffic, domestic fuel burning and industry is claimed to worsen the air quality in Kigali city, the comparison of air pollution levels between rural area and Kigali city was thought about to find out their extent in air pollution relative to one another.

The main objective of this study is to compare the air pollution levels in rural area and Kigali City based on Air Quality Index. It was customary to present air quality findings as time series plots, statistical analyses and other scientific techniques to analyse data which were not sufficient for a common person or the general public to get the clear picture of how good or bad the air is in a particular place. This has resulted in low awareness about air pollution problem and hence a less involvement of people in air quality improvement. This study has incorporated the concept of Air Quality Index in showing air pollution levels to overcome such difficulties. It has been considered air quality data for three months (November 2017, December 2017 and January 2018) collected at two stations from rural area (Gasaka and Kawangire) and two stations from Kigali city (Gitega and Nyabugogo) by using AQMesh monitors, and the other relevant information used in calculating the Air Quality Index was derived from internet. The key air pollutants to which analysis was made are $PM_{2.5}$, SO_2, NO, NO_2, CO and O_3 and the difference identified between rural area and Kigali city is based on the highest SO_2, NO and NO_2 concentrations observed at Nyabugogo and Gitega locations.

Though there are considerable vehicle emissions at Nyabugogo location, the measured air pollutant concentrations were at moderate levels as the calculated Air Quality Index at this location remained below 100 during the period of three months (91 days) and hence the air quality was acceptable. The higher O_3 and CO concentrations measured at Gasaka station affected the air quality of that location such that within 91 days, the air quality was acceptable in 67 days only. The air quality at Gitega location was acceptable in 38 days only out of 91 days and this is attributed to the highest level of O_3 concentrations characterized that place. The last location characterized by poor air quality is Kawangire where the highest $PM_{2.5}$ concentrations aggravated the air quality in such a way that within 91 days, the air quality was acceptable in 36 days only.

Key word: Air pollutants, Air Quality Index

LIST OF ACRONYMS

AQG: Air Quality Guideline

AQI: Air Quality Index

EAS: East African Standards

GPRS: General Packet Radio Services

NAAQS: National Ambient Air Quality Standards

NASA: National Aeronautics and Space Administration

NO_x: Nitrogen oxides

PM: Particulate Matter

PM_{10}: Particulate Matter which are greater than 2.5 but less than or equal to 10 micrometers in diameter

$PM_{2.5:}$ Particulate Matter which are less than or equal to 2.5 micrometers in diameter

PSI: Pollution Standards Index

SOx: Sulfur oxides

USEPA: United State Environmental Protection Agency

VOCs: Volatile Organic Compounds

WHO: World Health Organization

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CHAPTER1. INTRODUCTION

Air pollution is a growing problem in Rwanda. The pollution of air is caused by a variety of anthropogenic and natural sources of pollutants. Particularly, the increase in road traffic, domestic fuel burning and industry is claimed to worsen the air quality in Kigali city. In Rwanda, The key pollutants of more concern are Particulate matter ($PM_{2.5}$& PM_{10}), Sulfur dioxide (SO_2), Carbon monoxide (CO) , Nitrogen oxides (NO_x) and Ozone (O_3) [1].

The study conducted by WHO showed that in the year of 2012 over three million premature deaths around the world were associated to poor ambient air quality and in low and middle-income countries contributed approximately 87% of these deaths and that in Rwanda, 2227 deaths were attributed to ambient air pollution as consist of 940,738,496, 34 and 19 deaths due to stroke, acute lower respiratory disease, ischaemic heart disease, chronic obstructive pulmonary disease and lung cancer respectively [2]. However, the success to reach on air quality improvement depends on the support of country members who are well-informed about local and national air pollution problems and about the progress of mitigation efforts.

Normally, the air quality research findings are presented by using time series plots, statistical analyses and other complex findings related to air quality. The results presented in that way do not give a clear picture on how good or bad the air is, especially for the general public or for anyone with little relevant knowledge in Atmospheric Science. The possible efforts should be utilized to effectively communicate with the people from various disciplines in order to ensure the public awareness on air pollution problem. The concept of AQI has been incorporated to translate the complex scientific into public domain in simple linguistic terms that is easily understood for a common person. AQI makes easy communication with people about the levels of air pollution as well as its implication on human health [3].

Therefore, this project intends to compare the levels of air pollution in both rural area and Kigali city based on AQI in order to provide coherent information to the general public, decision makers and scientists about the state of air quality for the specific air pollutants monitored within areas considered as the case study.

1.1. Problem statement

Air pollution is an international problem, which has many effects to the life of the world population. African countries, including Rwanda are also concerned with air pollution problem. It requires both awareness and enhanced involvement of people to confront this issue. The general public need to know the quality of air so that they may involve in different mitigation measures taken by regulatory agencies. The main challenge arises from the way of communicating with people about air quality problem because the people will not be satisfied with only the raw air quality data, time series plots and other statistical analyses. It will finally tend to complicate people and lose their interests. Thus, the AQI is more effective to remove such difficulties and with AQI, it is easier to interpret the air pollution levels and to understand the health effects corresponding to each specific level of air pollution.

1.2. Main objective

The main objective of this study is to compare the air pollution levels in rural area and Kigali City based on Air Quality Index.

1.3. Specific objectives

To compare the air pollution levels of criteria pollutants considered in rural area and Kigali city based on Air Quality Index, the following specific objectives are undertaken:

- To analyse variation in concentrations of each air pollutant at different air quality monitoring stations considered.
- To compare the monthly mean concentration for each air pollutant with the known standards (WHO standards and EAS).
- To calculate the Air Quality Index (AQI) for each air pollutant and to find the overall AQI at each air quality monitoring station as well as to suggest its health implications.
- To make a comparison between the overall AQI for the air quality monitoring stations from rural area and Kigali city so that to identify the more polluted location.

1.4. Scope of the study

The study is to compare the air pollution levels in rural area and Kigali City based on Air Quality Index**.** The study considered the air quality data monitored at four stations during the period of 3 months (from 1st November 2017 up to 30th January 2018).

The two stations are located in rural areas while the remaining two are in Kigali city. For rural areas, one of the stations is installed at the Kawangire meteorological station in Gatsibo district in the Eastern province while the other one is installed at the Gasaka meteorological station in Nyamagabe district in the Southern province. In Kigali city, one station is installed at Engen petrol station at Nyabugogo bus terminal and another one at Gitega at the Meteo Rwanda headquarters.

The key air pollutants measured at all of air quality monitoring stations are $PM_{2.5}$, SO_2, NO, NO_2, CO and O_3. In the analysis of variation in concentration of each air pollutant at different locations, some factors including meteorological parameters which may affect the pollutant concentrations were not considered because of time constraint.

Regarding AQI, different countries around the world have developed their systems of reporting AQI and as the Government of Rwanda has not yet established its system of AQI, the USEPA Air Quality Index System was used to find the air quality index and to suggest the health effects at each AQI value.

1.5. Significance of the study

A. For the decision makers

As the project compared the levels of air pollution between rural area and Kigali city; the results from this project can help the decision makers to appreciate the extent for some specific air pollutants considered within particular areas studied when is moderately, or otherwise to take necessary actions to improve the air quality.

A. For the scientists

This project can help the scientists who engage in scientific researches related to air quality. For further investigation about the state of air quality within the same areas; the obtained results for this study could serve as reference.

B. For the general public

Air Quality Index can help many people to know the levels of air pollution as well as the associated health effects, especially for the areas considered in the particular time of the study. This can raise awareness and help people to appreciate the mitigation measures taken by regulatory agencies and get involved in air quality improvement when required. In addition, this can act as a hint for the software developers to bring a system for disseminating the daily Air Quality Index as it can be helpful for people to plan their daily activities; particularly for those with existing cardiovascular and respiratory diseases.

CHAPTER 2. LITERATURE REVIEW

Clean air is known as the basic requirement of human health and well-being but poor air quality continues to be a challenging problem worldwide. Exposure to air pollutants affects human health in different ways and can lead to increased mortality. Epidemiological indication on health effects of air pollution is increasing and evolving rapidly which explain why air pollution is the largest environmental risk factor [4].

2.1. Criteria pollutants

Air pollution is caused by a variety of anthropogenic and natural sources of pollutants. In Rwanda, the main sources of anthropogenic air pollution are road traffic, domestic fuel burning and industry. The key pollutants of more concern are particulate matter ($PM_{2.5}$& PM_{10}), Sulfur dioxide (SO_2), Carbon monoxide (CO) , Nitrogen oxides (NO_x) and Ozone (O_3) [1].

2.1.1. Particulate matter ($PM_{2.5}$& PM_{10})

Particulate matter is a mixture of solid particles and liquid droplets found in ambient air [5]. Some particles are large or dark that they can appear as soot or smoke while others are so small in the way that they can hardly be detected with the measuring instrument. **$PM_{2.5}$** is referred as the **fine particles** which are less than or equal to 2.5 micrometers in diameter while **Coarse particles** describe the particles of size which is greater than 2.5 but less than or equal to 10 micrometers in diameter [6]. Thus, PM_{10} refers to all particles less than or equal to 10 micrometers in diameter. Particulate matter can be emitted from stationary and mobile sources as well as from natural sources. Fine particles originate from the fuel combustion of motor vehicles, power generation, industrial facilities, residential fireplaces and wood stoves. Some gases such as SO_2, NOx, and VOCs can interact with other compounds in the air to form fine particles, their chemical and physical compositions vary depending on location, time of year, and weather .Coarse particles result from vehicles traveling on unpaved roads, materials handling, crushing or grinding operations and windblown dust and those are dominant in rural area [7].

When these particles are inhaled, they can get accumulate in the respiratory system where they can lead to numerous health effects. Exposure to fine particles is closely associated with different health effects such as premature mortality of elderly persons, increased hospital admissions, emergency room visits for heart and lung patients and the decrease in lung function in a large number of all population groups, while aggravation of respiratory conditions such as asthma is related to coarse particles [7].

2.1.2. Sulphur dioxide (SO_2)

Sulfur dioxide (SO_2) is the predominant form of sulphur oxides (SO_x) found in the lower atmosphere. Sulfur dioxide is a colorless gas which can be identified by taste and smell in the range of 1,000 to 3,000 micrograms per cubic meter ($\mu g/m^3$). Its odor becomes unpleasant when the concentration reaches to10,000 $\mu g/m^3$. Sulfur dioxide can dissolve in water present in the atmosphere and forming sulfurous acid (H_2SO_3). About 30% of the sulfur dioxide in the atmosphere is transformed into sulfate aerosol which in turn being removed by wet or dry deposition processes [8].

Sulfur dioxide is mostly produced by burning fuels containing sulfur or by roasting metal sulphide ores. It can be emitted naturally by volcanoes while the main anthropogenic sources of sulfur dioxide are thermal power plants burning sulfur containing compounds (coal), industrial boilers and nonferrous metal smelters. In addition, emissions from domestic coal burning and from vehicles may cause an increase in ambient concentrations of sulfur dioxide [9].

Exposure to sulfur dioxide in the ambient air has been attributed with different health effects such as reduced lung function, increased incidence of respiratory symptoms and diseases, irritation of the eyes, nose, throat as well as the premature mortality [10]. Apart from the human health, trees and other plants exposed to wet and dry acid (originating from SO_2) deposition may also be injured and then affecting the crops production. Emissions of sulfur dioxide may also affect building stone and ferrous and nonferrous metals because of the sulfurous acid formed by sulfur dioxide with moisture which can accelerate the corrosion of iron, steel, and zinc [8].

2.1.3. Carbon monoxide (CO)

Carbon monoxide (CO) is a colorless, odorless and a poisonous gas at high level resulting from incomplete combustion of carbon- containing fuels [7]. Anthropogenic sources of CO include motor vehicle exhaust, controlled vegetation burning, residential biomass combustion and industrial processes while the natural sources are forest fires, emissions from plants and oceans and the oxidation of methane and non-methane hydrocarbons. The major natural source of CO is oxidation of non-methane hydrocarbons and in non-urban areas, the human activities are responsible for approximately 60% of CO and natural processes account for the remaining 40% according to WHO. In Africa, the NASA observations indicate that a dominant source of CO is the seasonal agricultural burning [1].

Carbon monoxide affects both healthy and unhealthy people because when the level of carbon monoxide increases, it reduces the amount of oxygen carried by haemoglobin around the body in red blood cells. The vital organs, such as brain, nervous tissues and the heart, do not receive enough oxygen to work properly as a result. Health effects will begin to be seen when approximately 2.5% of haemoglobin is bound to CO and at very high concentrations of carbon monoxide, up to 40% of the haemoglobin can be bound to carbon monoxide and this level will almost certainly kill humans.
For healthy people, a small increase in the level of carbon monoxide is likely to affect them as they will have trouble concentrating. The result is that some people might become a bit clumsy as their coordination is affected, and they could get tired more easily. Particularly, those with heart problems are likely to suffer from more frequent and longer angina attacks, and they would be at greater risk of heart attack. In addition, children and unborn babies are at risk because they are smaller and their bodies are still growing and developing [11].

2.1.4. Nitrogen oxides (NO_x)

Nitrogen oxides **(NO_x)** is the term used to describe a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2). NO is a colorless gas and has no taste while NO_2 is a yellowish-orange to reddish-brown gas with a pungent, irritating odour and it is a strong oxidant. NO_x originates from high temperature combustion as a result of partially oxidised nitrogen in the atmosphere and in fuel via a series of reaction [1]. The main anthropogenic sources are fossil

fuel combustion, fertilizer application and prescribed burning. Naturally, they are released in the atmosphere as a result of lightning, wildfires and soil microbial activity [12].

For individuals with pre-existing respiratory difficulties, exposures to low levels of nitrogen dioxide (NO_2) for a short time (means, less than 3 hours) may lead to changes in airway responsiveness and lung function as well as an increase in respiratory illness in children between 5 and 12 years old. Long-term exposures to NO_2 may lead to increased vulnerability to respiratory infection and it may also lead to permanent alterations in the lung. Nitrogen oxides is a major precursor of ground- level ozone and aerosols which is associated with adverse health effects [7].

2.1.5. Ozone (O_3)

Ozone has a major significance, as the stratospheric ozone protects the earth from the sun's harmful ultraviolet radiation while in the troposphere (ground-level ozone) plays its role as a greenhouse gas and participating in the physicochemical processes [13]. For this study, emphasize is on ground-level ozone rather than stratospheric ozone because ground-level ozone is one of the key pollutants of more health concern. Ground-level ozone is a secondary air pollutant produced during the photochemical degradation of emitted VOCs in the presence of sunlight and NO_x. Due to the photochemical nature of ozone formation, it is strongly influenced by meteorological variables, particularly temperature. It influences ozone formation by speeding up the rates of chemical reactions and increasing the emissions of VOCs, such as isoprene from vegetation [14].

When NO and NO_2 are present in sunlight, the tropospheric ozone is formed as a result of the photolysis of NO_2 by producing NO and O which reacts with O_2 to form ozone (O_3). Ozone is also produced in the troposphere as a result of a complex set of reactions that involve VOCs and NO_x in presence of sunlight. VOCs and NO_x work together to form ozone as VOCs provide the radicals to react with NO and form NO_2. Then, photolysis of NO_2 produces NO and O which in turn combines with O_2 to form ozone. Ground-level ozone forms readily in the atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources.

Short-term (1–3 hours) and prolonged (6–8 hours) exposures to ambient O_3 have been linked to a number of health effects of concern. For example, increased hospital admissions and emergency room visits for respiratory causes have been associated with ambient O_3 exposures. Exposures to O_3 can make people more susceptible to respiratory infection, result in lung inflammation, and aggravate pre-existing respiratory diseases such as asthma. Other health effects attributed to O_3 exposures include significant decreases in lung function and increased respiratory symptoms, such as chest pain and cough.

