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# Estimation and Prediction of Atmospheric Pollutants Coming from Vehicles: Case of Yaounde City from 2005 to 2035

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***Authors' contributions***

*Author AT designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the analyses of the study. Author PM managed the literature searches. All authors read and approved the final manuscript.*

***Original Research Article***

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## ABSTRACT

**Aims:** The aim of the present work is to estimate and to predict the pollutant concentrations coming from vehicles in Yaounde city.
**Study Design:** A sample of vehicles was selected and experimental measurements of pollutants were made using a combustion analyser.
**Place and Duration of Study:** October 2012 to June 2013 in the University of Yaounde I, National Advanced School of Engineering, and the Energizing and Water and Environment Laboratory, Yaounde, Cameroon.
**Methodology:** We used, for this study, the statistical data, from the National institute of Statistics, concerning the importation of vehicles in Cameroon estimated at 312,259 in 2005. The measurements of pollutant concentrations in gas, coming from a sample of 218 vehicles, were made using a combustion analyser. Using the statistical data obtained, the correlation of the evolution of importation of vehicles in Cameroon was established following the case of Yaounde city. The evolution of the number of vehicles, the measurements of pollutant concentrations and the quantities of fuel consumed were used to estimate the pollutant concentrations, during the emergence prediction year 2035 in Yaounde city, representing a population of 1.82 million inhabitants. Analysed atmospheric pollutants, for motor vehicle exhausts, were carbon dioxide ($CO_2$), carbon monoxide (CO),

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nitrogen oxide (NOx) and hydrocarbon (HC).
**Results:** Until 2005, the estimate of the pollutant concentrations coming from vehicles in Yaounde city showed that the average quantities emitted every year were 82.26×$10^6$ kg of $CO_2$, 1.16×$10^6$ kg of CO, 2.35×$10^6$ kg of HC and 9.18×$10^6$ kg of NOx. According to the provision alem ergence in the year 2035, the quantities of the four pollutants would attain the following values: 472×$10^6$ kg of $CO_2$, 6.65×$10^6$ kg of CO, 13.51×$10^6$ kg of HC and 52.72×$10^6$ kg of $NO_x$.
**Conclusion:** The results obtained from this work are a useful tool to monitor the air pollution levels caused by urban transport.

*Keywords: Atmospheric pollution; vehicle engines; urban transport; pollutant concentrations.*

## *ABBREVIATIONS*

| | |
|---|---|
| ***Spc*** | *Small personal car* |
| ***INS*** | *National Statistic Institute* |
| ***$A_2$, B*** | *Specific factors of fuel* |
| ***FR*** | *Fuel consumption* |
| ***K*** | *Recuperative factor of latent heat* |
| ***P*** | *Engine power (W)* |
| ***PCI*** | *Low calorific power (kWh)* |
| ***$P_f$*** | *Power read on vehicle licence (Horse power* |
| ***$T_f$*** | *Smoke temperature (°C)* |
| ***Ta*** | *Air temperature (°C)* |
| $\lambda$ | *Excess of air rate* |
| $\eta$ | *Combustion efficiency* |

## 1. INTRODUCTION

The atmospheric pollution is usually used to refer to the gaseous by-product of man-made processes such as energy production, waste incineration, transport, deforestation and agriculture. Some atmospheric particles come from natural sources. These included wind-blown dust, pollen, sea salt and materials from volcanic eruption. The variety of atmospheric pollutants and their quantity depend on the sources of emission. Human activities have begun to significantly alter the composition of the atmosphere through pollution. The level of many trace gases has increased and in some cases new gases are released into the atmosphere. Some of these trace gases, present in elevated concentrations, can be harmful to plants, animals and the environment [1]. Pollutants are substances which if present at high concentrations, produce harmful effects on people and (or) the environment. For example, carbon monoxide is absorbed by blood more readily than oxygen, reducing the amount of oxygen been carried through the body. Particles in the air, (also known as aerosols) come from a number of sources including vehicle engines, industrial processes and wood burning. Secondary formation of particles, formation of gaseous emissions, can also contribute significantly to the level of particles.

