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Quantification of Air Pollution in Kigali City and Its Environmental and Socio-Economic Impact in Rwanda

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Abstract This 9-months study was conducted in Kigali City and Nyamagabe District during the 2012-2013 period with the overall aim of raising awareness about the benefits of cleaner energies (biodiesel) and human health risks and negative environmental and socio-economic impact of fossil fuels (petrol and petro diesel) that are commonly used in Rwanda. MAHA MGT 5 Emission Tester and MAHA MDO 2 LON Emission Tester/Opacimeter were used to measure gas emissions (CO_2, CO, Unburned Hydrocarbons and Opacity) from gasoline or petrol and diesel vehicles respectively. Air composition (HCl, NO_2, NO_3, SO_2, H_2S, TVOC, O_3, CO, CO_2) in the study sites was measured using Gray Wolf-Advanced Sense HVAC Environmental Test Meter while water quality was analyzed at the Water Laboratory of the National University of Rwanda. Annually, a total of 526,327.1 tons of carbon dioxide (CO_2), 18,405.5 tons of carbon monoxide (CO) and 354,967.0 m^3 of unburned hydrocarbons (HC) are released into the atmosphere of Kigali City by both petrol and diesel vehicles. Using 100% Biodiesel reduced emission of CO by 50% and Opacity by 76.9% while using a Biodiesel-blend or Biodiesel-Diesel mixture (B_{50}) reduced CO and Opacity by 35.2% and 71% respectively. In the Kitabi area surrounded by Nyungwe Forest Reserve air contaminants HCl, NO_2, TVOC and O_3 were reduced by 76.6%, 54.6%, 74.8% and 72.7% while NO_3, SO_2 and CO were reduced by 100% as compared with Kigali City respectively. Water contaminants were also higher in Kigali City than forested areas of Nyamagabe. It is concluded that continuous use of expensive fossil fuels may result in increased human health deterioration, environmental degradation, lowered human work productivity and slow economic growth in Rwanda. Using cleaner energies (i.e. biodiesel), however, results in improved human health, living environment and socio-economic development. Planting suitable tree species, frequent monitoring of imported fuel quality and establishment of new fuel quality regulations and guidelines, national ambient air quality standards and national air quality emission standards are very crucial if we are to assure our future generations of a quality life and living environment. However, more studies on pollution by all types of motor-vehicles, industries and other machinery are needed in Rwanda. Detailed studies on mathematical modeling of air pollutants in major cities of Rwanda are also urgently required to evaluate air pollution dispersion and assist in forecasting the air quality.

Keywords Petrol, Petro diesel, Biodiesel, Pollution, Environment, Health, Economic development

1. Introduction

Rising costs of fossil fuels and their associated pollution problems are among other serious threats to the economic development of Rwanda. Pollution is the undesirable change in the physical, chemical or biological characteristics of air, land and water that may be harmful to the human life, living conditions and cultural assets or that may waste or deteriorate raw natural resources [1].

Petro diesel and gasoline/petrol are two types of fuels that are commonly used as major sources of energy and vehicle fuel in Rwanda. Fossil diesel also known as Petroleum diesel or Petro diesel is a liquid fuel (density: 0.832 kg/l) produced from the fractional distillation of crude oil between 200℃ (392℉) and 350℃ (662℉) at atmospheric pressure, resulting in a mixture of carbon chains that typically contain between 8 and 21 carbon atoms per molecule and hydrocarbons (75% saturated hydrocarbons and 25% aromatic hydrocarbons- naphthalenes and alkylbenzenes) having a high boiling point in the range of 180-360℃ (360-680℉) (i.e. The average chemical formula for common diesel fuel is $C_{12}H_{23}$, ranging approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$) [2, 3].

Gasoline or petrol is a mixture of various hydrocarbons dominated by octane (C_8H_{18}) or a combination of heptanes, octane, a handful of other alkanes, plus additives including detergents, and possibly oxygenators such as methyl tert-butyl ether or ethanol/methanol (density: 0.745 kg/l) [4].

Indoor and outdoor air pollution associated with the use of fossil fuels is a major environmental health problem affecting everyone in developed and developing countries

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like Rwanda. The indoor air pollution is estimated to cause approximately 2 million premature deaths mostly in developing countries with almost half of these deaths being attributable to pneumonia in children under 5 years of age, while the outdoor air pollution is estimated to cause 1.3 million deaths worldwide per year [5, 6]. Poor indoor air quality may pose a risk to the health of over half of the world's population [6]. In developing countries, exposure to pollutants from indoor combustion of solid fuels on open fires or traditional stoves increases the risk of acute lower respiratory infections and associated mortality among young children [6]. Indoor air pollution from solid fuel use is also a major risk of factor for chronic obstructive pulmonary diseases and lung cancer among adults [6]. Even relatively low concentrations of air or exhaust pollutants (eg. Hydrocarbons, nitrogen oxides- NOx, carbon monoxide-CO, and carbon dioxide - CO_2) have been related to a range of adverse health effects [6]. Approximately 1.5% of annual lung cancer deaths are attributable to exposure to carcinogens form indoor air pollution. Small particulate matter and other pollutants in indoor smoke inflame the airways and lungs, impairing immune response and reducing the oxygen-carrying capacity of the blood. Indoor air pollution was also reported to be closely linked with low birth weight, TB, ischaemic heart disease, nasopharyngeal and laryngeal cancers [5].

Particulate matter (PM) composed mainly by sulfate, nitrates, ammonia, sodium chloride, carbon, mineral dust and water or consisting of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air affects more people than other pollutant (Max. $PM_{2.5}$: 10μg/m^3 annual mean and 25 μg/m^3 24-hour mean and Max. PM_{10}: 20 μg/m^3annual mean and 50 μg/m^3 24-hour mean) [7-9, 6, 10]. Particles with an aerodynamic diameter smaller than 2.5 μm or $PM_{2.5}$ are more dangerous since, when inhaled, they may reach the peripheral regions of the bronchioles, and interfere with gas exchange inside the lungs [6]. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases as well as lung cancer [6, 10]. In cities with high levels of pollution, the mortality exceeds that observed in relatively cleaner cities by 15-20% [6].

Ozone at ground level (not to be confused with the ozone layer in the upper atmosphere) formed by the reaction with sunlight (photochemical reaction) of pollutants such as nitrogen oxides (NOx) from vehicles and industry emissions and volatile organic compounds emitted by vehicles, solvents and industry, is one of the major constituents of photochemical smog (Max. O_3: 100 μg/m^3 8-hour mean). Excessive ozone in the air can have a marked effect on human health by causing breathing problems, triggering asthma, reducing lung function and causing lung diseases. Several studies in Europe reported that the daily mortality rises by 0.3% and that increase in ozone exposure by 10 μg/m^3 results in increased heart diseases by 0.4% [6].

Nitrogen dioxide (NO_2) is the main source of nitrate aerosols, which form an important fraction of particulate matter ($PM_{2.5}$) and of ozone in the presence of ultraviolet light (Max. NO_2: 40 μg/m^3 annual mean and 200 μg/m^3 1-hour mean). Epidemiological studies have shown that long-term exposure to NO_2 resulted in increased symptoms of bronchitis in asthmatic children and reduced lung function [6, 10].

