

# PM2.5 and PM10 Emission Inventory from Road Dust in Abidjan City

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## Abstract

Atmospheric pollution linked to fine particles constitutes an important environmental issue in Africa. The city of Abidjan (Côte d'Ivoire) is also impacted by this air poor quality related to intense road traffic resulting from combining factors such as rapid demographic, socio-economic and urbanization. This rapid urbanization is often poorly planned leading to the presence of important unpaved roads mobilizing important amount of dust to be released into the atmosphere contributing fine particle pollution. This work focused on establishing Particulate Matter (PM2.5 and PM10) emissions inventory related to road dust from 2010 to 2019 in Abidjan. The results showed that dust road emissions due to vehicles are highly variable without a specific trend, estimated at  $991.8 \pm 232.8$  kilotons for PM10 and  $146.8 \pm 34.3$  kilotons for PM2.5 per year. This lack of trend is probably due to their dependence on rainfall and vehicle category annual mean mileage traveled. Moreover, among the different vehicle categories contributing to the road dust emissions, trucks stand out with 70% and 50% of total emissions on paved and unpaved roads, respectively. Furthermore, the RD emission factors obtained in Abidjan are up to 50 times higher than those provided in the literature for high-income countries, where road infrastructure is often more developed. This inventory will enrich existing data and improve PM mapping and modeling in Abidjan, providing a valuable tool for developing public policies to reduce air pollution across Côte d'Ivoire.

## Keywords

Emission Factor, PM10, PM2.5, Road Dust Emissions, PM Modeling

## 1. Introduction

Air quality degradation in urban areas has become a major global concern, particularly due to its profound impacts on human health and the environment. Among the most critical air pollutants are suspended fine particles, commonly known as particulate matter (PM). These particles are classified by their size, with PM<sub>2.5</sub> and PM<sub>10</sub> referring to particles with a diameter less than 2.5 and 10 micrometers, respectively. Their small size allows them to penetrate deep into the respiratory system and bloodstream, leading to a range of severe health issues, including respiratory and cardiovascular diseases [1] [2]. These air pollutants are diverse sources, often distinguished between their natural and anthropogenic origins. The anthropogenic sources of atmospheric pollution are often closely related to greenhouse gases.

Air quality modeling and forecasting meet various challenges, including those related to the availability of accurate high-resolution (spatial and temporal) emission inventory data (used as input data) as well as in-situ measurements (for model calibration and validation) [3] [4]. In their review of real-time air quality forecasting, [4] identified several inaccuracies and their possible cause, which include factors related to meteorology, boundary conditions, emissions and model processes. Thus, these factors contribute to remarkable differences between simulation and forecast results and measured values. Therefore, accurate and high-resolution (temporal and spatial) emission inventories are essential to improve model performance. However, Africa and particularly West Africa suffer from a lack of accurate and high-resolution emission inventories. The few regional inventories that have been published for Africa for anthropogenic emissions, such as [5]-[7], have addressed combustion sources and some at the city level, such as [8]. These inventories cover gases (CO, NO<sub>x</sub>, SO<sub>2</sub> and NMVOC) and aerosols (black carbon, organic carbon, PM<sub>2.5</sub> and PM<sub>10</sub>) at regional level (10 km × 10 km horizontal resolution) and at city level (1 km × 1 km horizontal resolution) and have been developed taking into account certain sources, namely domestic fires, traffic, waste combustion, industries and thermal power plants [5], but not yet road dust emissions.

De Longueville *et al.* [9] found that out of 231 articles published over the last decade on the direct links between desert dust and human health, only one of these studies concerned West Africa, even though this region is very close to the Sahara, the largest contributor to global dust levels. Furthermore, Semerjian *et al.* [10] showed that very few studies have been conducted on road dust in Africa, given the lack of publications on the subject from these regions. Yet West Africa is one of the areas where morbidity rates are significantly higher than in other parts of the world, and where respiratory infections alone account for more than 20% of infant mortality causes [9] [11]-[13].

Haynes *et al.* [14] showed that very few studies exist on the chemical composition of road dust in Africa. Furthermore, these few studies [15] [16] found high levels of heavy metals such as copper, lead, zinc, and cadmium in roadside dust, which is resuspended by vehicles and therefore likely to increase the concentra-

tions of these pollutants in the atmosphere.

