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Using a Gaussian model to estimate the level of particle matter concentration on paved and unpaved roads in urban environment

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ABSTRACT

Introduction: In both developed and developing countries, re-suspension of dust particles along the road owing to tire and brake wear is the most common source of Particulate Matters (PM) pollution in metropolitan areas. This study in Douala analyses the effects of paved and unpaved roads on particle matters concentration thresholds in urban environments.

Materials and methods: The United States Environmental Protection Agency (US EPA)'s model AP-42 equations were used to calculate the amount of particle matter emissions on the roads. Between 6 am and 8 pm, a traffic analysis using information from the city of Douala was conducted. The busiest times for traffic were from 8 to 9 a.m. and 6 to 7 p.m. We applied a two-dimensional Gaussian model to determine the particle concentration. Two different scenarios were taken into account: Compared to Scenario 2 (S_2), Scenario 1 (S_1) represents an unpaved road. The PM_{10} and $PM_{2.5}$ types of particles were the main topics of interest.

Results: We obtained for S_1, around 917.70 µg/m^3 and 559.00 µg/m^3 respectively for PM_{10} and $PM_{2.5}$. We got roughly 170.00 µg/m^3 and 103.90 µg/m^3 for S_2, respectively for the two particles. The amount of silt deposited on the road, the kind of road (paved or unpaved), the number, and the types of vehicles moving all influence the emission of road dust re-suspension. Regardless of particle size, these pollution levels are beyond World Health Organization (WHO) recommended norms.

Conclusion: This study offers important information on Douala's pollution levels, which can be a significant cause of disease in the area and should be considered.

Introduction

Road infrastructure construction is still a serious issue in most African countries. In terms of Cameroon, there is still a lot of work to be done. Only 8% of the overall road network is paved, with a total length

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of 77588 km [1]. This proportion may have changed as of this writing, but the growth is still quite modest given that just 65% of the 3500 km of paved roads set by the transport minister between 2010 and 2020 were actually completed [2]. Douala, the country's economic centre and home to a rapidly growing population, suffers from a critical lack of road infrastructure. It is interesting to see the government's efforts in recent years, but we also note the presence of dusty roads in Douala. Due to high population density, an increase in the number of motor vehicles, the use of fuels with poor environmental performance, poorly maintained transportation networks, and, most all, inefficient environmental rules and policies, air pollution in urban areas has increased fast [3, 4]. Road dust can be a substantial source of fine particles, which has a negative influence on human health and air quality [5-9]. According to the World Health Organization, fine particles (PMs), which are a complex mixture of extremely minute particles and liquid droplets, are pollutants that cause poor air quality and have been a global issue as an air pollutant since the 1990s [10, 11]. Possible sources of fine particles can be natural (e.g., forest fires, volcanic activities, and sea sand) or anthropogenic (e.g., road traffics, industrial activities, and bonfires) [7]. Fine particles are designated as PM_{10} or $PM_{2.5}$ depending on their size (PMs). PM_{10} particles have an aerodynamic diameter of 10 µm or less, whereas $PM_{2.5}$ particles have an aerodynamic diameter of up to 2.5 µm. These two particles sizes ranges have been demonstrated to have serious consequences for human health, the environment, and transportation safety [12-14]. Researchers found that there is a very important relationship between certain concentrations of PM_{10} and multiple hospital admissions for asthma [15]. Stomata openings in plants can become clogged by PMs, leading to failures in photosynthetic processes, which can cause poor crop production. Furthermore, fine particle pollution in the atmosphere, often known as haze pollution, is one of the main reasons of diminished visibility [16]. According to recent studies, reduced visibility increases the probability of traffic accidents owing to poor driver performance [17]. To protect public health, the WHO Air Quality Guidelines provide policymakers with information on the daily and annual average concentration limits of important air contaminants [18]. The Extreme Learning Machine (ELM) approach and statistical properties are used by certain researchers to simulate, predict, and estimate the PM concentration distribution [19, 20].

For PM_{10}, these concentration limits are respectively 50 $\mu g/m^3$ and 20 $\mu g/m^3$, whereas $PM_{2.5}$ has daily and annual average concentration limits of 25 $\mu g/m^3$ and 10$\mu g/m^3$, respectively. There are two types of road emissions: exhaust and non-exhaust [21]. The incomplete combustion of gasoline inside the engine chamber causes exhaust PM to be released from the tailpipe. Non-exhaust PM is produced through tire, road, and brake abrasion, as well as the re-suspension of dust from the road surface owing to vehicle-induced turbulence [8, 22]. New cars are increasingly reducing the amount of PMs in their exhaust emissions year after year as vehicle technology improves. This resulted in emission reduction standards such as EURO and BHARAT. Non-exhaust particle emissions are becoming incredibly valuable due to their growing share of overall automotive emissions [23]. The AP-42 methodology by United state Environmental Protection Agency [24] is the widely used method to calculate road dust re-suspension emission [25-27]. Traffic volume also plays an important role in PM emissions due to re-suspension of dust, but it is possible that these emissions do not increase proportionately [28]. The silt loading is an important factor in the inventory of road dust emissions since it helps to calculate the re-suspension, which adds to non-exhaust emissions. The rate at which small particles are emitted from a road is determined by this factor. The greatest important contribution from non-exhaust sources is road surface wear: paved or unpaved [29]. According to the US EPA, road dust is commonly referred to "silt loading", which is defined as the mass of sedimentary material with a physical diameter of 75 µm or smaller per unit area of road evaluated. This measure, the Silt loading (sL), is an important variable in the Fugitive Road Dust (FRD) emission inventory since it may reflect the degree of road cleaning [30, 31]. It should be noted that silt loading (sL) describes emissions from paved roads, whereas silt content describes emissions from unpaved roads.

The AP-42 method is used in this study to assess how airborne particles from two different kinds of highways are discharged. With the intention of showing how paved and unpaved roads differ in terms of road dust. The next step is to estimate the various emissions quantities by type of road and assess the emission factors for each kind of road using the empirical equations recommended by the AP-42 approach. We then use a two-dimensional Gaussian model to estimate concentrations on a spatiotemporal scale.

This study will empower the different decision-makers to assume accountability for the significance of having pristine asphalt roads in urban areas. This research, which was not previously conducted in Cameroon, will open the path for future studies on non-exhaust emissions in big cities.

Materials and methods

Description of the study area

Douala, Cameroon's economic capital is recognized for its fast-growing population. The population growth and increasing urbanization of Cameroonian cities may explain the high mobility density in Douala. In the city of Douala, road transport is highly homogeneous in the sense that we encounter various types of vehicles on our roads, such as trucks, tanks, vans, taxis, buses, two-wheeled and three-wheeled vehicles. The routing network in Cameroon is constrained: Only 6,207 of Cameroon's 77,588 km of roads are paved, or 8% of all roads, according to the country's road network [32]. In addition to having unpaved roads, the City of Douala also has paved roads that are poorly maintained and of poor quality. These narrow natures of major roads in particularly at the Ndokoti roundabout with multiple users is one of the determinants of traffic congestion in the metropolis of Douala [33, 34]. The temperature varied between 20˚C and 40˚C with an average of 29˚C and a relative humidity of 85%. The prevailing wind direction is southwest (SW) with a frequency of about 32.8%. The study's route is from PK14 (Direction C, see Fig. 1.) to the Ndokoti intersection, where traffic flow is heavy and is assessed using traffic counts from 2008 [35]. Around 20% of the total length of the road is partially unpaved from section to section, but the rest is paved. Road dust estimates must take traffic density into consideration because more traffic means more road dust. Due to the large number of automobiles in Tianjin, road dust pollution is a significant problem, as shown by reserachers in a study [36].