Table 1. Chemical components/contaminants found in diesel exhaust and their health risks

Contaminant	Health risks
Acetaldehyde	IARC group 2B carcinogens
Acrolein	IARC group 3 carcinogens
Aniline	IARC group 3 carcinogens
Antimony compound **	Toxicity similar to arsenic poisoning
Arsenic**	IARC group carcinogens, endocrine disrupter
Benzene	IARC group 1 carcinogens
Beryllium compound	IARC group 1 carcinogens
Biphenyl	It has mild toxicity
Bis (2-ethyl exyl) phtholate	Endocrine disrupter
1,3-butodiene	IARC group 2A carcinogens
Cadmium	IARC group 1 carcinogen, endocrine disrupter
Chrolobenzene	Low moderate toxicity
Chromium compound	IARC group 3 carcinogens
Cresol isomers	-
Cyanide compound	-
Dibutyl phtholate	Endocrine disruptor
1,8-dinitropyrene	carcinogens
Dioxyns and dibenzofurans	-
Ethyl benzene	-
Formaldehyde	-
Inorganic lead	Endocrine disruptor
Mercury compound	IARC group 3 carcinogens
Methanol	It may cause brindness
Methyl ethyl ketone	It may cause birth defect
Naphthalene	IARC group 2B carcinogens
Nickel	IARC group 2B carcinogens
3-nitrobenzatrone	One of the strangest carcinogens known
4-nitrobiphenyl	Endocrine disruptor
Polycyclic organic matter including polycyclic aromatic hydrocarbons	-
Propionaldehyde	-
Selenium compound	IARC group 3 carcinogens
Stylen	IARC group 2B carcinogens
Toluene	IARC group 3 carcinogens
Xylen isomers and mixtures:0-xylens, m-xylenes, p-xylenes	IARC group 3 carcinogens

Reference: [7, 9]

Sulfur dioxide (SO_2) is a colourless gas with a sharp odour which is produced from the burning of sulfur-containing fossil fuels and the smelting of mineral ores that contain sulfur (Max. SO_2: 20 μg/m^3 24-hour mean and 500 μg/m^3 10-minute mean) [6, 10]. Sulfur dioxide can affect the respiratory system and the functions of the lungs, and cause irritation of the eyes. Studies indicate that a proportion of people with asthma experience changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2 as short as 10 minutes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract. Hospital admissions for cardiac diseases and mortality increase on days with higher SO_2 levels. When SO_2 combines with water, it forms sulfuric acid (H_2SO_4) which is the main component of acid rain [6].

Carbon monoxide (CO) is a product of incomplete combustion and occurs when carbon in the fuel is partially oxidized rather than being fully oxidized to carbon dioxide (CO_2) [11, 12]. Carbon monoxide reduces the flow of oxygen in the bloodstream and is particularly dangerous to people with heart disease. Emission of carbon dioxide (CO_2) can contribute to climate change which is a serious national and trans-national socio-economic complex problem caused by air pollution and the build-up of greenhouse gases into the atmosphere. Other chemical components found in the diesel exhaust and their health risks are given in Table 1 [7, 9].

The use of biodiesel seems to be a practical option for solving the above-mentioned problems. Consumption of biodiesel by vehicles results in substantial reductions of unburned hydrocarbons, carbon monoxide (CO) and particulate matter [11, 13]. Studies in Rwanda and other countries revealed that using biodiesel reduced carbon monoxide (a poisonous gas) emissions by 48% and 50% respectively compared to most petro diesel fuels [11, 13, 8, 14]. Studies in USA showed that production and use of biodiesel reduced carbon monoxide (CO) by 48% and carbon dioxide (CO_2) emissions by 78.5% as compared with petroleum diesel [14]. The exhaust emissions of particulate matter from biodiesel have been found to be 30-47% lower than overall particulate matter emissions from petro diesel [11, 13, 12]. The exhaust emissions of total hydrocarbons (ie. a contributing factor in the localized formation of smog and ozone) are up to 93% lower for biodiesel than diesel fuel. The ozone (smog) forming potential of biodiesel by hydrocarbons is 50% less than the one of petroleum diesel. Sulfur emissions are essentially eliminated with pure biodiesel. Biodiesel may also reduce health risks associated with petroleum diesel. Biodiesel emissions showed decreased levels of polycyclic aromatic hydrocarbon and nitrited polycyclic aromatic hydrocarbon compounds, which have been identified as potential cancer-causing compounds. Recent studies showed that polycyclic aromatic hydrocarbon compounds were reduced by 75-85%, except for benzanthracene which was reduced by 50%. Targeted n-polycyclic aromatic hydrocarbon compounds were also reduced dramatically with biodiesel fuel, with 2-nitrofluorene and 1-nitropyrene reduced by 90% [11, 13, 8, 14]. Producing and using biodiesel in Rwanda, may result in numerous beneficial environmental and health effects including creation of employment and increased workers income, beneficial environmental and health effects, low exploitation cost, use in engine without engine modification, storage in traditional fuelling infrastructure, possibility of blending with petroleum diesel fuel, safe handling and transportation, greater engine lubrication than petroleum diesel, engine fuel mileages similar to engine using petro diesel, pleasant aroma, useful glycerin and support to domestic economy [12]. Although there has been some Governmental efforts directed at protecting and conserving our living environment with the major aim of improving people's welfare and socio-economic conditions, there is increasing evidence showing that very little is known about cleaner energies and health risks caused by pollution from fossil fuels. Also, while some countries have already established their air quality standards and emission standards (Table 2) [15] there is increasing recognition that such standards are inexistent in Rwanda.

Table 2. Australia's first ambient air quality standards established in 1998

Pollutant	Averaging period	Maximum (ambient) concentration
Carbon monoxide	8 hours	9.0 ppm
Nitrogen oxide	1 hour	0.12 ppm
	1 year	0.03 ppm
Photochemical oxidants (as ozone)	1 hour	0.10 ppm
	4 hours	0.08 ppm
Sulfur dioxide	1 hour	0.20 ppm
	1 day	0.08 ppm
	1 year	0.02 ppm
Lead	1 year	0.50 μg/m^3
Particles as PM_{10}	1 day	50 μg/m^3
Particles as $PM_{2.5}$	1 day	25 μg/m^3
	1 year	8 μg/m^3

Reference: [15]

The main objective of this study, therefore, was to raise awareness about the benefits of cleaner energies like biodiesel and human health risks and negative environmental and socio-economic impact of fossil fuels that are commonly used in Rwanda. More specifically, the objectives were:

(i) To quantify gas emissions in Kigali City
(ii) To compare air composition and quality of water used to irrigate edible plants in various home gardens
(iii) To assess health risks, environmental and socio-economic impacts of both fossil fuels and biodiesel

It was hypothesized that biodiesel improves human health, environmental and socio-economic conditions as compared with fossil fuels.

2. Materials and Methods

2.1. Study Site Description

This 9-months study was carried out in Kigali City (Latitude: 1° 57' 13" S; Longitude: 30° 3' 38" E; Altitude: 1567 m a.s.l; Average temperature: 20.5°C; Average humidity: 39%; Pressure: 1021 mbar; Rainfall: 1007 mm) and Nyamagabe District (Latitude: 2° 24' 29" S; Longitude: 29° 28' 5" E; Altitude: 2237 m a.s.l; Average temperature: 18°C; Rainfall range: 1300-1450 mm; humid tropical climate moderated by the effect of high altitude) during the 2012-2013 period (November 2012 - July, 2013).

a) The sub-study on gas emissions by vehicles residing in Kigali City and those entering the city from outside was conducted at the Rwanda National Police Motor-vehicle Inspection Centre and 4 axes of Nyacyonga, Giticyinyoni, Gahanga and Regende which allow entrance in Kigali City.
b) The sub-study on irrigation water quality was carried out at Rwintare water stream, Kinamba 2 water stream also known as Car-wash and Gitega Meteorology Station in Kigali and Kitabi Tea Factory Meteorology Station, Mwumba water stream in Kitabi (Latitude: 2°33'16" S; Longitude: 29°24'41" E; Average humidity: 38%; Pressure: 1009.26 mbar) and Nyamagabe Meteorology Station.
c) A comparative sub-study on air composition was also carried out in Kigali City and Kitabi Tea Factory.

