Interactive comment on "Personal exposure to $PM_{2.5}$ emitted from typical anthropogenic sources in Southern West Africa (SWA): Chemical characteristics and associated health risks" by Hongmei Xu et al.

Anonymous Referee #1

Received and published: 11 November 2018

We would like to thank the reviewer for both comments and suggestions on our manuscript. We have addressed and responded to each comment below.

Comments and suggestions for improvement:

- I understand that the authors are not native speakers but in some parts of the manuscript, the clumsy phrasing hinders comprehension. This point should be taken care of.

Response: The manuscript has been proofread by a native speaker.

- In the chemical analysis, I am surprised by the choice of Fe as a tracer of the crustal component of the aerosol. It is well known that at least a part of its concentration is contributed by anthropogenic activities. Wouldn't Al or Ca be a better choice? By the way, why were these elements not quantified by the XRF analysis?

Response: This is a good point. In order to analyze the carbonaceous aerosol, the authors selected quartz fiber filters to collect personal exposure $PM_{2.5}$ samples in this study. Due to the limitations of personal exposure sampling, it is difficult to collect both quartz and Teflon filter samples simultaneously.

Moreover, the analytical uncertainties by using ED-XRF for small molecular weight crustal elements in quartz fiber filter (due to high background for Na, Al, Ca and Mg), such as Al, Si and Ca, are high. So, Al, Si and Ca are not suitable to be used as a tracer for the crustal component of the aerosol in this study. Meanwhile, the high accuracy of Fe analysis with ED-XRF has been demonstrated in our previous publication (Xu et al., 2016b), and it has been often used as a tracer for crustal component in $PM_{2.5}$ (e.g., Cao et al., 2005b; Hao et al., 2007; Sun et al., 2014; Wu et al., 2012; Xu et al., 2016b).

Furthermore, based on the previous references (Gelado-Caballero et al., 2012; Zhuang et al., 2001), the enrichment factors of Fe in dust storm period and non-dust storm were both 1-2, always < 10, proving that Fe in aerosol was still mainly derived from the crustal source. Therefore, taking into account the above points, the authors finally picked Fe as a tracer of the crustal component in this study.

Reference:

Cao, J. J., Rong, B., Lee, S. C., Chow, J. C., Ho, K. F., Liu, S. X., and Zhu, C. S.: Composition of indoor aerosols at emperor Qin's terra-cotta museum, Xi'an, China, during summer, China Part., 3(3), 170-175, 2005b.

Gelado-Caballero, M. D., López-García, P., Prieto, S., Patey, M. D., Collado, C., and Hérnández-Brito, J. J.: Long-term aerosol measurements in Gran Canaria, Canary Islands: Particle concentration, sources and elemental composition, J. Geophy. Res.-Atmos., 117, D03304, doi:10.1029/2011JD016646, 2012.

Hao, Y. C., Guo, Z. G., Yang, Z. S., Fang, M., and Feng, J. L.: Seasonal variations and sources of various elements in the atmospheric aerosols in Qingdao, China, Atmos. Res., 85, 27-37, 2007.

Sun, Y. Y., Hu, X., Wu, J. C., Lian, H. Z., and Chen, Y. J.: Fractionation and health risks of atmospheric particle-bound As and heavy metals in summer and winter, Sci. Total Environ., 493, 487-494, 2014.

Wu, F., Zhang, D. Z., Cao, J. J., Xu, H. M., and An, Z.S: Soil-derived sulfate in atmospheric dust particles at Taklimakan desert, Geophy. Res. Lett., 39, L24803, doi:10.1029/2012GL054406, 2012.

Xu, H.M., Cao, J. J., Chow, J. C., Huang, R.-J., Shen, Z. X., Chen, L. W. A., Ho, K. F., and Watson, J. G..: Inter-annual variability of wintertime $PM_{2.5}$ chemical composition in Xi'an, China: Evidences of changing source emissions, Sci. Total Environ. 545-546, 546-555, 2016b.

