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Article

Emissions from the road traffic of West Africa's cities: Assessment of vehicle fleet and fuel consumption.

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Abstract: Traffic source emissions inventories for the rapidly growing West African urban cities are necessary for better local characterization of vehicle emissions released into these cities atmosphere. This study based on local field campaign in a representative site of anthropogenic activities over West African cities such as Yopougon (Abidjan, Côte d'Ivoire) during 2016, provided useful information on vehicle type and age, traveling time, fuel type and amount for fuel consumption estimation. Also, high traffic flow of personal car were recorded on highway, boulevard and backstreet whereas high flows of intra-communal sedan taxi are recorded on main and secondary roads. In addition, the highest daily fuel consumption value of 56 $L.day^{-1}$ was recorded in heavy vehicle while the lowest value of 15 $L.day^{-1}$ is recorded for personal car using gasoline. This study will be useful for the improvement of uncertainties related to the different databases used to estimate inventories emissions either national or international reports. This work provides useful information for future studies on urban air quality, climate and health impacts assessment in African cities. It may also be useful for policy makers to support implementation of emission reduction policy in West African cities.

Keywords: West Africa cities, urban transport, traffic flows, fuel consumption, emissions inventories, Yopougon.

1. Introduction

Air quality deterioration in West Africa is accentuated by an increase in urbanization across cities such as Abidjan (Côte d'Ivoire), Accra (Ghana), Conakry (Guinea), Dakar (Sénégal), Lagos (Nigeria) associated with rapid population growth (WMO, 2012). This urbanization will lead to development into mega-cities with estimated population to reach by 2030: 7.773 million for Abidjan, 6.046 million for Dakar, 3.262 and 3.134 million for Accra and Conakry and 24.239 million for Lagos [1]. This rapid urbanization is associated with an increase of atmospheric pollution through gases and particulate emissions from anthropogenic sources [2–5]. However, the characterisation of anthropogenic emissions in sub-Saharan Africa especially across West Africa remains uncertain and is one of the major challenges of the scientific community. The car fleet of West African cities is mainly constituted of used vehicles from European and American countries [6–8]. These old vehicles often lack emission reduction technology [9,10]. Uncertainties associated with the characterization of the traffic emissions in these countries are linked to inaccurate estimation of the fuel consumption and of the daily variability of the traffic, emissions factors [11–14], and the assumptions used to geographically distribute pollutant emissions.

Consequently, uncertainties remain both in the "top down" and "bottom-up" methods to determine the emissions. However, the "bottom-up" methods estimates better the levels of emissions using highest spatial resolution information on fuel consumption, traffic and local emission factors, than the "top-down" methodology, which relies on more general information [13,15–17]. Existing works mostly relied then on national reports and/or international reports from United Nations (UN), International Energy Agency (IEA) and Africa clean database for the estimation of fuel consumption of the number of vehicles in the traffic [2,18,19]. These reports and database provide rough necessary information about the inventories of anthropogenic emissions sources but no studies are yet conducting on real case and on a local field of a West African city. This needs to be addressed for the improvement and the assessment of uncertainties related to the different databases as well as national and international reports.

Therefore, the current work aims to investigate in this first part the road traffic and the associated fuel consumption at a local scale, in a site representative of West African cities, and in a second part, to provide more accurate and useful information of emissions estimation for both the scientific community engaged in the understanding of climate change and the West African policy makers involved in the implementation of mitigation measures with respect to the Paris Agreement. The area of the study site and its particularity are presented in section 2; Section 3 is dedicated to the observing strategy implemented to collect the information on the traffic by focusing both on the vehicle fleet and the fuel consumption. Section 4 provides preliminary results and discussions while the conclusion and future implications of our approach are presented in section 5.

2. Materials and Methods

2.1. Presentation of the area of study: Characteristics of Yopougon

Our study area is Yopougon (5.34°N and 4.01°W) located in North-western part of Abidjan (Figure 1). Yopougon is representative of the rapid urban development of African cities with a significant increase of population and economic activities in the last 30 years. From 1965 to 2005,

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Yopougon area extent has been multiplied by more than 200 with 65 ha in 1965, 6 667 ha in 1996 and 14 800 ha in 2014 [20–24]. This extent growth was associated with high population growth [25–27], estimated to be around 1,071,500 inhabitants in 2014, which represent 1/4th of the total population of Abidjan (Figure 2.a and 2.b). With its 23 sub-areas (Figure 1), Yopougon can be considered as a city within the wide town of Abidjan since it has its own residential areas, with an intense traffic, an industrial zone and a central thermal power plant. Yopougon industrial zone is the most important in the country [22,28]. The high population growth and spatial extension have led to an increase in transportation demand and high traffic emission levels. Yopougon vehicle fleet comprises personal cars, local public taxis called intra-communal sedan taxis or "Taxi Woro-woro", ordinary taxis (or inter-communal taxis), small buses or minicars known as minibuses or "Gbaka", heavy vehicles (buses, trucks and long vehicles) and very few motorcycles. In addition, Yopougon has neighbourhoods of various standings with habitats belonging to different economic strata [29].