2.2. Experimental Procedures

2.2.1. Data Collection and Vehicle Sampling

(i) Gas emissions from a representative sample of 1002 vehicles were measured at the Rwanda National Police Motor-vehicle Inspection Centre using MAHA MGT 5 Emission Tester for gasoline vehicles and MAHA MDO 2 LON Emission Tester/Opacimeter for diesel vehicles. The emission measurement probe CAR (10 mm) with 1.5 m hose was placed as far downstream in a section of the exhaust pipe where the distribution of smoke is approximately uniform. At the same period of gas emissions measurement at the Rwanda National Police Motor-vehicle Inspection Centre, 1535 vehicles entering Kigali City via Gahanga, Rugende, Giticyinyoni and Nyacyonga axes were also recorded.

(ii) The air composition at Kitabi Tea Factory and the Rwanda National Police Motor-vehicle Inspection Centre working place at below ground and above ground levels was measured using Gray Wolf-Advanced Sense HVAC Environmental Test Meter.

(iii) Samples for irrigation water quality determination were collected from Kitabi Tea Factory Meteorology Station, Mwumba water stream -Kitabi, Nyamagabe Meteorology Station, and Kigali (i.e. Rwintare water stream, Kinamba-2 water stream and Gitega Meteorology Station).

2.2.2. Calculation of Gas Emissions

(i) The combustion chemistry equation followed in the present study is shown below [16]:

Fuel $_{\text{(hydrogen, carbon, sulfur)}}$ + Air $_{\text{(nitrogen, oxygen)}}$
= Carbon dioxide + water vapor + oxygen
+ carbon monoxide + hydrocarbon
+ oxides of nitrogen + sulfur oxides (1)

(ii) When gasoline dominated by octane (C_8H_{18}) is burned under ideal conditions (i.e. with plenty of oxygen), CO_2, H_2O and lots of heat are obtained (i.e. C_8H_{18} reacts with oxygen exothermically) as follows [4]:

$$2\,C_8H_{18\,\text{(liquid)}} + 25\,O_{2\,\text{(gas)}} \longrightarrow 16\,CO_{2\,\text{(gas)}} + 18\,H_2O_{\text{(gas/vapour)}};$$

Heat = -10.86 MJ/mole of octane (2)

$$2\,(12 \times 8 + 1 \times 18) + (25 \times 16 \times 2) \longrightarrow 16\,(12 + 16 \times 2) + 18\,(1 \times 2 + 16)$$

$$228\text{ g}_{\text{(liquid petrol)}} + 800\text{ g}_{\text{(gas-O2)}} \longrightarrow 704\text{ g}_{\text{(gas- CO2)}} + 324\text{ g}_{\text{(gas-water)}}$$

(iii) Thi means that 228 g of petrol requires 800 g of oxygen to burn and generate heat, CO_2 and water vapour.

(iv) Weight of air volume at sea level at 20°C equals to 1.184 kg/m^3; Oxygen proportion is 20.9% (ie. 21%) by volume of air;

(v) Since 1 m^3 of air weighs 1,184 kg; 1 mole of air/gas is equivalent to 22.4 liters under ideal conditions; 1 mole of O_2 weighs 32 g (molecular weight of O_2 is 32 g); 1 mole of CO_2 weighs 44.0g (i.e. molecular weight of CO_2 is 44.0 g), it implies that 1 mole of CO_2 is equivalent to 22.4 liters.

Now $P_1V_1/T_1 = P_fV_f/T_f$ (Ideal gas law–Boyle's law) (3)

and if the pressure is constant, then:

$V_1/T_1 = V_f/T_f$ or $V_f = V_1T_f/T_1$ (Charles' law); (4)

where P_1 and P_f represent initial pressure and final pressure respectively while V_1 and V_f are initial and final volumes respectively.

Partial pressure law:

(i) Since 1 mole of air contain 21 mole % O_2 and 79 mole % N_2 or 0.21 O_2 + 0.79 N_2; Given the volume of air at 25°C and 1 atm (atmospheric pressure) equivalent to 24.4654 liters; then the volume of N_2 will be 19.3277 liters while that of O_2 will be 5.13774 liters; the weight volume of air at 0°C will be:

$V_f = V_1T_f/T_1$; V_f : volume at 0°C; V_f + 24.4654 x 273/298 = 22.41 liters (where 0°C is 273° Kelvin); 1 mole of air at 0°C equals to 22.41 liters at 20°C Vf will be 24.054 liters;

Partial gas of air:

(i) VO_2 at 0°C = 5.13774 X 273/298 = 4.707 liters or 22.41 x 0.21 = 4.7061 liters;
VN_2 at 0°C = 19.3277 X 273/298 = 17.707 liters or 22.41 x 0.79 = 17.704 liters

(ii) Since $1m^3$ of air is equivalent to 1000 liters of air, 22.41 liters of air will contain 4.707 liters of O_2 and 1000 liters will contain 4.707 liters of O_2 x 1000/22.41= 210 liters of O_2 or 1000 x 21% O_2=210 liters of O_2

(iii) Similarly, 1000 liters of air will contain 790 liters of N_2

(iv) Since 1 mole of O_2 weighs 32 g, there are 9.375 moles in 210 liters of O_2 or 210 liters/22.41 liters/mole = 9.371 moles of O_2

(v) Mass of oxygen in 1 m^3 of air = 9.375 x 32 = 300 g; mass of N_2 in 1 m^3 of air = 790 x 28/22.4 = 987.5 g;

(vi) Total mass of 1 m^3 of air at 0^oC = 1287.5 g/m^3

(vii) Oxygen weight ratio = 300 x 100%/1287.5 = 23.3% O_2 by weight or 21 % O_2 by volume

(viii) The oxygen-fuel mass ratio for gasoline (petrol):
228 g of C_8H_{18} require 800 g of O_2; implying that 1 g of gasoline will require 800 g of O_2/228 = 3.51 g of O_2; 1000 g of gasoline will require 3.51 g of O_2 x 1000 = 3510 g of oxygen or 1 kg of gasoline will require 3.51 kg of O_2

(ix) Since 23.3% of air mass is occupied by O_2; the air required to burn 1kg of gasoline= 3.51 x 100/23.3 = 15.06 kg of air; Every 1 kg of gasoline require 15.06 kg of air containing 3.51 kg of O_2

(x) Although the calculated stoichiometric air- gasoline fuel ratio is 15.06, the commonly used ratio is 14.7 which will also be used in this study. It implies, therefore, that every 1kg of gasoline requires 14.7 kg of air;

(xi) Volume of stoichiometric mass-air at 0^oC will be:

1.2875 kg of air $\longrightarrow$ 1 m^3 of air; implying that 14.7 kg of air equals: $1m^3$ of air x 14.7/1.2875 = 11.42 m^3 of air; every 1 kg of gasoline requires 11.42 m^3 of air.