Abidjan is undergoing rapid urbanization and population growth, resulting in a significant increase in road traffic. This situation is intensified by the presence of unpaved roads, which are a major source of dust. The dispersion of this dust in the ambient air increases PM<sub>2.5</sub> and PM<sub>10</sub> concentrations, contributing to the deterioration of the city's air quality [17].

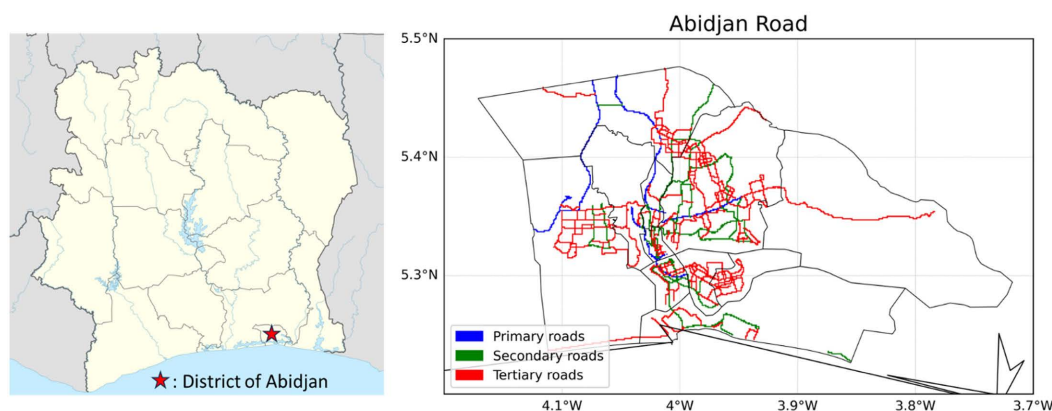
The development of a PM<sub>2.5</sub> and PM<sub>10</sub> emission inventory, specific to road dust raising, is essential to assess the impact of this source on Abidjan's air pollution. This inventory will be spatialized at a horizontal resolution of 1 km × 1 km, and at an annual temporal resolution. It will enhance existing inventories in Abidjan and improve the PM mapping derived from modelling, providing a valuable tool for local authorities in managing and reducing pollution levels. Section 2 describes the methodology, the data, the tools, and techniques used for estimating and spatializing emissions. Finally, the third section presents the results obtained, followed by a discussion.

## 2. Methodology

### 2.1. Study Area

Abidjan, the economic capital of Côte d'Ivoire, is a major metropolis in West Africa, home to some 6.321 million inhabitants according to the latest general population and housing census in Côte d'Ivoire [18], and covers an area of 2119 km<sup>2</sup>. Located in the south-eastern part of the country, it is the main economic and urban center, with a significant concentration of industrial, commercial and service activities. The city is characterized by rapid urbanization and an expanding road infrastructure, essential for linking its various districts.

Abidjan's road network is vast and varied, comprising freeways, paved main roads and secondary roads, some of which are unpaved. The latter are particularly prone to dust generation, especially during the dry season due to traffic, in areas with high vehicle density. The city's geographical configuration and rapid development make it a relevant study site for the analysis of road dust emissions. **Figure 1** shows a map of primary, secondary and tertiary paved roads in Abidjan district.



**Figure 1.** Map of primary, secondary and tertiary roads in Abidjan district.

## 2.2. Determination of the PMs Road Dust Emissions in Abidjan

The methodology used to derive PMs Road Dust (RD) emissions emission was based on the AP-42 method [19] that is an empirical model developed by the US Environmental Protection Agency (EPA). RD PMs emissions are then calculated using Equation (1):

$$E_t = \sum_l (Veh_l \cdot D_l) \cdot EF_{l,k} \quad (1)$$

where  $E_t$  was a total emission of compound;  $Veh_l$  a number of vehicles per type;  $D_l$  the distance traveled in a year per vehicle type,  $EF_{l,k}$  emission factor of compound per road type. The emissions factor is calculated using Equation (2) and Equation (3) respectively for paved and unpaved road:

$$EF_{pav} = \left[ k \cdot (sL)^{0.91} \cdot W^{1.02} \right] \left( 1 - \frac{P}{4N} \right) \quad (2)$$

$$EF_{unpav} = \left[ \frac{k \cdot \left( \frac{s}{12} \right)^{0.8} \cdot \left( \frac{W}{3} \right)^{0.4}}{\left( \frac{M}{0.2} \right)^{0.3}} \right] \left( 1 - \frac{P}{365} \right) \quad (3)$$