African cities are hubs of socio-economic development and are becoming areas where important part of the population lives. Abiodun et al. [30] predicted that 50% of the African population will be urban population by 2020 and that more than half of them will be in West Africa. This represents an increase of 100% in less than 30 years [31]. The high population growth and its accumulation into the urban area and mega-cities lead to social-economic problems, enormous environmental problems, and mostly, to strong stress on the existing public transportation facilities which contribute to the increasing number of used vehicles [4]. For example, the fleet in Abidjan city represents 80 % of the national vehicle fleet. The number of vehicles has increased enormously over time reaching approximately 477265 in 2015 (Figure 2.c) [32–36]. The car fleet in West African cities is characterized by vehicles with diesel engines with around 60% in Abidjan and Dakar and it is composed of personal cars, buses, minibuses, taxis and other modes of transport such as common passenger cars or motorcycles [6,34,37,38]. Minibuses, which carry roughly 8 to 25 passengers, tend to have colloquial names, such as "Trotro" in Accra, "Danfo" in Lagos, "Gbaka" in Abidjan. In Accra for example, minibuses constitute more than half of traffic fleet with 52% of "Trotro", 9% of taxis, 13% of personal vehicles and 20% of buses [39]. Knowing that the governments in Africa do not invest enough in sustainable infrastructure (around 2%-3% of the Gross Domestic Product), this under-investment in road transport will have an impact on air quality and on emissions of greenhouse gases in these African cities [40].

2.2. The traffic monitoring strategy

A field campaign is implemented to observe and to collect data on the number of cars as well as the quantity and quality of fuel used by all vehicles. The observing and counting points were uniformly distributed in different road types in Yopougon during two different intensive observing periods (from 22nd to 24th February 2016 and from 4th to 7th April 2016) performed on the same areas. The second period of measurement was undertaken to correct biases that might have occurred during the first period of measurement and to distinguish daytime and night time traffic that were not observed during the first period of measurement. In addition to information on hourly counting (between 6am and 6pm), this second period also provided information on the flow or volume of vehicles at 9-10pm, 01-02am and 05-06am. Night vehicle counting was conducted at specific times

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regarding the prevailing insecurity on the sites and the availability of police officers to protect investigators. We distinguish several classes of vehicles such as personal cars, intra-communal sedan taxis, inter-communal taxis, minibuses and heavy vehicles (buses, trucks and long vehicles). Figure 3a displays the different road classes in Yopougon, with 1501 road segments separated between highways, boulevards, main roads, secondary roads and backstreets. The field measurements campaign estimated traffic flows over few road types representative of road networks in Yopougon (Figure 3b). Generally in African cities and particularly in Yopougon, one of the difficulties is that the increase in vehicles number is not associated with an improvement of the road network and the quality of the infrastructures; There are an important number of backstreets (85% of the total road network; Figure 3.a). Therefore, the vehicles presence on these backstreets will definitively enhance traffic emissions. The traffic flow or volume is defined as the number of vehicles (in each class) per hour moving on a given road. The traffic flow is assessed hourly across different road types or classes. A parallel survey was also conducted to provide necessary information about the fuel type and the consumption, the vehicles types and ages, the traveling time of each vehicle type. From 22nd February to 16th March 2016, a total of 472 drivers choose randomly in Yopougon has been interviewed during the survey to help in the assessment vehicle fleet and of traffic emissions.

3. Results and discussion

3.1. Validation of traffic flow measurement data

As there is no available database, the traffic data collected during the survey are validated using the nascent available data provided by Bureau National d'Etudes Techniques et de Développement (BNETD) which is the national bureau of standards for monitoring and verification to support elaboration and implementation of development plans and policies of Côte d'Ivoire. The BNETD data have been collected from 9th to 13th August 2014 in one highway where our measurements were made and thus, the comparison with our data is performed in this unique highway (Table 1). Table 1 shows that we recorded higher number of vehicles than BNETD. The differences between the two datasets may be explained by the difference of season (our measurements were made during the school season (February) while those of BNETD are collected during the holidays season (August). The school season corresponds to the period of regular and high demand of personal car, intra-communal sedan taxis and inter-communal taxis by schoolchildren, middle and high school students may explain why we record more vehicles that BNETD. It should also be noted that holiday periods correspond to travel times, which could explain the increase of travel car through minibuses and buses (heavy vehicles). Officially, since the intra-communal sedan taxi (or local taxi) are not supposed to use the highway, the BNETD considered zero vehicles in their report. However, during our field measurement, we recorded their presence on the highway.

3.2. Traffic flow

Figure 4 shows daily traffic flows from linear sources for each road class (highway, boulevard, main roads, secondary roads and backstreet) during the counting day. It can be seen that maximum total traffic flows varies between 36872 and 78360 vehicles per day on the highway (red line). The

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blue line corresponds to roads inside so called "backstreet" and is associated with weak traffic flows varying between 0 and 700 vehicles between 06 am to 06 pm. Traffic flows for boulevards, main roads, and secondary roads are respectively shown in orange, pink and green lines.

