Open Journal of Air Pollution, 2019, 8, 108-117
https://www.scirp.org/journal/ojap
ISSN Online: 2169-2661
ISSN Print: 2169-2653

Exposure to $PM_{2.5}$ Related to Road Traffic: Comparison between Crossroads and Outside of Crossroads at Cotonou, Benin

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How to cite this paper: Houngbégnon, P., Ayivi-Vinz, G., Lawin, H., Houessionon, K., Tanimomon, F., Kêdoté, M., Fayomi, B., Dossou-gbété, S. and Agueh, V. (2019) Exposure to $PM_{2.5}$ Related to Road Traffic: Comparison between Crossroads and Outside of Crossroads at Cotonou, Benin. *Open Journal of Air Pollution*, **8**, 108-117.
https://doi.org/10.4236/ojap.2019.84006

Received: May 27, 2019
Accepted: November 9, 2019
Published: November 12, 2019

Abstract

Background: Several studies have analysed the pollution issues owing to road traffic in Cotonou, Benin. Concentration levels of particles are higher on high traffic than a low traffic. The exposure of human populations to air pollution is more intense on the roads. In Benin, the density of traffic on the crossroads is indeed more important. Are traffic locations such as crossroads, areas where the level of exposure $PM_{2.5}$ is increased? **Methods:** This study was conducted along the 5 km high-traffic road in the city of Cotonou. It is a high traffic lane with two crossroads. Sampling and measurements were carried out in dry season (January and February) and rainy season (June and July). For each season the measurements were made over two months from 7 am to 9 pm. $PM_{2.5}$ measurements were made at different locations at crossroads and also along the track. To compare concentrations of $PM_{2.5}$ at crossroads and outside of roundabout, we used the Generalized Linear Mixed Model. **Results:** In the rainy season the $PM_{2.5}$ hourly concentrations ranged between 400 μg/m^3 and 500 μg/m^3 while in the dry season 100 μg/m^3 and 300 μg/m^3. In the rainy season, the average of $PM_{2.5}$ concentration was 463.25 ± 66.21 μg/m^3 at crossroads and 264.75 ± 50.97 μg/m^3 outside of crossroads. In the dry season, the average of $PM_{2.5}$ concentration was 232.75 ± 97.29 μg/m^3 at crossroads and 123.31 ± 63.79 μg/m^3 outside of crossroads. Both in dry and rainy seasons, $PM_{2.5}$ concentration level peaks are observed from 7 am to 9 am and from 7 pm to 9 pm. The Generalized Linear Mixed Model showed that there is high significant difference between concentrations of $PM_{2.5}$ at crossroads compared to outside of crossroads. Occupation of the roadside (in particular crossroads) for various economic activities is common practice in Cotonou thus health risk for people working around crossroads increases. **Conclusion:** Locations such as crossroads are areas where the level of exposure $PM_{2.5}$ is highest on road traffics.

Keywords

Air Pollution, $PM_{2.5}$, Crossroads

1. Introduction

Urban population growth has caused the need for the increase in means of transport, especially in the absence of an organized system of public transport. The motorcycle taxis, expanding in several West African capitals provide cross-country mobility of the populations. These social facts contribute to enhance the level of air pollution in most urban areas in particular in Benin West Africa [1] [2].