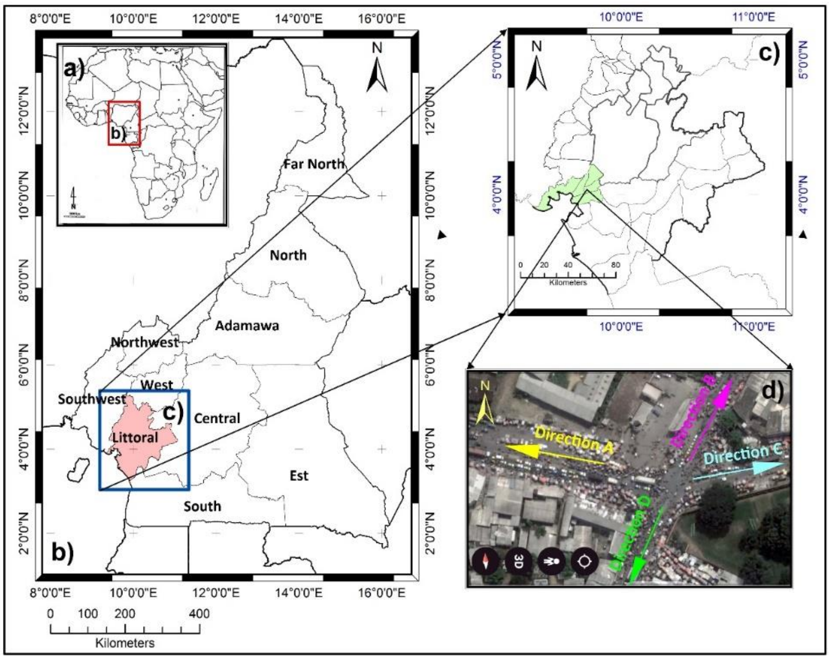


Fig. 1. Study area

Amount of emission of fine particles

The work of a study made it possible to estimate the emission rate in this study by using Eq. 1 [36]:

$$Q = R \sum_{k=HDV,LCV,VP}^{n} EF_k \times A_k \qquad (1)$$

Where, k is the vehicle categories (HDV, LCV and VP); A_k the activity of the transmitters (generally expressed in vehicles.km); EF_k is the the emission factor (g/VKT: paved roads or 1b/VMT: unpaved roads) category k ; R: is the length of road Km . In this study we took 1 Km for R value.

The emission factor (EF)

The primary instrument for creating national, regional, state, and local emission inventories for use in making choices about how to manage air quality and creating emission control plans has long been emission factors. In reality, an emissions factor is a representative number that connect the quantity of a pollutant released into the atmosphere with a particular activity. These factors make easier to estimate air pollution emissions from various sources. Using the emission factor expressions provided in the US EPA document, the emission factors of paved and unpaved roads are calculated in this study [24].

- ***Paved roads***

The USEPA first developed equations for paved road emission factors in 1985 [37]. The empirical expression for quantifying fine particle emissions for paved roads includes silt loading and average vehicles road weight factors is given by Eq. 2.

$$EF_k = K_\mu \left(sL\right)^{0.91} \left(W_k\right)^{1.02} \qquad (2)$$

Where, K is the particle size multiplier, EF the dust emission factor (g/VKT), sL the loading of the road surface silt (g/m^2) and W the average vehicle weight (tonnes). The indices (μ, K) respectively represent fine particles (PM_{10} and $PM_{2.5}$) and k the different categories of vehicles (HDV: heavy Duty vehicles (7.5 tons); LCV: light commercial vehicles (2.5 tons); VP: passenger cars (1.4 tons) [38]). Table 1 includes the various particle size multipliers (PM_{10} and $PM_{2.5}$).

- ***Unpaved roads***

Road dust emission factors show how much dust is present in the air in relation to the activity that causes it. For an unpaved road during the dry season, the equation for the dust emission factor looks like this [39].

$$EF_k = 5.9 \times K_\mu \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W_k}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5} \quad (3)$$

EF: the dust emission factor (1b / VMT); K: the particle size multiplier (dimensionless parameters); s: the silt content of the road surface material (%); S: the average speed of the vehicle (MPH); W: is the average vehicle weight (ton); w: the average number of wheels.

As earlier, the indices (μ, K) respectively represent fine particles (PM_{10} and $PM_{2.5}$) and the different categories of vehicles (HDV: heavy Duty vehicles; LCV: light commercial vehicles; PC: passenger cars). The equation shows that dust emission linearly depends on both vehicle speed and silt content. Table 1 and Table 2 includes the various particle size multipliers (PM_{10} and $PM_{2.5}$).

Table 1. Particle size multiplier for paved roads [24]

Size range	Particle size multiplier (K)		
	g/VKT	g/VMT	1b/VMT
$PM_{2.5}$	0.15	0.25	0.00054
PM_{10}	0.62	1	0.0022

Table 2. Particle size multiplier for unpaved roads [40]

Aerodynamic Particle Size Multiplier (K)				
$\leq 30\ \mu m$	$\leq 15\ \mu m$	$\leq 10\ \mu m$	$\leq 5\ \mu m$	$\leq 2.5\ \mu m$
0.80	0.50	0.36	0.20	0.095

Eq. 2 allowed us to estimate the fine particle emission factors according to the different categories of vehicles. For the three categories of vehicles we have:

$$EF_{HDV} = k_{PM_{10};PM_{2.5}} \left(sL\right)^{0.91} \left(W_{HDV}\right)^{1.02} \quad (4)$$

$$EF_{LDV} = k_{PM_{10};PM_{2.5}} \left(sL\right)^{0.91} \left(W_{LDV}\right)^{1.02} \quad (5)$$

$$EF_{PC} = k_{PM_{10};PM_{2.5}} \left(sL\right)^{0.91} \left(W_{PC}\right)^{1.02} \quad (6)$$

The size range K_{μ} takes these values from Table 1. The choice of the parameter (sL) depends on the volume of daily traffic on a paved road. The effect of traffic on measures of silt loading on paved roads in urban areas has been demonstrated by several authors [41,42].