Figures 5a and 5b show the traffic flows per hour in each road type. In general, an important traffic flows are observed at 6 – 7 am and 5 – 6 pm and correspond to peak times which are periods when most persons go to work and back to home. The maximum number of vehicles is observed at 9 – 10 am in the highway (8099 vehicles) while the minimum is noted at 10 – 11 am in the backstreet (7 vehicles). These figures also show structures with one peak (Backstreet at 6 - 7am, main road at 10 - 11am and boulevard at 5 – 6pm) or with two peaks (Highway at 9 - 10 AM and 5 - 6 PM, and secondary road at 4 - 5 pm and 5- 6pm). On the highway, the weak traffic flow is estimated at 1049 vehicles/hour at 6 - 7am. Boulevard traffic flow extends from 2002 vehicles/hour observed at 6 – 7 am to 2826 vehicles/hour at 5 – 6pm. Maximum traffic is estimated at 1770 vehicles/hour on main roads and minimum is recorded 1374 vehicles/hour. On Secondary roads, traffic flow is between 1300 and 1793 vehicles/hour. Maximum is observed at 4 – 5pm while minimum is recorded at 06 – 07am. Maximum traffic flow on backstreet was recorded between 6-7am (232 vehicles), while the minimum traffic was observed at 10 – 11am (7 vehicles/h). Similar total traffic flows are observed on main and secondary roads in the same times (6 -7 am, 9-10 am) (Figure 5b). Figures 6 shows the number of each vehicle types per hour per each type of road. Figure 6.a shows a similar evolution of traffic flows in the highway for the personal car and inter-communal taxi. From 2-3 pm a decrease in traffic is observed for different vehicle type with the exception of intra-communal sedan taxi. Traffic flow on main road are more important than secondary road for personal cars, Minibus and heavy car (Figure 6b). The opposite trend is observed for intra-communal sedan taxi. Furthermore, the important personal cars flows of each road type is observed at 6-7am and 5-6pm and corresponds to peak hours. Intra-communal sedan taxi corresponds both peak and off-peak hours (10-11am, 4-5pm, 6-7am and 5-6pm).

Table 2 summarised the total traffic flow per classes of road and per type of vehicles. The minimum and maximum of total traffic flows are respectively 700 vehicles (on the backstreet) and 78360 vehicles (on the highway) per half-day (6 am to 6 PM) Personal cars contribute to the high traffic flows over the highway, boulevard and backstreet while intra-communal sedan taxi are more important in the main and secondary roads.

3.3. Composition and information of fleets from survey

The survey revealed that for each class of vehicles (Personal car, intra-communal sedan taxi "Woro woro", inter-communal taxi, Minibuses "Gbaka", and heavy vehicle), more than 60% of vehicles are older than 10 years (Table 3). The age of some vehicles like personal car (1%) and heavy vehicle (3%) are sometimes beyond 30 years old. The older of engine can conduced to poorly burnt fuel and allowed high consumption [41]. Moreover, survey revealed that 100 % of the intra-communal sedan taxi, inter-communal taxi, Minibuses and heavy vehicle use gasoil while Personal cars use gasoline at 26% and 74% gasoil. However, at the country level, reports estimated 58% of vehicles used gasoil against 39% using gasoline [33]. In Senegal for example, gasoline vehicles are estimated to be 60% of the national fleet [37]. Since the SICTA's values are based on the number of vehicles controlled, the difference in fuel proportions could be explained by not taking into account uncontrolled or non-conventional vehicles. In West Africa, vehicle age tends to be somewhat higher with some minibuses being 20 years old [6]. Also, gasoil used by transportation cars such as intra-communal sedan taxis minibuses and buses can be explained in the relatively low coast of diesel compared to gasoline. This difference in price contribute to high usage of gasoil in

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many West African countries where poverty is high and ecological and environmental concerns are not yet well spread in population. However, over the last 10 years, gasoline and gasoil prices are very similar [42–44] and the SICTA has underlined an increase in gasoline vehicles (report SICTA, [33]).

3.4. Fuel consumption (C_{day}) and travelling time (t_p).

The quantity and type of fuel consumed per sort of vehicles was collected during the survey. Because vehicles are not running continuously through a given day (24hours), the daily consumption (C_{day}) of a car is defined as the amount of fuel consumed by the vehicles during its travelling time (t_p). Given the key importance of the travelling time or the actual period in which the vehicle is running to estimate C_{day}, the starting and stopping times for each vehicle type were recorded during the field campaign. Depending on the activity of each driver, travel time varies. A summary is provided in Table 4. It is also worth to note that the starting and stopping times may vary from one driver to another but with the same travel time means. For example, the public transport vehicles such as intra-communal sedan taxi, inter-communal taxi, minibus and bus, start between 4 AM and 5 AM and end at 9 PM and 1 AM. The highest t_p is recorded for inter-communal taxis (19 hours), while the lowest t_p belong to personal car (3 hours). Similar t_p is observed for heavy vehicle, minibus and Intra-communal sedan taxi and presents gap different. The range of t_p is estimated between 12 and 19 hours for minibus, 14 and 21 hours for intra-communal sedan taxi, 13 and 22 hours for inter-communal taxi, 1 and 4 hours for Personal car and 6 and 24h for heavy vehicle. Again, high variability is observed in the C_{day} of heavy vehicles compared to public transport vehicles (Intra-communal sedan taxi, inter-communal taxi and Minibus), underlined by their high difference between maximum and minimum values. The range of C_{day} (inliter per day, hereafter L day^{-1}) for Intra-communal sedan taxi, inter-communal taxi and Minibus is recorded between 20 and 61 L.day^{-1}, 17 and 35 L.day^{-1} and 18 and 53 L.day^{-1}respectively. Highest C_{day} value is 56 L.day^{-1} and corresponds to heavy vehicle. The range of heavy vehicle is estimated between 5 and 100 L.day^{-1}, which is explained by their weight and powerful engine. The lowest value of 15 L.day^{-1} is observed with Personal cars using gasoline and the range is estimated to 1 and 53 L.day^{-1}. This lowest C_{day} found with Personal cars is in agreement with the fact that it is well established that diesel engines consumed more than gasoline engines, because it's the most frequently used [43,45,46]. Fuel consumption in Yopougon is related to vehicle type, travelling time and the vehicle's age. In addition, fuel-consumption rate increases with its weight and decreases with vehicle's technology and electronic diesel engine control [47–50].