Zhuang, G. S., Guo, J. H., Yuan, H., and Zhao, C. Y.: The compositions, sources, and size distribution of the dust storm from China in spring of 2000 and its impact on the global environment, Chinese Sci. Bull., 46(11), 895-900, 2001.

- In the health risk assessment, it would be useful to detail the type of risk quantified. The categories 'cancer risk' and 'non-cancer risk' are very broad. Also, is the risk a long-term or a short-term one? Why did you assess only the risks resulting from exposure to Mn, Ni, Zn, Pb, the PAHs and the PAEs? There is also a risk due to exposure to $PM_{2.5}$ and given the large concentrations reported in your work, I expect this one might be very important.

Response: We do agree and understand the reviewer's concern. The details of these categories have been clarified and revised in the manuscript:

"*The heavy metals non-carcinogenic risks and toxic organics carcinogenic risks of $PM_{2.5}$ via inhalation were calculated according to the U.S. EPA health risk assessment model (USEPA, 2004, 2011).*"

U.S. EPA health risk assessment model is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future. The reason for choosing Mn, Ni, Zn, Pb, PAHs and PAEs to assess the health risks in personal exposure $PM_{2.5}$ samples is because these chemicals (among all the chemicals we analyzed in this study) are included in this model and they are assessed to be hazardous to human health in the previous studies (e.g., Hu et al., 2018; Kong et al., 2015; Sun et al., 2014; Xu et al.,

2018a).

Moreover, indeed, as the reviewer said "There is also a risk due to exposure to $PM_{2.5}$", but $PM_{2.5}$ is a complex mixture containing a lot of chemicals. There is no clear and better way to assess its whole health risks for now based on $PM_{2.5}$ chemical concentrations (except for the model simulation and medical animal exposure experiments). So, at this moment, we calculated the risks of the certain toxic chemicals in $PM_{2.5}$ to estimate $PM_{2.5}$ health risks.

Reference:

Hu, Y. J., Bao, L. J., Huang, C. L., Li, S. M., Li, Liu, P., and Zeng, E. Y.: Assessment of airborne polycyclic aromatic hydrocarbons in a megacity of South China: Spatiotemporal variability, indoor-outdoor interplay and potential human health risk, Environ. Pollut., 238, 431-439, 2018.

Kong, S. F., Li, L., Li, X. X., Yin, Y., Chen, K., Liu, D. T., Yuan, L., Zhang, Y. J., Shan, Y. P., and Ji, Y. Q.: The impacts of firework burning at the Chinese Spring Festival on air quality: insights of tracers, source evolution and aging processes, Atmos. Chem. Phys., 15, 2167-2184, 2015.

Sun, Y. Y., Hu, X., Wu, J. C., Lian, H. Z., and Chen, Y. J.: Fractionation and health risks of atmospheric particle-bound As and heavy metals in summer and winter, Sci. Total Environ., 493, 487-494, 2014.

Xu, H. M., Guinot, B., Cao, J. J., Li, Y. Q., Niu, X. Y., Ho, K. F., Shen, Z. X., Liu, S. X., Zhang, T., Lei, Y. L., Zhang, Q., Sun, J., and Gao, J. J.: Source, health risk and composition impact of outdoor very fine particles (VFPs) to school indoor environment in Xi'an, Northwestern China, Sci. Total Environ., 612, 238-246, 2018a.

- In the results section (line 328-330), you cannot extrapolate to the whole SWA region your results collected during two weeks at three very specific locations.

Response: Thank you for pointing out. The authors have revised this statement to:

> "*The average PE $PM_{2.5}$ mass concentrations were 331.7±190.7, 356.9±71.9 and 242.8±67.6 μg m^{-3} for women at Domestic Fires (DF), students at Waste Burning (WB) and drivers at Motorcycle Traffic (MT), respectively, in this study.*"

Moreover, the authors have checked related issue and made corresponding changes throughout the revised manuscript.