Ozone also affects vegetation and ecosystems, leading to reductions in agricultural and commercial forest yield, reduced growth and survivability of tree seedlings, and increased plant susceptibility to disease, pests, and other environmental stresses. In long-lived species, these effects may become evident only after several years or even decades, thus having the potential for long-term effects on forest ecosystems. Ground-level ozone can cause the damage to the foliage of trees and other plants by decreasing the aesthetic value of attractive species as well as the natural beauty of our national parks and recreation areas [7].

2.2. Air Quality Index (AQI)

2.2.1. Back ground

In addition to land and water, the human needs clean air for sustaining life. With the technological advancements, a vast amount of data on ambient air quality is generated and used to establish the quality of air in different areas around the world. The large monitoring data result is presented by using time series plots, statistical analyses, and other complex findings related to air quality. Such information neither gives a clear picture to a decision maker nor to a common man who simply wants to know how good or bad the air is, particularly for those who suffer from illnesses caused by exposure to air pollution. The result is that people tend to lose interest and they can neither appreciate the state of air quality nor the pollution mitigation measures taken by regulatory agencies. To address that problem of communication, AQI concept has been developed and used effectively in many developed countries around the world for over last three decades.

An AQI is defined as “an overall scheme that transforms the weighed values of individual air pollution related parameters into a single number or set of numbers” [3].

The AQI is an index for reporting the daily air quality. It is an important tool of risk communication because it informs the public of the local level how clean or unhealthy the air is and the potential health risk it would impose, particularly on vulnerable groups such as children, the elderly, and those with existing cardiovascular and respiratory diseases. AQI is used to help people in making decisions on different outdoor activities based on health effects that people may experience within a few hours or days after breathing unhealthy air [15].

2.2.2. Application of Air Quality Index

According to the report on National Air Quality Index done by Central Pollution Control Board **(CPCB**) of the Indian Government, the six applications of Air Quality Index have been identified.

1. Resource Allocation: To help managers in allocating funds and determining priorities. Enable evaluation of trade-offs involved in alternative air pollution control strategies.

2. Ranking of Locations: To assist in comparing air quality conditions at different locations/cities. Thus, pointing out areas and frequencies of potential hazards.

3. Enforcement of Standards: To determine extent to which the legislative standards and existing criteria are being adhered. Also helps in identifying faulty standards and inadequate monitoring programs.

4. Trend Analysis: To determine change in air quality which have occurred over a specified period. This enables forecasting of air quality and plan pollution control measures.

5. Public Information: To inform the public about environmental conditions. It is useful for people who suffer from illness aggravated or caused by air pollution. Thus it enables them to modify their daily activities at times when they are informed of high pollution levels.

6. Scientific Research: As a means for reducing a large set of data to a comprehendible form that gives better insight to the researcher while conducting a study of some environmental phenomena. This enables more objective determination of the contribution of individual pollutants and sources to overall air quality. Such tools become more useful when used in conjunction with other sources such as local emission surveys [3].

2.2.3. Construction of Air Quality Index

AQI is calculated in order to express the levels of one or more air pollutants, over various critical averaging periods, against a reference. Different countries around the world such as Singapore, China, Thailand, Malaysia, South Korea, Taiwan, Hong Kong, and Macau established their Air Quality Index systems based on the US system. In Rwanda, the national Air Quality Index has not yet been designed and the calculation of Air Quality Index for this study is based on the USEPA system. While constructing or designing Air Quality Index system, individual country will need to select the key air pollutants and the averaging time of air pollutant concentration.

Key air pollutant: In the selection of key air pollutants, different countries prefer to include pollutants that are associated with the most significant impact on their residents but the commonly air pollutants used to assess Air Quality Index, include nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), particulate matter ($PM_{2.5}$ &PM_{10}), and lead. On the other hand, pollutants with no significant impacts in a particular country, they may be omitted from the national Air Quality Index system.

Averaging time: Another important aspect in constructing an Air Quality Index is the choice of the averaging time (s) for each pollutant. As the primary objective of an Air Quality Index system is to communicate the health effect associated with short-term exposure to air pollutants, it would be necessary for a given Air Quality Index system to track pollutant concentrations over a shorter averaging time. Based on experience around the world, calculation of the Air Quality Index is usually based on 1-hour, 8-hour, or 24-hour average monitoring data, depending on the pollutants [15]**.**

2.2.4. Air Quality Guideline

In 1987, the first AQG was published by WHO with an ambition of informing policy-makers and providing the appropriate targets for a broad range of policy options for air quality management in different parts of the world, and as well as to offer global guidance on reducing the health impacts associated with polluted air for both developed and developing countries. AQGs were updated in 1997, based on expert evaluation of current scientific evidence and in the new version of AQGs; the four common air pollutants were considered as particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2).

In addition to guideline values, interim targets are given for each indicator so that to suit the situation for developing countries. These targets aim to promote a shift from high air pollutant concentrations to lower air pollutant concentrations step by step. If these targets were to be achieved, one could expect significant reduction in risks for acute and chronic health from air pollution [16].

In 2005, the WHO updated its AQG, an international reference on the health effects associated with exposure to air pollution and a policy tool for reducing these effects worldwide. The current update is intended to be relevant and applicable worldwide and takes into consideration large regional inequalities in exposures to air pollution. It recommends guideline levels for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, as well as the set of interim targets for these pollutants' concentrations, encouraging gradual improvement of air quality and reduction of health impacts of the pollution[17] and with help of WHO Guidelines, most of EAS were established as shown in table 2.1.

Table 2.1: Air Quality Standards

	EAS			WHO standards
Pollutant	Time weighted average	Industrial area	Residential, rural & other areas	
SOx	Annual mean	80 µg/m^3	60 µg/m^3	20 µg/m^3 (SO2), 24-hour mean
	24-hour mean	125 µg/m^3	80 µg/m^3	500 µg/m^3 (SO2), 10-minute mean
NOx	Annual mean	80 µg/m^3	60 µg/m^3	
	24-hour mean	150 µg/m^3	80 µg/m^3	
NO_2	Annual mean	150 µg/m^3	0.05 ppm	40 µg/m^3 (Annual mean)
	24-hour mean	100 µg/m^3	0.1 ppm	200 µg/m^3 (1-hour mean)
PM (<10µm)	Annual mean	70 µg/m^3	50 µg/m^3	
	24-hour mean	150 ug/Nm^3	100 ug/Nm^3	
$PM_{2.5}$	Annual mean	35 µg/m^3		10 µg/m^3 (Annual mean)
	24-hour mean	75 µg/m^3		25 µg/m^3 (24-hour mean)
CO/ CO_2	1-hour mean	10.0 mg/m^3	4.0 mg/m^3	
	8-hour mean	5.0 mg/m^3	2.0 mg/m^3	
O_3	1-hour mean	200 µg/m^3	0.12 ppm	
	8-hour mean	120 µg/m^3	1.25 ppm	100 µg/m^3 (8-hour mean)

Source:[4],[18]

2.2.5. USEPA Air Quality Index

Initially, instead of using AQI they used PSI to represent the air pollution indices. PSI was established because of a dramatic increase in the number of people suffering respiratory irritation due to the worsening of air quality. In 1999, the PSI was then revised and implemented by the USEPA, and became known as AQI [19].

USEPA has set the NAAQS under the Clean Air Act which was last amended in 1990. This NAAQS was for pollutants considered harmful to public health and the environment as identified in two types by the Clean Air Act. The **primary standards** are designed for public health protection, including protecting the health of sensitive people such as asthmatics, children, and the elderly while the **secondary standards** focus on public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings [20]. The USEPA had also to review its NAAQS every five years in order to reproduce evolving health effects information and then the AQI is adjusted periodically to

reflect these changes. Thus, AQI is a nationwide air quality rating system based on the NAAQS. As was required by Clean Air Act, USEPA has set NAAQS for six principal pollutants, which are called "criteria" pollutants as they are listed in table 2.2

Table 2. 2:Criteria pollutants set by USEPA under Clean Air Act

Pollutant [final rule cite]		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide [76 FR 54294, Aug 31, 2011]		primary	8-hour	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Lead [73 FR 66964, Nov 12, 2008]		primary and secondary	Rolling 3 month average	0.15 $\mu g/m^3$ (1)	Not to be exceeded
Nitrogen Dioxide [75 FR 6474, Feb 9, 2010] [61 FR 52852, Oct 8, 1996]		primary	1-hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	Annual	53 ppb (2)	Annual Mean
Ozone [73 FR 16436, Mar 27, 2008]		primary and secondary	8-hour	0.075 ppm (3)	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
Particle Pollution Dec 14, 2012	$PM_{2.5}$	primary	Annual	12 $\mu g/m^3$	annual mean, averaged over 3 years
		secondary	Annual	15 $\mu g/m^3$	annual mean, averaged over 3 years
		primary and secondary	24-hour	35 $\mu g/m^3$	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24-hour	150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide [75 FR 35520, Jun 22, 2010] [38 FR 25678, Sept 14, 1973]		primary	1-hour	75 ppb (4)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year

Source:[21]

Units of measures for the standards in above table are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air ($\mu g/m^3$).

Even though USEPA has set the NAAQS for six principal pollutants, the USEPA's AQI is based on daily measurements of up to five of the six air quality criteria pollutants which are carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulate matter ($PM_{2.5}$& PM_{10}), and sulfur dioxide (SO_2). The standard for lead (Pb) is not involved in the AQI as it requires averaging concentrations over a three-month period, and it can take several weeks to collect and analyse lead samples.

The value of each pollutant concentration is given on a scale relative to the air quality standard for that pollutant. The daily AQI is based on the single pollutant with the highest index value that day [22]. USEPA has divided the Air Quality Index scale into six categories in order to make it easier to understand and it is made of AQI level of health concern, numerical value, meaning and the color code as shown in table 2.3.

Table 2. 3:AQI level of health concern, numerical value, meaning and the color code

AQI Level of Health Concern	Numerical Value	Meaning	Color Code
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk.	Green
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Yellow
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Orange
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Red
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.	Purple
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects.	Maroon

Source: [20]

2.2.6. Calculation of Air Quality Index (AQI)

According to USEPA, the AQI is calculated by using equation (2.1)

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}\left(C - C_{low}\right) + I_{low} \qquad (2.1)$$

Where :

I = the Air Quality Index

C = the pollutant concentration

C_{low} = the concentration breakpoint that is ≤ C,

C_{high} = the concentration breakpoint that is ≥ C,

I_{low} = the index breakpoint corresponding to C_{low},

I_{high} = the index breakpoint corresponding to C_{high}.

Equation (2.1) is used to find the AQI of a single pollutant (sub-index) and the overall AQI is given by the pollutant with the highest value of index. The value for the breakpoint concentration is given in table 2.4.

Table 2. 4:Breakpoint concentration

O_3 (ppb)	O_3 (ppb)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	CO (ppm)	SO_2 (ppb)	NO_2 (ppb)	AQI	AQI
C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low}- C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	C_{low} - C_{high} (avg)	I_{low} - I_{high}	Category
0-54 (8-hr)	-	0.0-12.0 (24-hr)	0-54 (24-hr)	0.0-4.4 (8-hr)	0-35 (1-hr)	0-53 (1-hr)	0-50	Good
55-70 (8-hr)	-	12.1-35.4 (24-hr)	55-154 (24-hr)	4.5-9.4 (8-hr)	36-75 (1-hr)	54-100 (1-hr)	51-100	Moderate
71-85 (8-hr)	125-164 (1-hr)	35.5-55.4 (24-hr)	155-254 (24-hr)	9.5-12.4 (8-hr)	76-185 (1-hr)	101-360 (1-hr)	101-150	Unhealthy for Sensitive Groups
86-105 (8-hr)	165-204 (1-hr)	55.5-150.4 (24-hr)	255-354 (24-hr)	12.5-15.4 (8-hr)	186-304 (1-hr)	361-649 (1-hr)	151-200	Unhealthy
106-200 (8-hr)	205-404 (1-hr)	150.5-250.4 (24-hr)	355-424 (24-hr)	15.5-30.4 (8-hr)	305-604 (24-hr)	650-1249 (1-hr)	201-300	Very Unhealthy
-	405-504 (1-hr)	250.5-350.4 (24-hr)	425-504 (24-hr)	30.5-40.4 (8-hr)	605-804 (24-hr)	1250-1649 (1-hr)	301-400	Hazardous
-	505-604 (1-hr)	350.5-500.4 (24-hr)	505-604 (24-hr)	40.5-50.4 (8-hr)	805-1004 (24-hr)	1650-2049 (1-hr)	401-500	

Source:[23]

CHAPTER3. METHODOLOGY

3.1. DATA

3.1.1. Study design

The study was to compare the air pollution levels in rural area and Kigali city based on Air Quality Index**.** Data was collected from four air quality monitoring stations (AQMesh monitors), the two installed in Kigali and the remaining two in rural area.

In rural area, data is monitored at Kawangire and Gasaka meteolorogical station from Gatsibo and Nyamagabe district respectively while in Kigali city, one air quality monitoring station is located at Nyabugogo and the remaining one is installed at Gitega (Rwanda Meteo). The air pollutants measured at each station are $PM_{2.5}$, SO_2, NO, NO_2, CO and O_3.
The study considered the data measured from 1st November 2017 up to 30th January 2018 (3 months). The comparison among air pollutant concentrations at different locations were achieved through plotting of data by using Python programming language; and then the USEPA Air Quality Index system was used to calculate the AQI and also to suggest its health implications.

3.1.2. Description of air quality monitoring stations

- **Nyabugogo air quality monitoring station**

The AQMesh monitor was installed at Engen petrol station at Nyabugogo bus terminal located approximately two metres from the main road to Uganda. It was installed over six metres from the ground for the safety purposes. The road to Uganda is one of the main import routes into the country and that is why the main sources of pollution at this location are petrol and diesel fuelled heavy vehicles, buses and Moto taxis travelling in Kigali. In additional air pollutants may result from wood and charcoal used as domestic fuel in the closest residential community (Gatsata- rubonono); located approximately 200m from where the AQMesh monitor is installed.

- **Gitega (Meteo Rwanda) air quality monitoring station**

The AQMesh monitor was installed at the Meteo Rwanda headquarters located approximately 100m from the main road and the closest communities are Gitega and Kimisagara. The main air pollutants originate from wood and charcoal used as fuel by these communities. The other source of pollution is a diesel generator located within the Meteo buildings which is used approximately once a week for less than one hour when there is a power cut. As the main road is a bit far from the AQMesh monitor, the traffic emissions have no significant contribution at this location.

- **Kawangire air quality monitoring station**

The AQMesh monitor was installed at the Kawangire meteorological station, precisely at the Kawangire cell headquarters in Gatsibo district in the Eastern province. The closest households are located approximately 10m from the AQMesh monitor with the Kawangire High School which is approximately 600m away. Therefore, as there are no major roads located within 200 metres of the monitoring site, the main source of pollution is wood used as fuel by the surrounding communities.

- **Gasaka air quality monitoring station**

The AQMesh monitor was installed at the Gasaka meteorological station in Nyamagabe district in the Southern province. In the Surrounding of the station there are SACCO Bank offices and a honey making industry. The main potential source of pollution is traffic on the main road to Rusizi town from Huye town located approximately 200m from where the AQMesh monitor was installed.

3.1.3. Instrumentation

As it was discussed before, the raw dada used was collected with help of instruments called "AQMesh monitors". The AQMesh monitors are designed in such a way that they collect data at 15 minute intervals and this helps to obtain a longer term averages to use while making different analyses in the study. Different air pollutants measured by AQMesh monitors are $PM_{2.5}$, SO_2, NO, NO_2, CO and O_3. The AQMesh monitors also can detect each air pollutant in a certain range and limit as shown in table 3.1.