For various road types (paved and unpaved), estimates of air pollutant emissions ($PM_{2.5}$; PM_{10}) are made. It is important to understand that the research area's total traffic is taken into account, and the following general equation describes the emission:

$$Q_{k,\mu} = \sum_{k=HDV,LDV,PC} EF_k \times A_k \quad (7)$$

Where $A_k = A_{PC} + A_{LDV} + A_{HDV}$ represents the total traffic density or activity; k the different categories of vehicles, μ the different particle sizes. The emission amounts for the particles that we interested in this study are estimated as follow:

$$Q_{k,\mathrm{PM}_{10}} = A_k \times \sum_{k=HDV,LDV,PC} \left(EF_{HDV} + EF_{LDV} + EF_{PC}\right) \quad (8)$$

$$Q_{k,\mathrm{PM}_{2.5}} = A_k \times \sum_{k=HDV,LDV,PC} \left(EF_{HDV} + EF_{LDV} + EF_{PC}\right) \quad (9)$$

For the next sections the following considerations are taken:

1. The density of road traffic is the same for the types of roads (paved and unpaved).

2. Scenario 1 (S_1) is assigned for unpaved roads and scenario 2 (S_2) for paved roads

The activity

When determining the amount of fine particulate matter emission, activity (A) is a crucial factor. In this study, the activity is evaluated by calculating the flow or density of the traffic on the roads by counting the number of cars that pass through the study region. When it comes to the estimation of activity with reference to road traffic, we simply analyze the flow or rate of vehicle movement over the study area. In Cameroon, this approach of calculating activity was applied to predict particle matter (PM_{10} and $PM_{2.5}$) dispersion in calm wind circumstances in urban areas [34]. Because the goal of this work is to demonstrate how roads (paved and unpaved) affect the rise in concentration thresholds in urban areas, we decided to utilize the same traffic flow for the two types of roads (paved and unpaved) in this study. To track the pattern or even the amount of fine particle emissions on various types of roadways, we'll use the same activity (paved and unpaved).

The Douala Urban Community (CUD) database from 2008 provided the information we used in this investigation. The hourly fluctuation in the volume of traffic on the roads in the study region is depicted by the histogram in Fig.2. All vehicle groups taken together, the daily traffic volume estimated, is over than 5000 vehicles, this number falls under the Hi-ADT category (High Average Daily Traffic) [41].

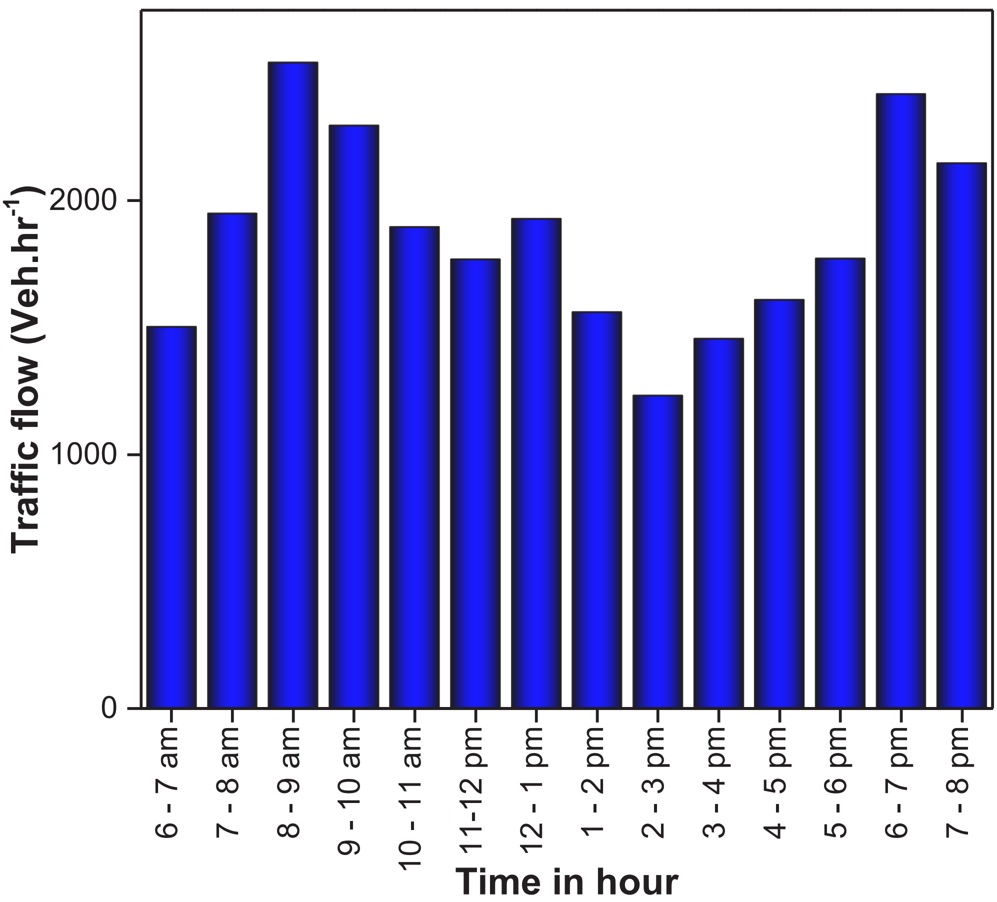


Fig. 2. Hourly traffic flow rate [42]

Air quality model

Modeling air quality allows us to estimate the concentrations of the few pollutants in the atmosphere. Currently, the modeling of air pollution due to traffic is done mainly with Gaussian dispersion models to estimate pollution near roads on one hand and by Eulerian models with three-dimensional mesh to calculate background pollution on the other hand [43–46]. The concentration of traffic-related pollutants was estimated using the Gaussian plume model. This model estimates the concentration of air pollutants from road dust on different types of roads. The two-dimensional Gaussian plume model is given by Eq. 10, neglecting the reflection due to a low-level source and assuming that the main source is road:

$$C(x,y,z,H)=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{y^2}{2\sigma_y^2}-\frac{(z-H)^2}{2\sigma_z^2}\right) \quad (10)$$

Where C is the concentration of g/m^3 at a point with coordinates (x, y, z), x being the distance from the emission source point along the wind direction and is expressed in meters, y and z are lateral distances from the direction of the wind; u is the mean wind speed at the receptors in m/s; Q is the quantity of emission in unit of mass; σ_y (x) and σ_z (x) are the diffusion coefficients in the horizontal and vertical directions, respectively (note that these parameters depend on whether you are in an urban or rural environment); H is the initial height of emissions at the source. The analytical expressions of these diffusion coefficients according to the Pasquill stability classes are given by Eq. 11 and Eq. 12:

$$\sigma_y\left(x\right)=\frac{\alpha x}{\sqrt{1+\beta x}}=\frac{0.32x}{\sqrt{1+0.0004x}} \quad (11)$$

$$\sigma_z\left(x\right)=\alpha x\left(1+\beta x\right)^{\gamma}=0.24x\sqrt{1+0.001x} \quad (12)$$

Where α, β and γ are constants which depend on the Pasquill stability classes [45].

This methodological approach is based on estimating the Emission Factor depending on particles size and the calculation the roadside concentration using a Gaussian steady state model.

Statistical analysis

Linear regression demonstrates the association between particle pollution emissions and traffic. However, the coefficient of determination are determinate using Eq. 13.

$$R^2=1-\frac{\sum_{i=1}^{n}\left(y_i-\hat{y}_i\right)^2}{\sum_{i=1}^{n}\left(y_i-\overline{y}\right)^2} \quad (13)$$

Where: n is the number of measurements (n =14, which is equal to the number of hours of traffic measurements); y_i is the traffic flow value of measurement i; $\hat{y}_i$ is the equivalent predicted value (emission quantity); and $\overline{y}$ is the average of the measurements. The range of the coefficient of determination is 0 to 1. The more closely the linear regression matches the parameters under study, the closer it is to 1.

Results and discussion

Emissions factors

To calculate the various emission components from different types of roads, we employ the formulae suggested in the US EPA Model AP-42 approach. These equations are successful used to calculate Dust emission for several roadways [4,39,46,47]. In the context of this study, the daily traffic density is regarded as High ADT. The default value for the parameter sL, which we utilized, is equivalent to the daily traffic density, which is roughly 0.1 g/m^2 [41]. The obtained values of Emissions factor, for different types of vehicles are reported in Table 3.