- Line 400: you say that total carbon was the most important chemical species in PE $PM_{2.5}$ but it contributes only about 20% to the mass concentration. Isn't this contradictory? What about mineral dust?

Response: We are sorry for the confusion. In section "3.1.2. PE $PM_{2.5}$ chemical compositions", the authors were talking about the PE $PM_{2.5}$ chemical compositions,

which include carbon fractions (OC and EC), water-soluble inorganic ions and heavy metals. Total carbon (TC=OC+EC) was the most important chemical species in PE $PM_{2.5}$, which means TC was the most important chemical species among these three kinds of major components of $PM_{2.5}$.

Strictly speaking, the mineral dust in $PM_{2.5}$ is not directly analyzed by the instrument. It is estimated by empirical formula based on the concentration of some chemical components (mineral elements). Therefore, mineral dust cannot be regarded as the chemical composition of $PM_{2.5}$. It should be considered as the source of $PM_{2.5}$. On this issue, the authors will standardize the terms used in the text to avoid ambiguity. Thank you for your suggestion!

-Paragraph 705-724: First, you say that there is no non-carcinogenic risk linked with the exposure to Mn, Pb, Ni, and Zn (line 709), then you discuss the fact that the risk is much higher in the dry season (line 718). What is the point of discussing the magnitude of this risk, especially before repeating (line 723-724) that it is negligible?

Response: Although our results show that the average non-carcinogenic risk linked to heavy metals in this study was below the international thresholds, we have noticed that it has a seasonal behavior, especially for the driver group. We now first present the risk and then highlight this latter point by giving the dry/wet season ratios.

Anonymous Referee #2

Received and published: 27 November 2018

We would like to thank the reviewer for all the suggestions and comments. Below we have responded to each comment in point to point format.

Megacities in Africa are pollution hotspots, for which very little data have been published. Personal exposure in such environments have also received virtually no research attention. Therefore, the authors are commended for this work.

General comments: I regard the language in this paper as poor. In many instances, this prevents proper knowledge transfer to the reader and can cause misunderstanding/interpretation of the text. Additionally, it makes the paper difficult/cumbersome to read. It is not the job of the reviewer/editor to do language and/or text editing. In my opinion, this paper should not have been published in ACPD before the language and text was acceptable. Therefore, I recommend that final review of this paper should only be considered once the language/text is improved. In the current form, too many uncertainties exist in the paper, because of the poor language.

Response: The manuscript has been revised by a native speaker before re-submission.

I am also not 100% convinced that the content of this paper fits into the scope of ACP. According to the journal, ACP ". . . is an international scientific journal dedicated to the publication and public discussion of high-quality studies investigating the Earth's atmosphere and the underlying chemical and physical processes." My uncertainty arises from the fact that this paper focused more on personal exposure and not on ". . . underlying chemical and physical processes." Would the paper not fit better into a journal specifically considering atmospheric exposure and/or health impacts? I leave the decision to the editor. This comment should not be considered as negative in any way and it is also not a reflection of the science presented.

Response: We understood the reviewer's concern and respected the decision from the editor. We would like to explain that our work is absolutely related to the $PM_{2.5}$ chemical composition, emission sources and variability. This topic should be within the scope of ACP. Moreover, there are some related works on air quality conducted in sWA (same work package on Air pollution and Health) published in the ACP/AMT DACCIWA special issue, forming a coherent whole.

Specific comments: The authors must please not use the name "South West Africa" as they did in line 105, but rather keep to the term "southern West Africa", as it the rest of the paper. "South West Africa" was the name for modern-day Namibia from 1915 to

1990. I would even go so far as to recommend that the term "southern West Africa" that is abbreviated at "sWA" ("southern" in lower case) be consistently used, instead of "Southern West Africa" that is abbreviated at "SWA" ("Southern" in upper case), to ensure that the reader does not confuse the area investigated with "South West Africa" that was abbreviated at "SWA".

Response: We totally agreed. The abbreviation for southern West Africa (sWA) has been revised throughout the document.