Table 3. 1:Range and limit of air pollutant detection

Pollutant	Range	Limit of detection
NO_X	0-800ppb	< 10ppb
NO_2	0-400ppb	< 10ppb
SO_2	0-10,000ppb	< 10ppb
O_3	0-1,800ppb	< 5ppb
CO	0-6,000ppb	< 5ppb
$PM_{2.5}$	0-500mg/m3	-

Source:[24]

AQMesh monitor uses an optical particle counter for particle mass estimation, each individual particle within the sample taken is counted and sized. The AQMesh monitors send the results in real time through GPRS communication to an online data webpage. The delivered data is calibrated and the calibration process is carried out by the manufacturers of the monitoring equipment.

3.2. METHODS

3.2.1. Calculation of Air Quality Index (AQI)

The AQI was calculated by using equation (2.1). The air pollutants for which the AQI was calculated are O_3, $PM_{2.5}$, CO, SO_2 and NO_2. According to table 2.4, the air pollutant concentrations were averaged as follow:

O_3: its concentration is averaged over 1hour and 8hours and since the values of 1hour average at all of stations were found to be less than 125 ppb, the AQI for O_3 was calculated based on 8hours average.

CO and NO_2: they were averaged over 8hours and 1hour respectively as usual

SO_2: It is averaged over 1hour and 24hours but all stations indicated the concentration of SO_2 which is very low such that it can't reach to 305ppb. Therefore, the AQI for SO_2 considered only the 1hour average.

PM2.5: it was averaged over 24hours as usual.

The values for breakpoint concentration and the corresponding index breakpoint were obtained through the literature as they are presented in table 2.4. Equation (2.1) was used to find the AQI of a single pollutant (sub-index) and then, the overall AQI at each air quality monitoring station was given by the air pollutant of the highest value of index. The health effects associated with each AQI value is known by reading in table 2.3.

3.2. 2.Data analysis

- **Trends analysis**

Daily variation in concentrations within a month for each air pollutant was plotted by using Python programming language in order to visualise the peaks of each air pollutant and compare it with the WHO standards. This has helped to identify where the highest concentrations of a specific air pollutant are found among Nyabugogo, Gitega, Kawangire and Gasaka locations. The reference standards used while making a comparison were obtained through the literature as shown in table 2.1.

- **Air Quality Index analysis**

Based on equation (2.1), the daily Air Quality Index is based on the single pollutant with the highest index value that day. Referring to table 2.3, an AQI value of 100 has been set as the air quality standard for pollutant to protect the public health and below this value, AQI values are generally considered as satisfactory. On the other hand when AQI values are above 100 , the air quality is considered to be unhealthy at first for certain sensitive groups of people and then unhealthy for every one as AQI values get higher [25]. The table 2.3 summarizes the possible AQI values with its heath implications and it is the center of some important analyses made on Air Quality Index.

CHAPTER 4. RESULTS AND DISCUSSION

Variations in concentrations for each air pollutant at different locations are discussed in this section. Based on that, the comparison was made between rural area and Kigali city to highlight the more polluted location based on a specific air pollutant. Air Quality Index was also incorporated for more clarification of the results obtained with the health consequences that could be expected at each AQI value.

4.1. Variation in concentrations of air pollutant at different locations

Before producing time series plots showing variation in concentrations of each air pollutant, the mean concentrations were needed. The time for which the mean of a specific air pollutant concentration was computed is based on the WHO air quality guidelines designed to offer guidance in reducing the health impacts of air pollution as mentioned in chapter 2 (table 2.1). The analysis is based on air quality data measured during the period of three months (November 2017, December 2017 and January 2018).

4.1.1. Comparison of particulate matter ($PM_{2.5}$)

The measured concentrations of $PM_{2.5}$ at four air quality monitoring stations have been averaged over 24 hours. The figure 1ullustrates the daily variation in concentration of $PM_{2.5}$ for the period of three months and $PM_{2.5}$ concentrations measured at all of stations increase from November up to January. The highest $PM_{2.5}$ concentrations were measured at Kawangire station while the lowest $PM_{2.5}$ concentrations were obtained at Gasaka station as shown in figure 4.1.1(addendum I) and table 4.2.1(addendum II). $PM_{2.5}$ concentrations for the remaining sites are nearly the same but with slightly larger values at Gitega and Nyabugogo stations. The larger values of $PM_{2.5}$ concentrations at Gitega and Nyabugogo locations were expected as a result of vehicle emissions. The particular difference in $PM_{2.5}$ concentrations obtained at Kawangire station is associated with residential biomass burning and mainly intensified by the small distance that was between one household's kitchen and the AQmesh monitor, as described in section 3.1.2. This has caused the almost $PM_{2.5}$ emitted from the kitchen to be measured by the sensor and then resulted in showing the higher values of $PM_{2.5}$ concentrations. It has significantly affected the calculated values of AQI at Kawangire station during those three months where the $PM_{2.5}$ remained as responsible pollutant to worsen the air quality as discussed in section 4.3.1 and particularly in December

up to January, the AQI level of health concern was dominated by "Unhealthy for sensitive groups" and "Unhealthy" categories as shown in table 4.3.1.2 and table 4.3.1.3 (addendum III).

4.1.2. Comparison of sulfur dioxide (SO_2)

The calculated 24-hour mean of SO_2 concentrations measured at four air quality monitoring stations is shown in figure 4.1.2 (addendum I). The 24-hour mean SO_2 concentrations measured during three months are generally low and less than 2 ppb at Kawangire and Gasaka station and a bit more 24-hour mean SO_2 concentrations but less than 8 ppb at Nyabugogo staion. The largest SO_2 concentrations were obtained at Gitega station and there was sudden increase in SO_2 concentrations at some particular days, especially the higher peaks are observed in January. Normally, the sulphur dioxide can be emitted naturally by volcanoes while the main anthropogenic sources of sulfur dioxide are the burning of fuels containing sulfur or by roasting metal sulphide ores, industrial boilers and nonferrous metal smelters. In addition, emissions from domestic coal burning and from vehicles may cause an increase in ambient concentrations of sulfur dioxide [9].

As described in section 3.1.2, apart from Nyabugogo and Gitega Stations, there are no significant sources of sulphur dioxide that could be observed at other stations and this resulted in lower SO_2 concentration values. On other hand, a bit more concentrations of SO_2 found at Nyabugogo station is mainly associated to the vehicle emissions while the sudden increase or decrease in SO_2 concentrations observed at Gitega station could be probably attributed to the combined effect of emissions from vehicles and mainly from a diesel generator located within the Meteo buildings which is used approximately once a week for less than one hour when there is a power cut. The measured SO_2 concentrations didn't contribute to the daily AQI calculated except at Gitega station for 2 days of November as shown in table 4.3.3.1 (addendum III).

4.1.3. Comparison of carbon monoxide (CO)

The observed 1-hour mean and 8-hour mean concentration of CO at different stations are shown in figure 4.1.3.1 and figure 4.1.3.2 respectively (addendum I). For both 1-hour mean and 8-hour mean concentrations of CO, the largest CO concentrations were measured at Gasaka station in November and decreased progressively until January. The remaining stations indicated the CO concentrations which exhibit a nearly constant variation with a bit larger values at Nyabugogo location and the lowest values at Kawangire location. Oxidation of non-methane hydrocarbons with the human activities such as controlled vegetation burning, residential biomass burning could be the main source of CO, but the human activities may cause more significant change in CO concentrations, especially in non-unburn area and this could be the case of Gasaka in November.

The motor vehicle exhaust can be the leading cause for lager values of CO concentrations measured at Nyabugogo location in comparison with values obtained from Gitega and Kawangire stations.

4.1.4. Comparison of nitric oxide (NO)

The figure 4.1.4.1 (addendum I) shows the 24-hour mean of NO concentrations measured at four different locations within three months. The highest concentrations were observed at Nyabugogo station where the monthly mean reached the value of 63.361 ppb, 64.7006 ppb and 57.849 ppb in November, December and January respectively. The second higher concentrations were measured at Gitega station and the monthly mean are 30.6016 ppb, 31.8077 ppb, 28.8189 ppb in November, December and January respectively as presented in table 4.2.1 (addendum II). For the remaining locations, the measured concentrations are low with the lowest values at Gasaka station. The combustion of petrol and diesel fuel by the heavy vehicles, buses and Moto taxis travelling in Kigali could mainly explain the highest NO concentrations measured at Nyabugogo location since the AQmesh monitor was installed at approximately two metres from the main road to Uganda. Similarly, for Gitega station, the biomass burning (wood and charcoal) by the surrounding community can remain as the major contributor to the significant amount of NO measured while the diesel fuelled generator which operates during power cut time with some traffic emissions could have the minor contribution.

4.1.5. Comparison of nitrogen dioxide (NO_2)

NO_2 is a secondary air pollutant formed through conversion of NO via a reaction with O_3. As shown in figure 4.1.5.1 and figure 4.1.5.2 (addendum I), the highest 1-hour mean and 24-hour mean of NO_2 concentrations observed at Nyabugo and Gitega stations are the results of the highest NO concentrations as primary air pollutant already emitted from those particular locations and it was discussed in section 4.1.4. For the remaining stations, the low NO concentrations measured give rise to the low NO_2 concentrations as well. The highest monthly mean of 1-hour mean NO_2 concentrations were measured at Nyabugogo station, the second higher measurements are observed at Gitega location and their numerical values are shown in table 4.2.1 (addendum II). Similarly, the monthly mean of 8-hour mean NO_2 concentrations monitored from Nyabugogo and Gitega locations are higher than the measurements obtained from rural areas (Kawangire and Gitega locations).

4.1.6. Comparison of ozone (O_3)

Ground-level ozone is a secondary air pollutant produced during the photochemical degradation of emitted VOCs in the presence of sunlight and NO_x. The VOCs provide the radicals to react with NO and then forming NO_2. Photolysis of NO_2 produces NO and O which in turn combines with O_2 to form ozone. At a specific location, the level of ozone concentration depends on emission to its precursors (VOCs and NOx), the long-range transport of ozone and meteorological parameters[26]. The rate of ozone production is controlled by the two regimes (low NOx limit and high NOx limit). At a given level of VOC, there exist NOx concentrations at which a maximum ozone production occurs and that is the optimum VOC/NOx ratio. Then, for ratios less than this optimum ratio, the increase in NOx leads to the decrease in ozone while for ratios larger than this optimum ratio, increase in NOx leads to increase in ozone[6].

The observed 1-hour mean and 8-hour mean of O_3 concentrations at different locations are the result of a complex set of reactions that involve VOCs and NO_x in presence of sunlight and they are shown in figure 4.1.6.1 and figure 4.1.6.2 (addendum I). The difference in O_3 concentrations observed among stations provides a comparison in two pairs, Gitega and Gasaka locations and then, Nyabugogo and Kawangire locations. In December and January, it has been observed a relatively high amount of monthly mean for both 1-hour and 8-hour

mean of O_3 concentrations at Gitega location while in November, the highest monthly mean value was measured at Gasaka location. Though the measured monthly mean values of 1-hour and 8-hour mean of O_3 concentrations at Nyabugogo and Kawangire locations are comparable, the higher values were obtained at Kawangire station for both in December and January while in November, the higher monthly mean value was measured at Nyabugogo location. The numerical monthly mean values for 1-hour and 8-hour mean of O_3 concentrations measured at four stations can be found in table 4.2.1 (addendum II).

4.2. Comparison of the measured air pollutant concentrations with EAS and WHO standards

The monthly maximum, minimum and mean concentration for each air pollutant was computed and they are presented in table 4.2.1 (addendum II). The monthly mean concentrations for air pollutants were compared with the EAS and WHO standards (presented in table 2.1). It was observed that the highest 1-hour and 8-hour mean O_3 concentrations measured at Gitega station were less than the values suggested by EAS, means that they were less than 120ppb and 1250 ppb respectively. But the highest monthly mean SO_2 concentration observed at Gitega location exceeded 20 $\mu g/m^3$ set by WHO, especially in November and January. Both Nyabugogo and Gitega locations were identified to have the highest concentrations of NO_2 but their monthly mean values for 24-hour mean were still low compared to 100 ppb suggested by EAS.

The concentrations for the remaining air pollutants have exceeded the reference standards, especilally for the highest $PM_{2.5}$ concentrations measured at Kawangire station. The monthly mean is higher than 25 $\mu g/m^3$ recommended by WHO but less than this value for other stations.

Then, the significant amount of CO measured at Gasaka and Nyabugogo stations resulted in monthly mean value for 8-hour mean which was higher than 2.0 mg/m^3 recommended by EAS. That standard value was exceeded for three months at Nyabugogo location while for Gasaka location, it was exceeded only in November and December and also 4.0 mg/m^3 recommended by EAS for 1-hour mean was exceeded in November at Gasaka location.

Even though the monthly mean concentrations of some air pollutants were less than the reference standards, some daily values of pollutant concentrations may be much higher than

EAS and WHO standards as shown by the maximum values in table 4.2.1. That could be explained by the air quality at a specific location which may be unhealthy at some days while the monthly mean concentration of responsible pollutant remained below the recommended value.

4.3. AQI at different stations

The AQI has been found using equation 2.1 and the averaging time for air pollutants considered is discussed in chapter 3 (section 3.2.1). Particulate Matter ($PM_{2.5}$) is averaged over 24 hours and this implies that a full 24 hours was required to obtain each AQI value. The other air pollutants are averaged over their proper averaging time and only the maximum concentration value for each air pollutant in a 24-hour period was selected while calculating the AQI for individual air pollutant. Then, the overall AQI for a specific day at each air quality monitoring station is reflected by the pollutant with highest index value at that particular day. The daily AQI values for November 2017, December 2017 and January 2018 are shown with bar graphs and tables of color code for each AQI value. Nitric oxide (NO) was excluded while calculating the AQI since it was not considered in USEPA air quality index system.
The meaning regarding health effects expected at each AQI value can be seen in the table 2.3, but simply the six level of health concern and their meaning are:

"**Good**" shown by a green color for AQI in the range of 0 to 50. The air quality is considered satisfactory or acceptable, and air pollution poses little or no risk.

"**Moderate**" shown by yellow color when AQI ranges from 51 to 100. The air quality is acceptable; but, a very small number of people may by some pollutant and experience a moderate health concern. As an example, people who are remarkably sensitive to ozone may experience respiratory symptoms.

"**Unhealthy for Sensitive Groups**" indicated by orange color is when AQI ranges from 101 to 150. The general public is not likely to be affected, but exposure to ozone may lead at great risk for people with lung disease, older adults and children while those with heart and lung disease are at greater risk from the presence of particulates in the air.

"**Unhealthy**" is shown by red color and AQI is 151 to 200. At this level of AQI, everyone may commence to experience some adverse health effects which may be intensified for members of the sensitive groups.

"**Very Unhealthy**" shown by purple color is when AQI ranges from 201 to 300. Everyone may experience more serious health effects.

"**Hazardous**" is shown by maroon color and that is when AQI exceed 300. For this case the entire population is more likely to be affected[23].

4.3.1. AQI at Kawangire air quality monitoring station

As discussed in section 4.1.1, the highest $PM_{2.5}$ concentrations observed at Kawangire location have been responsible for the daily AQI calculated from November 2017 up to January 2018.

The highest AQI values obtained fall in the range of 151-200 corresponding to "Unhealthy" category with red as its color code. Especially in January 2018, this Unhealthy category repeated for 13 days as shown in table 4.3.1.1 (addendum III). This suggests that at those particular days, individuals exposed on that level of air pollution were expected to experience some healthy effects which could be more serious for sensitive groups as explained in table 2.3. The lowest AQI values are observed only for 5 days in November and fall in the range of 0-50 corresponding to "Good" category indicated by a green color as shown in table 4.3.1.1. This level of air pollution is satisfactory since it can pose little or no risk on human health.