where  $EF$  (g/VKT) represents the particle emission factor,  $k$  (g/VKT) is the particle size multiplier (paved road:  $k = 0.15$  for PM2.5 and  $k = 0.62$  for PM10, unpaved road:  $k = 107.12$  for PM2.5 and  $k = 732.94$  for PM10),  $sL$  (g/m<sup>2</sup>) is the average silt load,  $W$  (tons) is the average weight of vehicles on the roads,  $P$ : number of rainy days with precipitation of at least 0.254 mm,  $S$  (%) is the silt content of the surface material and  $M$  (%) is the moisture content of the surface material.

Thus, road dust emission factor is calculated on the basis of several variables, such as traffic, nature of the road soil, weather, average vehicle weight and annual mileage.

### Road and traffic data

Statistics on road characteristics (paved and unpaved) are essential for estimating PM emissions on these two categories of road. In this study we used the Greater Abidjan urban transport master plan report of the Greater Abidjan urban planning master plan development project (SDUGA) data ([https://openjicareport.jica.go.jp/pdf/12230645\\_01.pdf](https://openjicareport.jica.go.jp/pdf/12230645_01.pdf)). The Abidjan district has a total of 1772.2 km of roads, 854.6 km of which are paved (48%) and 917.5 km unpaved (52%).

To date, there are no official statistics on the number of vehicles on the road in Côte d'Ivoire. We therefore needed to collect data on the number of vehicles, their average weight and the annual mileage covered by these vehicles for Abidjan. The fleet data were estimated by the study of [8], whose methodology is based on data from the Ministry of Transport via its technical structures, notably the Guichet Unique du Transport Terrestre de Côte d'Ivoire (which provides the first registrations) and SICTA (the technical structure in charge of technical inspections to estimate the annual mileage traveled, fleet exits, etc.).

The average distance traveled per vehicle category per year is determined using roadworthiness test data, as in the study of [8]. These average distances are available for the years 2012 to 2019, and for the missing years in the study period, the annual average value per category was used. Thus, the average annual distances traveled by category from 2010 to 2019 are obtained.

Average weight values are taken from the literature. For each vehicle category, values are given in interval form, but average values are used for each category. We have used 1.225 tons, 1.75 tons, 20 tons, 0.2 tons and 16 tons respectively for cars, vans, trucks, motorcycles and buses.

#### *Annual mileage traveled by vehicle category*

The average annual number of kilometers traveled (VKT) per vehicle category is taken from the work of [8]. Due to the lack of available data on vehicle counts by road type (paved and unpaved), the distribution of VKT by road type (paved and unpaved) was obtained based on the assumption of an even distribution of traffic volume across these two road types. We therefore multiplied the number of VKT per vehicle category by the proportion of each type of road (48% for paved roads and 52% for unpaved roads) to obtain these VKT for paved and unpaved roads in Abidjan, respectively.

#### *Meteorological data and other parameter*

The meteorological data from the Ogimet website (<http://www.ogimet.com/>) providing synoptic information for the city of Abidjan (station ID: 65578) from 2010 to 2019 were used for this work. For this dataset the total precipitation for the 24-hour period from 6:00 a.m. to 6:00 a.m. is reported at 6:00 a.m. with reference code 4. We have carried over this value when it is neither 0 nor NaN; otherwise, we check the precipitation values from the previous 24 hours to see if there was an error in carrying over the cumulative total at 6:00 a.m. For this work, a day is accounted for rainy day if at least 0.254 mm was recorded. This threshold of 0.254 mm represents the minimum amount of precipitation needed for mitigating suspended particulate emissions on an hourly basis according to [19]. We then applied this threshold and retained only the days on which precipitation exceeded it.

Other useful parameters for calculating road dust emissions are soil silt content (S), surface moisture (M) and average silt load (sL). These parameters are all taken from the literature. Due to the lack of data on silt content for all of Abidjan's municipalities, and given that most of the city's roads (paved or unpaved) are made of clayey sand, given its availability (Kouassi *et al.*), we calculated an average based on the limited data available in the literature for municipalities and assumed that these average values were representative. Indeed, the silt content of the soil was estimated at 5.6% based on the values  $S = 7.6\% \pm 3.9\%$  and  $S = 3.6\%$  for the municipalities of Marcory and Cocody, respectively, located in the Abidjan district, as reported by [20]. Furthermore, the surface moisture content in Abidjan is taken from the study in [20] and estimated at  $M = 4\%$ , because during the dry season, unpaved road surfaces experience extreme moisture loss due to high evaporation rates, leading to significant dust emissions and surface degradation (Kamara *et al.*

2025). Finally, the average silt load used in this study is taken from the study by [21] and is estimated at  $sL = 0.531 \text{ g/m}^2$ .