Theoretical CO_2 requirement:

(i) 228 g of C_8H_{18} gasoline produce 704 g of CO_2; 1g of C_8H_{18} produces: 704 g of CO_2/228 = 3.09 g of CO_2 or 1 kg of gasoline produces 3.09 kg of CO_2

(ii) Moles of CO_2 in exhaust pipe = 3.09 g/44 g per mole = 0.07 moles of CO_2

(iii) Moles of N_2 in exhaust pipe = 14.7 x 79/100 x 28 = 0.415 moles of N_2

(iv) Total moles of CO_2 + moles of N_2 = 0.07 + 0.415 = 0.485 moles of exhaust gases (CO_2 + N_2)

(v) Theoretical CO_2 % by volume = moles of CO_2 x 100/total moles = 0.07 x 100/0.485 = 14.44% CO_2 vol.

Actual CO_2:

(i) Now that we know the theoretical air requirements and theoretical CO_2 content of the exhaust pipe, the next step is to determine the actual CO_2 % in the exhaust pipe gases.

(ii) The % excess air will be calculated as follows:

% Excess air = [(Theoretical CO_2 %/Actual CO_2) – 1] x 100 = [(14.44/10 measured CO_2 – 1] = 44.4% (5)

(iii) Theoretical air required for 1 kg gasoline burnt is 14.7; total quantity of air supply required with 44.4% excess air = 14.7 + 14.7 X 44.4/100 = 21.23 kg air for each 1 kg of gasoline

(iv) Excess air quantity (actual - theoretical) = 21.23 – 14.7 = 6.53 kg

(v) Excess O_2 in excess air = 6.53 x 23.3/100 = 1.521 kg of O_2; Excess N_2 in excess air = 6.53 – 1.521 = 5.01 kg of N_2; Produced water = 324/228 = 1.42 kg

(vi) At the end of 1 kg of fuel burning, constituents of the exhaust pipe gases with 44.4% excess air is as follows:

CO_2 = 3.09 kg; H_2O = 1.42 kg; O_2 = 1.521 kg from excess O_2 only (theoretical air being consumed in oxidation process) and N_2 = [(14.7-3.51)kg in theoretical air + 5.01 kg in excess air]= 11.19 + 5.01 = 16.2 kg of N_2

Calculation of CO_2 and CO emission using collected data (measured parameters):

11.97% of theoretical air volume is CO_2
1.69% of theoretical air volume is CO

(i) 11.42 m^3 of air required to burn 1 kg of gasoline x 11.97% of CO_2 = 1.367 m^3 of CO_2
1 kg of gasoline produces 1.367 m^3 of CO_2 equivalent to 1367 liters of CO_2
1 mole of CO_2 equals 22.4 liters of CO_2; 1367 liters of CO_2 will be 1 mole of CO_2 x 1367 liters/22.4 liters = 61.03 moles of CO_2; Since 1 mole of CO_2 weighs 44 g, it implies that 61.03 moles of CO_2 will weigh: 61.03 x 44 g = 2685.1 g of CO_2 or 2.685 kg of CO_2

(ii) 11.42 m^3 of theoretical air contains: 11.42 x 1.69% of CO = 0.192998 m^3 of CO= 0.192998 m^3 x 1000 liters/m^3 = 192.998 liters or 193.0 liters;
1 mole of CO occupies 22.4 liters or 22.4 liters of CO is equivalent to 1 mole of CO; implying therefore, that 193.0 liters of CO equals to 1 mole of CO x 193.0/22.4 = 8.62 moles of CO; Since 1 mole of CO weighs 28 g, 8.62 moles of CO will weigh: 8.62 x 28 g = 241.25 g of CO or 0.24125 kg of CO.

(iii) Based on available records indicating that the total number of vehicles in Rwanda is 65 286 with 33 % of the total national fleet being diesel vehicles [14] (i.e. equivalent to 128, 411 motor-vehicles x 33/100 = 42376 diesel vehicles); it can be noted that petrol vehicles = 65286 – 42376 = 22 910 petrol vehicles.

Since estimates from Kigali City indicate that 70% of the total vehicles in the country are found in Kigali City (Refer: Eng. Ahimbisibwe Reuben), it can be noted that diesel vehicles in Kigali City equal to: 42376 x 70% = 29663 vehicles while those driven by petrol equal to: 22910 x 70% = 16037 petrol vehicles.

1) Based on available records in Rwanda [17], it can be noted that the annual relative increase of diesel import is 11.97% implying therefore, that in 2013 a total amount of 195, 432,575.0 liters of diesel will be imported;
2) It can also be noted that petrol vehicles represent 54.1% of diesel vehicles;
3) Since 42376 diesel vehicles consume 195 432 575 liters of diesel; 54.1% of diesel vehicles equivalent to petrol vehicles will consume: 195 432 575 x 54.1% = 105 729 023 liters of petrol;
4) Based on the reported density of gasoline (petrol) equivalent to 737.22 kg/m^3 at 60^{o}F, it can be noted that the weight of imported petrol is: 105 729 023 liters x 737.22 kg/1000 liters = 77 945 550.3 kg of petrol;
5) Given that 1 kg of petrol (gasoline) produce 2.685 kg of CO_2 and 2.0286 g of CO, it can be noted that 77 945 550.3 kg of petrol will release: 77945550.3 kg of petrol x 2.685 kg of CO_2/kg of petrol = 209 283 802.6 kg of CO_2 or 209 284 tons of CO_2 and 77 945 550.3 kg of gasoline x 0.24125 kg of CO per 1 kg of gasoline = 18 804 364.01 kg of CO or 18 804.4 tons of CO.
6) Unburned hydrocarbons (HC): 555.4 ppm; since 1 ppm is equivalent to 0.0001 %, it can be noted that 555.4 ppm correspond to: 0.0001% x 555.4 = 0.05554% of the theoretical air; 11.42 m^3 of theoretical air contains: 11.42 m^3 x 0.05554% of hydrocarbons (HC) = 6.342668 liters of HC; 1 kg of petrol releases 6.342668 liters of unburned hydrocarbons (HC). It implies that 77 945 550.3 kg of petrol consumed annually will release: 77 945 550.3 kg of petrol x 6.342668 liters per kg of petrol = 494 382 747.6 liters of hydrocarbons = 494 382.75 m^3 of hydrocarbons (HC) in the whole country.
7) Based on the estimates by Kigali City indicating that 70% of the national fleet is found in the city of Kigali, it can be noted that emissions of hydrocarbons in Kigali City will be: 494 382.75 m^3 of HC x 70% = 346 068.0 m^3 of HC annually.
8) Since 1 903 123 liters of petrol is consumed by vehicles coming to Kigali; the density of petrol being 737.22 kg/m^3 and based on the fact that 1 kg of petrol releases 6.342668 liters of unburned hydrocarbons, therefore 1903123 liters of petrol consumed annually will release: (1903123 liters of petrol x 737.22 kg of petrol per 1000 liters of petrol) x 6.342668 liters of unburned hydrocarbons (HC) per kg of petrol = 8 899 m^3 of HC.
9) Based on the estimates by Kigali City indicating that 70% of the national fleet is found in the city of Kigali, it implies that 70% of the total emission is also found in Kigali City as follows:

(i) Carbon dioxide (CO_2) emitted by gasoline/petrol vehicles in Kigali City will be: 209 283 802 kg of CO_2 x 70% = 146 498 661 kg of CO_2 = 146 498.7 tons of CO_2 or 146 500.0 tons of CO_2 per year.