In the tropical West African countries the following sources generally contribute to air pollution [2]: traffic with high emissions from passenger cars, utility vehicles and various types of industries. A number of pollutants affecting urban air quality are released by motor vehicles. Pollutants produced by vehicle exhausts include: carbon monoxide, hydrocarbons, nitrogen oxides, particles, volatile organic compounds and sulphur dioxide [3]. Hydrocarbons and nitrogen oxides react with sunlight and warm temperatures to form ground-level ozone. Ground-level ozone, the main ingredient in smog, can cause upper respiratory problems and lung damage. Emissions from vehicle engines do contribute to acid rain. Acid pollutants released in one country can travel hundreds or even thousands of kilometres before being deposited. In both developed and developing countries, the major threat to clean air is now posed by traffic emissions. Petrol and diesel-engine motor vehicles emit a wide variety of pollutants, principally carbon monoxide, carbon dioxide, volatile compounds and particles which have an increasing impact on urban air quality.

Researchers are working towards measuring individual exposure to pollutants. That is the measurement of the actual exposure that people have to air pollutants during the day. Several studies were carried out to analyse and foresee the atmospheric pollution [1,2, 3,4,5,6,7,8,9]. Some studies concern the dependency of pollution levels on street configuration and meteorological parameters [10]. In Africa, several researchers have worked on air pollution [11,12,13,14,15,16] but very few have focus edonair pollutants from vehicles [17,18]. Moral et al [19] used a new methodology based on the formulation of the Rasch model to obtain a measure of the atmospheric pollution. The daily index studied is also highly correlated with meteorological variables and this index studied by Euro Cogliani [20] is capable of identifying the variables that significantly affect the air pollution.

Compared with other cities in Europe and North America air pollution problems in Yaounde city are minor. This may be due to the fact that in Yaounde city, representing a population of 1.82 million inhabitants [21], there are fewer sources of pollution. Nevertheless, each year, industrial activities, power generations and the number of vehicle in Yaounde are still increasing. Most of those vehicles are very old and motor vehicles present a significant and growing air pollution threat and are the Yaounde's greatest source of atmospheric pollution. This city may suffer from poor air quality caused by traffic fumes or nearby industrial plants. We measured the rate of pollutants contained in vehicle gaseous exhausts and estimated the quantities of pollutants from urban transport in the next 22 years corresponding to the prediction emergence year 2035 in Cameroon.

## 2. MATERIALS AND METHODS

### 2.1 How to Measure Pollutant Concentrations

Several methods can be used to obtain the amount of atmospheric pollution. Moral FJ et al [19] proposed a methodology based on the formulation of the Rasch model. Two main results were obtained after applying this method: (1) A classification of all locations according to the pollution level, which was the value of the Rasch measure; (2) The influence on the environmental deterioration of each individual pollutant (particularly, in this work, $NO_2$, NO, $CO_2$, CO and noise). The main sources of air pollution in Yaounde are the traffic of vehicles because industries are not sited near and around the city. For the measurement of the pollutant concentrations, the combustion analyser TESTO 325 was used. It measures the following parameters directly: ambient temperature, gas pressure, concentrations of oxygen and carbon monoxide. The other parameters i.e. carbon dioxide concentrations, excess air rate and combustion efficiency are then calculated using the following relations incorporated in the memory of the apparatus:

- The carbon dioxide concentration is calculated using the relation (1):

$$CO_2 = \frac{CO_{2\max} \times (0.21 - O_2)}{0.21} \quad (1)$$

where $CO_{2max}$: specific maximum value of carbon dioxide concentration. That is the maximum rate of carbon rejected by a fuel.

- Relation (2) was used to calculate the excess air rate λ:

$$\lambda = \frac{CO_{2\max}}{CO_2} \quad (2)$$

- The combustion efficiency is calculated using relation (3):

$$\eta = 100 - q_a \quad (3)$$

$$q_a = \left[ (T_F - T_A) \times \left( \frac{A_2}{0.21 - O_2} \right) + B \right] - K \quad (4)$$

with

$T_f$: smoke temperature (°C),
$T_a$: air temperature (°C),
$A_2$ and B: specific factors of fuel,
K: recuperative factor of latent heat.