### 2.3. Spatial Distribution of RD PMs Emissions

RD PMs emissions, obtained for each type of road (paved and unpaved) have been distributed on map, using a road density map for the city of Abidjan, based on the shapefiles (spatial distribution) of the roads collected from <https://extract.bbbike.org/> (last access: 19 July 2025) combined to road occupancy per type of vehicle. Using a methodology similar to that described in [8], emissions were spatially distributed across different road types. The gridding steps are described as follows: 1) extraction of primary, secondary, and tertiary roads from Shapefiles, 2) calculation of road density and its normalization, 3) application of vehicle occupancy weights by road category (primary, secondary, and tertiary) based on the work in [22] and finally 4) allocation of road traffic emissions by road type (paved and unpaved).

## 3. Results

In this section, we present the results of the inventory covering the period from 2010 to 2019. Emission factors are analyzed by vehicle category, followed by annual changes in emissions over the period 2010-2019. The number of vehicles by category and the average annual distances traveled by category from 2010 to 2019 is shown in **Table 1**.

**Table 1.** Vehicles number and the average mileage in Abidjan by category from 2010 to 2019.

Parameters	Categories	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vehicle number	Private car	283,740	294,210	301,288	320,151	336,034	354,584	377,824	405,158	411,469	428,656
	Taxis	50,072	51,919	53,169	56,497	59,300	62,574	66,675	71,497	72,612	75,645
	Van	55,495	58,079	61,050	66,925	71,564	76,555	82,333	88,043	91,448	96,213
	Truck	41,570	43,325	45,385	48,698	51,350	54,748	59,392	63,930	65,385	68,571
	Two wheels vehicle	43,455	44,863	46,963	50,929	54,762	59,249	64,539	77,654	75,577	80,082
	Bus	13,637	13,949	14,015	14,452	14,603	14,833	15,149	15,597	15,725	15,991
Annual mileage	Private car	14,650.1	14,650.1	14,367.4	14,999.9	15,073.2	15,103.9	13,705.9	14,650.1	14,650.1	14,650.1
	Taxis	56,409.3	56,409.3	61,622.3	64,944.8	54,457.3	58,240.4	42,781.6	56,409.3	56,409.3	56,409.3
	Van	19,858.6	19,858.6	20,969.8	20,726.8	20,206.6	20,029.3	17,360.6	19,858.6	19,858.6	19,858.6
	Truck	84,525.6	84,525.6	133,271	70,326.3	107,568	69,670.2	41,792.5	84,525.6	84,525.6	84,525.6
	Two wheels vehicle	14,650.1	14,650.1	14,367.4	14,999.9	15,073.2	15,103.9	13,705.9	14,650.1	14,650.1	14,650.1
	Bus	81,394.7	81,394.7	75,977.3	138,262	72,472.1	65,856.3	54,405.6	81,394.7	81,394.7	81,394.7

### 3.1. RD PM<sub>2.5</sub> and PM<sub>10</sub> Emissions Factors in Abidjan

The average emission factors for PM<sub>2.5</sub> and PM<sub>10</sub> from paved and unpaved roads for the period 2010-2019 are presented in **Table 2**. Same emission factors are used

for private cars and taxis since they belong to the same vehicle category and the average weight of vehicle were used for emission calculation. Moreover, emission factors for particulate matter are classified by vehicle respective weights, and by year as rain height parameter is taken into account in Equation (2) and Equation (4). Highest emission factor is found for trucks, followed respectively by buses, vans, cars and motorcycles (TW) which exhibit the lowest value. The emission factor is strongly influenced by vehicle weight since heavier a vehicle is, the more dust it raises. This is explained by the pressure exerted by the vehicle on the road surface. On paved roads, PM<sub>2.5</sub> EF values range from 0.01 to 1.61 g/VKT, PM<sub>10</sub> EF values range from 4.8 to 30.4 g/VKT, while on unpaved roads, PM<sub>2.5</sub> EF values range from 4.8 to 30.4 g/VKT, and PM<sub>10</sub> EF values range from 32.9 to 207.9 g/VKT.