The theme of air pollution has been widely explored in Benin [1] [3]-[11]. Several studies have analysed the issue of air pollution related to road traffic in Cotonou and the exposure of motorcycle taxi drivers to Benin. These air pollution studies focus primarily on measuring the air concentration of carbon monoxide (CO), sulphide dioxide (SO_2) on the one hand, and the study of perceptions and exposure of populations, on the other hand. The research reveals that in Benin the level of gases (CO, SO_2) is considerably higher than the environmental standards in force, especially on the roads [12]. In addition, there has few works on fine particles such Particulate Matter ($PM_{2.5}$). In 2018, a comparative study of $PM_{2.5}$ concentrations in the cities of Cotonou and Abidjan shows that the concentration of $PM_{2.5}$ is three times higher than the concentrations recommended by the World Health Organization. In addition, there is a significant difference in carbon aerosols between the Abidjan and Cotonou circulation sites. The average OC/EC ratio averages 4.0 for Cotonou and 2.0 for Abidjan, which clearly indicates the higher contribution of emissions from two-wheeled motorcycles in Cotonou compared to Abidjan [7]. For two decades, Benin's main cities have been experiencing an explosion in the number of motorized vehicles whose average age is very high as a result of urbanization. These second-hand vehicles imported from Europe or America, as well as motorcycles, have become the most used means of transport in Benin [13] [14] [15]. Thus, land transport is the primary source of ambient air pollution by exhaust gases followed by industrial activities and other anthropogenic activities [12] [16]. It is obvious that the roads in Cotonou are places at high risk of exposure of the population. The exposure of the population to air pollution on the roads is more intense according to schedules. Indeed, the level of pollutant in the air is higher on working days than on weekends. Similarly, the level of particle concentration is higher on high traffic than on low traffic [12]. In addition, the occupation of the roadside for various economic activities is common practice in Cotonou. The exposure of urban populations to fine particles ($PM_{2.5}$) is therefore a current public health problem in Benin, particularly in Cotonou.

Although few in West Africa, particularly in Benin, studies on $PM_{2.5}$ concentrations in outdoor air show that factors such as season, intensity/density of road traffic, wind, temperature. For example, the study by Wu, McNaughton [17] assessed the vertical distribution of $PM_{2.5}$ and found that road traffic pollution has a small influence on ambient air exposure in the homes of participants in the area study. However, considering individual exposure and factors such as wind and traffic density, exposure to $PM_{2.5}$ becomes important [17]. A study in Canada of $PM_{2.5}$, NO_2 and Black Carbon concentrations in vehicles in circulation showed that $PM_{2.5}$ and NO_2 concentrations in vehicles exceeded the level of regional concentrations. In addition, $PM_{2.5}$ and Black Carbon have higher concentrations inside vehicles than outdoors (>15%); this according to the traffic density [18]. A study in Turkey has shown that the daily values of PM 10 and $PM_{2.5}$ exceed the recommendations of the European Union and especially in winter [19]. The same results were found in Marseille but only on $PM_{2.5}$ [20].

Exposure to $PM_{2.5}$ causes many health risks. After finding non-standard concentrations of $PM_{2.5}$ in the air, one study found that chronic exposure to $PM_{2.5}$ is associated with mortality in the eastern and central United States [21]. Similarly, Dziubanek and Spychala [22] have confirmed a link between life expectancy and long-term inhalation of PM_{10} with a higher risk in women. This result was reiterated by another study that focuses on the development of cardiovascular diseases [23]. Fuertes and Bracher [24] specify, from the paralleling of air quality and spirometric data, that long-term exposure to NO_2 and $PM_{2.5}$ contributes to weakening pulmonary function in the less of 15 years while identifying asthmatics as the most at risk population which has been corroborated by another study on health effects [25].

Indeed, the roadsides are places where many sellers settle to perform their daily activities. The bottleneck of markets and the desire to ensure proximity with customers are factors that perpetuate the phenomenon of occupation of the roadside. The finding is that crossroads and roadsides are favorite sites for sellers and shops selling all kinds of items. The various health risks to residents living near road traffic are a major public health concern in Benin's socio-economic context.

In this case in Cotonou, Benin, crossroads are points of high traffic. The density of traffic on the intersections is indeed more important. Are road locations such as intersections areas where the $PM_{2.5}$ exposure level is increased? Are people who work on the roadside more exposed according to traffic intensity schedule? The interest of this work is to study the concentrations of $PM_{2.5}$ and the risk of exposure of the occupants near the roads according to the road locations and traffic intensity schedule in the city of Cotonou.