The concentrations of the other pollutants ($NO_x$, hydrocarbon) were calculated, using empirical correlations. The correlations used for the estimation of the concentrations of $NO_x$ and hydrocarbon were from PERE (Physical Emission Rate Estimator). This method was based on the rate of flow of fuel of a motor when it is working. According to the mass conservation, the method considers the amount of carbon during combustion reaction. The fuel consumption FR was given by relation (5).

$$FR = \left( \frac{CO_2}{44} + \frac{CO}{28} \right) \times (12 + 1.85) + HC \quad (5)$$

where 12 and 1.85 were respectively the molecular mass of carbon and the ratio hydrogen/carbon in the fuel used.

This ratio characterized octane index in the fuel. The unit used for components in relation (5) was g/s. The rate of HC was estimated using relation (5) when the value of FR was known.

Nam EK [22] used the Comprehensive Modal Emission Model (CMEM) to evaluate the rate of HC and $NO_x$. The correlations given by equations (6), (7) and (8) between the rates of HC and FR were established.

$$HC = 0.01FR + 0.049 \quad \text{(g/s)} \quad (6)$$

$$NO_x = 0.043FR \quad \text{(g/s)} \quad (7)$$

$$NO_x = 0.022\,(FR + FR_{th}) \quad \text{(g/s)} \quad (8)$$

Where $FR_{th}$ was the theoretical fuel consumption.

The rates of HC and $NO_x$ were estimated by combining relations (6) and (8) with the mass conservation. A mean velocity and low temperature in the engine were assumed; that prevented the formation of quick $NO_x$.

The apparatus Testo 325 gave the results of CO rate, containing in the smoke, in ppm and those of $CO_2$ in % of $O_2$. The concentrations of the other pollutants estimated using the above correlations were in g/s. For the conversion, 1 ppm corresponded to $10^{-3}$ g/kg and 1% corresponded to 10g/kg of fuel. Consequently relations (9) and (10) were used to convert ppm and % into g/kg.

$$R_p(g/h) = \frac{10^{-3} R_p(ppm)}{PCI} \times P \tag{9}$$

$$R_p(g/h) = \frac{10 R_p(\%)}{PCI} \times P \tag{10}$$

with

P: engine power (kW)

PCI: low calorific power of fuel (kWh)

Motor power was calculated using relation (11)

$$P = \left(40 P_f\right)^{1/6} \tag{11}$$

with

P: motor power (kW)

$P_f$: power on the vehicle licence (horse power).

## 2.2 Method of Estimation of Quantities of Pollutants

For the estimation of the quantity of each pollutant the unit chosen for their concentration was g/kg. In order to take into account the fuel consumption of vehicles, the following assumptions were made:

- The average distances covered each day were 150 km for taxis, 10 km for small personal cars, 100 km for buses, 50 km for trailers and 50 km for trucks.
- The average velocity of all categories of vehicle was 60 km/h.
- the average quantity was considered constant and equal to the value obtained in 2005 for each pollutant,
- the growth rate of number of vehicles was constant and equal to $\alpha$ = 6%.

Thus, the average value $\overline{X}$ of each pollutant was calculated using relation (12).

$$\overline{X} = n_{spc} X_{spc} + n_{trucks} X_{trucks} + n_{bus} X_{bus} + n_{trailers} X_{trailers} \tag{12}$$

where

$n_i$: vehicle number $$n_i = n_0 (1 + \alpha)^k \tag{13}$$

$X_i$: quantity of pollutant per vehicle (kg),

with i: spc, trucks, bus, and trailers respectively,

k: year of prevision.

The measurements of quantities of pollutants were performed around 2 pm for taxis and buses. For small personal vehicles, we chose the moment of arrival of their owners to their offices.

## 2.3 Data Source

The rate of pollutants studied in this paper was estimated using the data obtained with the combustion analyser Testo 325 [23] concerning 109 vehicles using gasoline and 109 vehicles using diesel and statistic method [24]. A total of 218 drivers were interviewed after their agreement to use their vehicles to support this work.

The following information was obtained from drivers: the vehicle utilization (individual or collective transport), the distance covered daily. This information permitted to eliminate some data in order to obtain results near the reality.