**Table 2.** Particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) emissions factors from paved and unpaved roads in Abidjan.

Categories	PM <sub>2.5</sub> EF (g/VKT)		PM <sub>10</sub> EF (g/VKT)	
	Paved road	Unpaved road	Paved road	Unpaved road
Private car and taxi	0.09	9.9	9.9	68.0
Van	0.13	11.5	11.5	78.5
Truck	1.61	30.4	30.4	207.9
Two wheels vehicle	0.01	4.8	4.8	32.9
Bus	1.28	27.8	27.8	190.1

Unpaved roads exhibit much higher (from 8 to 400 time) EF than paved road (Table 2). This may be explained by significant differences in surface conditions and the amount of dust available. Paved roads are characterized by a smooth, solid surface, with less available dust ready to be released into the atmosphere by traveling/moving vehicles. Therefore, these paved roads generate limited/less amount of fine particles to be dispersed in the air. However, unpaved roads have a crumbly surface, with a large amount of available dust on the surface due to their rapid deterioration. This facilitates the particles mobilization and released by passing vehicles. The high PM EF values found for the unpaved roads in this study, highlight the major impact of road infrastructure on particulate emissions. Therefore, the outlying districts of Abidjan, where the most of unpaved roads are located, will tend to emit more PM due to their traveling/moving vehicles (light or heavy).

### 3.2. Annual Vehicle Kilometers Traveled and Total Rainy Day per Year

Table 1 shows the average annual mileage used to calculate vehicle kilometers traveled (VKT) on paved and unpaved roads in Abidjan. The VKT of unpaved roads is slightly higher than that of paved roads. This could be due to factors linked to urban growth, road infrastructure structure and traffic patterns. Indeed, the city of Abidjan has undergone rapid expansion, particularly in outlying areas where unpaved roads are more numerous. These developing neighborhoods are

home to a significant proportion of the population. Residents of these areas have to use unpaved roads to travel to paved roads, which increases the number of kilometers traveled on these roads. In addition, the difficulty of circulating on paved roads, often due to traffic jams and poor road conditions, can lead drivers to prefer unpaved roads as an alternative, especially cab drivers and transporters seeking to avoid traffic jams. These peripheral areas also concentrate a large proportion of informal economic activities. This includes markets and small-scale industries, leading to frequent use of unpaved roads by heavy vehicles such as trucks and minibuses for goods and passenger transport. In short, rapid urbanization, the lack of paved roads in outlying areas and the importance of economic activities in unpaved areas explain why the VKT of unpaved roads in Abidjan can be higher than that of paved roads.

In terms of rainy days per year, the total number of rainy days per year with at least 0.254 mm in Abidjan ranged from 72 in 2013 to 172 in 2017.

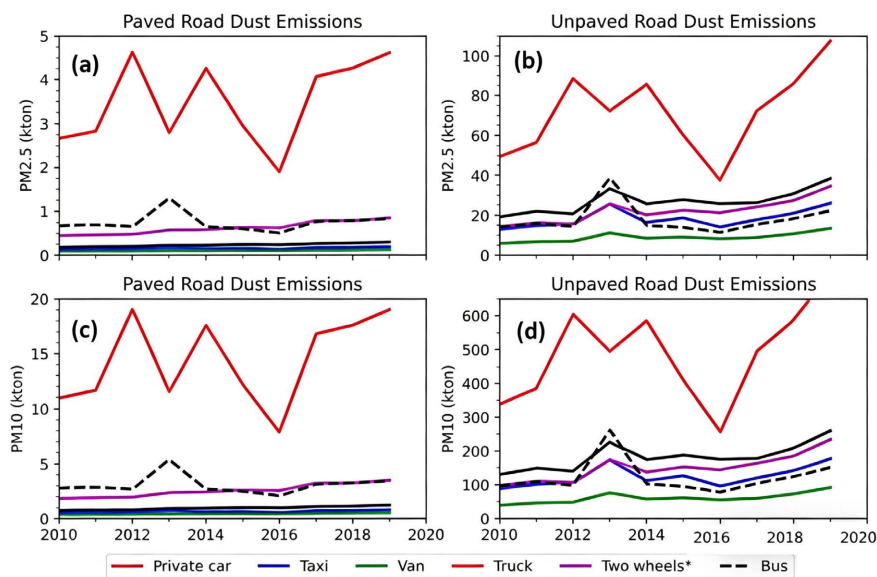
### 3.3. PM<sub>2.5</sub> and PM<sub>10</sub> Emissions from RD in Abidjan