2. Materials and Methods

2.1. Study Areas

The study took place in Cotonou, economic capital of Benin republic. Located in the department of "Littoral", this city is heart of economic activities of people living in Cotonou and areas nears. The measurements were done along one of the main traffic road through the downtown (**Figure 1**). The traffic on this road is very high throughout the day because it serves the largest market and the port in the city. Two crossroads R1 and R2 been considered along this road. For each crossroad, two points were chosen before and after to measure the exposure of $PM_{2.5}$ outside the crossroad. **Figure 1** illustrates the points of measure chart along the road.

2.2. Study Site and Data Collection

$PM_{2.5}$ concentrations were measured with Quest 3M, a handy portable device that continuously measures different air quality parameters with the desired measurement time. Measurements were carried out in dry season and rainy seasons. For each season the measurements were made over two months either one week per month. For each week measurements were carried out from Monday to Saturday from 7 am to 9 pm. This time slice was chosen because it determines the period of significant human activity in the study area. The device was placed at 1.5 meters on floor and calibrated to record the data at 5 minutes interval. Measurements were carried out in January and February 2018 (dry season) and June and July 2018 (rainy season).

2.3. Statistical Analysis

The average concentrations of $PM_{2.5}$ on hourly basis at each point were graphically represented using GraphPad software Prism 6 and Ms-Excel 2016. The Generalized Linear Mixed Model was used to identify factors influencing the level

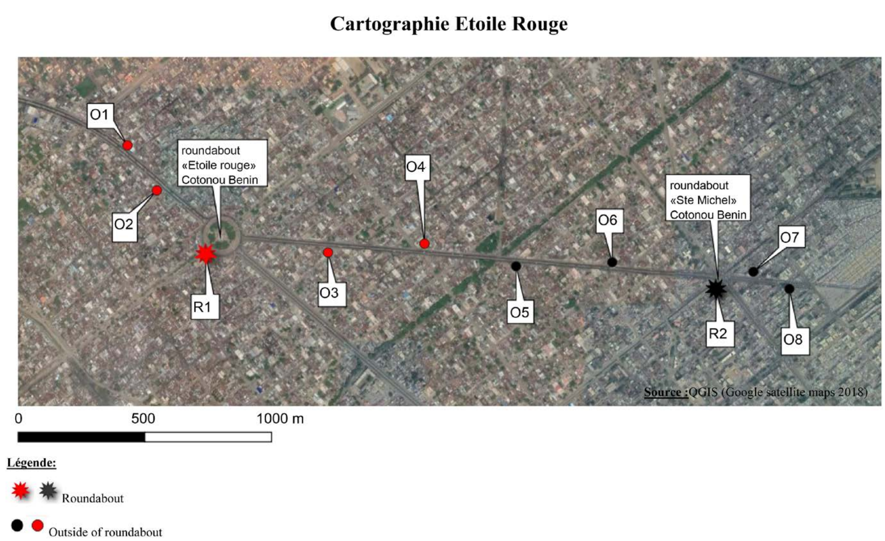

Figure 1. Different points of measure along the road.

of $PM_{2.5}$ concentrations along road traffic. The dependent variable was concentration of $PM_{2.5}$. The explicative variables were location (L) and season (S). L was dichotomized in crossroads and outside roundabout. S was dichotomized in dry and rainy season. Statistical analyzes were performed using package lme4 in R3.5.1 and $p < 0.05$ was considered significant.

3. Results

3.1. Hourly Variations of $PM_{2.5}$ Concentrations

In the rain season the $PM_{2.5}$ hourly concentrations ranged between 400 μg/m^3 and 500 μg/m^{3}while in the dry season hourly $PM_{2.5}$ concentrations recorded ranged between 100 μg/m^3 and 300 μg/m^3. It can also be observed in Figure 2 and Figure 3 that from 7 am to 9 pm the variations were remarkable in the dry season compared to the rainy season. In dry season and rainy season, peak value (respectively 244.45 ± 37.19 μg/m^3 and 468.08 ± 14.71 μg/m^3) was observed between 7 am and 9 am. From 10 am, a continuous decrease in the average hourly concentration was observed. Then, starting at 6 pm, the $PM_{2.5}$ concentration levels begin to rise again, reaching a peak between 7 pm and 9 pm respectively 177.88 ± 53.65 μg/m^3 and 466.07 ± 12.87 μg/m^3.