3.5. Which implication for emission estimate in African cities?

The inventory of emission in Africa especially across West Africa still have uncertainties related to the methodology applied ("bottom-up" and "top down"), the emission factors, the fuel consumption, the spatial keys and the annual registrations of vehicle by country [11,12,51]. Many works [2,11,18,19] focusing on the inventory of African anthropogenic emissions, by lack of local and well documented information relied on national, regional and international reports which have significant limitations. Often, information is collected by non-scientists who are not aware of importance and accuracy in data and the implications for research. This study aimed to provide a very first details information on some of the key parameters that impact the estimation of anthropogenic emission. The availability of information about the age of vehicles, the quantity and quality of fuel consumed, the traffic flow, and the type of the road, may help the scientists to improve the inventory of emissions and limit the uncertainties link to the existing data-base all over Africa. Though this study did not investigate, emissions factors (one of the key points in emission inventories establishment), our study showed that the proportion of vehicles using gasoil may be underestimated in the available traffic emission inventories. Diurnal information about traffic flow and daily fuel consumption and activity may help providing accurate daily emission. Additional information about vehicles age underlined the important proportion of aged cars in West African vehicles fleets. Despite the limited period of measurement (22nd February to 7th April 2016) and shortcomings related to the hourly vehicle counting methodology manually, the non-consideration of weekend and holidays during measurement, basic statistics and survey information that are the limitation of this study, preliminary results presented here will surely be useful for building and/correcting emission inventories for African cities. Future work will assess the impacts and/or implications that information provided here will have on a local traffic emission inventories.

4. Conclusions

The results, based on a combination of survey and vehicle counting, during a field campaign in urban area of Yopougon (Abidjan, Cote d'Ivoire) from 22 to 26 February 2016, are provided like very first details local information on some of the key parameters that attempt to measure and quantify vehicular emission and incorporate them into urban emission inventory. A classification of vehicles was carried out, in order to know each vehicle flow or volume type contribution by traffic road type. The presence of all vehicle types is observed over classes of road. Also, highway, boulevard and backstreet contribute to the high traffic flows for the Personal car whereas high flows of intra-communal sedan taxi is recorded by a main and secondary road. Minimum and maximum of hourly traffic flows is 7 vehicles/hour at 10 – 11am and 8099 vehicles/hour at 9 – 10am respectively, on the backstreet and highway respectively. Structures with one peak (Backstreet at 6 - 7 AM, main road at 10 - 11 AM and boulevard at 5 - 6 PM) or two peaks (Highway at 9 - 10 AM and 5 - 6 PM, and secondary road at 4 - 5 PM and 5- 6 PM) are shown in the traffic flows of each road type and hour. Moreover, the proportion of vehicles using diesel is underestimated, compared to the national fleet. Thus, survey revealed that 100 % of the intra-communal sedan taxi, inter-communal taxi, Minibuses and heavy vehicle use gasoil while Personal cars use gasoline at 26% and 74% gasoil. The highest daily fuel consumption value of 56 L.day^{-1} is recorded heavy vehicles whiles the lowest value of 15 L.day^{-1} is recorded for personal car using gasoline. In addition, the highest t_p is recorded for public transport vehicles such as inter-communal taxis (19 hours), while the lowest t_p belong to personal car (3 hours). This study may be useful for the improvement of uncertainties related to the different databases used to estimate inventories emissions either national or international reports. It may also be useful for decision makers for vehicular emission reduction policy elaboration for West African cites, especially Abidjan.

4.1. Figures, Tables and Schemes

All figures and tables should be cited in the main text as Figure 1, Table 1, etc.

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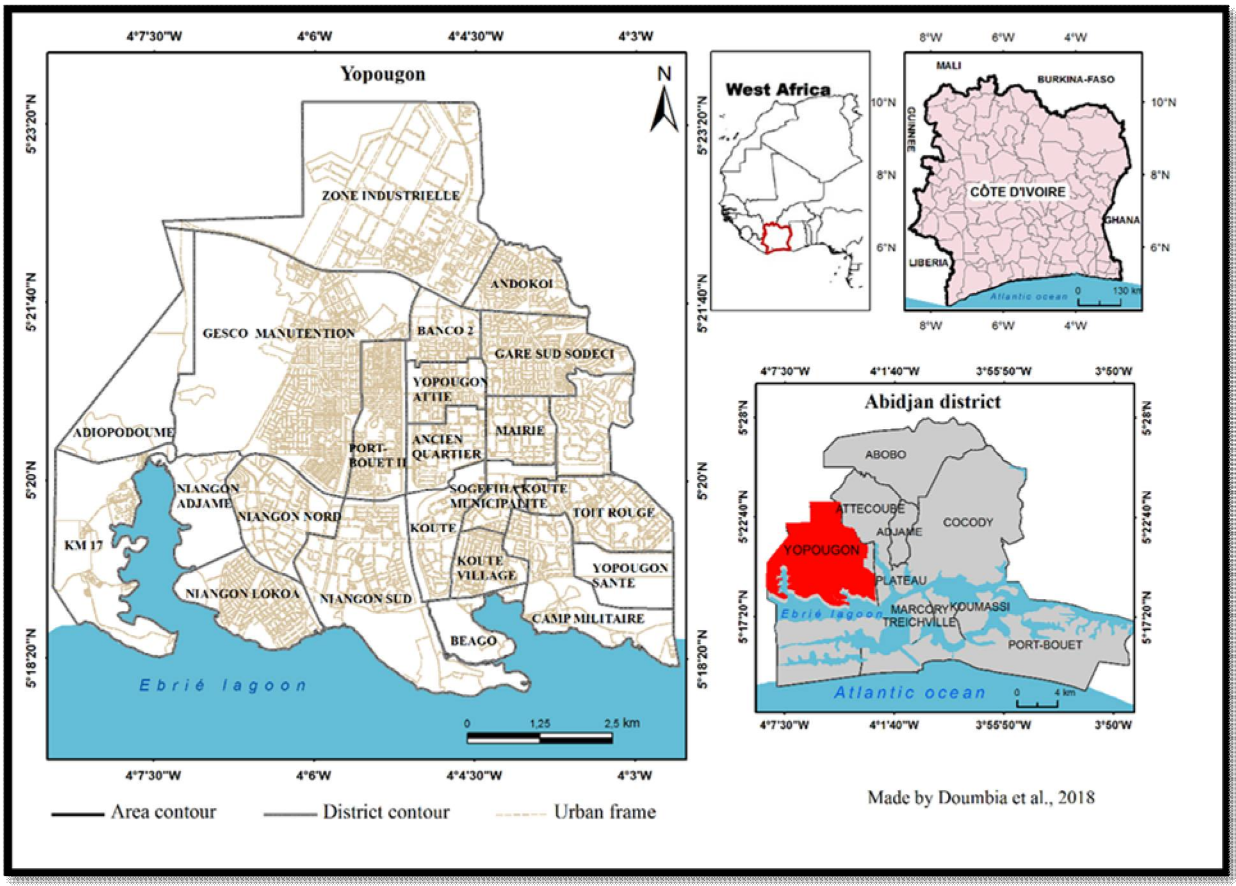