**Figure 2** shows the evolution of PM<sub>2.5</sub> and PM<sub>10</sub> emissions from paved (**Figures 2(a)-(c)**) and unpaved (**Figures 2(b)-(d)**) roads, respectively, over the period 2010 to 2019. The highest emissions of PM<sub>2.5</sub> and PM<sub>10</sub> are found on unpaved roads. Among the different categories of vehicles, trucks have the highest emissions over the entire study period. For example, for PM<sub>2.5</sub>, trucks emitted about 56.5 kilotons (48% of the total) in 2011 and 107.8 kilotons (51% of the total) in 2019 on unpaved road. Their emissions on the paved road reached 2.6 kilotons (72% of total) in 2010 and 4.6 kilotons (76% of total) in 2019. Moreover, the truck category PM<sub>2.5</sub> emissions were lower in 2013 and 2016, while an increasing trend was observed from 2017 onward. This increasing trend in PM<sub>2.5</sub> emission by truck category could be attributed to an increase in trade and also infrastructure construction. The decrease in PM<sub>2.5</sub> emissions observed in 2013 and 2016 may be related to the low VKT in these years. All categories, with the exception of trucks, show higher PM emissions in 2013, which may be related to the low number of rainy days (days with at least 0.254 mm) recorded that year. PM<sub>10</sub> emissions from paved and unpaved roads in Abidjan for the period 2010 to 2019 show similar trends to those for PM<sub>2.5</sub>.

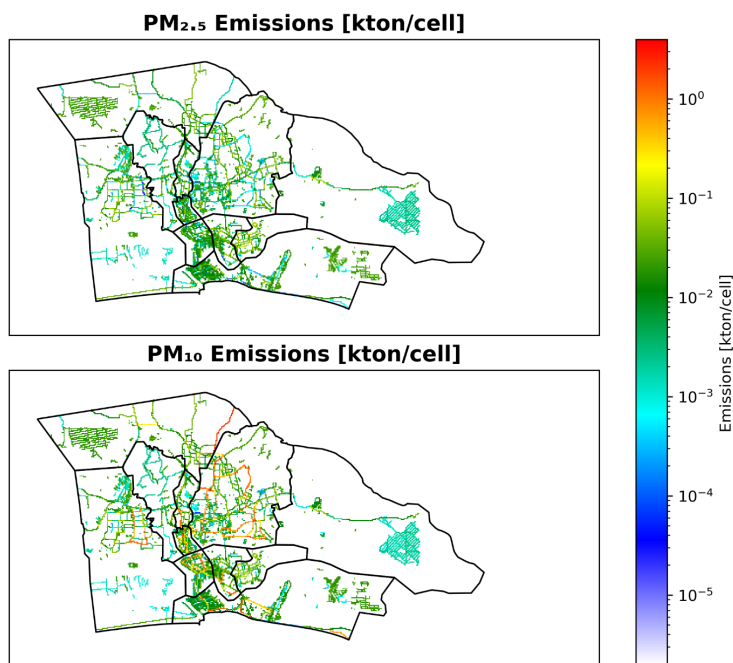
In terms of main contributors, trucks are followed by private cars and taxi, which are frequently used on the city's inland roads for public and private transport. Variations in emissions are strongly linked to VKT and EF, which in turn depend on the parameters such as vehicle weight, road type and precipitation. These results highlight the importance of road infrastructure as well as the contribution of vehicle type and their impact on road dust emissions. More paved roads, in good conditions, may contribute in limiting PM<sub>2.5</sub> and PM<sub>10</sub> emissions from road. Unpaved roads, without appropriate treatment, emit more PM<sub>2.5</sub> and PM<sub>10</sub>, contributing to air quality degradation in surrounding areas.