3.2. Concentrations of $PM_{2.5}$ According along the Road

Levels of $PM_{2.5}$ concentrations were appeared to be higher in the rainy season compared to dry season (see Figure 4 and Figure 5). At crossroads, the average of $PM_{2.5}$ concentration was 463.25 ± 66.21 μg/m^3 in the rainy season against 232.75 ± 97.29 μg/m^3 in the dry season ($p < 0.001$). At outside of crossroads, the average of $PM_{2.5}$ concentration was 264.75 ± 50.97 μg/m^3 in the rainy season against 123.31 ± 63.79 μg/m^3 in the dry season ($p < 0.001$).

Whether in the dry season or the rainy season, the average concentrations of $PM_{2.5}$ were seemed to be more important at the crossroads than outside the crossroads. This was confirmed through the Generalized Linear Mixed Model of analysis (GLMM).

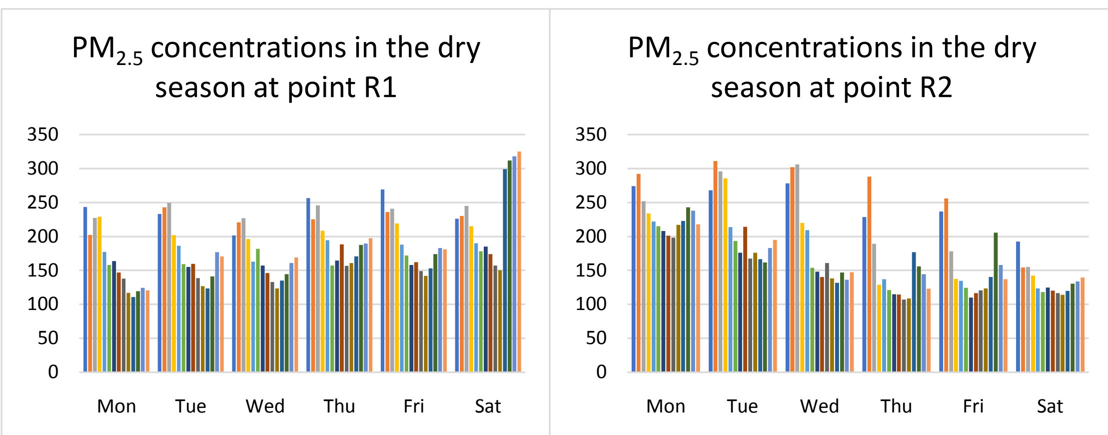

Figure 2. Hourly concentrations of $PM_{2.5}$ in dry season from 8 am to 9 pm.

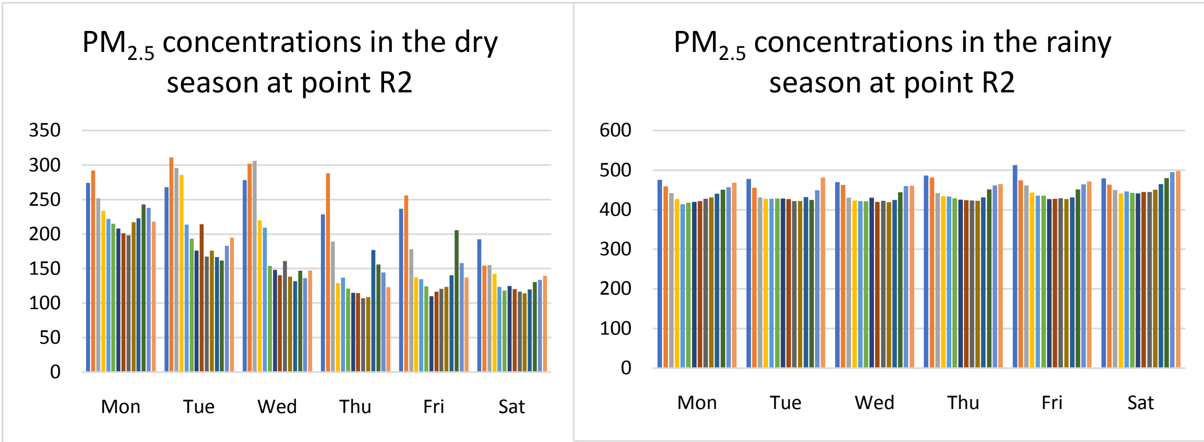

Figure 3. Hourly concentrations of $PM_{2.5}$ in rainy season from 7 am to 9 pm.