(ii) Carbon monoxide (CO) emitted by gasoline/petrol vehicles in Kigali City will be:

18 804 364 kg of CO x 70% = 13 163 055 kg of CO or 13 163 tons of CO per year

(iii) Unburned hydrocarbons (HC) emitted by gasoline/petrol vehicles in Kigali City will be: 494 382.75 m^3 of HC x 70% = 346 068 m^3 of unburned hydrocarbons (HC)

10) Based on CO_2 emission factors reported by GreenHouse Gas Protocol (GHG Protocol) (i.e. 2.22 for petrol and 2.68 for diesel) and the United States Environmental Protection Agency (EPA) (i.e. 2.32 for petrol and 2.664 for diesel), it can be noted that 195 432 572 liters of imported diesel in the whole country will release: 195 432 572 liters of diesel x 2.68 kg of CO_2/liter of diesel = 523 759 293 kg of CO_2 or 523 760 tons of CO_2.
11) Given that 70 % of diesel vehicles are in Kigali City, then CO_2 released in the city will be: 523 760 tons of CO_2 X 70 % = 366 632 tons of CO_2;
12) Based on the results from other studies [18] indicating that the mean value of CO emission is 42 g/kg of fuel (diesel) or 0.042 kg of CO per 1 kg of diesel consumed, and the reported density of petroleum diesel equivalent to about 0.832 kg/liter, the mass of imported diesel in Rwanda will be: 195 432 575 liters x 0.832 kg/liter = 162 599 902 kg of diesel and the carbon monoxide (CO) emitted will be: 162 599 902.0 kg of diesel x 0.042 kg of CO/kg of diesel = 6 829 195.9 kg of CO or 6 830 tons of CO; implying that emission of CO by diesel-driven vehicles in Kigali City will be : 6 830 x 70 % = 4781 tons of CO

Calculation of gases emitted by vehicles entering Kigali City:

1) Since more mouths to feed implies more food to be produced, it can similarly be assumed that the number of vehicles entering Kigali City increase with increasing imports of fuel (i.e. 11.97% or 12 %);
2) Since 195 432 572 liters of diesel fuel is consumed annually countrywide and based on the fact that 30% of vehicles are found outside Kigali, it can be noted that 30% of consumed diesel is used by diesel vehicles outside the city of Kigali: 195 432 572 liters of diesel x 30% = 58 629 772 liters of diesel. This means that 12 713 diesel vehicles found outside Kigali City consume 58 629 772 liters of diesel. If 12% of diesel vehicles come to Kigali every day and consume fuel at the same rate, the outside vehicles will consume: 58 629 772 x 12% = 7 035 573 liters of diesel;
3) Assuming that 50% of the fuel used by vehicles coming to Kigali City is used in internal circulation in the city of Kigali; then the amount of diesel consumed while in Kigali will be: 7 035 573 liters of diesel x 50% = 3 517 787 liters of diesel;
4) Based on the CO_2 emission factor of 2.68, it can be noted that 3517787 liters of diesel will release: 3517787 liters of diesel x 2.68 kg of CO_2/liter of diesel

= 9427668 kg of CO_2 or 9428 tons of CO2;

5) Based on the reported mean value of CO emission equivalent to 0.042 kg of CO per 1 kg of diesel, and the reported density of diesel equivalent to 0.832 kg/liter then, the mass of 3 517 787 liter of diesel will be: 3 517 787 liters of diesel x 0.832 kg/liter of diesel = 2 926 799 kg of diesel; the mass of CO emitted by diesel vehicles coming to Kigali while in circulation in the city of Kigali will be: 2 926 799 kg of diesel x 0.042 kg of CO/kg of diesel = 122 926 kg of CO or 123 tons of CO;
6) Since 105729023 liters of petrol is consumed annually in Rwanda, it can be noted that petrol vehicles found outside Kigali City will consume 30% of total consumed petrol as follows: 105729023 liters of petrol x 30%= 31 718 707 liters of petrol;
7) If 12% of petrol vehicles come to Kigali every day and consume fuel at the same rate, the total fuel consumption will be:31718707 liters x 12% = 3 806 245 liters
8) Assuming that 50% of the petrol used by vehicles coming to Kigali City is used during the internal circulation in the city of Kigali, then 3 806 245 liters x 50% = 1 903 123 liters of petrol will be consumed while in Kigali;
9) Based on the calculated CO_2 emission factor of 2.685 kg of CO_2 per 1 kg of petrol, and also based on the reported density of gasoline/petrol equivalent to 737.22 kg/m^3, it can be noted that 1 903 123 liters of petrol will release: (1 903 123 liters x 737.22 kg/1000 liters) x (2.865 kg of CO_2/1 kg of petrol) = 3 767 110 kg of CO_2 = 3 767.1 tons of CO_2;
10) Based on the calculated CO factor equivalent to 0.24125 kg of CO per 1 kg of petrol, the mass of CO emitted by petrol vehicles coming to Kigali city while circulating in the city will be: (1 903 123 liters of petrol x737.22 kg/1000 liters)x (0.24125 kg of CO/1kg of petrol)=338 479 kg of CO or 338.5 tons of CO;
11) Petrol vehicles coming to Kigali City will therefore, release 338.5 tons of CO and 3 767.1 tons of CO_2 while circulating in the city.

Biodiesel blends and gas emissions:

a) Relative decrease in CO emissions (%) = $(B_{100}–B_0)/B_0$ x 100%

$$= (0.027 -0.054)/0.054 \times 100\% = 50\%; \quad (6)$$

Where B_{100} refers to 100% Biodiesel and B_0: 100% Diesel + 0% Biodiesel.

b) Using a Biodiesel-Diesel mixture (B_{50}), the relative decrease in CO emission will be:

$$(B_{50}–B_0)/B_0 x100\%=(0.035–0.054)/0.054x100\%=35.2\%; \quad (7)$$

Where B_{50} refers to 50% Biodiesel–Diesel mixture and B_0: 100% Diesel + 0% Biodiesel.

c) Relative decrease in opacity (%) which is strongly correlated with properties of particulate air pollutants

$$= (B_{100}–B_0)/B_0 \times 100\% = (0.33–1.4255)/1.4255 \times 100\% = 76.9\%; \quad (8)$$

Where B_{100} refers to 100% Biodiesel and B_0: 100% Diesel + 0% Biodiesel.

d) Using a Biodiesel-Diesel mixture (B_{50}), the relative decrease in opacity will be:

$$(B_{50}–B_0)/B_0 x100\%=(0.414–1.4255)/1.4255x100\%=71\%; \quad (9)$$

Where B_{50} refers to 50% Biodiesel – Diesel mixture and B_0: 100% Diesel + 0% Biodiesel.

2.2.3. Water Quality Analysis

Water quality was analyzed using standard methods at the Kigali Water Laboratory of the National University of Rwanda, Faculty of Science-Department of Chemistry. Conductivity, pH, total dissolved solids, turbidity, total alkalinity, chemical oxygen demand, biochemical oxygen demand, dissolved oxygen, organic matter, sulfates, sulfides, iron, manganese, aluminum, copper, cadmium, chromium, lead, zinc, sodium, oil and greases are among the water parameters measured.

2.2.4. Statistical Analysis

Regression analysis following a linear regression model below was carried out to determine the pattern of correlation between age of the vehicle (manufacturing year) and concentrations of both CO, CO_2 and unburned hydrocarbons:

$$Y = a + bX \quad (10)$$

Where, X and Y are the variables; b = The slope of the regression line; and a = The intercept point of the regression line and the Y axis.