The authors refer to ". . . garbage spontaneous combustion. . ." a couple of times. Is the garbage really combusting spontaneously, or are garbage dumps being set alight to reduce the volume of waste, to reduce pests (rats and mice) and prevent disease?

Response: Akouédo dump in Abidjan is a vast and old landfill. We used the term of "spontaneous combustion" as we observed several smoke plumes in the middle of the dump, far from the working area. Spontaneous combustion is a well-known phenomenon in such outdated landfill, but there was difficulty in counting its frequency of occurrence compared to control ignition. Landfill workers often burn waste when they collect trashes and recycle some of useful items. The "controlled burnt" occurs in the active part of the dump. Both processes have a high occurrence during daytime and in the dry and hot season. Here we referred waste burning in a more general manner rather than specifying spontaneous combustion.

The quality of the Google Earth images presented in Figure 1 and the photos presented in Figure 2 are not good and might deteriorate further in page setting during publication (e.g. if the images are printed even smaller). I encourage the authors to ensure the best possible quality for these images.

Response: We definitely payed more attention to the pixel issues on the figures in the revised manuscript.

In its current form, the paper is long. If the authors and editor agree, I would suggest that Appendixes A, B, C and D, which present the questionnaires, rather be included as supplementary material, instead of appendixes. Appendixes are published as part of the paper, while supplementary material are published separately. Readers who want to assess the content of the questionnaires can download the supplementary material, instead of the paper becoming excessively long.

Response: We agreed with the reviewer's comment. We have moved the current Appendix A-D to the supplementary material as supporting information (SI A-D).

I agree with Referee #1 that the authors cannot interpolate their results obtained from

individuals with specific occupations and at specific locations to the wider southern West African region. All such statements should be revised.

Response: Thank you for this point. We have made the necessary changes within the text.

In general, there is little comparison of the results presented in this paper to results obtained elsewhere. I appreciate that very little, if any, personal exposure data have been presented for African cities. However, even if the results presented are compared to ambient/indoor air quality results obtained in the rest of Africa (or Asia, or some other developing settings, if African reference cannot be found), the reader will be able to easier contextualize the exposure concentrations reported here. For instance, indoor air quality in semi- and informal settlements (low-income households) in South Africa (Kapwata et al., Atmosphere 2018, 9(4), 124; https://doi.org/10.3390/atmos9040124) could be compared to "Night" personal exposure of individual in this study. Also, characterization of the plume of fire grilling of meat in an African context (Venter et al., S. Afr. J. Chem., 2015, 68, 181–194; DOI: http://dx.doi.org/10.17159/0379-4350/2015/v68a25) could possibly be compared to the exposure of woman by Domestic Fires (DF) ("grilling meat or roasting peanuts") in this study. Such comparisons will help the reader to contextualize the results presented – currently only comparing the different groups with one another does not enable the reader to contextualize the results. There might be many more references, such as the afore-mentioned, these two are just examples that I found with a quick online search.

Response: We understood this point of view. The citations on our work are related to either ambient concentrations or source characterization. The suggested references should not be applicable. Venter et al. (2015) presented a study on charcoal combustion with a specific type of barbecue, totally different from the conditions at DF (wood in barrel). Kapwata et al. (2018) showed the work on PM_4 (dissimilar with our $PM_{2.5}$) and no chemical composition was provided.

In lines 370 and 384 of our original manuscript, we firstly compared the average PE $PM_{2.5}$ levels to the weekly ambient $PM_{2.5}$ concentrations obtained in the same area and similar sampling period, and also compared the daytime PE $PM_{2.5}$ mass concentrations with the daytime ambient $PM_{2.5}$ in the same area and exactly the same sampling dates (Djossou et al., 2018). We also used the results of the PAHs exposure measured in Cotonou in a previous study (Fanou et al., 2006). We provide additional references of previous works on personal exposure to $PM_{2.5}$ in household in Tanzania (Titcombe and Simcik, 2011) and for students in Ghana (Arku et al., 2014). And we compared the results with our data in this study as follows:

> *"The 5-h $PM_{2.5}$ average personal exposure concentration was 1574 $\mu g\ m^{-3}$ (±287, n = 3) for open wood fires in households in the Njombe district of Tanzania (Titcombe and Simcik, 2011), and was comparable to the highest 12-h exposure level to $PM_{2.5}$ for women at DF site in this study (1164.7 $\mu g\ m^{-3}$, daytime in wet*

season, July 5th), and was 4.7 times of the daily average PE $PM_{2.5}$ concentration in dry and wet seasons (331.7±190.7 μg m^{-3})."

"In the study of Titcombe and Simcik (2011), the authors found that the 5-h average total PAH personal exposure concentration was 5040 ng m^{-3} (±909, n = 3) for open wood fires in households in the Njombe district of Tanzania, which was much higher (~65 times) than the women exposure PAHs at DF site in the current research. The highest 12-h exposure PAHs for women at DF site in this study was 469.7 ng m^{-3} (daytime in wet season, July 6th), approximately one-tenth of the PAHs concentration from open wood fires in Tanzania mentioned above. The large PE PAH concentrations difference between these two studies may be influenced by many factors such as wood type, combustion state, stove structure and sampling time."

"Student (10-17 years old) $PM_{2.5}$ exposures ranged from less than 10 μg m^{-3} to more than 150 μg m^{-3} (mean 56 μg m^{-3}) in four neighborhoods in Accra, Ghana (Arku et al., 2014), much lower than that for students at WB site (356.9±71.9 μg m^{-3}). It can be seen that the high exposure of students in this study is likely to be related to the waste burning emissions, while there was no obvious strong $PM_{2.5}$ emission source in the study of Arku et al. (2014)."

We have also added the comparisons as mentioned above in the revised manuscript.

Reference:

Arku, R. E., Dionisio, K. L., Hughes, A. F., Vallarino, J., Spengler, J. D., Castro, M. C., Agyei-Mensah, S., and Ezzati, M.: Personal particulate matter exposures and locations of students in four neighborhoods in Accra, Ghana. J. Expo. Sci. Environ. Epidemiol., 1–10, 2014.

Titcombe, M. E., and Simcik, M.: Personal and indoor exposure to $PM_{2.5}$ and polycyclic aromatic hydrocarbons in the southern highlands of Tanzania: a pilot-scale study. Environ. Monit. Assess., 180, 461–476, 2011.

Line 415. The author state that "The previous studies (Cao et al., 2008; Li et al., 2009; Tian et al., 2017) suggested that average OC/EC characterizes 1.1 as motor vehicle exhaust, 2.7 as coal combustion and 9.0 as biomass burning. The OC/EC in the present study points out that biomass burning emission was the main contributor to carbonaceous aerosols for women at DF, and the mixed emissions from biomass and coal burning, even or/and motor vehicle exhaust dominated the carbonaceous aerosol sources for students at WB and drivers at MT." However, the authors should clarify these statements, since OC/EC ratio will change in a plume with aging, with the formation of secondary OC and deposition of EC. Therefore, if the above OC/EC ratios are used to characterize fresh emissions/plumes, it should be stated as such and not left to the reader to interpret.

Response: The statements have been revised as follows:

"Previous studies (Cachier et al., 1989; Cao et al., 2005a; Cao et al., 2008; Li et al., 2009; Tian et al., 2017; Watson et al., 2001) summarized that average OC/EC characterizes 1.1 as motor vehicle exhaust, 2.7 as coal combustion and 9.0 as biomass burning from their source samples (i.e., fresh emissions/plumes)."

The reason why we could compare the OC/EC results of the personal exposure data in this study with the above source samples is because that the participants were close or around to the typical anthropogenic sources in this study. In addition, $PM_{2.5}$ emitted from the pollution sources still maintained a relatively fresh state (less aging) without long-distance transport, and then was inhaled into human body. Therefore, the OC/EC ratio comparison results in this study could yield reliable conclusions as described in the texts (originally lines 418-421).