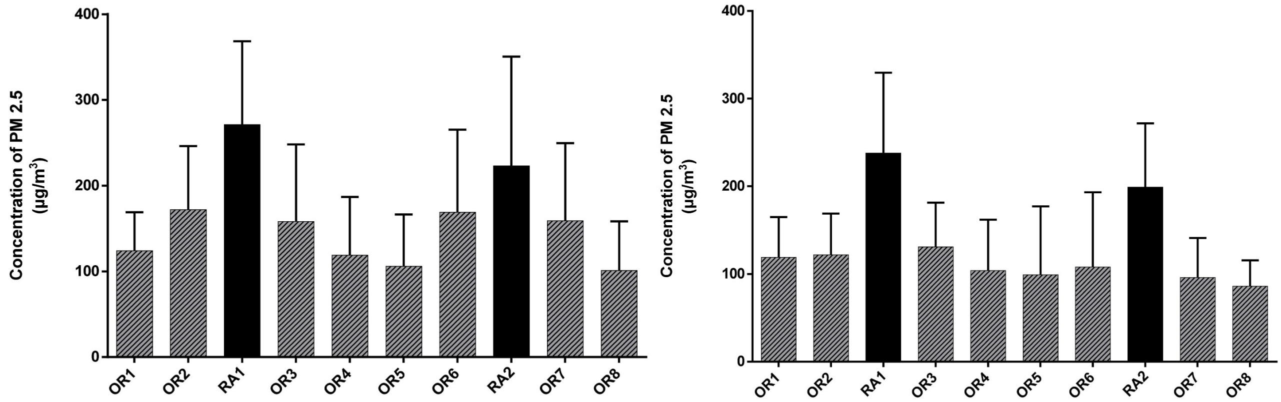

Figure 4. Concentrations of $PM_{2.5}$ along the road in January and February (dry season).

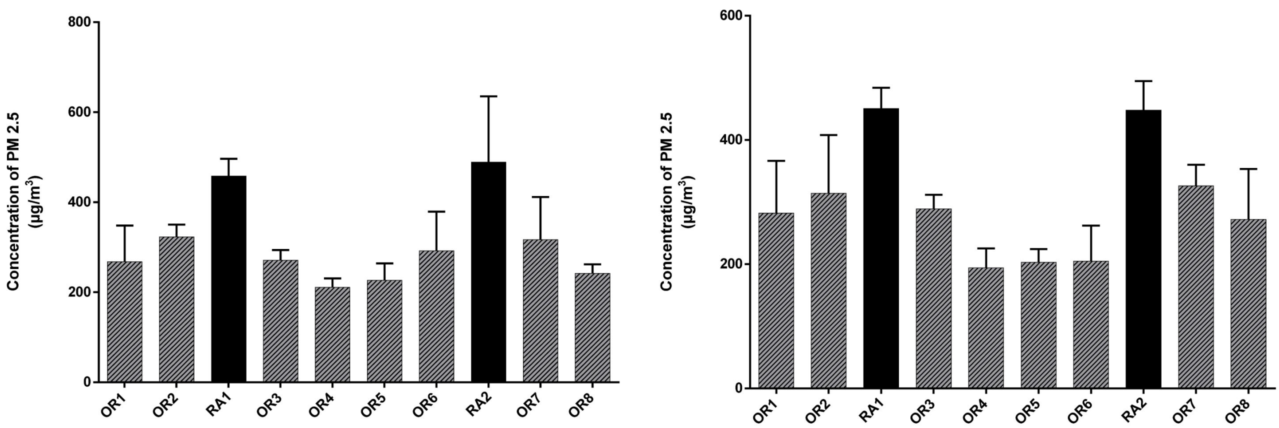

Figure 5. Concentrations of $PM_{2.5}$ along the road in June and July (rainy season).