Figure 1: Map of study Area (Yopougon in red) showing the 23 administrative districts. Yopougon is one of the 10 communes of the city of Abidjan. Yopougon is a coastal municipality, is the largest and most extensive of the 10.

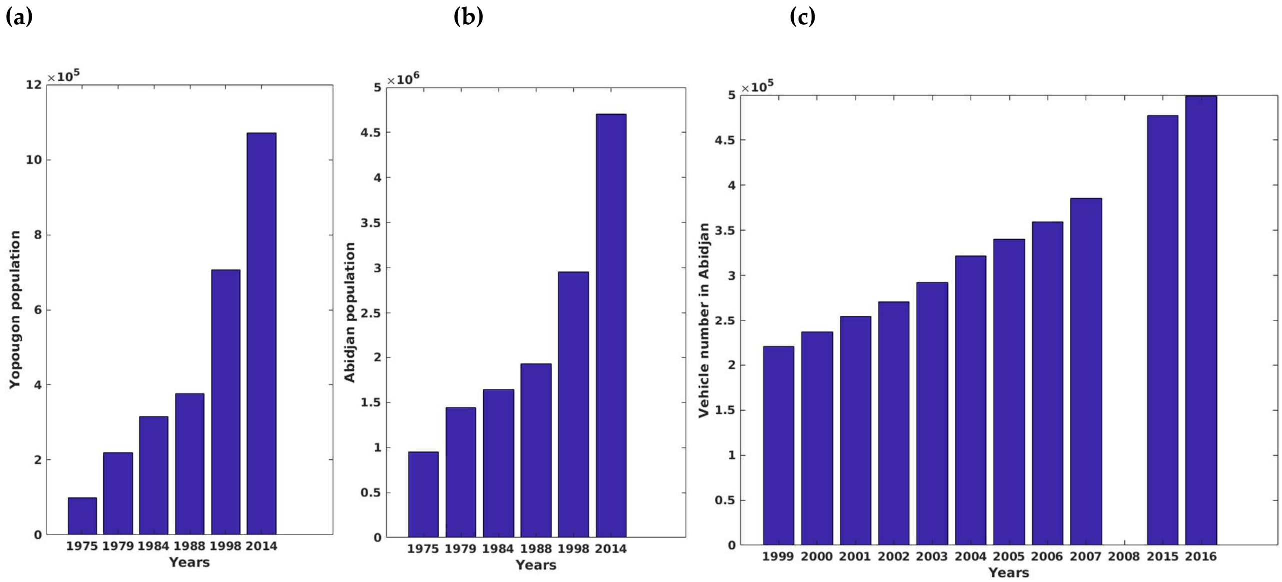

Figure 2: **(a)** Population growth in Yopougon; **(b)**Population growth in Abidjan; (c) Evolution of vehicle fleet in Abidjan (SICTA, 2008, 2016; Désiré, 2012). Missing data (Not a number (NA)) between 2008 and 2014.