The number of vehicles in Cameroon was estimated to be 312 259 in 2005 of which about 26 % were concentrated in Yaounde city. Their repartition in 2005 is presented in Table 1. Fig. 4 shows the evolution of number of vehicles imported in Cameroon during the period 1994-2005. The data used for this figure were obtained from National Statistic Institute [25].

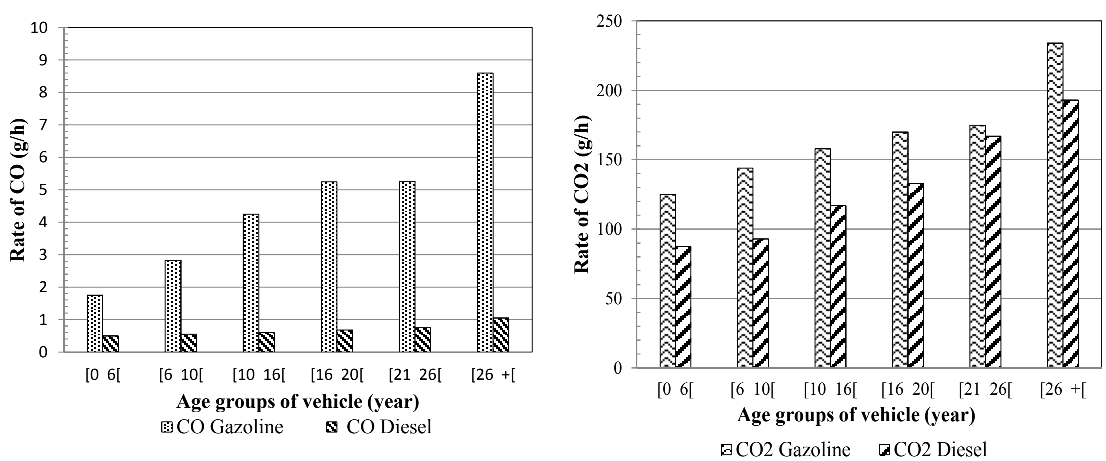
**Table 1. Distribution of vehicle numbers per category in Yaounde in the year 2005**

| Category of vehicle | SPC | Trucks | Bus | Trailers | Motorcycles |
|---|---|---|---|---|---|
| Number | 13187 | 8082 | 6381 | 5104 | 32754 |
| Proportion | 31% | 19% | 15% | 12% | 23% |

## 3. RESULTS AND DISCUSSION

### 3.1 Evaluation of Rates of Pollutant in Yaounde City for 2005

The rate of each pollutant studied increased with the age of the vehicle (Fig. 1). Vehicles using gasoline emitted more carbon monoxide, carbon dioxide and hydrocarbon then vehicles using diesel. This is due to the better combustion in Diesel engine. Diesel engines emit more nitrogen oxide than gasoline engines. It can be explained by the high rate of nitrogen in fuel oil and the higher combustion temperature in Diesel engines.