The result of Generalized Linear Mixed Model showed that there was high significant difference between concentrations of $PM_{2.5}$ at crossroads compared to outside of crossroads on the one hand and on the other hand, there was high significant difference between concentrations of $PM_{2.5}$ in the dry season compared to the rainy season (see Table 1).

Table 1. Result of generalized linear mixed model.

		Coefficient	95% of IC	p-value
	Intercept	114.61	[96.85; 132.36]	0.000
Place	Outside of crossroad			
	Crossroad	152.97	[123.38; 182.56]	0.000
Season	Dry season			
	Rainy season	158.85	[135.18; 182.52]	0.000

4. Discussion

The purpose of this study was to study the concentrations of $PM_{2.5}$ and the risk of exposure of the occupants near the roads according to the road locations and traffic intensity schedule in the city of Cotonou. After the collection, processing, and analysis of the data, it appears that:

- In the rain season the $PM_{2.5}$ hourly concentrations ranged between 400 µg/m^3 and 500 µg/m^3;
- In the dry season hourly $PM_{2.5}$ concentrations recorded ranged between 100 µg/m^3 and 300 µg/m^3;
- There was high significant difference between exposition of $PM_{2.5}$ in the dry season compared to the rainy season (p-value = 0.000, α = 5%);
- There was high significant difference between exposition of $PM_{2.5}$ at crossroads compared to outside of crossroads (p-value = 0.000, α = 5%);
- $PM_{2.5}$ concentrations highest level is observed in the schedules 7 am to 9 am and 7 pm to 9 pm.

Thus, the objectives of this study were achieved, looking the main results.

4.1. Strengths and Limitations of Study

Measurements of the concentration of $PM_{2.5}$ in air were made using suitable devices for measuring the concentration of air pollutants. The measurements were carried out by personnel trained in the handling of these devices. The use of the same devices when collecting data on the various targeted points, the meticulous verification of the data entered have made it possible to minimize the risk of erroneous data. In addition, the use of the statistical model Generalized Linear Mixed Model, to determine a predictive model of the concentration level of $PM_{2.5}$ based on road locations and the season is one of the main strengths of this study.

4.2. Factors Influencing $PM_{2.5}$ Concentration of Air

This study highlights factors that influence air $PM_{2.5}$ concentrations, including the season, the time of day, and road locations.

The level of $PM_{2.5}$ concentrations in the rainy season is significantly above the level in the dry season. In 2008 and 2009, through a study conducted in the city of Eskişehir, central Turkey, they found that concentrations of all the pollutants such nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter ($PM_{2.5}$ and

PM_{10}) showed a seasonal pattern increasing in winter period, except for ozone (O_3) having higher concentrations in summer season [19]. The similarity between the results is due to the fact that winter corresponds to rainy season in tropical areas. The high concentrations observed in the rainy season can be explained by the wet conditions. Indeed, moisture does not facilitate the dispersion of particles.

Further results, showed that others factors taking count of daily characteristics like winds. Indeed, authors highlighted that adding temporally-averaged vertical air pollution data had a small effect on residential ambient exposures for their population; however, greater effects were observed when individual days were considered (e.g., winds were off the highways) [17].

In urban areas such as the city of Cotonou, the intensity of road traffic varies according to peak hours. These are schedules that coincide with the hours of work start and the hours of closure. This explains the two peak periods of $PM_{2.5}$ concentrations, especially in the morning between 7 am and 9 am and in the evening between 7 pm and 9 pm. The traffic flow at these times of the day is intense because of shoreline travel to their place of professional activity, and schools, for example. In addition, the fact that official working hours in Benin are from 8 am to 6:30 pm, reinforces the density of road traffic observed at these times of the day.