4.3.2. AQI at Gasaka air quality monitoring station

At this location, the AQI has been reflected by three air pollutants consist of CO, O_3 and $PM_{2.5}$. the dominant pollutant within three months was O_3 and it is the one which exhibits the highest AQI value, exactly in November where the AQI varied in the range of 201-300 for four successive days. This value corresponds to "Very Unhealthy" category indicated by purple color as shown in table 4.3.2.1 (addendum III). According to table 2.3, there was a need for warning people who were exposed to that pollution level, otherwise the most of people were probably affected. For the remaining months, the O_3 repeated many times,

especially in December where the AQI in all 25 days was reflected by O_3 but for this case most of the AQI values varied in "Good" and "Moderate" category. The second highest AQI value was reflected by CO as it appeared for 17 days in November with AQI varying between "Moderate" and "Unhealthy for sensitive groups" category, except at 14th day of the month where the AQI value reached "Unhealthy" category. The AQI values reflected by $PM_{2.5}$ are observed in December and January with "Good" and "Moderate" category as shown in table 4.3.2.2 and table 4.3.2.3 (addendum III).

4.3.3. AQI at Gitega air quality monitoring station

Apart from the AQI obtained in November as shown in table 4.3.3.1 (addendum III), this the first among other locations characterized by the worst air quality during December to January and the responsible pollutant was mainly O_3**.** In December, the AQI was dominated by the range of 151-200 and 201-300 corresponding to "Unhealthy" and "Very Unhealthy" category respectively. The table 4.3.3.2 and table 4.3.3.3 (addendum III) show that for 19 days of December, the air quality was very unhealthy and also that 8 days the air quality was Unhealthy because of high ozone concentrations. Exposure to such level of air pollution may not only affect the members of sensitive groups but also everyone was more likely to be affected as mentioned in table 2.3. The remaining days, the air quality consist of "Unhealthy for Sensitive Groups" and "moderate" category. In January the ozone was also responsible to reflect the AQI of "Unhealthy" and "Very Unhealthy" category for 5 days and 7 days respectively. The remaining days of January the AQI was given by $PM_{2.5}$, NO_2 and O_3 with "Moderate" and "Unhealthy for Sensitive Groups" category.

4.3.4. AQI at Nyabugogo air quality monitoring station

Though there are a considerable vehicle emissions observed at Nyabugogo location, the levels of pollutant concentrations were moderate as shown by the table 4.3.4.1, table 4.3.4.2 and table 4.3.4.3 (addendum III) that the air quality was "Good" and "Moderate" category during the period of three months. The responsible pollutants were $PM_{2.5}$ for most of the days and NO_2. This suggests that in the vicinity of Nyabugogo station, the air quality was generally acceptable for that particular period of time. However, the obtained results of air quality at Nyabugogo location could be explained by the height at which the AQmesh monitor was installed. The AQmesh monitor was installed over six metres from the ground which is a bit higher distance, the recorded air pollutant concentrations could be less as well.

4.4. Comparison of AQI among different locations

In section 3.2.2, it was discussed that an AQI value of 100 has been set as the air quality standard for pollutant to protect the public health. Below this value, AQI values are generally considered as satisfactory while above this value, the air quality is considered to be unhealthy at first for certain sensitive groups of people and then unhealthy for every one as AQI values get higher. Table 4.4.1 (addendum IV) shows the status of air quality for studied locations within the period of 91 days (three months). The number of days for which the air quality was satisfactory is highlighted in green and yellow colors while the remaining columns consist of number of days for which the air quality was generally unhealthy and as well as the responsible air pollutants. Based on the AQI value of 100 and number of days to which this value is not exceeded, the studied locations can be arranged in the following order:

The first location where air quality is considered as satisfactory is Nyabugogo. In all of 91 days, the AQI at Nyabugogo station did not exceed 100 as its air quality was characterized by "Good" and "Moderate" category for 27 days and 64 days respectively. The second location is Gasaka with 67 days to which the air quality was satisfactory and the remaining days, the AQI was above 100. The third one is Gitega location with only 38 days for which the air quality was satisfactory and then, the fourth one is Kawangire location with 36 days for which the air quality was satisfactory.

Generally, the air quality at the last two locations was poor since the number of days for which the air quality was satisfactory is less than the number of days for which the air quality was unhealthy for sensitive groups of people and as well as unhealthy to everyone as it can be seen in table 4.4.1.

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

This research compared the air pollution levels in rural area and Kigali city based on Air Quality Index. The comparison made was based on data monitored in a period of three months, starting in November 2017 and ends in January 2018. In rural area, the data was collected at two different locations, the one is Kawangire from Gatsibo district in Eastern province while the other one is Gasaka from Nyamagabe district in Southern province. In Kigali city the two locations were also considered while collecting data and first location is Gitega at Meteo Rwanda headquarters and the remaining one is Nyabugogo, exactly at Engen petrol station at Nyabugogo bus terminal.

The analysis made is based on six air pollutants, $PM_{2.5}$, SO_2, NO, NO_2, CO and O_3 but NO was not considered in the calculation of AQI as explained in section 4.3. In terms of air pollutant concentrations, the results obtained show a significant difference in SO_2, NO and NO_2 concentrations observed between Kigali city and rural area. The vehicle emissions as the major sources of those particular air pollutants are more likely observed at Nyabugogo and Gitega locations and hence there is no difference in air quality between rural area and Kigali city other than the highest SO_2, NO and NO_2 concentrations measured at Nyabugogo and Gitega stations from Kigali city.

In Kigali city, the overall highest monthly mean of 24-hour mean SO_2 concentrations was recorded in January at Gitega station and it was 99.3 times higher than the overall highest value recorded in rural area at Gasaka station in December. The highest value recorded at Nyabugogo site was 6.6 times higher than the second highest value obtained in rural area at Kawangire site in November. For 24-hour mean of NO, the overall highest monthly mean concentration was recorded in December at Nyabugogo site and it was 2 times higher than the overall highest value observed in rural area in same month at Kawangire site. The second highest value was observed at Gitega site in December and it was 1.6 times higher than the second highest value in rural area obtained at Gasaka location in November. Similarly, in Kigali city, the highest monthly mean of 24-hour mean NO_2 concentrations were recorded in January such that the overall value obtained at Gitega site was 2.5 times higher than the highest one measured in rural area at Gasaka station in November. For the second highest

values, in Kigali city was observed at Nyabugogo site and it was 3.7 times the one observed in rural area at Kawangire location in January.

Based on the AQI calculated, the results showed that neither two locations from Kigali city nor other two locations from rural area have commonality in their AQI values. Though there are significant vehicle emissions at Nyabugogo, the concentrations of air pollutants measured were at moderate level as revealed by the AQI calculated at that location. During the period of three months (91 days), the AQI value at Nyabugogo site remained below 100 and hence the air quality was acceptable, but probably the higher distance (6m from the ground) at which AQmesh monitor was installed could be the main reason to measure less pollutant concentrations and low values of AQI as well. The higher concentrations of O_3 and CO measured at Gasaka station have also affected the AQI values obtained at this location as it was found that within 91 days, the air quality was only acceptable in 67 days while the remaining 24 days, 19 of them the air quality was unhealthy for sensitive groups of people and 5 days it was unhealthy for everyone.

The remaining locations, Gitega and Kawangire were generally characterized by unhealthy air quality. Particularly the highest O_3 concentrations observed at Gitega station have significantly affected the air quality such that in three months, 9 days the air quality was unhealthy for sensitive groups of people while 43 days were characterized by air quality which was unhealthy for every one and it was only acceptable in 38 days. As discussed in section 4.1.1, there was no pollutant to worsen the air quality at Kawangire location other than the highest $PM_{2.5}$ concentrations measured, as the sensor was very close to direct emissions from the kitchen. This was resulted in 36 days for acceptable air quality while in 55 days, 34 of them the air quality was unhealthy for sensitive groups of people and unhealthy for everyone in the remaining 21 days.

The overall results show that the more polluted or cleaned area between rural and Kigali city can not be easily identified by considering all of the six air pollutant concentrations simultaneously. It may be convenient to consider a single air pollutant and make a comparison in its concentrations at different locations but considering its source, distance from the source to the measuring instrument, chemical inter-conversion and as well as atmospheric conditions at each location. However, based on AQI the difference in air quality between two locations from the same area can be observed. For example, between Gitega and

Nyabugogo, it can be seen that Gitega location is more polluted while in rural area, Kawangire location can be identified as the more polluted one in comparison with Gasaka.

5.2. RECOMMENDATION

Due to time limitations, the study has used data measured for a short period of time (three months) and some detail analysis regarding health effects associated with poor air quality have remained beyond the scope of the study as the main objective was simply to compare the air pollution levels in rural area and Kigali City based on Air Quality Index. Also some results obtained, especially for Nyabugogo and Kawangire stations were not reflecting well the condition in air quality for those particular locations because of inappropriate position of the sensor relative to the source of emissions. These leave area of improvement for the future researchers, hence the following recommendations:

- Data sample size should be extended for further analysis of the seasonal variation of AQI at a specific location and as well as to ensure the more consistent results.
- Assessment on health effects associated with poor air quality observed at some locations should be done in order to prove the link between observed results and reality at the field site.
- Based on the results obtained, Nyabugogo location was apparently clean in comparison to other locations and this was not expected. Therefore, it can be convenient to install the AQmesh monitor at lower distance from the ground so that the recorded air pollutant concentrations can reflect the real condition in air quality at this site.
- Similarly, at Kawangire station, the air quality was characterized by highest $PM_{2.5}$ concentrations because the measuring instrument was very close to the kitchen. Therefore, the instrument should be put at suitable distance from any source of emissions in order to measure the proper concentrations for $PM_{2.5}$ and other air pollutants at this location.

Based on AQI, this thesis has attempted to provide a helpful trial in showing the situation of air quality of studied locations for that period of time but much more research need to be done in this field. This can be helpful for people, especially authorities to take the necessary actions to improve air quality for a specific location.

For the concerned institution, the existing air quality monitoring stations should be strengthened and increased in their number such that a system for disseminating Air Quality Index in real time can be established. This can help people especially those with the existing respiratory diseases to plan their daily activities accordingly.

ADDENDUMS LIST

ADDENDUM I: Figures which show variation in concentrations of air pollutant at different locations.

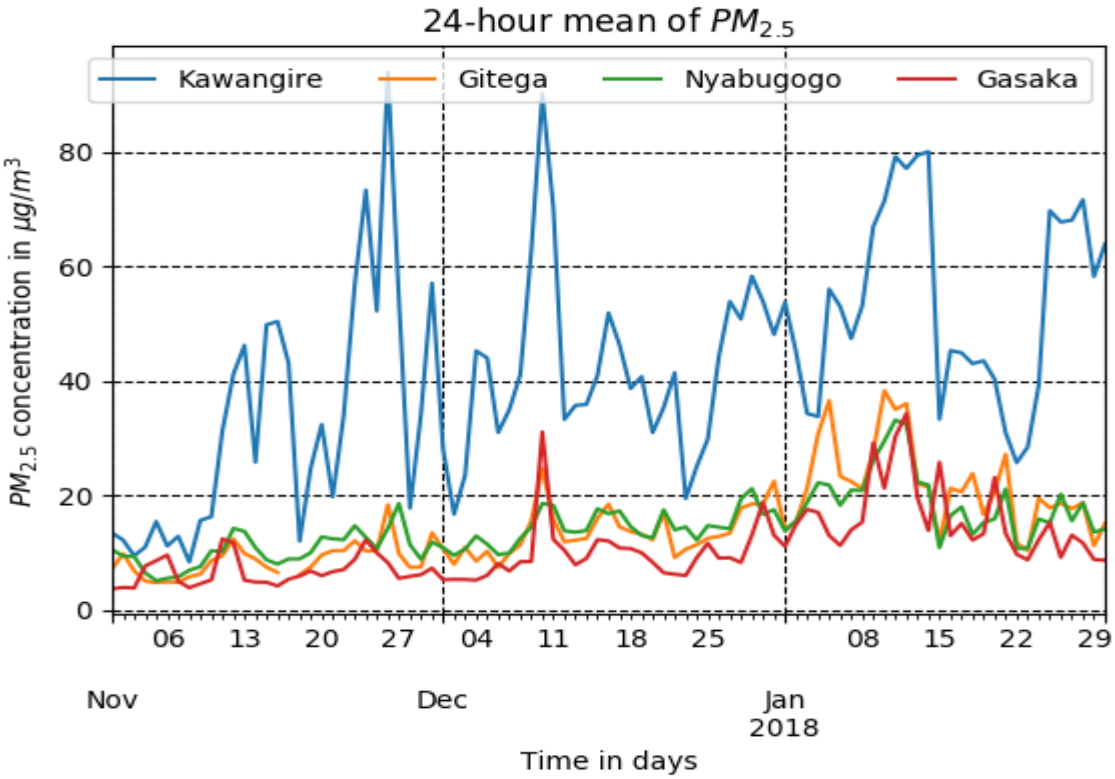

Figure 4.1. 1: Comparison of 24-hour mean of $PM_{2.5}$ measured at different stations