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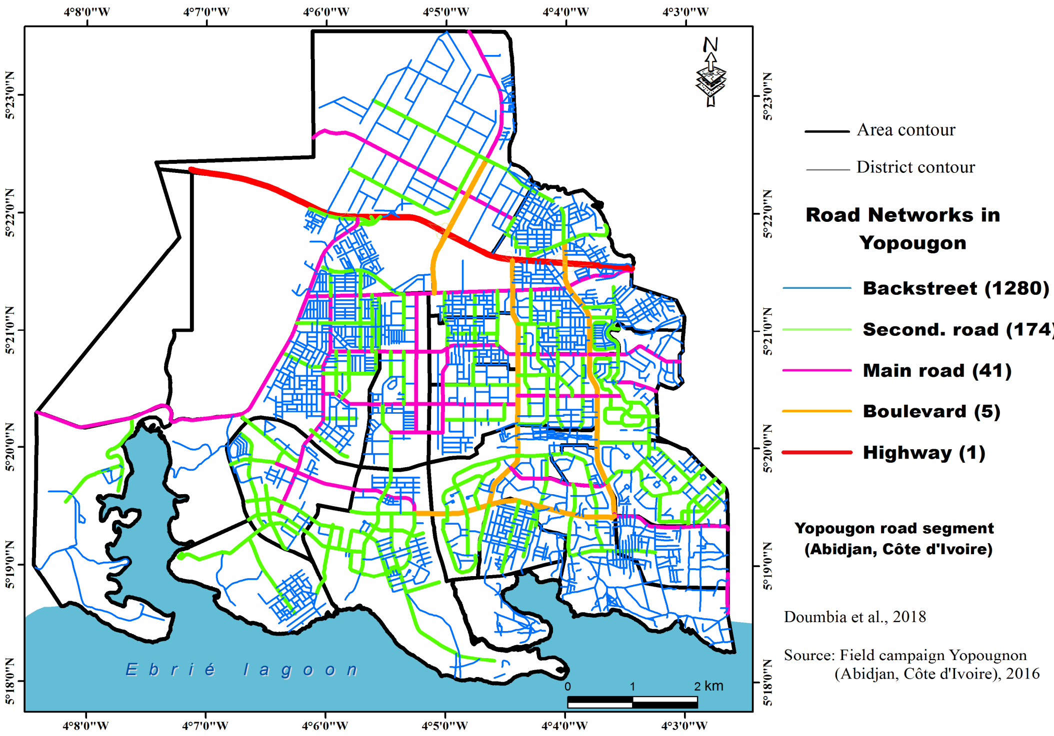
(a)



(b)

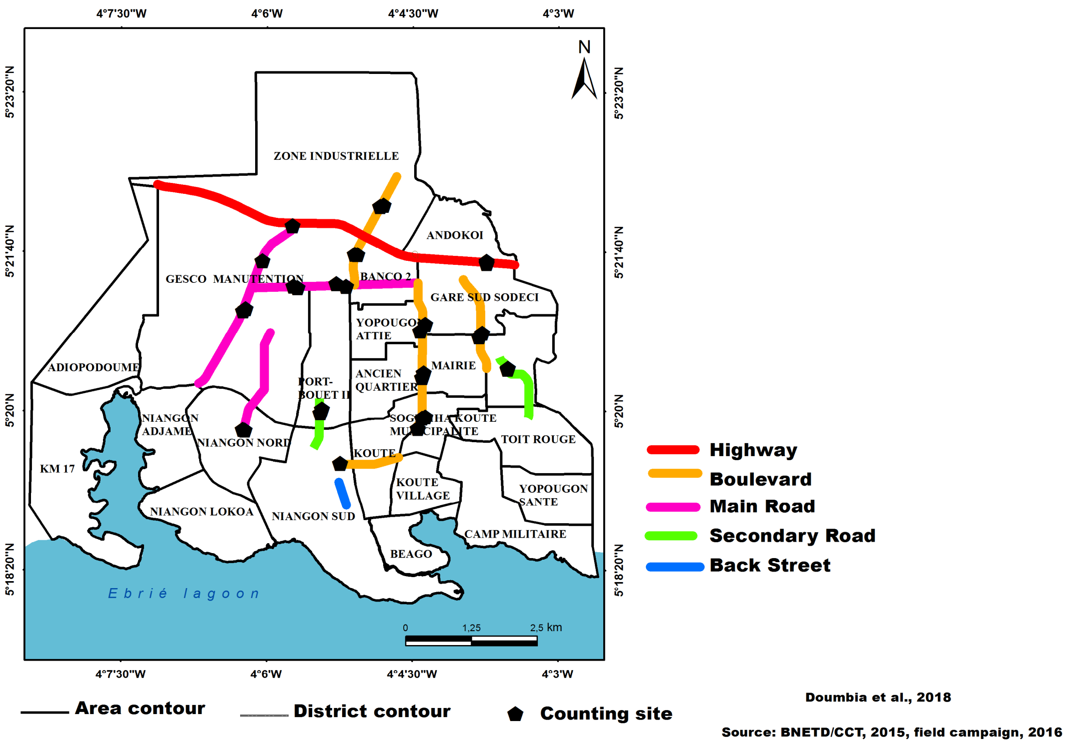


Figure 3: **(a)** Different road types of road network in Yopougon. Red line represents the highway, blue line is for back street, Pink line is the main road, green and orange are the secondary road and boulevard respectively.

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Number of road segment of each road type are in bracket; **(b)** Location of counting point of vehicle fleet composition over several road type in Yopougon.