Reference:

Cachier, H., Bremond, M. P., and Buat-Menard, P.: Carbonaceous aerosols from different tropical biomass burning sources. Nature, 340, 371–373, 1989.

Cao, J. J., Wu, F., Chow, J. C., Lee, S. C., Li, Y., Chen, S. W., An, Z. S., Fung, K. K., Watson, J. G., Zhu, C. S., and Liu, S. X.: Characterization and source apportionment of atmospheric organic and elemental carbon during fall and winter of 2003 in Xi'an, China. Atmos. Chem. Phys., 5, 3127–3137, 2005a.

Watson, J. G., Chow, J. C., and Houck, J. E.: $PM_{2.5}$ chemical source profiles for vehicle exhaust, vegetative burning, geological material, and coal burning in northwestern Colorado during 1995. Chemosphere, 43, 1141–1151, 2001.

Line 247. Fe and the heave metals reported (V, Cr, Mn, Co, Ni, Cu, Zn, Sb, Ba and Pb) were analyzed with ED-XRF. How sure are the authors that some of the heavy metals were not part of the GM and are therefore partially double accounted for in the mass balance (Figure 5, line 493 onwards), i.e. accounted as heavy metal mass and also contributing to the mass of the GM?

Response: The abundance of Fe in the earth's crust is about 4% (discussed in next comment detailly), and the abundances of the other nine elements (i.e., V, Cr, Mn, Co, Ni, Cu, Zn, Sb, Ba and Pb) in the earth's crust ranged from 0.2×10^{-6} (Sb) to 660×10^{-6} (Mn), which are 2-5 orders of magnitude lower than Fe (Taylor and McLennan, 1985). From the above crustal content comparison, the authors had reason to believe that the overlap contributions to $PM_{2.5}$ from the other nine elements and the estimated crustal material content (by using Fe) can be neglected.

Line 511. Although the authors give a citation (i.e. "Taylor and McLennan, 1985") to support the use of Fe as a tracer for geological material (GM), how accurate is this method? The authors state "Fe constitutes about 4.0% of the Earth's crust in dust of the earth's crust (Cao et al., 2005)". Are there any indications of Fe contents of local soils (and the variation on Fe contents) and how it differs from the global average value of 4%, which was used? Basically, I am asking how accurate the method is. Can the

authors give any indication of accuracy? This is important, since ". . . it is found that GM contributed 35.8%±2.1%, 46.0%±3.7% and 42.4%±4.7% of PE $PM_{2.5}$ mass concentrations for women at DF, students at WB and drivers at MT, respectively."

Response: Fe is the most important metal and one of the major constituents of the lithosphere. Its average content of the Earth's crust is about 5%. The global abundance of Fe is around 4.5% (Kabata-Pendias and Mukherjee, 2007). The typical range of Fe contents in soils is between 0.1 and 10% and its distribution in soil is variable, which is controlled by several soil parameters (Kabata-Pendias and Mukherjee, 2007). The authoritative study from Taylor and McLennan (1985) of elemental content in soils showed that the global abundance of Fe is around 3.5%.

Because of the lack of elemental composition obtained in topsoil of Africa, the authors used 4.0% (global mean Fe content from the mentioned literatures) as a percentage of Fe in the topsoil of African study area for geological material estimation in this study. The value was widely used in other literatures (Cao et al., 2005b; Hao et al., 2007; Sun et al., 2014; Wu et al., 2012; Xu et al., 2016b). In our opinion, this method can roughly indicate the contribution of the geological material to atmospheric particle matters to a certain extent. Moreover, since the geological material of three sampling sites in this study were estimated using a consistent method, the relative results were comparable.

Reference:

Hao, Y. C., Guo, Z. G., Yang, Z. S., Fang, M., and Feng, J. L.: Seasonal variations and sources of various elements in the atmospheric aerosols in Qingdao, China, Atmos. Res., 85, 27-37, 2007.