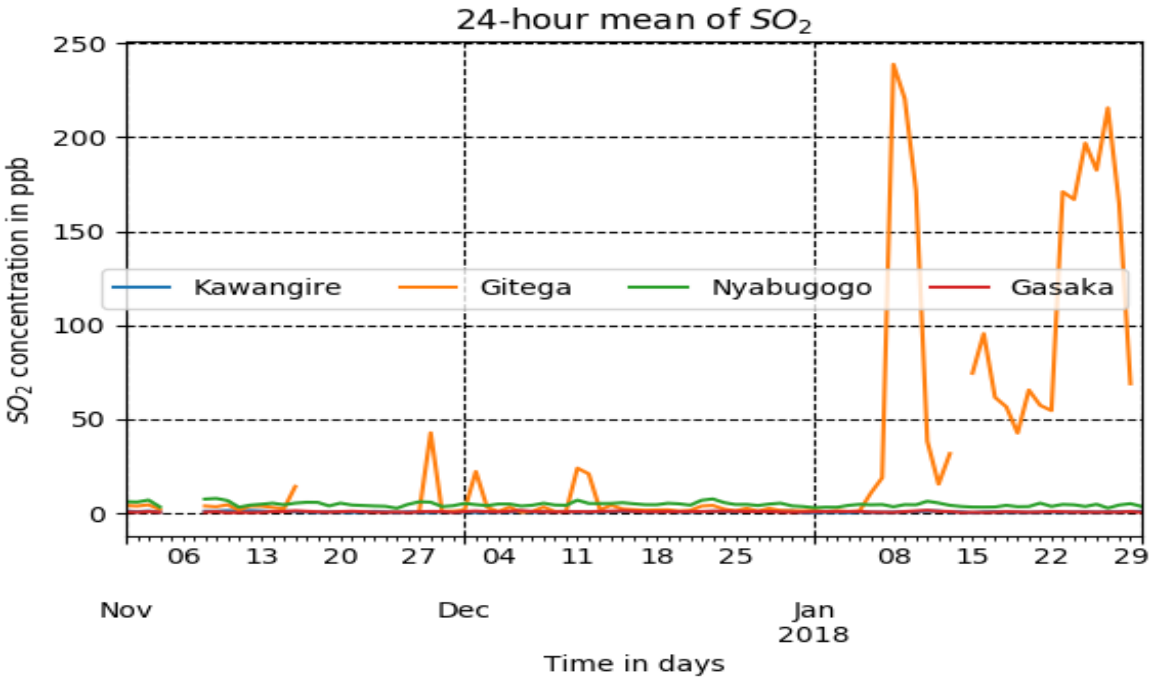

Figure 4.1. 2: Comparison of 24-hour mean of SO_2 measured at different stations

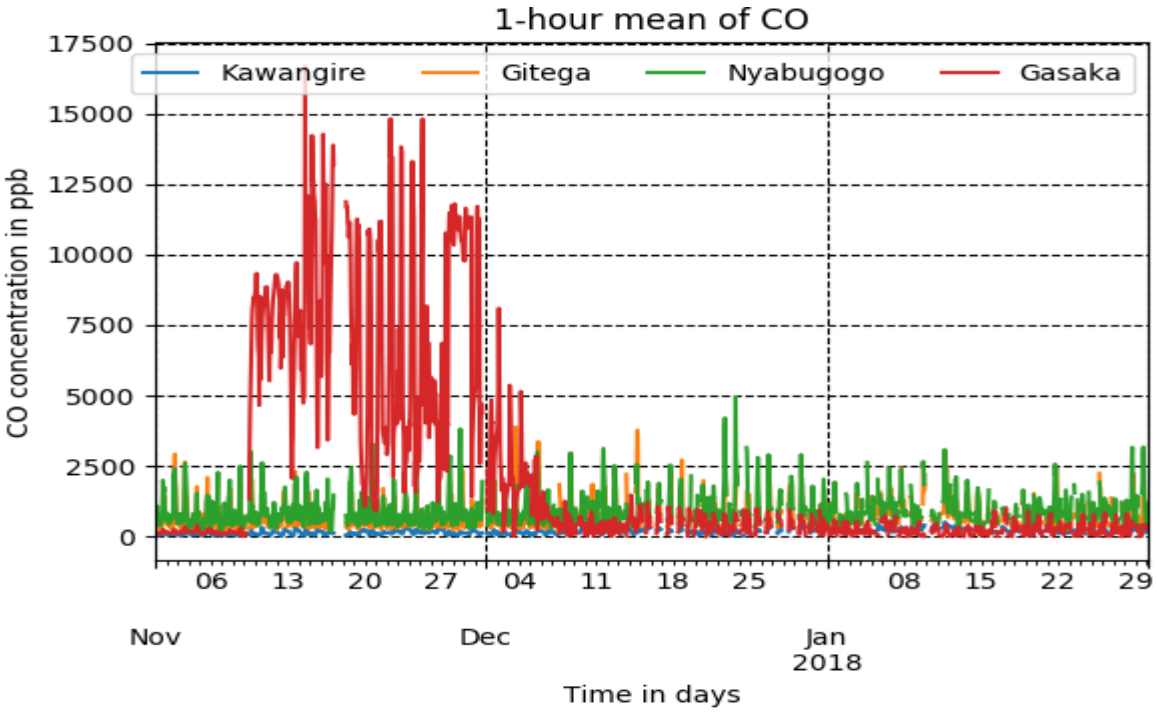

Figure 4.1.3. 1: Comparison of 1-hour mean of CO measured at different stations

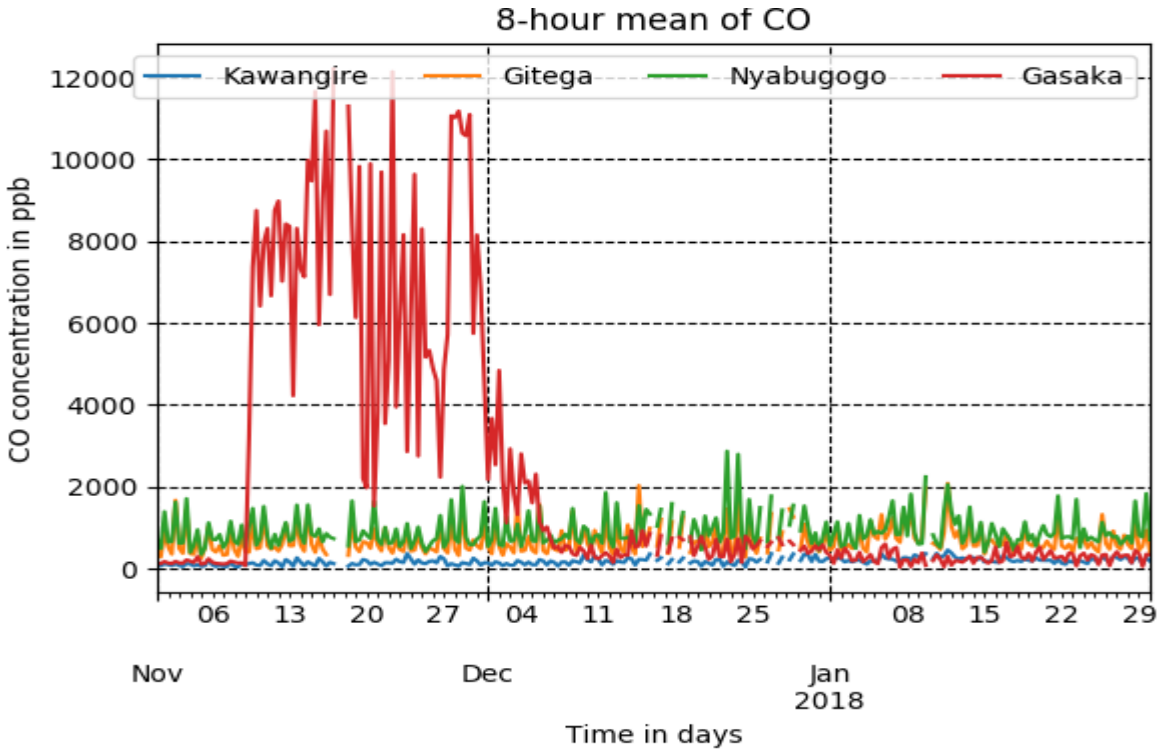

Figure 4.1.3.2: Comparison of 8-hour mean of CO measured at different stations

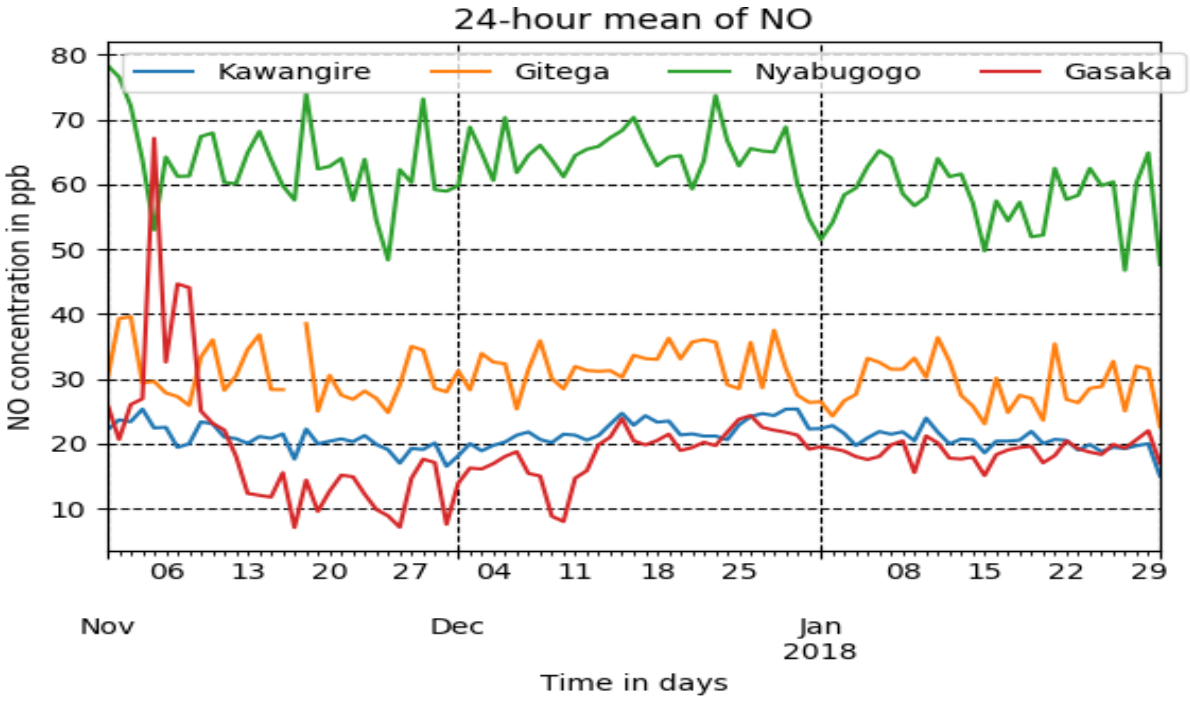

Figure 4.1.4. 1: Comparison of 24-hour mean of NO measured at different stations

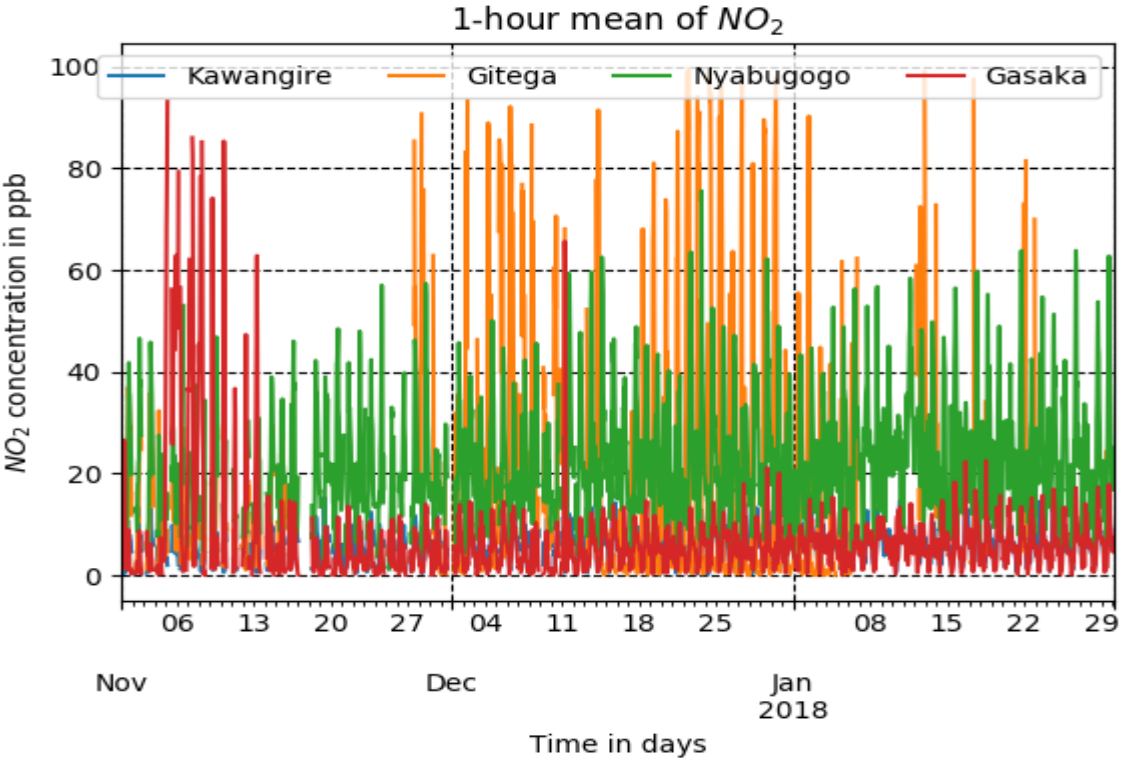

Figure 4.1.5.1: Comparison of 1-hour mean of NO_2 measured at different stations

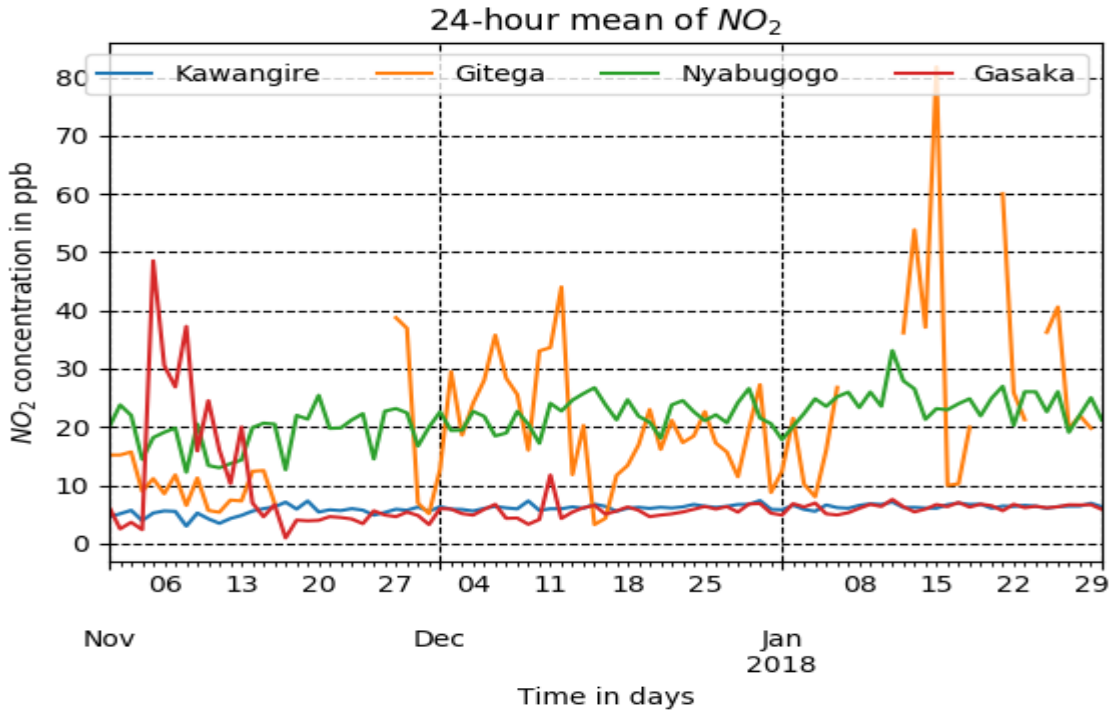

Figure 4.1.5.2: Comparison of 24-hour mean of NO_2 measured at different stations