Table 3. Emission factors by vehicle category and, by particle size on a paved road (g/VKT).

	Particle size multiplier	
	PM_{10}	$PM_{2.5}$
Vehicle categories	Emissions factors	
HDV	0.59	0.14
LDV	0.19	0.04
PC	0.10	0.02

Considering the obtained emissions factor, based on a default value of the Silt Loading, the Fig. 3a. and Fig. 3b show the influence of silt loading on the emission factors of fine particles (PM_{10}, $PM_{2.5}$). We find that the emission factor can also be influenced by the vehicle category. Silt loading is a parameter that plays a role in increasing the pollution thresholds, as the latter influences the emission factor.

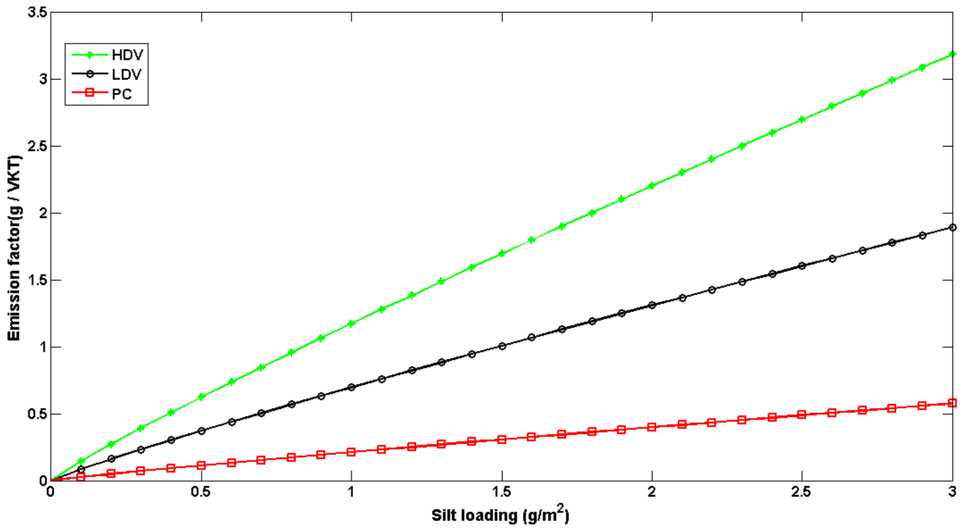


Fig. 3a. Variation of the emission factor as a function of the Silt loading for particles with the size range $PM_{2.5}$

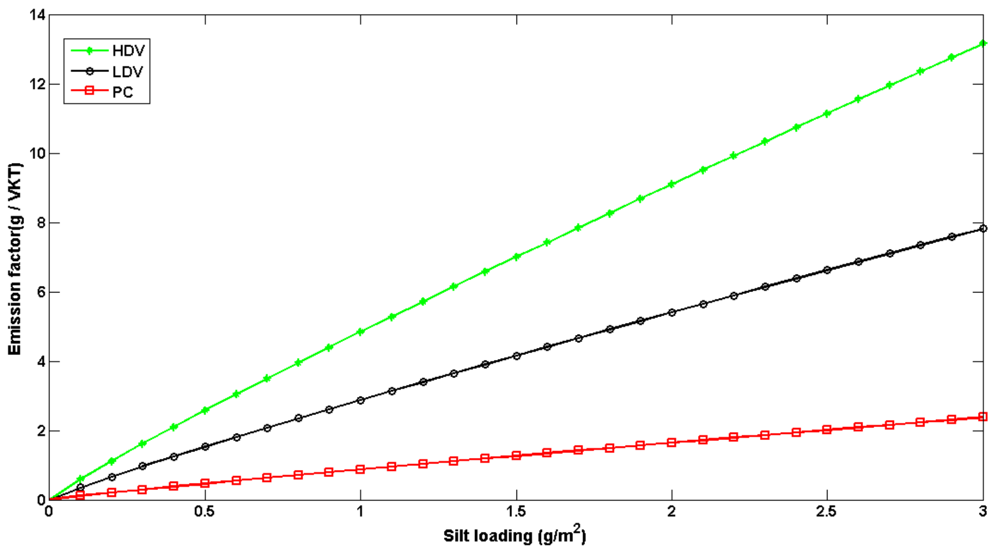


Fig. 3b. Variation of the emission factor as a function of the Silt loading for particles with the PM_{10} size range

Based on the calculated emissions factors and a default silt loading value, as presented above, Fig. 3a and Fig. 3b illustrate how silt loading affects the emission factors of fine particles (PM_{10}, $PM_{2.5}$). We observe that the vehicle type can have an impact on the emission factor as well. Because it affects the emission factor, silt loading is a parameter that contributes to raising the pollution thresholds. In Douala, Cameroon, researchers in a study showed a link between rising CO (carbon monoxide) concentration thresholds and rising emissions levels [34]. It's also crucial to keep in mind that the size range affects the emission factor (Fig.3a. and Fig.3b.). According to a study, estimations, trucks, buses, cars, and motorcycles contributed 69%, 23%, 5%, and 3% of the total $PM_{2.5}$ concentrations, respectively [48]. When evaluating emission dust using the AP-42 approach, there is a significant correlation between the weight of the vehicle and the amount of silt on a particular route towards re-suspension PM emission [49, 50]. This demonstrates that pollution is closely associated with the vehicle category. The emission factor of a vehicle increases with weight, and concentration values follow suit.

Common types of unpaved roads are generally gravel roads; thin bitumen membrane roads; roads with treated surface; roads with a cold laid asphalt mix. Unpaved roads are completely covered with dust (PM). This road dust in the context of unpaved roads is characterized by the parameter called silt content, which in a way represents the percentage of road dust on a road surface. If the specific silt content is not known at the location, the relevant mean value presented in Table 13.2.2-1 of AP-42, can be used as a default [24]. In this study, the default value of silt content considered is 15%, this value corresponds to unpaved roads considered to be very dirty, characteristic of unpaved roads in Africa [51]. We estimated the emission factors for an unpaved road for three vehicle categories (HDV, LDV, PC) assuming all of our vehicles have 04 wheels. The average speed of 20 km/h is considered, because this reference speed release a large amount of fine particles in paved roads [41]. Table 4 shows the different results.

Table 4. Emission factor by vehicle category and by particle size on an unpaved road (1b.$(VMT)^{-1}$).

Vehicle categories	Particle size multiplier			
	PM_{10}		$PM_{2.5}$	
	Emissions factors (EF)			
	$EF(b.(VMT)^{-1})$	$EF(g.VKT^{-1})$	$EF(b.(VMT)^{-1})$	$EF(g.VKT^{-1})$
HDV	0.012	3.3828	0.0034	0.958
LDV	0.0065	1.832	0.0017	0.479
PC	0.0041	1.156	0.0011	0.310

The difference in emission parameters between paved and unpaved roads (Table 3 and Table 4) confirms that unpaved roads discharged more dust than paved ones. Depending on the type of road and the type of vehicle, we can get different emission factor values for the same particle. Note that the units of the emission factors vary depending on the type of road, for paved roads we have the grams per Vehicle Kilometers Travelled ($g.VKT^{-1}$) and for unpaved roads. We have the pound per Vehicle Miles Travelled ($1b.VMT^{-1}$) [7]. Moreover $1b.VMT^{-1}$ is equivalent to 281.9 $g.VKT^{-1}$.