Kabata-Pendias, A., and Mukherjee, A. B.: Trace Elements from Soil to Human. Springer-Verlag, Berlin Heidelberg, Germany, pp. 381-393, 2007.

Sun, Y. Y., Hu, X., Wu, J. C., Lian, H. Z., and Chen, Y. J.: Fractionation and health risks of atmospheric particle-bound As and heavy metals in summer and winter, Sci. Total Environ., 493, 487-494, 2014.

Wu, F., Zhang, D. Z., Cao, J. J., Xu, H. M., and An, Z. S.: Soil-derived sulfate in atmospheric dust particles at Taklimakan desert, Geophy. Res. Lett., 39, L24803, doi:10.1029/2012GL054406, 2012.

Line 529 "From Figure 5, evident diurnal distinguishes are observed in two major chemical compositions (OM and GM) in this study. We can see that GM exhibits the lower proportion at night (35.3%) than daytime (47.5%), indicating its close relationship with human activities." However, does meteorology not also play a role? In Line 483 the authors imply that precipitation is higher during night-time, i.e. ". . . spontaneous combustion of waste occurs frequently during the day, because of less precipitation and higher air temperature at daytime. . ."

Response: As our best knowledge, the main source of the geological material in $PM_{2.5}$ is from crust dust. In addition to the effects of crust erosion by water and wind, it is largely related to the physical activities of human, such as resuspension from individual

activities, construction activities and etc. The second reason (meteorological factor) shown in original line 483 explained the day-night ratio of heavy metals in $PM_{2.5}$, that is, the absolute concentrations of heavy metals; while the content in original line 529 discussed the proportion of geological material in $PM_{2.5}$. The meteorological factors, including precipitation, indeed cause scouring action on particulate matters (i.e., wet deposition), but they have little effect on altering the proportion of geological material in $PM_{2.5}$. Therefore, lower geological material proportion in $PM_{2.5}$ at night in this study was mainly due to the resuspension of the geological material from the less individual activities.

Line 539 ". . . due to the influence from the damp wood burning at the working time." I could not find any place where the wood moisture content was reported. Therefore, this statement and previous, as well as subsequent deductions, based on this statement, are not fact based. However, I do agree with later statements (line 566) that the wood will be damper in the wet season, i.e. ". . . increase in humidity (moisture content) of the wood used for grilling meat in wet season. . .".

Response: In this study, we did not measure the moisture of the wood used for barbecue in women's work. Since the grilling fuel (wood) was placed in the open area (no shield or roof), the abundant rainfall in wet season inevitably led to moisture increase in the wood. With on-field observation, it frequently took a long time to ignite the wood, which emitted more plume from damp fuels in the wet season during the sampling period. In previous studies (Chen et al., 2010; Grandesso et al., 2011; Keita et al., 2018; Shen et al., 2012, 2013), the results showed that biomass fuel with high moisture often required additional energy to vaporize the water and hence resulted in low combustion efficiency and high pollutant emissions. The emission factor (EF) of OC increase with the fuel moisture content (Chen et al., 2010).

The authors have modified the original statement in lines 538-541 as follows:

> *"An exception is that OM proportion of women PE $PM_{2.5}$ at daytime (50.8%) was much higher than nighttime (38.2%) in wet season, due to the influences from the damp wood burning at the working time. Burning biomass fuel with high moisture often results in low combustion efficiency, long smoldering period and high air pollutant emissions (Grandesso et al., 2011; Shen et al., 2012, 2013). The emission factor of OC usually increases with the fuel moisture content (Chen et al., 2010; Keita et al., 2018). Therefore, burning the damp wood led to higher OC emission than dry wood, in-line with the observation for women PE results in this study."*

Reference:

Chen, L.-W. A., Verburg, P., Shackelford, A., Zhu, D., Susfalk, R., Chow, J. C., and Watson J. G.: Moisture effects on carbon and nitrogen emission from burning of wildland biomass. Atmos. Chem. Phys., 10, 6617–6625, 2010.