Gridded PM<sub>2.5</sub> and PM<sub>10</sub> emissions from road dust in Abidjan for the year 2019 are shown in **Figure 3** (a and b respectively) combining paved and unpaved

road. PM<sub>2.5</sub> and PM<sub>10</sub> from road dust are estimated to be 217.2 kilotons and 1469.4 kilotons respectively. The vast majority of emissions are found for unpaved roads, which accounted approximately for 97.2% of the total PM<sub>2.5</sub> and 98.3% for the total PM<sub>2.5</sub> emitted. The present road dust emissions inventory is complementing an existing anthropogenic emission inventory for Abidjan focused on combustion sources [8].



**Figure 2.** PM<sub>2.5</sub> emissions from (a) paved and (b) unpaved roads dust and PM<sub>10</sub> emissions from (c) paved and (d) unpaved in Abidjan from 2010 to 2019.



**Figure 3.** Spatial distribution of (a) PM<sub>2.5</sub> and (b) PM<sub>10</sub> emissions from roads dust in Abidjan for year 2019.

### 3.4. Sensitivity Analysis and Emissions Uncertainties

A sensitivity analysis was conducted to examine how PM<sub>2.5</sub> emission factors from unpaved roads vary around the chosen average value for silt content. The results of the sensitivity test show that, using the two extreme values for silt content, the PM<sub>2.5</sub> emission factors for unpaved roads will fluctuate between 7 - 12.7 g/VKT, 8 - 11.5 g/VKT, and 21.3 - 38.8 g/VKT, 3.3 - 6.2 g/VKT, and 19.5 - 35.5 g/VKT, respectively, for passenger cars, vans, trucks, motorcycles, and buses. This gives us a relative variation in the PM<sub>2.5</sub> emission factor compared to the average value, ranging from -29.8% to +27.7%.

A Monte Carlo simulation was conducted to quantify the uncertainty associated with emission estimates [26]. In this study, we assume that when the coefficient of variation (CV) is less than 30%, the distribution is normal, and that it is log-normal and asymmetric when it is greater than 30% [5]. The Monte Carlo method was then used to propagate the uncertainties related to silt content (S:  $5.6 \pm 2\%$ ), surface moisture (M:  $4 \pm 1\%$ ), and vehicle weight ( $\pm 1$ ) to obtain the uncertainty in the PM<sub>2.5</sub> emission factor and their emissions by vehicle type for the year 2019. The simulation involved repeating the test 100,000 times to obtain the mean value and estimated standard deviations with a 95% confidence interval. The results reveal significant variability in emission factors ( $\pm 30.7\%$ ), mainly due to uncertainties regarding silt content (S), moisture (M), and vehicle weight (W). The relative uncertainty in emissions remains consistent across vehicle categories ( $\pm 45.1\%$  to  $\pm 45.4\%$ ), as emissions vary linearly with the emission factor (EF). The sensitivity analysis shows that silt content dominates the uncertainty in emissions (S: 0.86), followed by vehicle weight (W: 0.07), while moisture content (M: 0.06) has a mitigating but weaker contribution.

## 4. Discussions

The PM<sub>2.5</sub> and PM<sub>10</sub> emission factors measured in our study for road dust from paved roads in Abidjan are much higher than those reported in the literature as shown in **Table 3**. This may be related to local factors favoring presence of more dust material on paved roads. For example, the proximity of uncovered surfaces to paved road may facilitate the transport of sand and clay on these paved roads which are then mobilised and release into the ambient air by vehicles when traveling/moving. Moreover, [23] highlighted that paved roads experiencing construction work were emitting 5 times more PM<sub>10</sub> than the paved roads with no construction work in Milan (Italy).

PM<sub>10</sub> emissions are significantly higher on unpaved roads than on paved roads. This is mainly due to the fact that unpaved roads are a major source of resuspension of dust particles, particularly PM<sub>10</sub>. This observation is consistent with the study by [27] [28], who showed that dust raised by passing vehicles on unpaved surfaces is a predominant source of PM<sub>10</sub> in both urban and rural environments. Heavy vehicles, such as trucks, play a key role in increasing PM<sub>10</sub> emissions, particularly on unpaved roads. This finding is supported by [29], who demonstrated

that heavy vehicles can significantly increase levels of suspended dust particles on unpaved roads, leading to elevated PM<sub>10</sub> concentrations. Unpaved roads emit much more fine particulate matter due to the nature of their more friable surface, which accumulates more dust and degrades more quickly when disturbed by vehicles [28] [29].

**Table 3.** Comparison of PM<sub>10</sub> emission factors obtained in several cities around the world using the USEPA method.