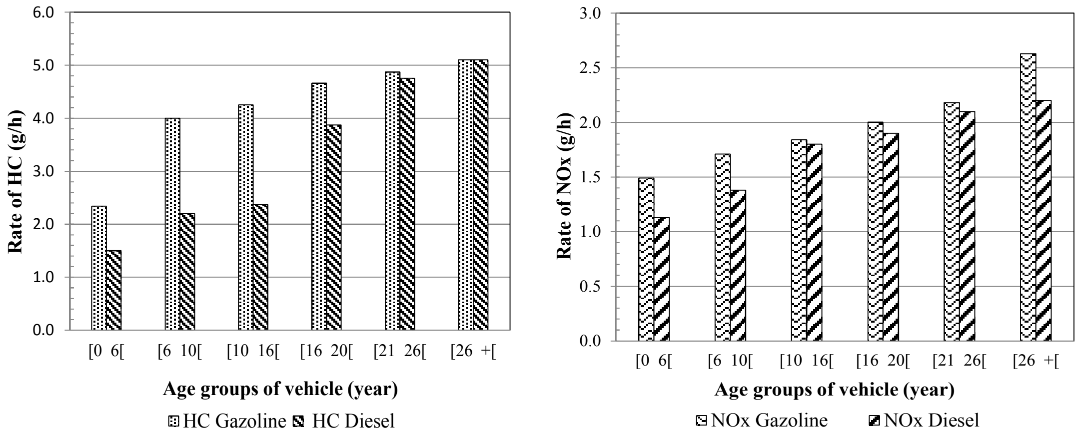
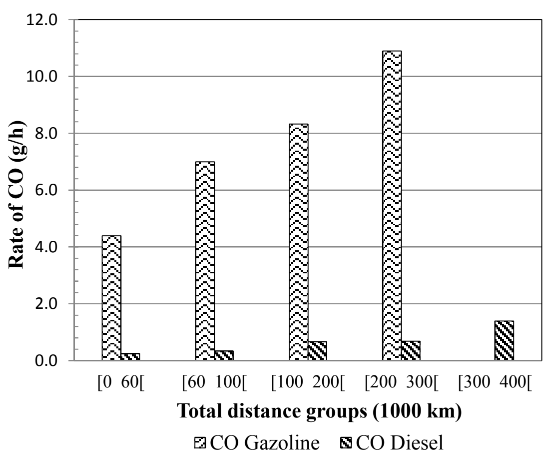
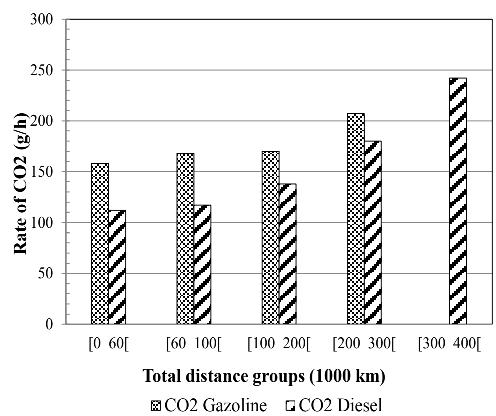



**Fig. 1. Rate of pollutants according to the age groups of vehicle**

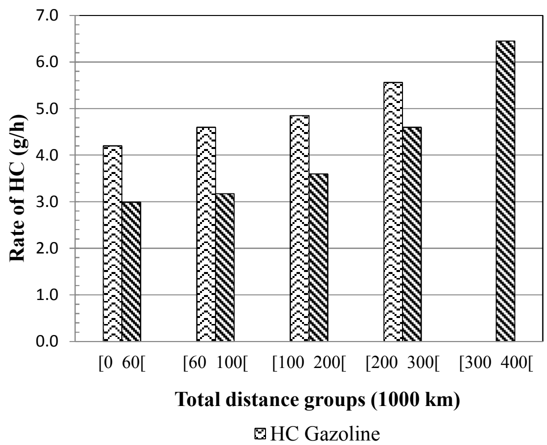
The rates of pollutants for the different total distances covered by the vehicles are presented in Fig. 2. This figure shows that the rate of pollutant emitted in the atmosphere does not depend only on the age of vehicle but also of the distance cumulated during its use. For example, a small personal car with the same age as a taxi covers a relatively shorter distance, and therefore emits less pollutant.