3. Results and Discussions

3.1. Quantity of Gas Emissions in Kigali City

Based on both the estimates by Kigali City indicating that 70% of vehicles in the country were in the city of Kigali and available records showing that 33% of the national fleet are diesel vehicles, it can be noted from Table 3 that in the country there are 42,376 diesel vehicles and 22,910 petrol vehicles with Kigali City having 29,663 diesel vehicles and 16,037 petrol vehicles. Petrol vehicles represent 54.1% of diesel vehicles.

Table 3. Motor-vehicles recorded by RRA and MININFRA during the January-June 2013 period

Type of motor-vehicle	Number of Non-Government motor-vehicles**	Number of Government motor-vehicles ++	Overall total
Caterpillar	4	-	4
Bus	505	-	505
Truck	3,426	-	3,426
Pick-up	14,050	-	14,050
Special Engine	650	-	650
Jeep	16,768	-	16,768
Microbus	153	-	153
Minibus	5,271	-	5,271
Motorcycle	60,867	-	60,867
Trailer	752	-	752
Half-Trailer	183	-	183
Unknown	13	-	13
Car	22,775	-	22,775
Tricycle	64	-	64
Overall Total:	125,481	2,930	128,411
-Vehicles -Motorcycles - Special Engine and Caterpillar	63, 896 60, 931 654	1390 1540	65,286

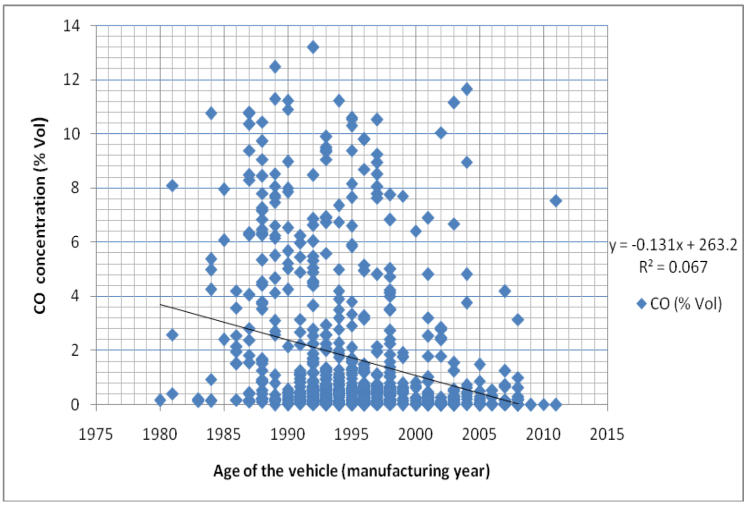
**Data from Rwanda Revenue Authority (RRA) and ++ Data from Rwandan Ministry of Infrastructure (MININFRA)

Table 4. Gas emissions by diesel-and-petrol-driven vehicles in Kigali City during the 2012-2013 period

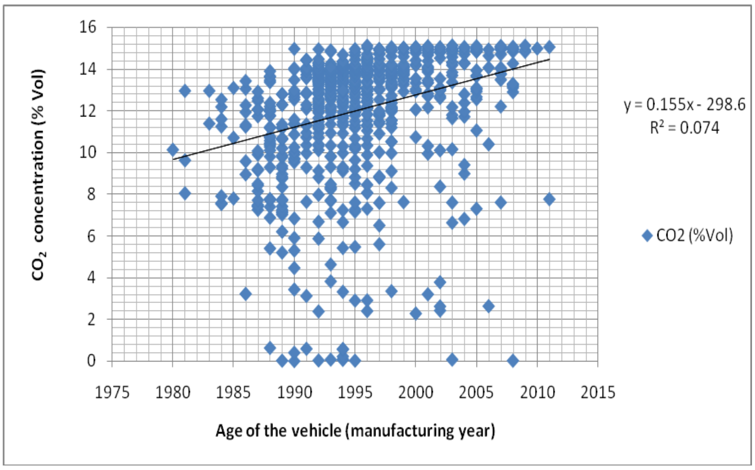
Vehicle & Fuel type	Gas emissions per each type of vehicle and fuel			Total emissions (tons/year or m^3/year)
	Chemical component	Vehicles from Kigali City	Vehicles from outside Kigali	
Petrol vehicles	CO_2 (tons/year)	146,500.0	3,767.1	150,267.1
	CO (tons/year)	13,163.0	338.5	13,501.5
	HC (m^3)	346,068.0	8,899.0	354,967.0
Diesel vehicles	CO_2 (tons/year)	366,632.0	9428.0	376,060.0
	CO (tons/year)	4,781.0	123.0	4,904.0
Overall total gas emission	CO_2 (tons/year)		526,327.1	
	CO (tons/year)		18,405.5	
	HC (m^3/year)		354,967.0	

As indicated in Table 4, gas emissions are increasingly being recorded in Kigali City, with petrol vehicles showing the highest level of carbon monoxide (CO) emission attributable to incomplete fuel combustion or partially oxidized fuel as compared with diesel-driven vehicles reported to produce less greenhouse gas emission and also have a better fuel economy and higher engine efficiency. This is in agreement with studies indicating that a diesel-powered vehicle emits 10-20% less greenhouse gas than comparable gasoline vehicle [11, 13]. Since carbon monoxide (CO) is a highly toxic gas associated with incomplete combustion caused mainly by excessive fuel pressure at the injectors, leaking fuel injectors, ruptured fuel pressure regulator diaphragm, malfunctioning EVP system or plugged PCV valves [16], efforts must be made to minimize its formation by improving fuel efficiency and reducing soot (black smoke) generation [11, 13].

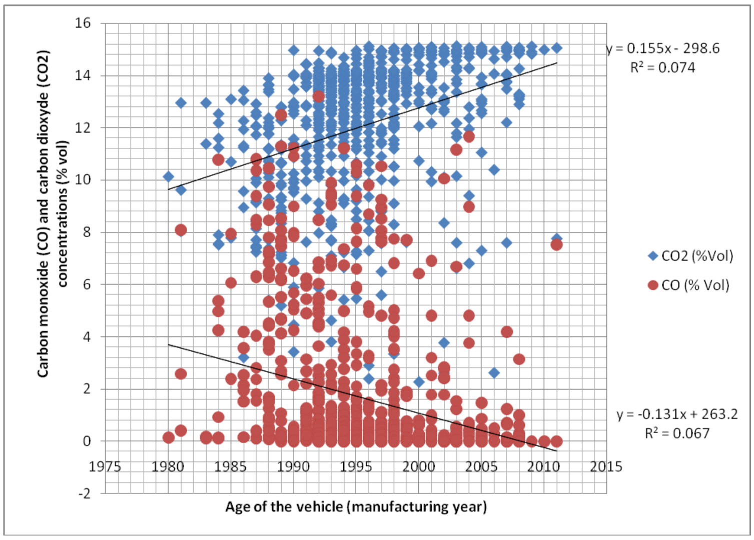
Carbon dioxide (CO_2) is a by-product of efficient and complete combustion and levels of this pollutant can be affected by air/fuel ratio and spark timing [11, 13, 4, 16]. This explains high levels of CO_2 emitted by modern vehicles (Table 4; Figure 1_{abc}) which were manufactured using more advanced technologies. The observed high levels of unburned hydrocarbons emitted into the atmosphere of Kigali City by old vehicles (Figure 2) is most commonly caused by incomplete combustion as a result of engine misfires attributable to ignition system failures, excessive EGR dilution, restricted or plugged fuel injectors, exhaust leakage, incorrect spark timing, excessive combustion blowby, insufficient cylinder compression and carbon deposits on intake valves [16].