The quantity of emission

The impact of increased vehicle traffic on the rise in fine particle emissions is illustrated in Fig. 4a. and Fig. 4b. No of the size or kind of road, hours with high traffic correspond to high particle emission values. It is obvious that the values of the emissions quantities increase as we travel on unpaved roads, which is supported by the fact that there are a lot of fine particles in the road dust. As a result, emissions are becoming increasingly significant with the growth in traffic on the roads, particularly in urban areas with heavy traffic. This results was obtained for similar studies on PM and CO in Netherlands and Cameroon [35, 52]. These findings also strongly align with those of researchers found in a study [36], who demonstrate that Tianjin's high vehicle density makes road dust pollution a significant problem.

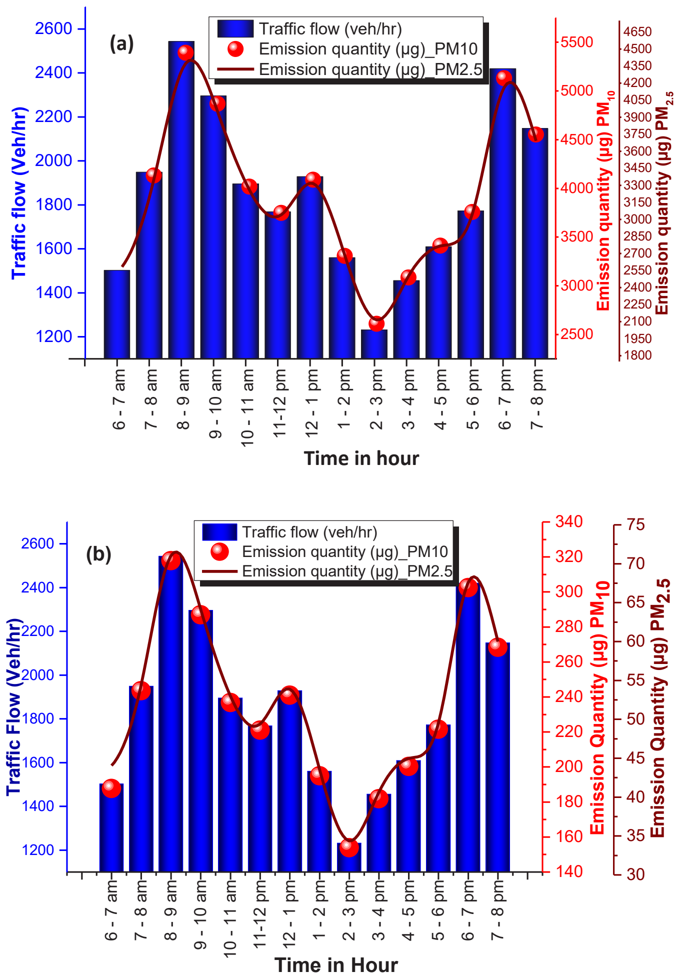


Fig. 4. Hourly variation in the amount of fine particle emissions depending on road traffic: (a) For unpaved roads; (b) For paved roads

Fig. 5a and Fig.5b, and Fig.6a, Fig. 6b depict the linear relationship between road traffic flow, fine particle emissions (PM_{10}, $PM_{2.5}$), and road types. These graphs show straight lines of linear regressions that accurately reflect the amount of traffic and emissions (Fig.5a., Fig. 5b., Fig. 6a. and Fig. 6b.).

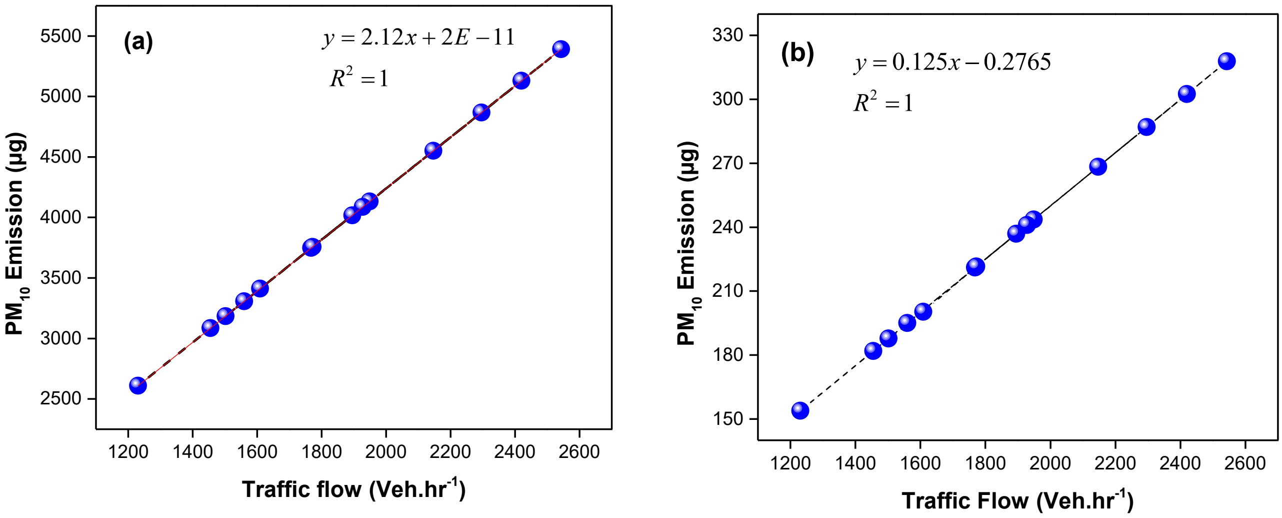


Fig. 5. Emission rate as a function of traffic density for PM_{10}: (a) unpaved roads, (b) paved roads

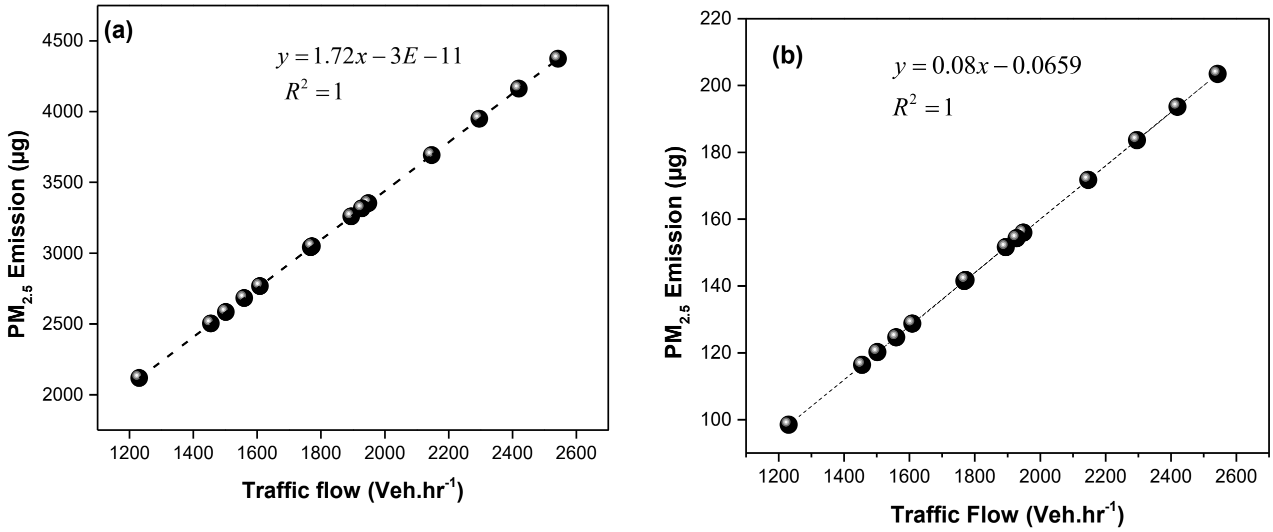


Fig. 6. Emission rate as a function of traffic density for $PM_{2.5}$: (a) unpaved roads, (b) paved roads