In addition, the crossroads are rallying points of the main roads of the city, so it is obvious that it represents locations where road traffic is particularly dense compared to other urban roads. The high $PM_{2.5}$ concentrations measured at the roundabout site are thought to be due to these characteristics of the crossroads of the city of Cotonou.

5. Conclusion

Locations as crossroads are areas where the level of exposure $PM_{2.5}$ is highest on road traffics. This research highlights significant difference exists between exposition to $PM_{2.5}$ at crossroads compared to outside of crossroads, particularly rainy season. Further research should be realized to better understand factors influencing population exposure to $PM_{2.5}$ in African urban areas.

Acknowledgements

"Le financement de cette étude a été accordé par le Centre de Recherches pour le Développement International (CRDI) dans le cadre du projet" Chairepol "(projet CRDI 107347) de la Communauté de pratique en écosanté pour l'Afrique de l'Ouest et du Centre (CoPES-AOC)/Chaire ECOSANTE".

Conflicts of Interest

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

References

[1] Fourn, L. and Fayomi, B.E. (2006) Pollution atmosphérique en milieu urbain à Cotonou et à Lokossa. *Sante Publique*.

[2] San Agossou, N. (2003) La diffusion des innovations: L'exemple des *zemijan* dans l'espace béninois. *Cahiers de géographie de Québec*, **47**, 101-120. https://doi.org/10.7202/007971ar

[3] Lawin, H., *et al.* (2017) Exhaled Carbon Monoxide: A Non-Invasive Biomarker of Short-Term Exposure to Outdoor Air Pollution. *BMC Public Health*, **17**, 320. https://doi.org/10.1186/s12889-017-4243-6

[4] Lawin, H., *et al.* (2018) Comparison of Motorcycle Taxi Driver's Respiratory Health Using an Air Quality Standard for Carbon Monoxide in Ambient Air: A Pilot Survey in Benin. *The Pan African Medical Journal*, **30**, 113. https://doi.org/10.11604/pamj.2018.30.113.14975

[5] Lawin, H., Ayi Fanou, L., Hinson, V., Tollo, B., Fayomi, B. and Ouendo, E.-M. (2018) Facteurs de risque professionnel et perceptions de la pollution de l'air chez les taxis motoristes à Cotonou, Bénin. *Sante Publique*, **30**, 125. https://doi.org/10.3917/spub.181.0125

[6] Lawin, H., *et al.* (2016) A Cross-Sectional Study with an Improved Methodology to Assess Occupational Air Pollution Exposure and Respiratory Health in Motorcycle Taxi driving. *Science of the Total Environment*, **550**, 1-5. https://doi.org/10.1016/j.scitotenv.2016.01.068

[7] Leon, J.F., *et al.* (2017) Particulate Matter in Southwestern Africa Cities of Cotonou (Benin) and Abidjan (Côte d'Ivoire). American Geophysical Union-Fall Meeting 2017.

[8] Emetere, M., Oladimeji, T.E. and Omodara, J. (2018) Evaluation of Air Pollution in Port Novo-Benin. *AIP Conference Proceedings*, **2043**, Article ID: 020027. https://doi.org/10.1063/1.5080046

[9] Ouafo-Leumbe, M.-R., *et al.* (2018) Chemical Composition and Sources of Atmospheric Aerosols at Djougou (Benin). *Meteorology and Atmospheric Physics*, **130**, 591-609. https://doi.org/10.1007/s00703-017-0538-5

[10] Djossou, J., *et al.* (2018) Mass Concentration, Optical Depth and Carbon Composition of Particulate Matter in the Major Southern West African Cities of Cotonou (Benin) and Abidjan (Côte d'Ivoire). *Atmospheric Chemistry and Physics*, **18**, 6275-6291. https://doi.org/10.5194/acp-18-6275-2018

[11] Ayi Fanou, L., *et al.* (2006) Survey of Air Pollution in Cotonou, Benin—Air Monitoring and Biomarkers. *Science of the Total Environment*, **358**, 85-96. https://doi.org/10.1016/j.scitotenv.2005.03.025

[12] Ministère de l'environnement de l'habitat et de l'urbanisme (2001) configuration d'une stratégie de réduction des émissions des transports motorisés au Bénin.