Road type	Cities	PM <sub>10</sub> EF (g·veh <sup>-1</sup> ·km <sup>-1</sup> )	Reference
Paved roads	Abidjan (Côte d'Ivoire)	0.06 - 6.67	This work
Paved roads (mean)	Milan (Italie)	0.013 - 0.032	Amato <i>et al.</i> [23]
Roads with construction work	Milan (Italie)	0.066 - 0.10	Amato <i>et al.</i> [23]
Paved roads	Braga (Portugal)	0.033	Alves <i>et al.</i> [24]
Unpaved roads	Abidjan (Côte d'Ivoire)	33.22 - 209.62	This work
Unpaved roads	Muscatine County (US)	444 - 795	Kacer <i>et al.</i> [25]

PM<sub>2.5</sub> is generally less abundant on paved roads, as PM<sub>2.5</sub> often originates from the disintegration of PM<sub>10</sub> and other combustion sources, rather than from the simple resuspension of road dust as shown by [30]. Therefore, results obtained in Abidjan, where road dust, especially on unpaved surfaces, is the main source of PM<sub>10</sub> emissions, are in line with those observed in other cities (Table 3). A study by [31] in Nairobi showed that unpaved roads contributed significantly to high PM<sub>10</sub> levels, while PM<sub>2.5</sub> was mainly associated with exhaust emissions. Furthermore, emission levels of carbonaceous particles from traffic in Abidjan in 2019 with 2198.8 kilotons and 2062.6 kilotons respectively for BC and OC [8], which are the majority constituents of PM<sub>2.5</sub> from fuel combustion [32]. For the same year 2019, we obtain PM<sub>2.5</sub> emissions from road dust estimated at 217.2 kilotons, *i.e.*, around 1/20th of carbon compound emissions. This observation is supported by the study by [30], which showed that the majority of fine particles (PM<sub>2.5</sub>) on paved roads come mainly from tire wear and incomplete fuel combustion, while road dust contributes more to PM<sub>10</sub>.

## 5. Conclusions

This work enabled us to draw up an inventory of fine particle emissions, in particular PM<sub>2.5</sub> and PM<sub>10</sub>, specific to Abidjan's road dust. The methodology main stages consisted in collecting and analyzing road network data, characterizing the traffic fleet and determining road dust emission factors for particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) specific to road (paved and unpaved) and vehicle (truck, pri-

vate, ...) types. Moreover, traffic data (VKT) and emission factors, were used to estimate PM<sub>2.5</sub> and PM<sub>10</sub> emissions. Emissions for 2019 are 25.1 and 6.1 kilotons for PM<sub>10</sub> and PM<sub>2.5</sub> respectively on paved roads, and 1444.3 and 211.1 kilotons for PM<sub>10</sub> and PM<sub>2.5</sub> respectively on unpaved roads. On paved roads, average emission factor values are 60.8 - 6670.3 mg/VKT for PM<sub>10</sub> and 14.7 - 1613.8 mg/VKT for PM<sub>2.5</sub>. On unpaved roads, they rise to 33.2 - 209.6 g/VKT for PM<sub>10</sub> and 4.8 - 30.6 g/VKT for PM<sub>2.5</sub>. The highest VKT values were obtained on unpaved roads, underling that unpaved roads are responsible for the highest levels of particulate emissions, particularly from heavy vehicles such as trucks and coaches. Furthermore, the emission factors calculated in this study were found to be significantly higher than those currently available in the literature. This difference is mainly due to the high density of unpaved roads in Abidjan. The results of this work thus reveal the importance of improving road infrastructure to reduce fine particle emissions in densely populated urban areas.

The limitations of this study include the lack of data on vehicle counts on different types of roads (paved and unpaved) and the experimental determination of certain parameters used (S, sL, and M).

These elements could help reduce uncertainties in these emission estimates and provide a better understanding of local variability in PM<sub>2.5</sub> and PM<sub>10</sub> concentrations based on microclimatic characteristics and economic activities. This inventory will enrich existing inventories in Abidjan (spatial resolution of 1 km × 1 km) and improve PM mapping based on modeling, thus providing a valuable tool for the development of public policies aimed at reducing air pollution levels in cities in Côte d'Ivoire.

### **Data Availability**

Data is provided within this link <https://doi.org/10.1594/PANGAEA.990397>.

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### **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

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