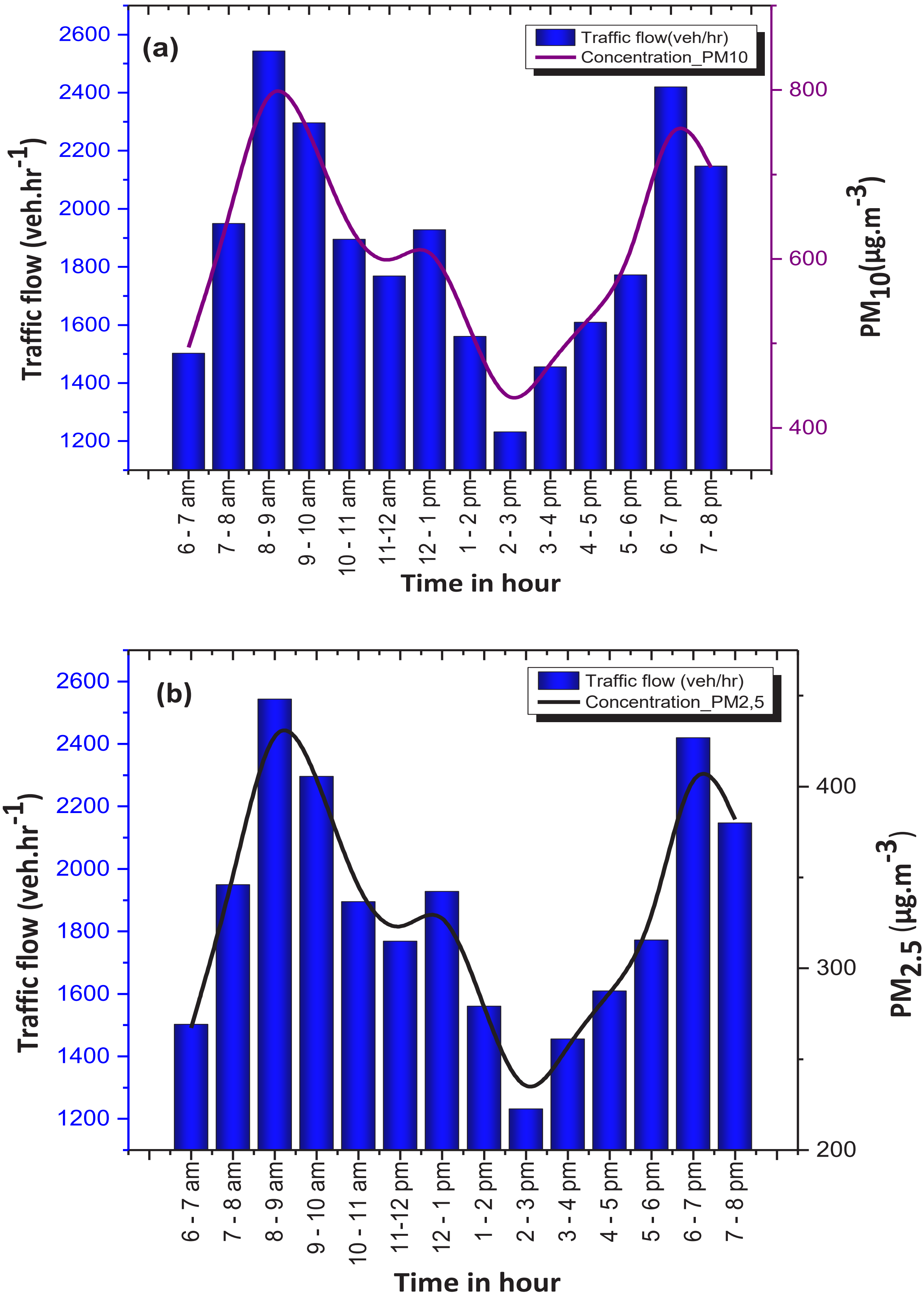


Fig. 7. Hourly variation of fine particle concentrations on an unpaved road: (a) PM_{10}, (b) $PM_{2.5}$