[13] CAPOD (2010) problematique de la gestion des dechets des garages automobiles au Bénin: Cas de la ville de cotonou. TP de France.

[14] Liousse, C., Assamoi, E., Criqui, P., Granier, C. and Rosset, R. (2014) Explosive Growth in African Combustion Emissions from 2005 to 2030. *Environmental Research Letters*, **9**, Article ID: 035003. https://doi.org/10.1088/1748-9326/9/3/035003

[15] Liousse, C. and Galy-Lacaux, C. (2010) Pollution Urbaine en Afrique de l'Ouest. *La Météorologie*, **8**, 45. https://doi.org/10.4267/2042/37377

[16] Aubier, M. and Lambrozo, J. (2000) Pollution atmosphérique liée aux transports. *Comptes Rendus de l'Académie des Sciences-Series III-Sciences de la Vie*, **323**, 641-

649. https://doi.org/10.1016/S0764-4469(00)01224-5

[17] Wu, C.-D., *et al.* (2014) Mapping the Vertical Distribution of Population and Particulate Air Pollution in a Near-Highway Urban Neighborhood: Implications for Exposure Assessment. *Journal of Exposure Science & Environmental Epidemiology*, **24**, 297-304.

[18] Weichenthal, S., Van Ryswyk, K., Kulka, R., Sun, L., Wallace, L. and Joseph, L. (2015) In-Vehicle Exposures to Particulate Air Pollution in Canadian Metropolitan Areas: The Urban Transportation Exposure Study. *Environmental Science & Technology*, **49**, 597-605. https://doi.org/10.1021/es504043a

[19] Gaga, E.O., *et al.* (2012) Evaluation of Air Quality by Passive and Active Sampling in an Urban City in Turkey: Current Status and Spatial Analysis of Air Pollution Exposure. *Environmental Science and Pollution Research*, **19**, 3579-3596. https://doi.org/10.1007/s11356-012-0924-y

[20] Grimaldi, F. and Viala, A. (2007) Individual Exposure to Air Pollution in Urban Areas: The Example of Marseille. *Bulletin de l'Académie Nationale de Médecine*, **191**, 21-33. https://doi.org/10.1016/S0001-4079(19)33112-7

[21] Zeger, S.L., Dominici, F., McDermott, A. and Samet, J.M. (2008) Mortality in the Medicare Population and Chronic Exposure to Fine Particulate Air Pollution in Urban Centers (2000-2005). *Environmental Health Perspectives*, **116**, 1614-1619. https://doi.org/10.1289/ehp.11449

[22] Dziubanek, G., *et al.* (2017) Long-Term Exposure to Urban Air Pollution and the Relationship with Life Expectancy in Cohort of 3.5 Million People in Silesia. *Science of The Total Environment*, **580**, 1-8. https://doi.org/10.1016/j.scitotenv.2016.11.217

[23] Rosenlund, M., Berglind, N., Pershagen, G., Hallqvist, J., Jonson, T. and Bellander, T. (2006) Long-Term Exposure to Urban Air Pollution and Myocardial Infarction. *Epidemiology*, **17**, 383-390. https://doi.org/10.1097/01.ede.0000219722.25569.0f

[24] Fuertes, E., *et al.* (2015) Long-Term Air Pollution Exposure and Lung Function in 15 Year-Old Adolescents Living in an Urban and Rural Area in Germany: The GINIplus and LISAplus Cohorts. *International Journal of Hygiene and Environmental Health*, **218**, 656-665. https://doi.org/10.1016/j.ijheh.2015.07.003

[25] Wagner, J.G., Morishita, M., Keeler, G.J. and Harkema, J.R. (2012) Divergent Effects of Urban Particulate Air Pollution on Allergic Airway Responses in Experimental Asthma: A Comparison of Field Exposure Studies. *Environmental Health*, **11**, 45. https://doi.org/10.1186/1476-069X-11-45