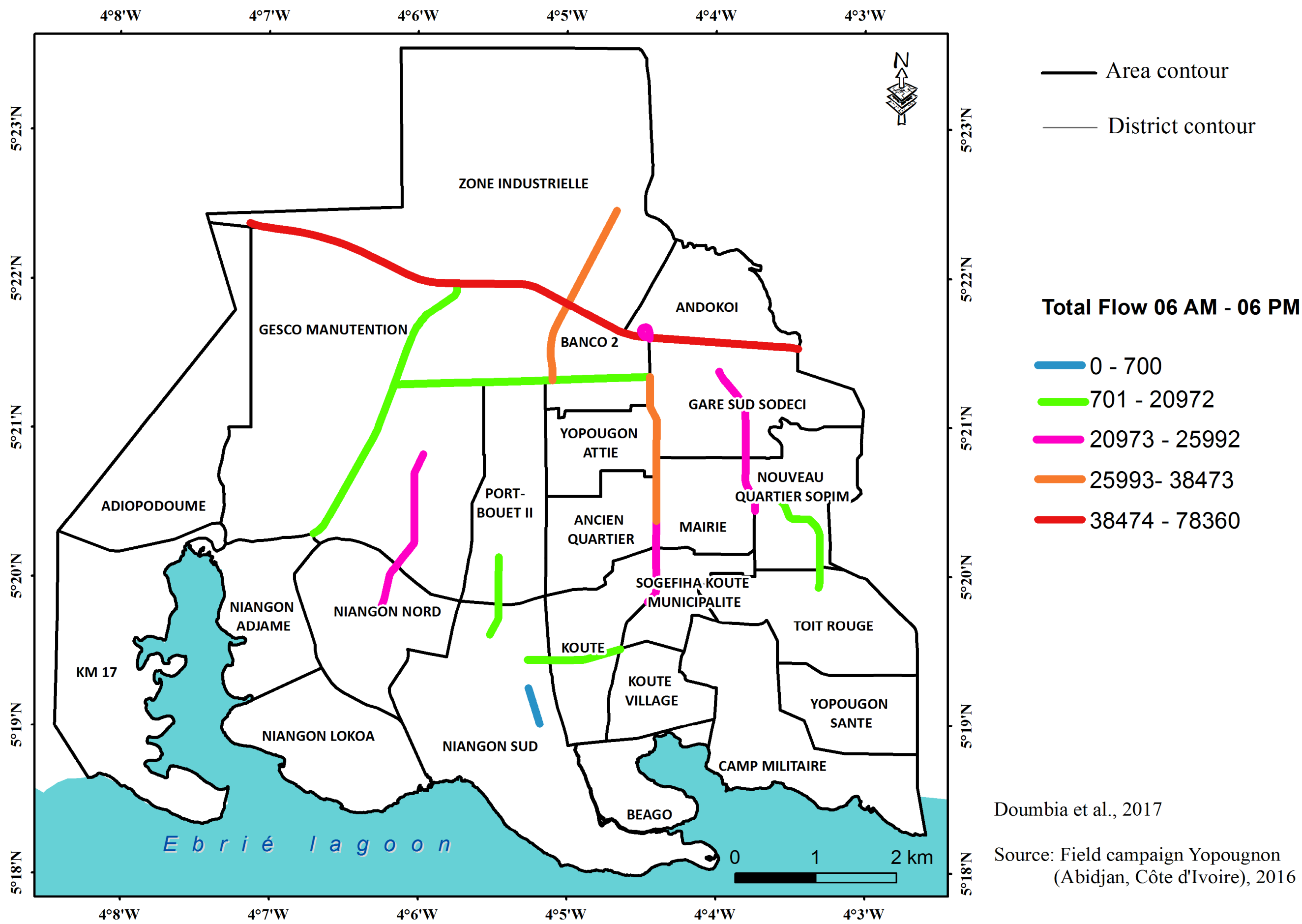

Figure 4 : Traffic flow rate on various road types in Yopougon. Red line represents the high road, blue line is for backstreet, orange, mango, green and blue turquoise lines are the overpass, main road, secondary road and boulevard

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(a) (b)

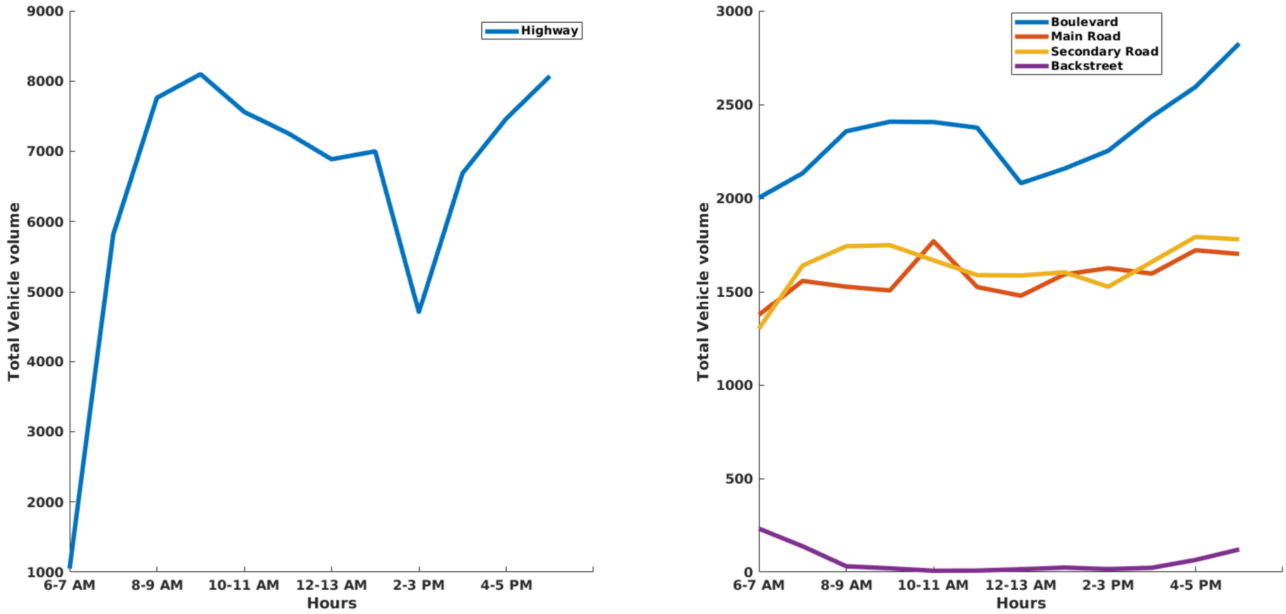

Figure 5 : (a) and (b) represent average total traffic flow per highway and boulevard, Main road, secondary road and backstreet, respectively.