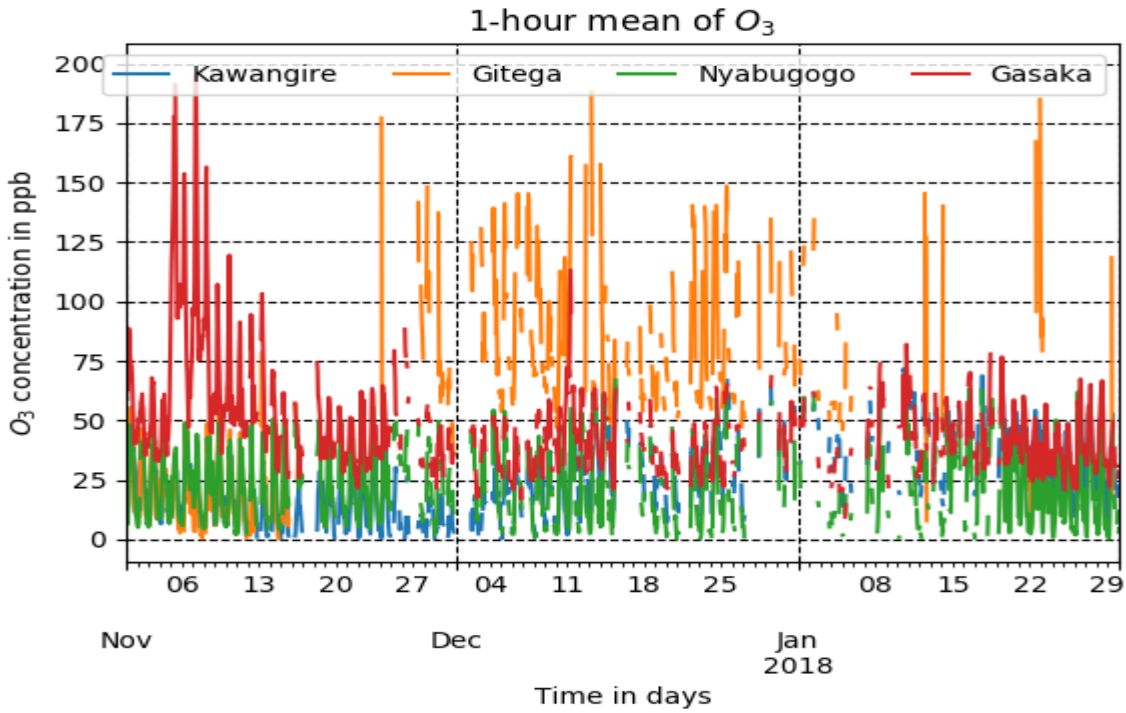

Figure 4.1.6.1: Comparison of 1-hour mean of O_3 measured at different stations

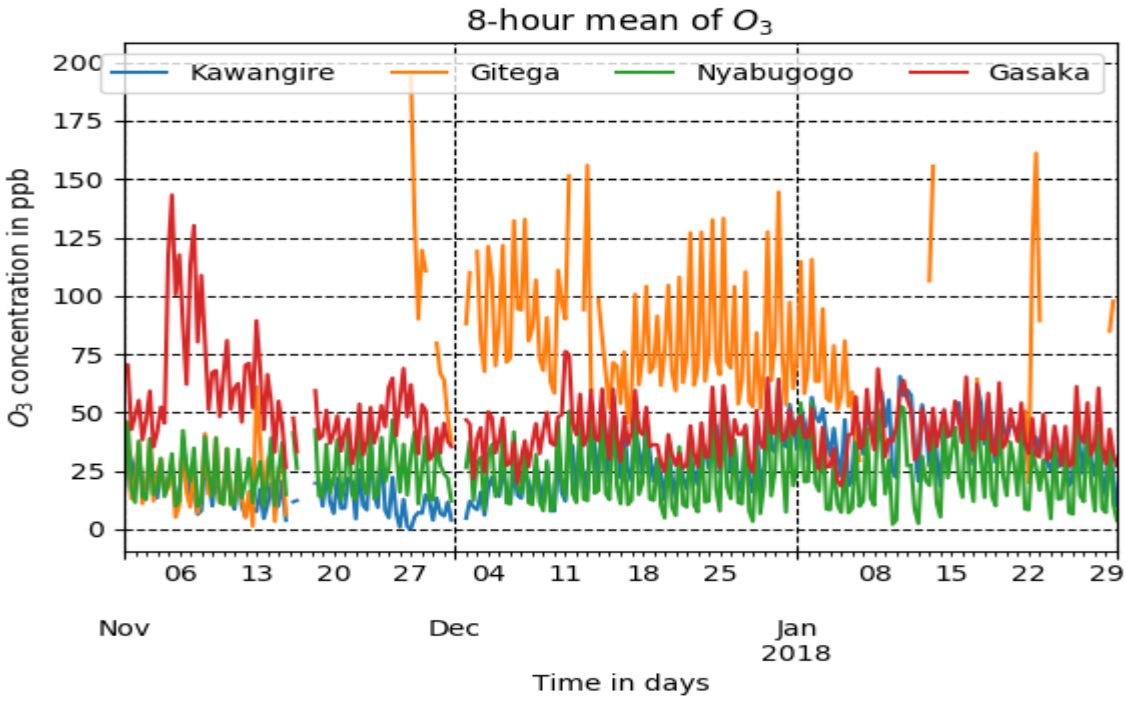

Figure 4.1.6.2: Comparison of 8-hour mean of O_3 measured at different stations

ADDENDUM II: Table for comparison of the measured air pollutant concentrations with EAS and WHO standards.

Table 4.2.1: Monthly maximum, minimum and mean value obtained for each air pollutant during the period of three months

Pollutant	Month	Kawangire			Gasaka			Gitega			Nyabugogo		
		24h-mean			24h-mean			24h-mean			24h-mean		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
$PM_{2.5}$	Nov-17	93.865	8.3235	32.484	12.358	3.6407	6.6511	18.324	4.7207	8.6291	18.515	5.0576	10.3152
(µg/m3)	Dec-17	90.109	16.672	41.961	31.01	5.1544	9.7726	24.733	7.3744	13.562	21.131	9.4756	14.4107
	Jan-18	79.974	25.672	53.427	34.229	8.6155	15.814	38.224	10.295	21.558	33.113	10.658	18.7211
SO_2	Nov-17	1.3655	0.2279	0.756	1.2559	0.2698	0.6463	141.06	1.0232	12.443	7.8121	2.5966	4.99717
(ppb)	Dec-17	1.1777	0.1925	0.7248	1.3932	0.4968	0.8728	23.92	0.4398	3.9091	7.5347	3.5099	4.91164
	Jan-18	1.1055	0.065	0.5734	1.4753	0.382	0.7006	238.85	0.7367	86.661	6.3152	2.7091	4.04534
NO	Nov-17	25.301	16.497	20.782	67.084	7.0428	19.872	39.568	24.777	30.602	78.347	48.327	63.361
(ppb)	Dec-17	25.322	18.105	21.978	24.309	7.9755	18.675	37.486	25.328	31.808	73.685	54.638	64.7006
	Jan-18	23.931	14.986	20.446	21.974	15.067	18.771	36.339	22.617	28.819	65.187	46.715	57.849
NO_2	Nov-17	7.2977	2.986	5.3585	48.51	0.9551	10.695	38.748	5.1065	12.398	25.423	12.23	18.9756
(ppb)	Dec-17	7.3659	5.5328	6.2278	11.744	3.2936	5.6703	44.02	3.2441	20.312	26.735	17.19	22.1144
	Jan-18	7.1276	5.5226	6.3798	7.5578	4.8762	6.2308	81.791	8.0104	27.269	33.105	17.82	23.9482
		8h-mean			8h-mean			8h-mean			8h-mean		
CO	Nov-17	366.71	39.826	128.42	12207	70.154	5218.7	1669.4	252.06	626.41	2008.2	344.86	847.856
(ppb)	Dec-17	362.73	40.908	178.8	4842	148.59	837.21	2028	284.07	714.57	2867	440.86	983.479
	Jan-18	453.94	105.49	224.49	641.28	34.354	278.05	2082.7	343.03	728.19	2240.7	402.25	922.334
O_3	Nov-17	35.82	0.2315	15.029	143.29	26.428	56.44	194.03	1.307	35.583	48.139	9.6849	24.0146
(ppb)	Dec-17	59.33	4.7047	27.369	76.241	19.925	40.715	155.98	45.513	85.094	64.328	3.373	23.3023
	Jan-18	65.53	9.9216	39.182	68.805	18.554	41.353	198.37	15.897	80.585	57.23	2.143	23.7335
		1h-mean			1h-mean			1h-mean			1h-mean		
NO_2	Nov-17	15.307	0.267	5.3205	93.182	0.019	9.882	90.722	0.149	12.659	57.369	1.088	19.2469
(ppb)	Dec-17	15.41	0.128	6.1077	65.675	0.088	5.578	99.532	0.031	21.34	75.571	1.2313	21.9944
	Jan-18	16.457	0.5613	6.3535	22.497	0.129	6.1898	99.003	0.009	20.036	63.849	3.426	23.9807
CO	Nov-17	482.27	13.268	128.43	16676	8.5375	5213.1	2927.7	112.3	624.97	3818.1	119.58	842.113
(ppb)	Dec-17	562.92	8.8297	181.01	8095.2	0.94	897.23	3885.5	244.97	748.01	4955.6	296.72	1009.02
	Jan-18	518.44	83.616	228.36	1006.8	3.764	282.27	2870.5	251.57	738.06	3177.2	265.08	930.618
O_3	Nov-17	47.021	0.2315	16.517	195.16	21.556	57.331	194.03	0.3565	29.934	57.05	1.943	24.055
(ppb)	Dec-17	67.884	0.382	26.453	113.24	16.742	40.509	188.34	25.522	83.894	66.976	0.224	22.3734
	Jan-18	71.736	6.3378	38.765	81.978	9.2308	41.562	198.37	6.8195	74.622	64.88	0.104	23.9998

ADDENDUM III: Figures and Tables showing the AQI at different stations during the period of three months.

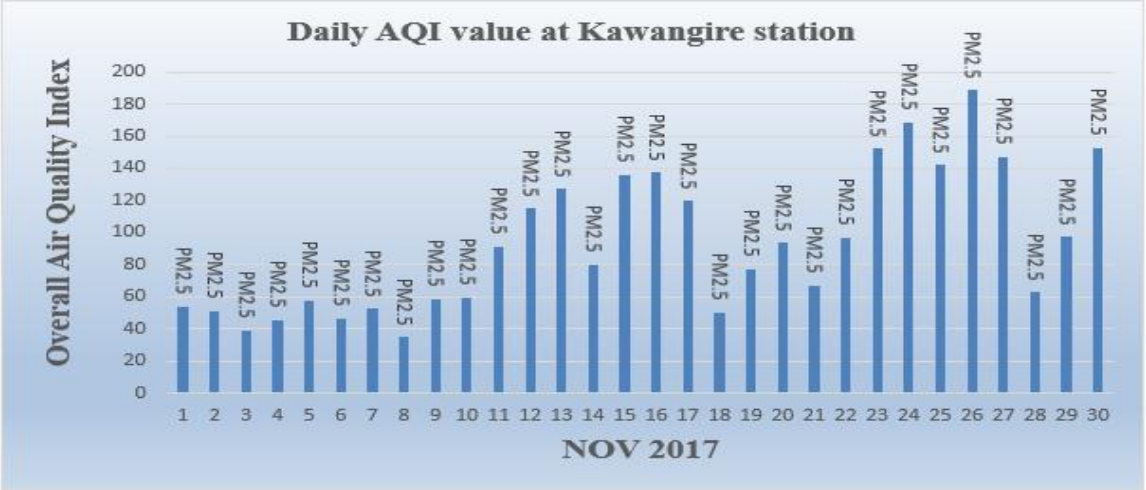

Figure 4.3.1.1: Calculated AQI value at Kawangire station in November 2017

Table 4.3.1.1: Color code associated with AQI obtained at Kawangire station in November 2017

NOV 2017	AQI range	Responsible pollutant	AQI category
1st -2nd	51-100	$PM_{2.5}$	Moderate
3rd-4th	0-50	$PM_{2.5}$	Good
5th	51-100	$PM_{2.5}$	Moderate
6th	0-50	$PM_{2.5}$	Good
7th	51-100	$PM_{2.5}$	Moderate
8th	0-50	$PM_{2.5}$	Good
9th-11th	51-100	$PM_{2.5}$	Moderate
12th-13th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
14th	51-100	$PM_{2.5}$	Moderate
15th-17th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
18th	0-50	$PM_{2.5}$	Good
19th-22nd	51-100	$PM_{2.5}$	Moderate
23rd-24th	151-200	$PM_{2.5}$	Unhealthy
25th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
26th	151-200	$PM_{2.5}$	Unhealthy
27th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
28th-29th	51-100	$PM_{2.5}$	Moderate
30th	151-200	$PM_{2.5}$	Unhealthy

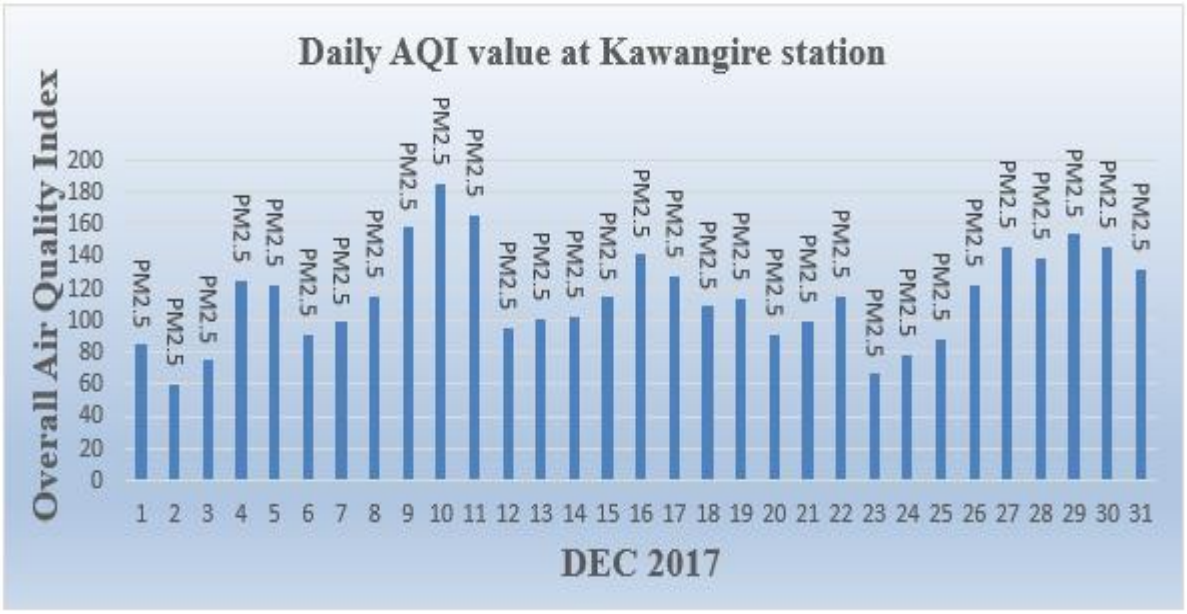

Figure 4.3.1. 2: Calculated AQI value at Kawangire station in December 2017

Table 4.3.1.2: Color code associated with AQI obtained at Kawangire station in December 2017

DEC 2017	AQI range	Responsible pollutant	AQI category
1st -3rd	51-100	$PM_{2.5}$	Moderate
4rd-5th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
6th-7th	51-100	$PM_{2.5}$	Moderate
8th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
9th-11th	151-200	$PM_{2.5}$	Unhealthy
12th	51-100	$PM_{2.5}$	Moderate
13th-19th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
20th-21st	101-150	$PM_{2.5}$	Moderate
22nd	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
23rd-25th	51-100	$PM_{2.5}$	Moderate
26th-28th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
29th	151-200	$PM_{2.5}$	Unhealthy
30th-31st	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups

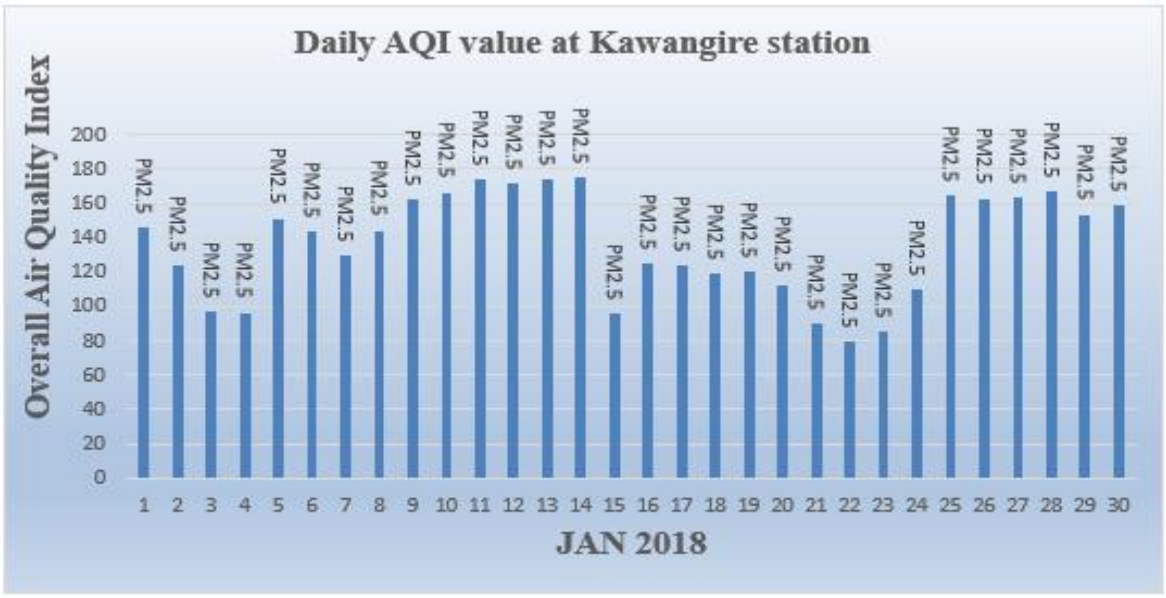

Figure 4.3.1. 3: Calculated AQI value at Kawangire station in January 2018

Table 4.3.1.3: Color code associated with AQI obtained at Kawangire station in January 2018