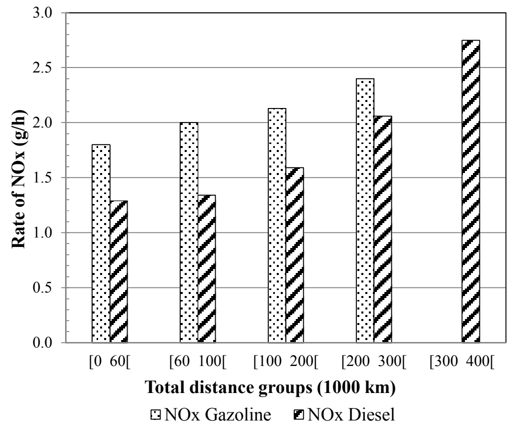

**a) Carbon monoxide**




**b) Carbon dioxide**



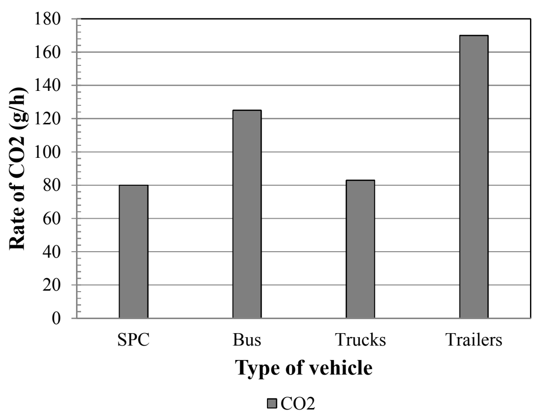

c) Hydrocarbon



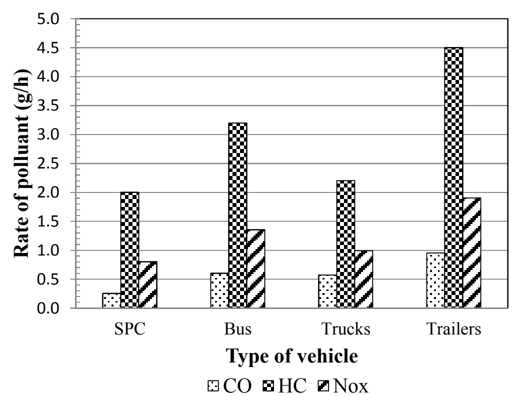

d) Nitrogenoxide

**Fig. 2. Rate of pollutants according to total distance**

The rate of pollutants increases with the power of engines as shown in Fig. 3. Small personal vehicles that can carry a maximum of five persons emit more than the half of quantity of pollutant emitted by bus whose capacity varies between 12 and 50 persons. That means that the use of collective transport in Yaounde city will contribute to reduce the quantities of pollutants produced by urban transport.




Carbon dioxide




Carbon monoxide, hydrocarbon and nitrogen oxide

**Fig. 3. Rate of pollutants according to categories of vehicles**

Considering the evolution of number of vehicles imported in Cameroon until 2005 (table 1) and its growth rate average equal to $\alpha$ = 6 %, the number of vehicles in Yaounde in the year 2013 was estimated at 497 693. A proposed mathematical model can be used to calculate the number of vehicle with an average of quadratic relative errors equal to $0.89\times10^{-3}$ (Fig. 4). These results will be used as reference for the projection of pollutants emitted by the vehicles at the prediction emergence year 2035

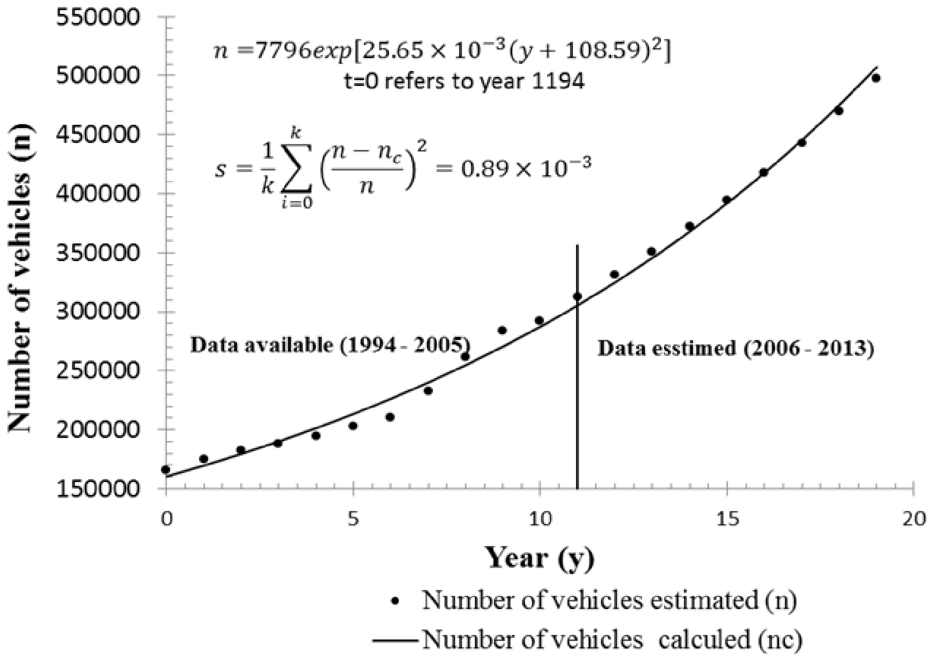



**Fig. 4. Evolution of the number of vehicles imported in Cameroon (1994-2013)**

The average annual value of the rate of each pollutant was estimated for different categories of vehicles and each type of fuel. For this estimation it was assumed that there are equal numbers of vehicles using petrol and fuel oil. In fact, according to the National institute of Statistics study [15], the difference between these two types of engine does not exceed 10%. The results of the pollutant concentrations are presented in Table 2.