(a) (b)

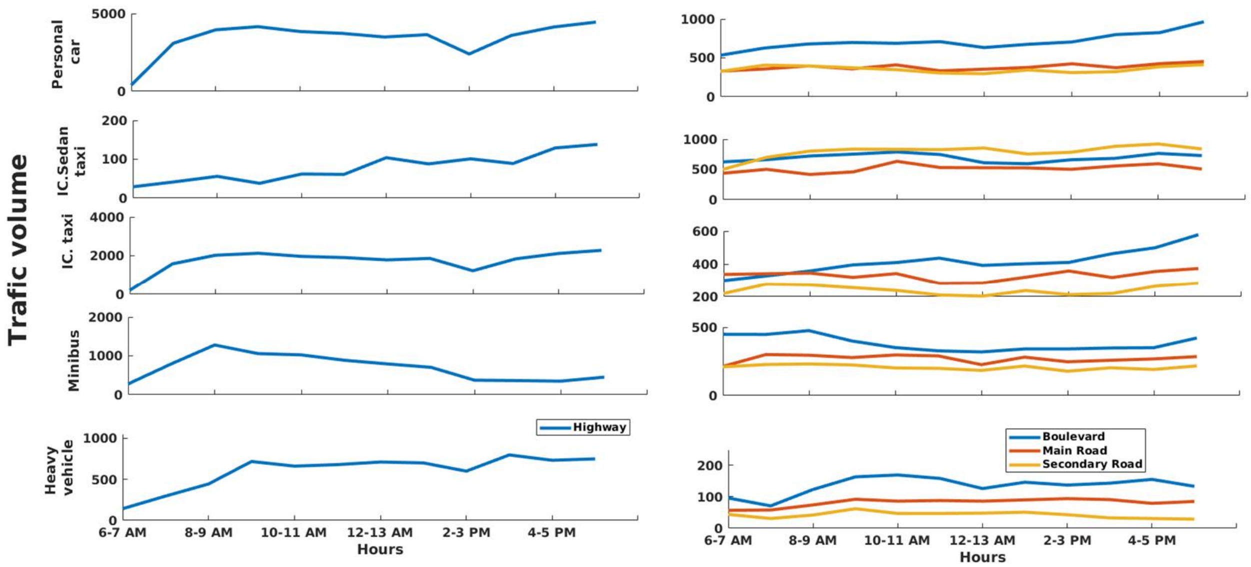

Figure 5 : (a) and (b) represent traffic flow of each vehicle class per type of road. Highway (left column) and boulevard, Main road, secondary road and backstreet (right column). From top to down respectively, personal car, Intercommunal sedan taxi, Intercommunal taxi, minibus and heavy vehicles.

Table 1: Comparison study with BNETD data collected in August 2014 over a highway in Yopougon

Counting Time	Personal car	Intra-communal sedan taxi " Wôro wôro "	Inter-communal Taxi	Minibus "Gbaka"	Heavy vehicle (car, bus and truck)	**Total**
Feb. 2016 06-18h	40863	937	20979	8363	7218	**78360**
Aug. 201406-20h	28539	0	14631	9281	7707	**60158**

Table 2 : Characterization of traffic flow total per clases of road and type vehicle (in bold the contribution in vehicle type for each road class).

Road Type	Total	Personal car	Intra-communal sedan taxi "Wôro wôro"	Inter-communal Taxi	Minibus "Gbaka"	Heavy vehicle (car, bus and truck)
Highway	78360	**40863**	937	20979	8363	7218
Boulevard	196210	**59960**	58363	34571	31975	11341
Main road	91329	23192	**28186**	20009	14907	5035
Secondary road	39276	8464	**19060**	5782	4959	1011
Backstreet	700	**370**	50	245	25	10

Table 3 : Repartition of the vehicle fleet and percentage by motorization type and age

Vehicle type	Engines	Age (%)	
		0 - 10 years	More than 10 years
Personal car	74% Diesel and 26% Gasoline	33	67
Intra-communal sedan taxi	100% Diesel	36	64
Inter-communal Taxi	100% Diesel	37	63
Minibus	100% Diesel	42	58
Heavy vehicle	100% Diesel	36	64

Table 4: Daily fuel consumption (C_{day}) and traveling time (t_p) for vehicle type, MIN and MAX represent the minimum and maximum of (C_{day}) and (t_p) respectively.

Vehicle type	Personal car		Intra-communal sedan taxi	Inter-communal taxi	Minibus	Heavy car
G: Gazoline; D: Diesel	(74%D)	(26%G)	(100%D)	(100%D)	(100%D)	(100%D)
Number of questionnaires sampled	142	49	75	24	145	37
Daily fuel consumption for a given vehicles	21	15	23	29	40	56
C_{day} (MIN)	1	1	17	20	18	5
C_{day} (MAX)	70	53	35	61	53	100
Daily average traveling time (hour) (t_p)	3	3	16	19	16	16
t_p (MIN)	1	1	14	13	12	6
t_p (MAX)	4	4	21	22	19	24

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