a)



b)



c)

Figure 1. Relationship between vehicle age and emission of both carbon monoxide (CO) and carbon dioxide (CO_2) during the 2012-2013 testing period

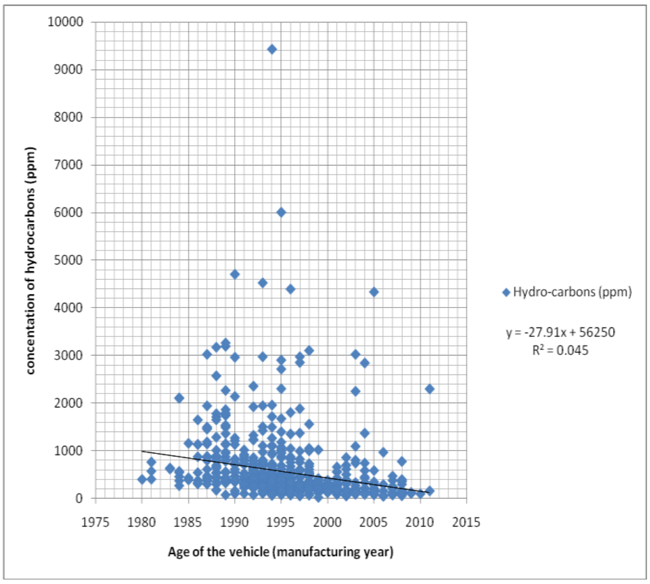


Figure 2. Relationship between vehicle age and unburned hydro-carbons (HC) during the 2012-2013 testing period

It is apparent from Figure 1abc that vehicle age and gas emission are strongly and negatively correlated suggesting that old vehicles showed the highest levels of CO emission probably due to incomplete fuel combustion, their condition and engine family [7, 9, 13] while on the other hand, modern or new vehicles showed the highest levels of CO_2 emission probably due to improved technologies resulting in complete combustion which occurs when carbon (C) in the fuels is fully oxidized to CO_2.

As shown in Figure 2, old vehicles also released into the atmosphere of Kigali City the highest amount of unburned hydro-carbons as compared with new vehicles due to incomplete combustion as a result of engine misfires [16].

3.2. Air Contaminants and Irrigation Water Quality in Both Kigali City and Kitabi Area (Nyamagabe District)

As summarized in Table 5, the Kitabi area surrounded by Nyungwe Forest Reserve showed the lowest air contaminants as compared with Kigali City. In Kitabi area, HCl, NO_2, TVOC and O_3 were reduced by 76.6% (from 0.214 to 0.05 ppm), 54.6% (from 0.119 to 0.054 ppm), 74.8% (from 1539.9 to 387.9 μg/m^3) and 72.7% (from 0.033 to 0.009 ppm) while NO_3, SO_2 and CO were reduced by 100% as compared with Kigali City respectively. These lowered levels of air pollutants in Kitabi area can probably be caused by high efficiency of photosynthetic process attributable to high and varied vegetation cover which is in conformity with other findings suggesting that trees and shrubs play an important role in the improvement of our living environment, climatic amelioration and carbon sequestration [19].

It is evident from Tables 6 and 7 that, in Kitabi area the recorded average water pH of 6.8 (i.e. irrigation water quality limit ranging between 6.5-8.4), average conductivity of 27 μS/cm (< 600 μS/cm irrigation water quality limit), average alkalinity of 22 ppm (i.e. below the irrigation water quality limit range of 30-60 ppm) and biochemical oxygen demand are below or within the recommended limits for irrigation water quality, while on the other hand, waters collected from Kigali City are characterized by high acidity (i.e. acid rains) and increased levels of contaminants suggesting, therefore, that Kitabi waters are suitable for irrigation of edible crops and fruit trees in home gardens. Heavy metals are micronutrients which are essential for growth and development of some agricultural crops. Since every agricultural crop have a well defined critical period of high nutrients demand and optimum dosage, the use of sampled water for irrigation will supply both macro-and-micronutrients needed for plant growth and development but its optimum dosage should not be exceeded.

3.3. Health Risks of Fossil Fuels and Benefits of Biodiesel

The lowered water pH levels (i.e. acid rain) and higher concentrations of air pollutants in Kigali City as compared with Kitabi area (Table 5) can lead to serious health and environmental problems in Rwanda. The findings from this study are in line with a wide range of studies on pollution [7, 10, 9, 18, 5-6] confirming that exposure to even relatively low concentrations of air pollutants results in increased incidence of premature mortality or morbidity and diseases such as cardiovascular and respiratory diseases, lung cancer, bladder cancer, aggravation of asthma, acute and chronic bronchitis, TB, chronic obstructive pulmonary disease, chronic inflammation and irreversible structural changes in the lungs, brain damage, impaired cognitive skills and difficulty in speaking and hearing. Studies in the United States [10] have also clearly demonstrated that the human health and environmental impacts of emissions include impaired air quality, damage to public health, degradation of visibility, acidification of lakes and streams, harm to sensitive and aquatic ecosystems and accelerated decay of materials, paints and cultural artifacts such as buildings, statues and sculptures which may also happen in Rwanda if no adequate measures are taken to effectively control pollution. SO_2 and NO_X emissions react to form acidic compounds that harm lakes and streams. Acidification (low pH) and the associated high aluminium levels make it difficult for some fish and other aquatic species to survive, grow and reproduce. Acid deposition can affect forest ecosystems directly by damaging plant tissues and indirectly by changing the chemistry of forest soils (eg. plant nutrients leaching from both plant parts and soils) and elevating levels of aluminium which can be directly toxic to plant roots. Acid particles and deposition also increased the rate of weathering for properties of aesthetic and historical value in the United States [10].

Table 5. Average air composition in different sampling sites of Kigali City (Rwanda National Police Motor-vehicle Inspection Centre- RNP at above-ground level) and Kitabi Tea Area– Nyamagabe District**

Air sampling site	Chemical concentration in the air							
	HCl (ppm)	NO_2 (ppm)	NO_3 (ppm)	SO_2 (ppm)	TVOC ($\mu g/m^3$)	O_3 (ppm)	CO ppm)	CO_2 (ppm)
Kitabi Tea Factory	0.050	0.054	0.000	0.000	387.9	0.009	0.000	208.2
Kigali City (RNP)	0.214	0.119	0.126	0.014	1539.9	0.033	3.148	316.9

** Data obtained using GrayWolf- AdvancedSense HVAC Environmental Test Meter

Table 6. Heavy metal and trace element content of water collected from water streams in Kigali City, Kitabi and Nyamagabe areas during 2013 compared with irrigation water quality/standard of both Botswana and FAO