**Table 2. Average annual value of pollutant concentrations**

| Category of vehicle | CO2 (g/kg of fuel) | | CO (g/kg of fuel) | | HC (g/kg of fuel) | | NOx (g/kg of fuel) | |
|---|---|---|---|---|---|---|---|---|
| | Diesel | Gasoline | Diesel | Gasoline | Diesel | Gasoline | Diesel | Gasoline |
| spc | 335 | 624 | 1.1 | 16 | 9 | 17 | 68 | 22 |
| Spc average | 479.5 | | 8.6 | | 13 | | 45 | |
| Trucks | 350 | 644 | 2,20 | 24,20 | 9,20 | 18 | 68 | 40 |
| Trucks average | 497 | | 13.2 | | 13.6 | | 54.5 | |
| Buses | 497 | 519 | 2,4 | 21,5 | 13 | 14,4 | 72 | 56.40 |
| Bus average | 508 | | 11.95 | | 19.68 | | 64.20 | |
| Trailers | 638 | - | 3 | - | 17 | - | 75 | - |
| Trailers average | 638 | | 3 | | 17 | | 75 | |

Table 3 presents the annual quantities of pollutants per vehicle estimated using the above assumptions (section 2.2). The annual quantity of each pollutant for the year 2005 was estimated using Table 3 and Fig. 4. The results are presented in Table 4.

**Table 3. Quantities of pollutants per vehicle estimated for the year 2005 in Yaounde city**

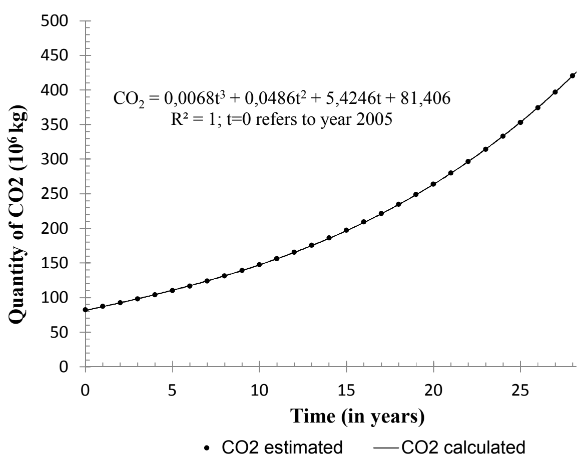
| Category of vehicle | $CO_2$ (kg) | CO (kg) | HC (kg) | $NO_x$ (kg) |
|---|---|---|---|---|
| SPC | 932 | 16.7 | 25.4 | 87.5 |
| Trucks | 2138 | 51.4 | 52.4 | 209.7 |
| Bus | 2469 | 54.0 | 95.9 | 311.9 |
| Trailers | 7236 | 34.7 | 192.2 | 850.5 |

**Table 4. Annual quantities of pollutants from vehicles estimated for the year 2005 in Yaounde city**

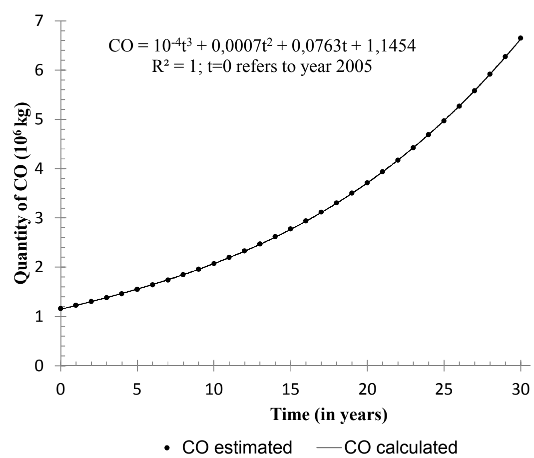
| Category of vehicle | $CO_2$ ($10^6$ kg) | CO ($10^6$ kg) | HC ($10^6$ kg) | $NO_x$($10^6$ kg) |
|---|---|---|---|---|
| SPC | 12.29 | 0.22 | 0.33 | 1.15 |
| Trucks | 17.28 | 0.42 | 0.42 | 1.69 |
| Buses | 15.75 | 0.34 | 0.61 | 1.99 |
| Trailers | 36.93 | 0.18 | 0.98 | 4.34 |
| Total | 82.25 | 1.16 | 2.34 | 9.17 |