JAN 2018	AQI range	Responsible Pollutant	AQI category
1st -2nd	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
3rd-4th	51-100	$PM_{2.5}$	Moderate
5th	151-200	$PM_{2.5}$	Unhealthy
6th-8th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
9th-14th	151-200	$PM_{2.5}$	Unhealthy
15th	51-100	$PM_{2.5}$	Moderate
16th-20th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
21st-23rd	101-150	$PM_{2.5}$	Moderate
24th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
25th-30th	151-200	$PM_{2.5}$	Unhealthy

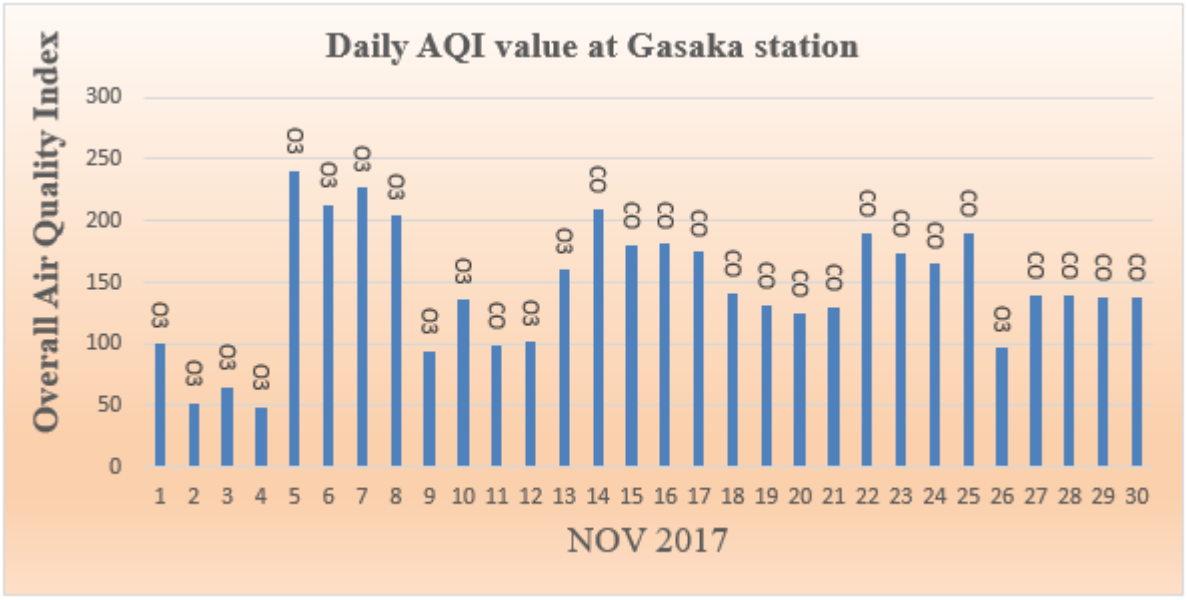

Figure 4.3.2.1: Calculated AQI value at Gasaka station in November 2017

Table 4.3.2.1: Color code associated with AQI obtained at Gasaka station in November 2017

NOV 2017	AQI range	Responsible pollutant	AQI category
1st-3rd	51-100	O_3	Moderate
4th	0-50	O_3	Good
5th-8th	201-300	O_3	Very Unhealthy
9th	51-100	O_3	Moderate
10th	101-150	O_3	Unhealthy for Sensitive Groups
11th	51-100	CO	Moderate
12th-13th	101-150	O_3	Unhealthy for Sensitive Groups
14th	151-200	CO	Unhealthy
15th-25th	101-150	CO	Unhealthy for Sensitive Groups
26th	51-100	O_3	Moderate
27th-30th	101-150	CO	Unhealthy for Sensitive Groups

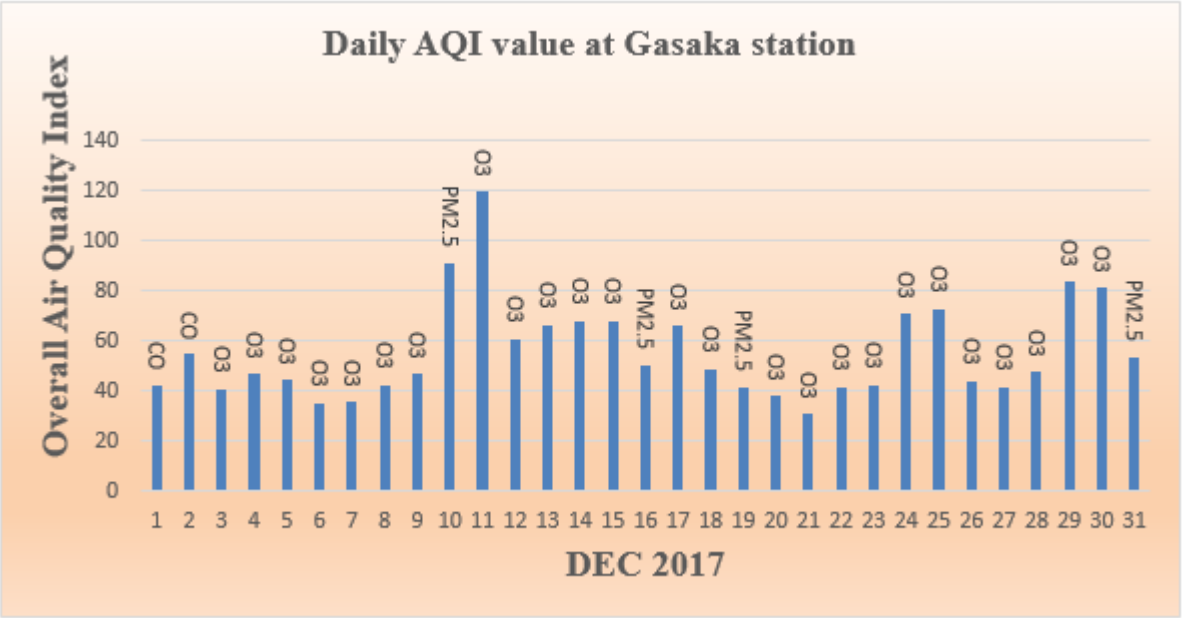

Figure 4.3.2. 2: Calculated AQI value at Gasaka station in December 2017

Table 4.3.2. 2: Color code associated with AQI obtained at Gasaka station in December 2017

DEC 2017	AQI range	Responsible pollutant	AQI category
1st	0-50	CO	Good
2nd	51-100	CO	Moderate
3rd-9th	0-50	O_3	Good
10th	51-100	$PM_{2.5}$	Moderate
11th	101-150	O_3	Unhealthy for Sensitive Groups
12th-15th	51-100	O_3	Moderate
16th	0-50	$PM_{2.5}$	Good
17th	51-100	O_3	Moderate
18th	0-50	O_3	Good
19th	0-50	$PM_{2.5}$	
20th-23rd	0-50	O_3	
24th-25th	51-100	O_3	Moderate
26th-28th	0-50	O_3	Good
29th-30th	51-100	O_3	Moderate
31st	51-100	$PM_{2.5}$	

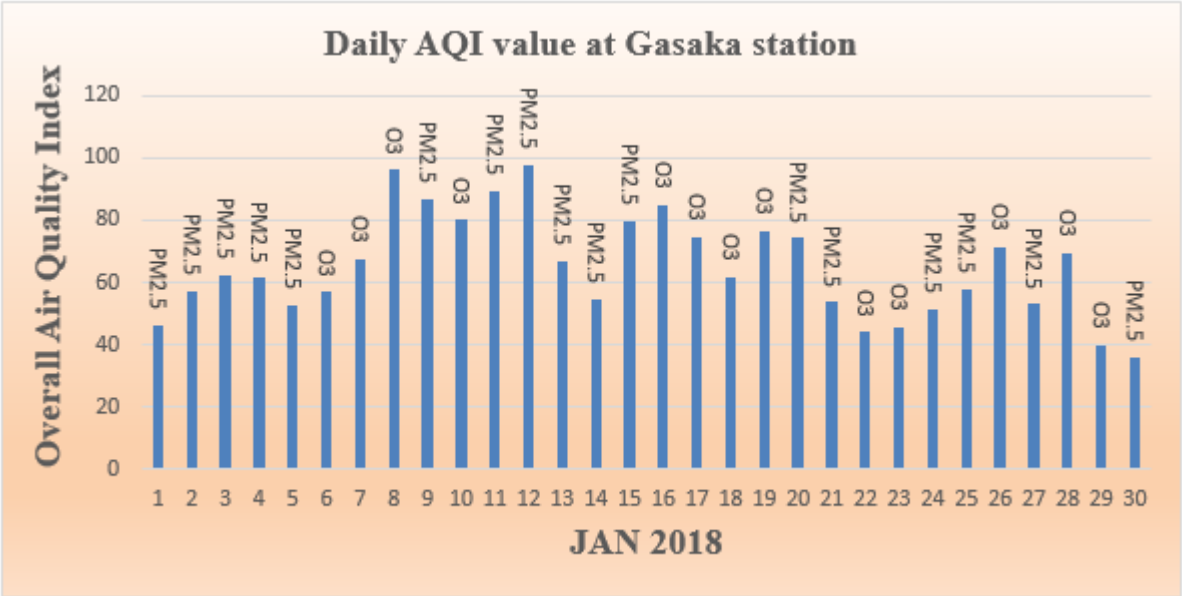

Figure 4.3.2. 3: Calculated AQI value at Gasaka station in January 2018

Table 4.3.2. 3: Color code associated with AQI obtained at Gasaka station in January 2018

JAN 2018	AQI range	Responsible Pollutant	AQI category
1st	0-50	$PM_{2.5}$	Good
2nd-5th	51-100	$PM_{2.5}$	Moderate
6th-8th	51-100	O_3	
9th	51-100	$PM_{2.5}$	
10th	51-100	O_3	
11th-15th	51-100	$PM_{2.5}$	
16th-19th	51-100	O_3	
20th-21st	51-100	$PM_{2.5}$	
22nd-23rd	0-50	O_3	Good
24th-25th	51-100	$PM_{2.5}$	Moderate
26th	51-100	O_3	
27th	51-100	$PM_{2.5}$	
28th	51-100	O_3	
29th	0-50	O_3	Good
30th	0-50	$PM_{2.5}$	

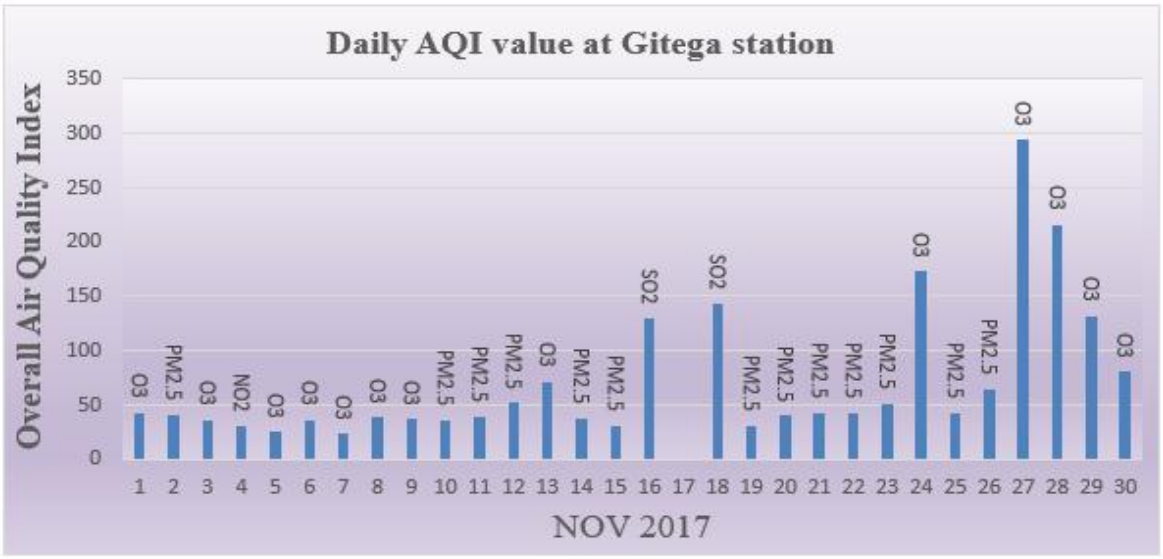

Figure 4.3.3. 1: Calculated AQI value at Gitega station in November 2017

Table 4.3.3. 1: Color code associated with AQI obtained at Gitega station in November 2017

NOV 2017	AQI range	Responsible pollutant	AQI category
1st	0-50	O_3	Good
2nd	0-50	$PM_{2.5}$	
3rd	0-50	O_3	
4th	0-50	NO_2	
5th-9th	0-50	O_3	
10th-11th	0-50	$PM_{2.5}$	
12th	51-100	$PM_{2.5}$	Moderate
13th	51-100	O_3	
14th-15th	0-50	$PM_{2.5}$	Good
16th	101-150	SO_2	Unhealthy for Sensitive Groups
18th	101-150	SO_2	
19th-22nd	0-50	$PM_{2.5}$	Good
23rd	51-100	$PM_{2.5}$	Moderate
24th	151-200	O_3	Unhealthy
25th	0-50	$PM_{2.5}$	Good
26th	51-100	$PM_{2.5}$	Moderate
27th-28th	201-300	O_3	Very Unhealthy
29th	101-150	O_3	Unhealthy for Sensitive Groups
30th	51-100	O_3	Moderate

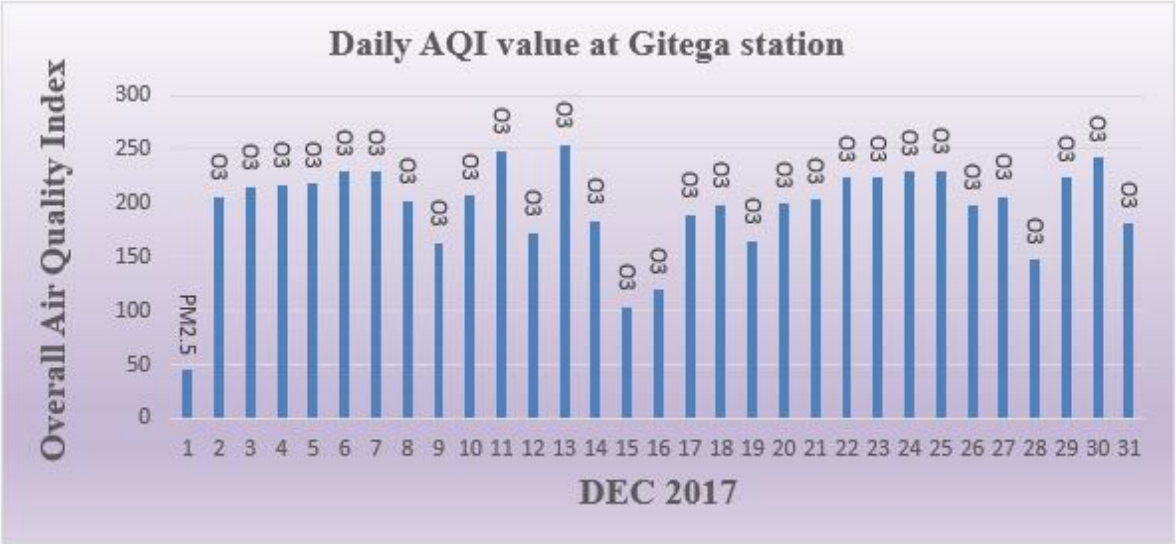

Figure 4.3.3. 2: Calculated AQI value at Gitega station in December 2017

Table 4.3.3. 2: Color code associated with AQI obtained at Gitega station in December 2017