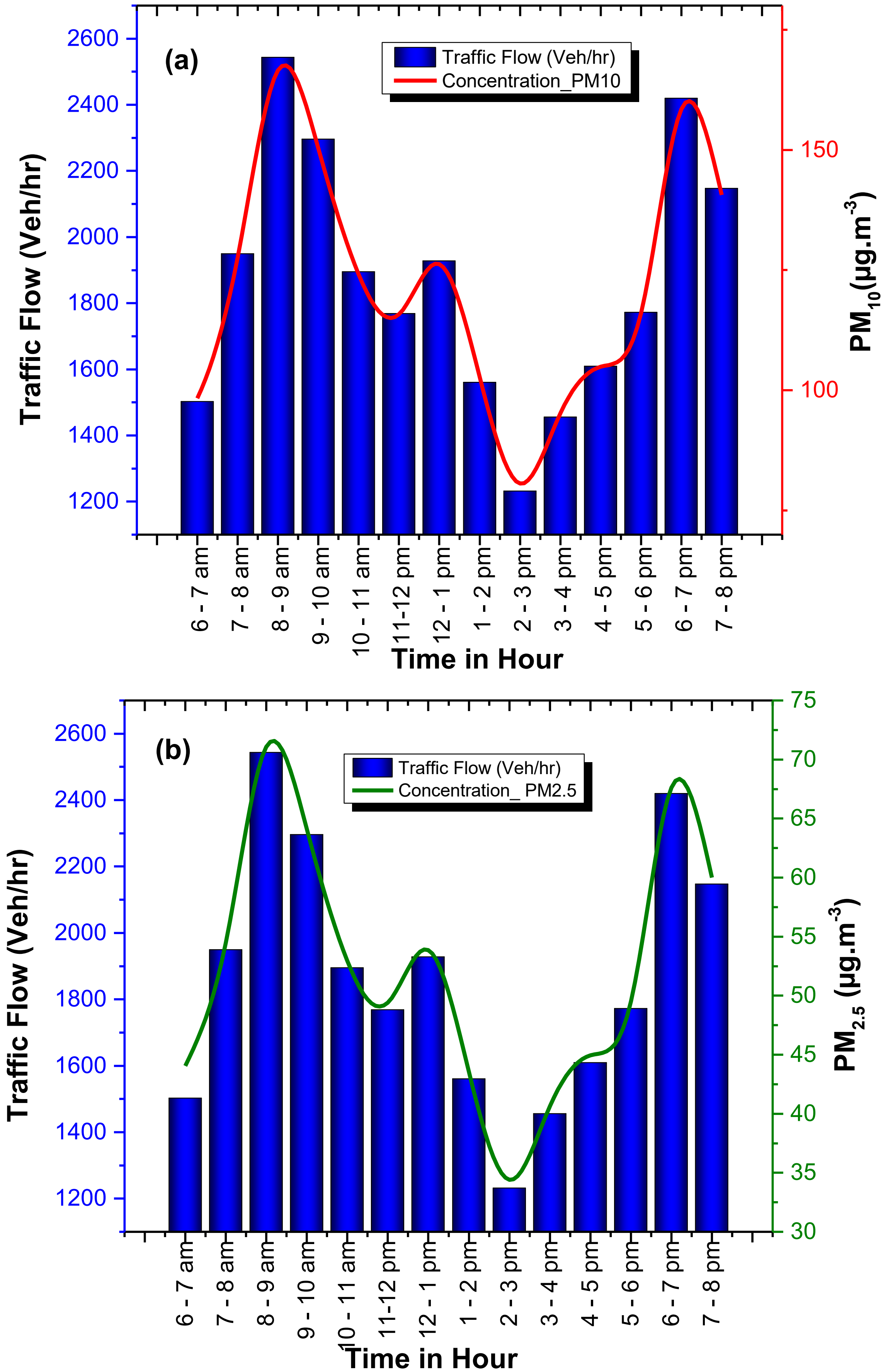
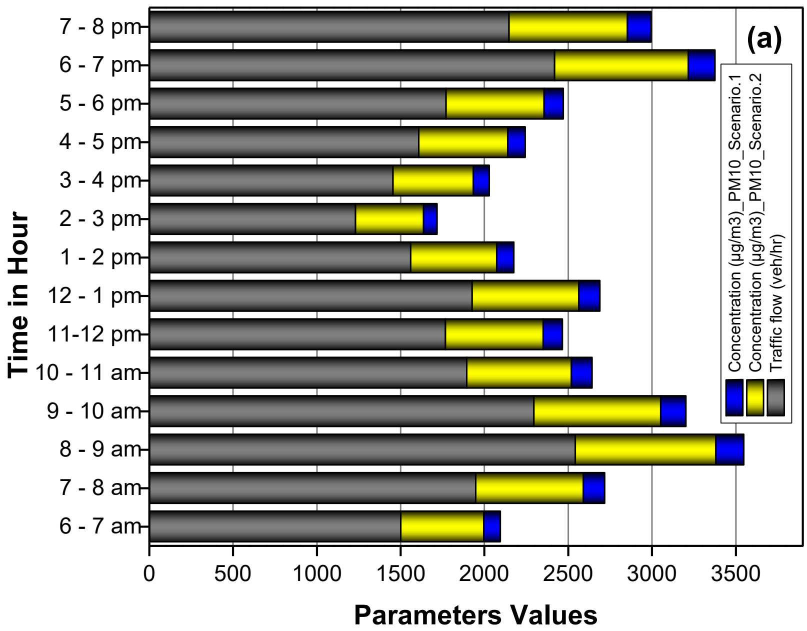


Fig. 8. Hourly variation of fine particle concentrations on a paved road: (a) PM_{10}, (b) $PM_{2.5}$

In the two scenarios (S_1 and S_2) of our investigation, road traffic density and concentrations of fine particles of the same sizes are compared in Fig. 9a and Fig. 9b We observe that there is a correlation between the density of vehicle traffic and the concentration of fine particles (PM_{10}, $PM_{2.5}$). These findings are completely consistent with several research based on urban air quality in various cities [34, 53, 54]. The estimated amounts of fine particulate matter (PM_{10}, $PM_{2.5}$) are nearly 12 times higher than the WHO guidance limits, as shown in Fig. 9a and Fig. 9b, indicating that road traffic is a significant contributor to poor urban air quality. The works of [55], which claim that traffic is one of the main causes of bad air quality in the world, are in perfect accord with the previous claim.



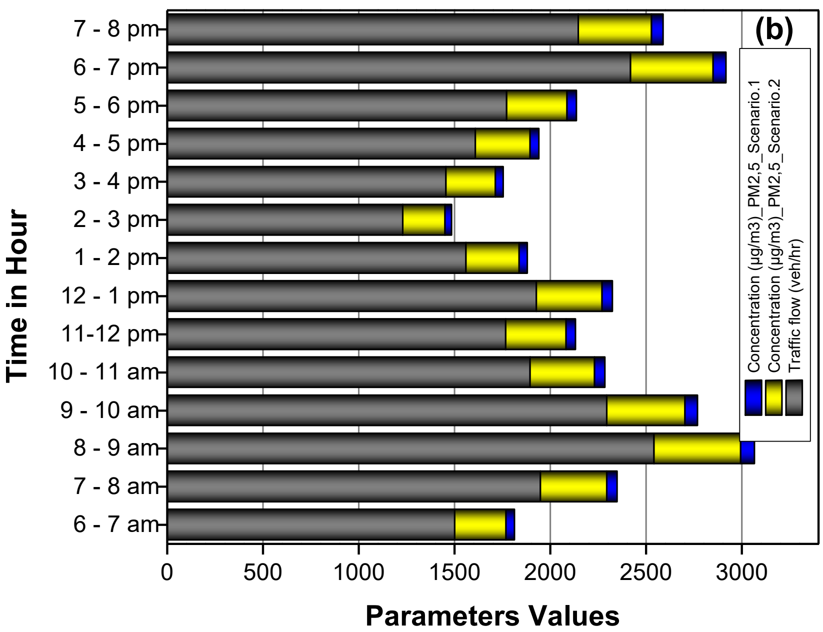


Fig. 9. Hourly variations in concentrations according to road traffic corresponding to the different scenarios: (a) PM_{10}; (b) $PM_{2.5}$

Daily average of PMs concentrations according to the distance from the emission source

Using the two-dimensional Gaussian model and taking into account that point O is the road's center (origin of the source). Based on the typical traffic rate on our road, we were able to estimate the average concentration values for a paved and unpaved road (study area). The fluctuation in concentration along S_1 and S_2 for the particles $PM_{2.5}$ and PM_{10} is shown in Fig. 10a and Fig.10b, respectively. No matter the particle, we observe that the peaks are always roughly 20 meters from the source. The turbulence of air masses caused by moving vehicles can be used to justify this. The research demonstrates that significant turbulence, which is what causes the phenomena of suspension here, is frequently observed in regions with high traffic [56, 57]. The wind's speed and direction also have an impact on this phenomenon, which is why the peak is situated around 15 meters from the source and encourages PM dispersion. The daily mean concentration values for scenario 1 (S_1) and scenario 2 (S_2) are provided in Table 6. In order to estimate the daily average peak concentrations from paved and unpaved roads, we first evaluated the daily emission quantities of each type of particle on each type of road. We next found the average of the daily emissions (Table 5).