## 3.2 Estimation of Quantities of Pollutants in Yaounde City for the Next Few Years

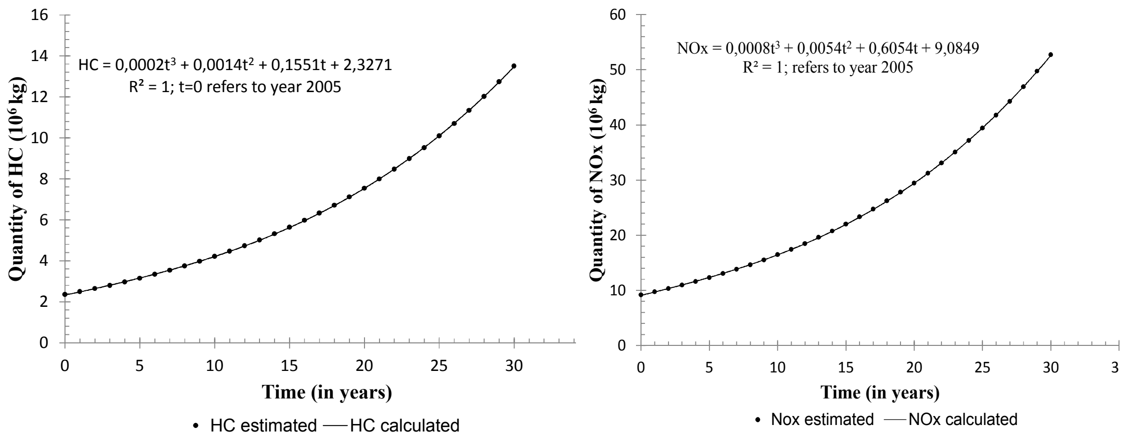
Using Tables 1 and 3, the average quantities of each pollutant was calculated, for the prediction emergence year 2035, using relation (12). The different values of pollutants emitted every year are $82.26\times10^6$ kg of $CO_2$, $1.16\times10^6$ kg of CO, $2.35\times10^6$ kg of HC and $9.18\times10^6$ kg of $NO_x$. With the growth rate of 6%, the evolution of each pollutant quantity was then estimated. The results are presented in Fig. 5.




a) Carbon dioxide




b) Carbon monoxide




c) Hydrocarbon  d) Nitrogen oxide

**Fig. 5. Estimation of pollutants in Yaounde city from 2005 to provisional emergence year 2035**

These figure show that in the provisional emergence year 2035, the quantities of the four pollutants would attain the following values: $472\times10^6$ kg of $CO_2$, $6.65\times10^6$ kg of CO, $13.51\times10^6$ kg of HC and $52.72\times10^6$ kg of NOx. Thus, the atmospheric pollutants, coming from the vehicles, would reach proportions of about six times the values obtained in 2005. To contribute to the environmental protection, it becomes essential to take measures in order to avoid attaining the above quantities of pollutants due to urban transport in Yaoundecity. Note that in Cameroon, for the moment, there are no specific measures to control air pollution. Similarly, no emission norms on air pollution are in force in this country.

## 4. CONCLUSION

The air quality of Yaounde city in particular, and in the agglomerations of Cameroon in general, will be degraded in the next few years due to the fact that major vehicles used from individual and collective transports are more than ten years old. In the provisional emergence year 2035 in Cameroon, a very significant increase of the quantities of pollutants studied will be observed. Local authorities have to manage the urban traffic to prevent the air pollution from exceeding alarming levels during the next few years. This could be achieved by higher use of public transport and by car-pooling. For this reason, the air pollution index is a useful tool to monitor pollution levels due to urban transport.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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