Property	Units	Botswana irrigation water quality**	FAO Irrigation water quality**	Mwumba Stream (Kitabi-Nyamagabe District)	Rwintare Stream (Kimicanga-Kigali City)	Kinamba-1 Stream (Kigali City)
pH	-	-	-	6.61	7.3	7.54
Conductivity	µS/cm	-	-	38	630	650
Total Dissolved Solids	mg/l	-	-	19	316	324
Turbidity	NTU	-	-	53.6	13.34	95.6
Total Alkalinity	mg/l $CaCO_3$	-	-	22	122	154
Chemical O_2 Demand	mg/l O_2	-	-	84.1	39.4	58.6
Biochemical O_2 Demand	mg/l O_2	-	-	6.5	32.5	47
Dissolved oxygen	mg/l	-	-	-	3.44	1.77
Organic matter	mg/l	-	-	6.3	10.5	14.5
Sulfates	mg/l	-	-	3	28	26
Sulfides	µg/l	-	-	21	12	28
Aluminium (Al)	mg/l	5	<5	0.013	0.013	0.023
Copper (Cu)	mg/l	0.2-1.0	0.2-1	0.26	0.17	0.33
Iron (Fe)	mg/l	5.0-20	<5	1.46	0.42	0.84
Manganese (Mn)	mg/l	0.2	<0.2	0.103	0.305	0.283
Zinc (Zn)	mg/l	2.0-10	<2	0.19	0.06	0.312
Cadmium (Cd)	µg/l	0.01	0.01	BDL	BDL	BDL
Chromium (Cr)	µg/l	0.1	0.1	BDL	BDL	BDL
Lead (Pb)	µg/l	0.1	5	BDL	BDL	BDL
Sodium (Na)	mg/l	-	-	1.158	12.336	12.224
Oil & Grease	g/l	-	-	2.160	1.286	6.940
Arsenic (As)	µg/l	0.1	0.1	-	-	-
Beryllium (Be)	µg/l	0.1	0.1	-	-	-
Mercury(Hg)	µg/l	0.002	0.001	-	-	-
Molybdenum (Mo)	mg/l	0.05	<0.01	-	-	-
Selenium (Se)	µg/l	0.02	0.2	-	-	-
Vanadium (V)	µg/l	1	2	-	-	-

** Reference: [1]; Dash means no standard developed and BDL means Below detection limits.

Table 7. Heavy metal and trace element content of rain water collected from Meteorological Stations in Kigali City, Kitabi and Nyamagabe areas during 2013 compared with irrigation water quality/standard of both Botswana and FAO

Property	Units	Botswana irrigation water quality**	FAO Irrigation water quality**	Gitega Rain Water	Nyamagabe Rain Water	Kitabi Rain Water
pH	-	-	-	4.92	6.58	7.12
Conductivity	µS/cm	-	-	80	12	32
Total Dissolved Solids	mg/l	-	-	41	6	16
Turbidity	NTU	-	-	33	6.06	2.37
Total Alkalinity	mg/l $CaCO_3$	-	-	24	20	24
Chemical O_2 Demand	mg/l O_2	-	-	18.6	35.5	24
Biochemical O_2 Demand	mg/l O_2	-	-	8.5	3.5	5
Dissolved oxygen	mg/l	-	-	3.5	-	-
Organic matter	mg/l	-	-	11.2	1.2	2.3
Sulfates	mg/l	-	-	2	1	1
Sulfides	µg/l	-	-	9	12	23
Aluminium (Al)	mg/l	5	<5	0.082	0.019	0.017
Copper (Cu)	mg/l	0.2-1.0	0.2-1	0.22	0.12	0.11
Iron (Fe)	mg/l	5.0-20	<5	0.15	0.03	0.05
Manganese (Mn)	mg/l	0.2	<0.2	0.021	0.01	0.016
Zinc (Zn)	mg/l	2.0-10	<2	0.042	1.47	1.2
Cadmium (Cd)	µg/l	0.01	0.01	BDL	BDL	BDL
Chromium (Cr)	µg/l	0.1	0.1	BDL	BDL	BDL
Lead (Pb)	µg/l	0.1	5	BDL	BDL	BDL
Sodium (Na)	mg/l	-	-	0.931	-	0.801
Oils & Grease	g/l	-	-	0.960	-	0.660
Arsenic (As)	µg/l	0.1	0.1	-	-	-
Beryllium (Be)	µg/l	0.1	0.1	-	-	-
Cobalt (Co)	µg/l	0.05	0.05	-	-	-
Mercury(Hg)	µg/l	0.002	0.001	-	-	-
Molybdenum (Mo)	mg/l	0.05	<0.01	-	-	-
Selenium (Se)	µg/l	0.02	0.2	-	-	-
Vanadium (V)	µg/l	1	2	-	-	-

** Reference: [1]; Dash means no standard developed and BDL means Below detection limits.

The results from the present study clearly demonstrated that biodiesel reduces health risks and environmental problems associated with petroleum diesel. As shown by the results from this study, using 100% Biodiesel in Rwanda, reduced emission of CO by 50% and Opacity by 76.9% while using a Biodiesel-blend or Biodiesel-Diesel mixture (B_{50}) reduced CO and Opacity by 35.2% and 71% respectively which is a clear testimony that Biodiesel is, indeed a cleaner environmental-friendly energy for the future. These results are also in agreement with those from other studies showing that use of biodiesel reduced the exhaust emissions of sulfur by 100%, CO by 48%, CO_2 by 78.5%, particulate matter by 30-47%, total hydrocarbons by 93%, polycyclic aromatic hydrocarbon compounds by 75-85%, 1-nitropyrene by 90% and the ozone (smog) forming potential of biodiesel by hydrocarbons by 50% as compared with petroleum diesel [11, 13, 8, 12, 14, 20]. Other studies also showed that on average the biodiesel blend (B_{20}) caused particulate matter (PM), CO and unburned hydrocarbons emissions to be reduced by 16%, 17% and 12% relative to petroleum diesel respectively [21]. Lowering the concentrations of air pollutants will reduce greenhouse gases and contribute to the mitigation of climate change and global warming. The lower the levels of air pollution in a city, the better respiratory and cardiovascular health of the population will be [5], and the higher will be the work productivity and increased economic growth in the country.

4. Conclusions and Recommendations

From this study, it is concluded and recommended that:

- The continuous use of expensive fossil fuels may result in increased human health deterioration, environmental degradation, lowered human work productivity and slow economic growth in a highly populated and landlocked country like Rwanda

- Using cleaner energies like biodiesel, however, results in improved human health, living environment and socio-economic development
- Introducing a pollution tax and using this tax in tree planting program may result in increased vegetation cover and reduced gas emissions to the atmosphere
- Beautification of cities, towns, settlements and avenues using suitable mixed ornamental tree species with high potential of increasing photosynthetic efficiency is advisable
- Frequent monitoring of imported fuel quality and establishment of new fuel quality regulations and guidelines (eg. Ultra-low-sulfur diesel standard), national ambient air quality standards and national air quality emission standards are very crucial if we are to assure our present and future generations of a quality life and living environment
- Since old vehicles showed the highest gas emissions as compared with new modern vehicles, the current tax policy needs to be revised to take into consideration of environmental concerns by reducing importation of highly-polluting motor- vehicles
- Most staff at the Rwanda National Police Motor-vehicle Inspection Centre does not use the available protection equipment and materials. The use of these materials, therefore, need to be re-enforced.
- To minimize health risks, staff at the Motor- vehicle Inspection Centre also need to be rotated frequently implying that training of more operators is imperative.
- However, more studies on pollution by all types of motor-vehicles, industries and other machinery are needed in this country
- Also assessment of the current health status of people exposed in highly polluted environments is required
- Frequency of vehicle entrance in Kigali City also requires further investigations
- Detailed studies on mathematical modeling of air pollutants in major cities of Rwanda are also urgently required to evaluate air pollution dispersion and assist in forecasting the air quality.

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