Table 5. Daily average of the quantities of emissions according to the different scenarios

Daily average of emission quantities (μg)		
Range of sizes	PM_{10}	$PM_{2.5}$
Scenario.1	658.08	533.90
Scenario.2	232.75	148.00

Table 6. Average of concentrations according to the different scenarios

Daily average concentrations (μg/m^3)		
Range of sizes	PM_{10}	$PM_{2.5}$
Scenario.1	917,70	559.00
Scenario.2	170,00	103.90

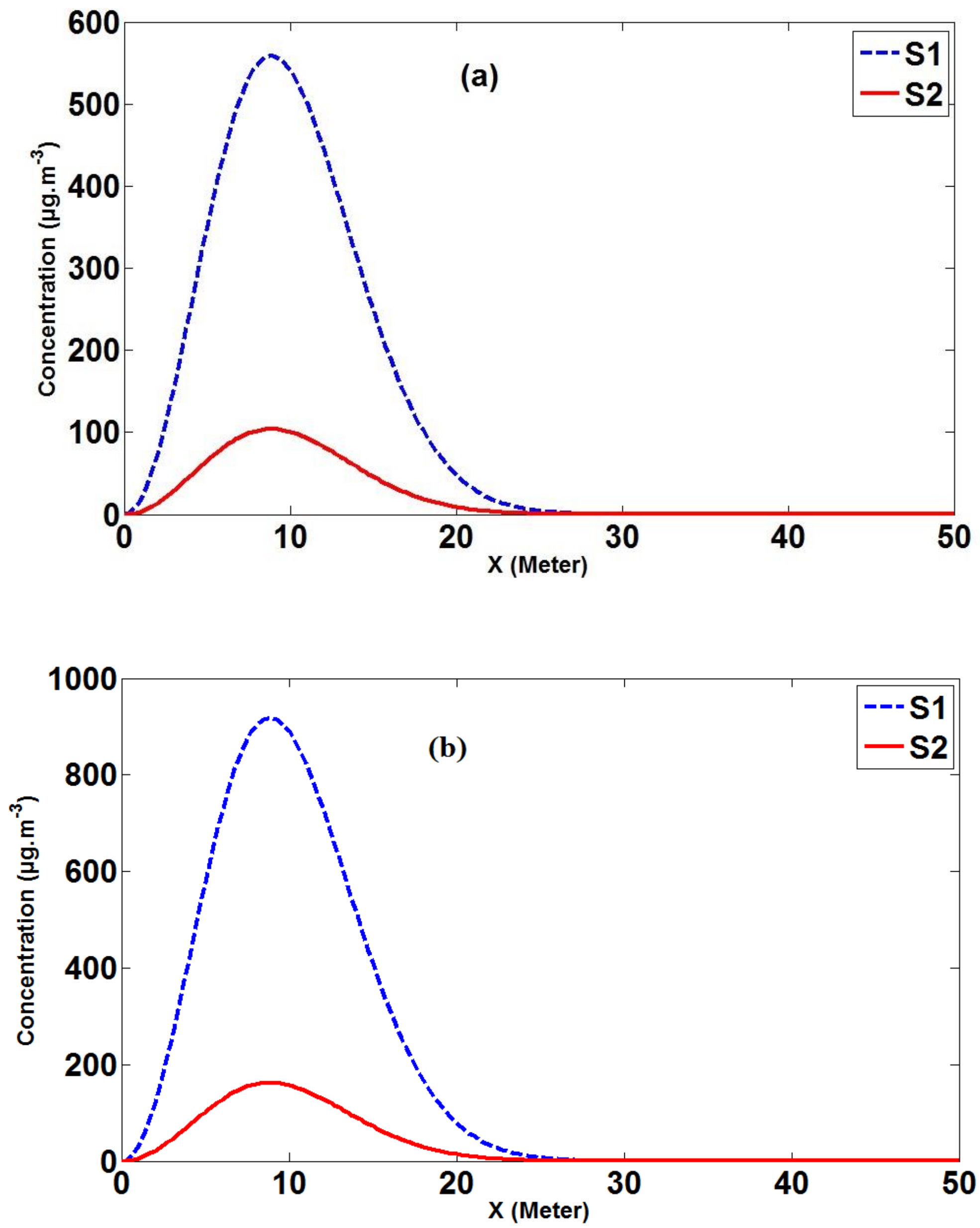


Fig. 10. Daily average of PMs Concentrations according to the different scenarios: (a) $PM_{2.5}$, (b) PM_{10}

Table 6 presents the mean values of PMs Concentrations according to S_1 and S_2 by particle size. The estimated average values are even greater at S_1 than at S_2 depending on the particle ranges. These estimated values correspond to the work of a study [58] who found that suspended particulate matter (TSP) concentrations from roads (paved or unpaved) are approximately between 300 and 1000 µg/m^3.

In order to demonstrate how roads, contribute to the rise in non-exhaust emissions in urban areas, the goal of this work is to estimate the non-exhaust emissions on paved and unpaved roads. Roads are significant emitters of particulate matter in metropolitan areas, according to several studies [52]. Numerous studies have demonstrated how non-exhaust emissions affect pollution levels in big cities around the globe. According to a study [59], non-exhaust emissions in India were reported to be six times higher than exhaust emissions. Since we are in a tropical location and there aren't many studies on the study area, these earlier works amply demonstrate the significance of our study. In comparison to WHO regulations, this study reveals extremely high levels of pollution on both types of roads. The Gaussian Dispersion Model we used to predict the daily mean concentration values yielded extremely significant results (Table 6). It is crucial to note that an increase in the fleet of vehicles will result in higher concentration levels. 54% of Africans would live in urban environments by 2030, according to a research [53]. Strong urbanisation results in a rise in vehicle ownership in cities, which increase traffic. Additionally, areas with large traffic volumes typically have greater PM concentrations [56, 57].

Traffic snarls can last for many hours during rush hours, especially in the morning when school, work, and other economic activities are starting and in the evening when those activities are ending [53]. Currently, several scientific studies are being conducted in the world's most industrialized nations to discover a solution to these types of urban pollution [46, 59, 60]. On dirt roads, water sprinkling is the most typical form of control [46]. The application rate, the time between sprinkles, the volume of traffic, and the weather all have an impact on how successful it is. Furthermore, chemical compounds such as calcium magnesium acetate, magnesium chloride, and calcium chloride can be utilized to prevent road dust from re-suspending in metropolitan areas [46]. In wealthy nations, these methods of reducing road dust using chemicals are frequently applied broadly. These chemical reagents have the potential to be new sources of pollution for both air and water (it is not recommended to use these chemical reagents during the rainy season out of concern for their permeability to groundwater) The majority of chemicals that are used to lessen road dust are damaging to the environment.

Conclusion

In our study, non-exhaust emissions from paved and unpaved roads are estimated. This study demonstrates how roads play a significant role in raising pollution levels in cities. Because we have traffic data at this point in the city, the technique of this work can be applied to one of the axes of one of the biggest intersections in Douala (the Ndokotti roundabout). The outcomes demonstrate an exact link between emissions, concentrations, and traffic. Heavy traffic is prevalent throughout the morning and evening rush hours, and whether we are on a paved or unpaved road, emissions and concentrations are particularly high at these times. There are many different ways to reduce the amount of road dust suggested in the literature, however some are highly expensive and occasionally have negative environmental effects. Douala is a sandy and coastal city, so we recommend to the authorities that they pave the roads in the urban areas and to sweep the pavement very early in the morning before traffic begins to prevent the phenomena of traffic resumption.

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Competing interests

The authors declared no conflicts of interest with respect to concerning the authorship and/or publication of this article.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors.

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