DEC 2017	AQI range	Responsible pollutant	AQI category
1st	51-100	$PM_{2.5}$	Moderate
2nd-11th	201-300	O_3	Very Unhealthy
12th	151-200	O_3	Unhealthy
13th	201-300	O_3	Very Unhealthy
14th	151-200	$PM_{2.5}$	Unhealthy
15th-16th	101-150	O_3	Unhealthy for Sensitive Groups
17th-20th	151-200	O_3	Unhealthy
21st-25th	201-300	O_3	Very Unhealthy
26th	151-200	O_3	Unhealthy
27th	201-300	O_3	Very Unhealthy
28th	151-200	O_3	Unhealthy
29th-30th	201-300	O_3	Very Unhealthy
31st	151-200	O_3	Unhealthy

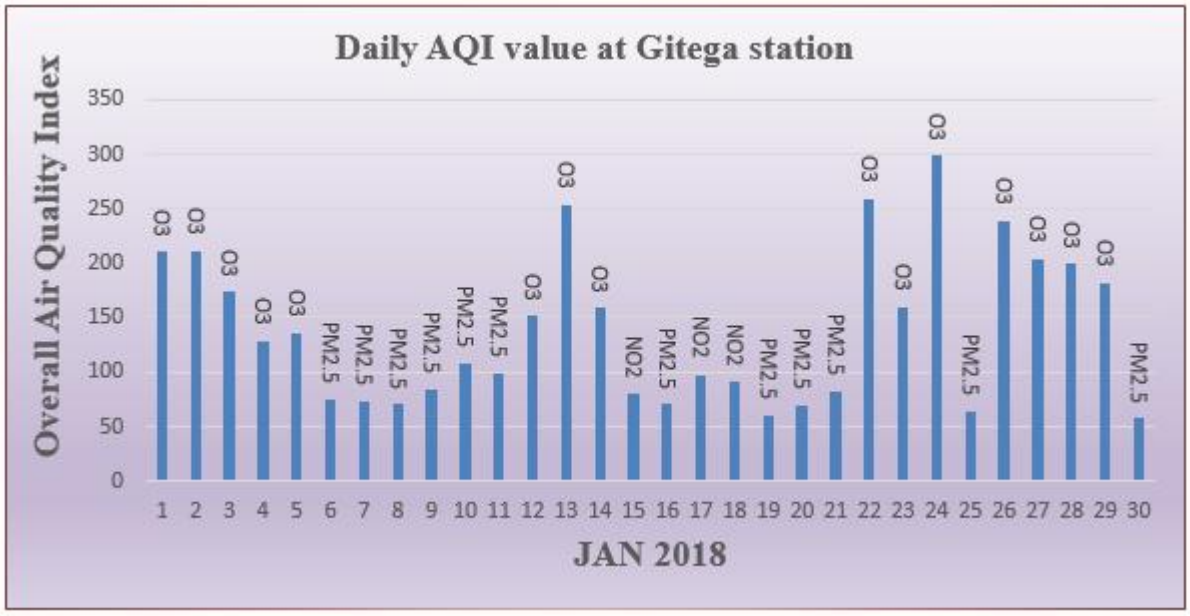

Figure 4.3.3. 3: Calculated AQI value at Gitega station in January 2018

Table 4.3.3. 3: Color code associated with AQI obtained at Gitega station in January 2018

JAN 2018	AQI range	Responsible pollutant	AQI category
1st-2nd	201-300	O_3	Very Unhealthy
3rd-5th	101-150	O_3	Unhealthy for Sensitive Groups
6th-9th	51-100	$PM_{2.5}$	Moderate
10th	101-150	$PM_{2.5}$	Unhealthy for Sensitive Groups
11th	51-100	$PM_{2.5}$	Moderate
12th	151-200	O_3	Unhealthy
13th	201-300	O_3	Very Unhealthy
14th	151-200	O_3	Unhealthy
15th	51-100	NO_2	Moderate
16th	51-100	$PM_{2.5}$	
17th-18th	51-100	NO_2	
19th-21st	51-100	O_3	
22nd	201-300	O_3	Very Unhealthy
23rd	151-200	O_3	Unhealthy
24th	201-300	O_3	Very Unhealthy
25th	51-100	$PM_{2.5}$	Moderate
26th-27th	201-300	O_3	Very Unhealthy
28th-29th	151-200	O_3	Unhealthy
30th	51-100	$PM_{2.5}$	Moderate

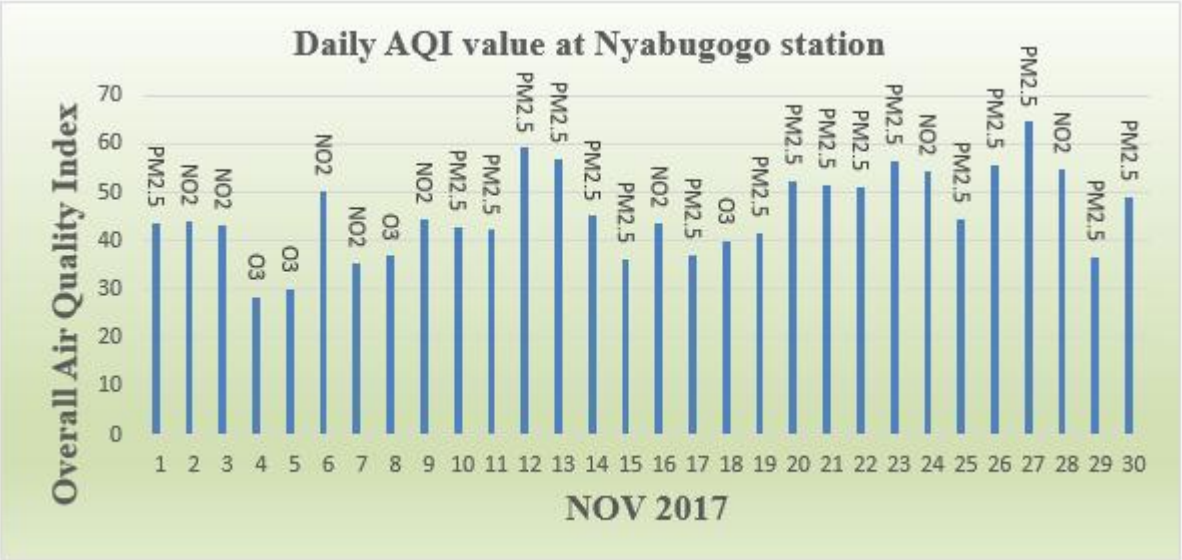

Figure 4.3.4. 1: Calculated AQI value at Nyabugogo station in November 2017

Table 4.3.4. 1: Color code associated with AQI obtained at Nyabugogo station in November 2017

NOV 2017	AQI range	Responsible pollutant	AQI category
1st	0-50	$PM_{2.5}$	Good
2nd-3rd	0-50	NO_2	
4th-5th	0-50	O_3	
6th-7th	0-50	NO_2	
8th	0-50	O_3	
9th	0-50	NO_2	
10th-11th	0-50	$PM_{2.5}$	
12th-13th	51-100	$PM_{2.5}$	Moderate
14th-15th	0-50	$PM_{2.5}$	Good
16th	0-50	NO_2	
17th	0-50	$PM_{2.5}$	
18th	0-50	O_3	
19th	0-50	$PM_{2.5}$	
20th-23rd	51-100	$PM_{2.5}$	Moderate
24th	51-100	NO_2	
25th	0-50	$PM_{2.5}$	Good
26th-27th	51-100	$PM_{2.5}$	Moderate
28th	51-100	NO_2	
29th	0-50	$PM_{2.5}$	Good
30th	0-50	$PM_{2.5}$	

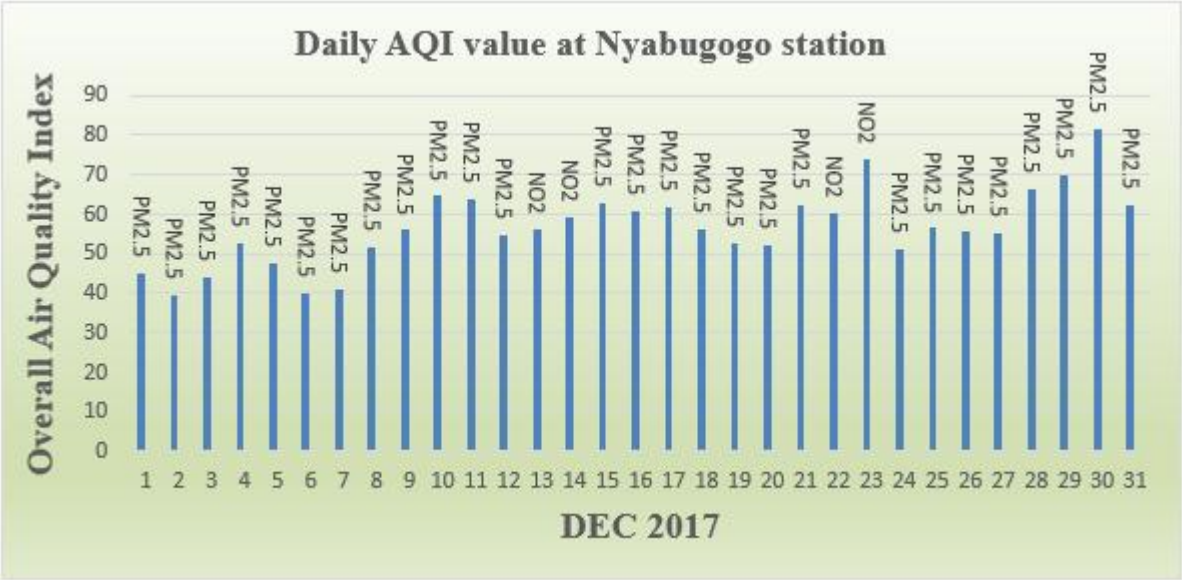

Figure 4.3.4. 2: Calculated AQI value at Nyabugogo station in December 2017

Table 4.3.4.2: Color code associated with AQI obtained at Nyabugogo station in December 2017

DEC 2017	AQI range	Responsible pollutant	AQI category
1st-3rd	0-50	$PM_{2.5}$	
4th	51-100	$PM_{2.5}$	Moderate
5th-7th	0-50	$PM_{2.5}$	Good
8th-12th	51-100	$PM_{2.5}$	
13th-14th	51-100	NO_2	
15th-21st	51-100	$PM_{2.5}$	Moderate
22nd-23rd	51-100	NO_2	
24th-31st	51-100	$PM_{2.5}$	

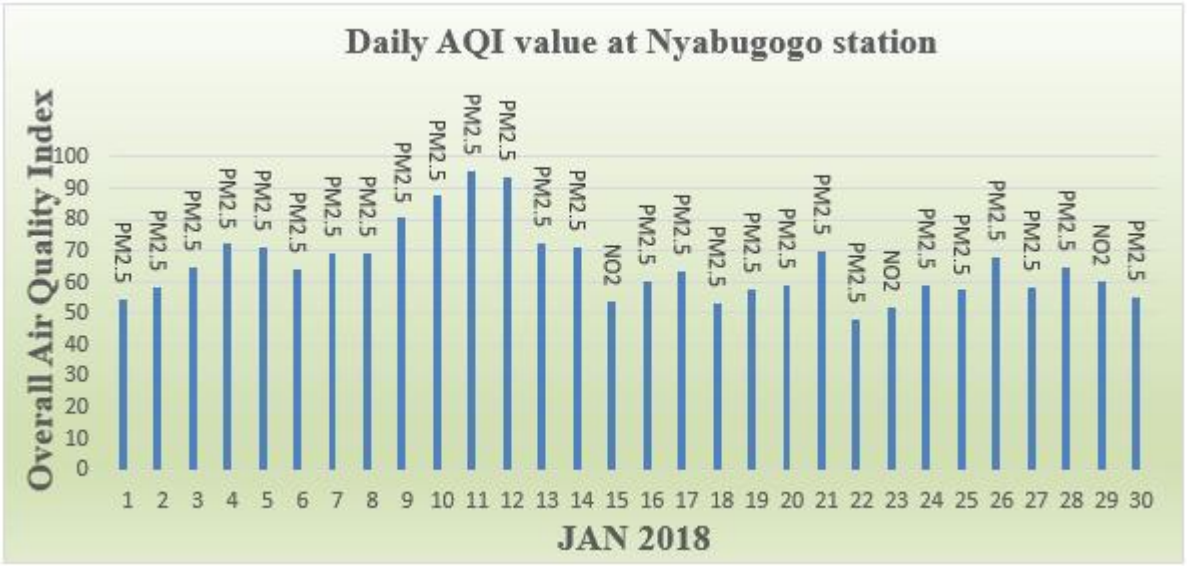

Figure 4.3.4. 3: Calculated AQI value at Nyabugogo station in January 2018

Table 4.3.4.3: Color code associated with AQI obtained at Nyabugogo station in January 2018

JAN 2018	AQI range	Responsible pollutant	AQI category
1st-14th	51-100	$PM_{2.5}$	Moderate
15th-21st	51-100	$PM_{2.5}$	
22nd	0-50	$PM_{2.5}$	Good
23rd	51-100	NO_2	Moderate
24th-28th	51-100	$PM_{2.5}$	
29th	51-100	NO_2	
30th	51-100	$PM_{2.5}$	

ADDENDUM IV: Table for comparison of AQI among different locations during the period of three months.

Table 4.4.1: Status of air quality at the monitoring stations for the period of three months (Nov 2017-Jan 2018).

		AQI level of health concern						
Air quality monitoring Station	Monitoring period (Month)	Air quality is acceptable		Air quality is unhealthy			Number of days for Unhealthy air quality	Responsible air polltants
		Good (0-50)	Moderate (51-100)	Unhealthy for Sensitive Groups (101-150)	Unhealthy (151-200)	Very Unhealthy (201-300)		
Kawangire	Nov-17	5 days	14 days	7 days	4 days	0	55	$PM_{2.5}$
	Dec-17	0	11 days	16 days	4 days	0		
	Jan-18	0	6 days	11 days	13 days	0		
Gasaka	Nov-17	1 day	6 days	18 days	1 day	4 days	24	O_3
	Dec-17	18 days	12 days	1 day	0	0		CO
	Jan-18	5 days	25 days	0	0	0		
Gitega	Nov-17	18 days	5 days	3 days	1 day	2 days	52	SO_2
	Dec-17	0	1 day	2 days	9 days	19 days		O_3
	Jan-18	0	14 days	4 days	5 days	7 days		$PM_{2.5}$
Nyabugogo	Nov-17	20 days	10 days	0	0	0	0	
	Dec-17	6 days	25 days	0	0	0		
	Jan-18	1 day	29 days	0	0	0		

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