Grandesso, E., Gullett, B., Touati, A., and Tabor, D.: Effect of moisture, charge size, and chlorine concentration on PCDD/F emissions from simulated open

burning of forest biomass. Environ. Sci. Technol., 45, 3887–3894, 2011.

Shen, G., Wei, S., Wei, W., Zhang, Y., Min, Y., Wang, B., Wang, R., Li, W., Shen, H., Huang, Y., Yang, Y., Wang, W., Wang, X., Wang, X., and Tao, S.: Emission factors, size distributions, and emission inventories of carbonaceous particulate matter from residential wood combustion in rural China. Environ. Sci. Technol., 46, 4207−4214, 2012.

Line 584. "Students at WB: nighttime PE PAHs were higher in dry season and lower in wet season compared with daytime levels, with the average D/N ratios of 0.7 and 1.8, respectively. The higher concentrations of combustion markers-BbF and BeP were observed during the day, while the higher concentrations of gasoline vehicle emission markers-DahA and BghiP were found at night (Baek et al., 1991; Wang et al., 2006), which was related to the garbage truck for waste transportation from city to the landfill during night." I am not sure that the latter explanation can be so simple, i.e. only due to "garbage truck".

Response: We apologized for the misleading. Referring to the middle panel of Figure 6A, it shows that the distributions of PAHs in students' $PM_{2.5}$ personal exposure samples in the dry and wet seasons were basically the same, with the higher concentrations in the dry season. The authors discussed the diurnal variation of PAHs concentration in different seasons and the dominant PAH species in daytime and nighttime. Both PAH profiles had a similar feature of high combustion markers of BbF and BeP, and gasoline emission markers of DahA and BghiP. Besides, with the large error bars (standard deviations) of PAH concentrations shown in this Figure, we believe that the previous statements about the dominant PAHs species in the daytime and nighttime are not so supportive, and thus the statements have been deleted from the revised manuscript.

In addition, the statements in lines 586-591 have been revised as following:

"Both the PAH profiles were featured with high combustion markers of BbF and benzo[e]pyrene (BeP), and high gasoline vehicle emission markers of dibenzo[a,h]anthracene (DahA) and BghiP (Baek et al., 1991; Wang et al., 2006)."

Line 706. Can the authors please explain the selection of species included in the "Noncancer risks", wherein only "four heavy metals (Mn, Ni, Zn and Pb)" were considered?

Response: The non-carcinogenic risks of heavy metals in $PM_{2.5}$ via inhalation were calculated according to the U.S. EPA health risk assessment model (USEPA, 2004, 2011). U.S. EPA health risk assessment model is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future. The reason we only chose Mn, Ni, Zn and Pb to assess the health risks in personal exposure $PM_{2.5}$ samples is because

these four metals (among all the chemicals we analyzed in this study) are included in this U.S. EPA health risk assessment model and they are assessed to be hazardous to human health in the previous studies (e.g., Hu et al., 2018; Kong et al., 2015; Sun et al., 2014; Xu et al., 2018a).

Personal exposure to $PM_{2.5}$ emitted from typical anthropogenic sources in ~~Southern~~ southern West Africa (~~SWA~~sWA): Chemical characteristics and associated health risks

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Abstract

Urbanization is an ~~strongly emerging~~ issue strongly emerging in ~~in Southern~~ southern West African (~~SWA~~sWA)~~ region~~. There is a ~~general~~ lack of full understanding ~~about~~ on chemical compositions and ~~the~~ personal exposure (PE) levels to fine particulate matter ($PM_{2.5}$)~~, its chemical components~~ and its health risks related to ~~the~~ various anthropogenic sources in this region. In ~~the current~~this study, ~~personal exposure to $PM_{2.5}$ (~~PE $PM_{2.5}$~~)~~ ~~sampling~~ was for the first time ~~carried out~~studied in dry ~~season~~ (January) and wet (July) seasons ~~(July)~~ of 2016 to characterize ~~PE $PM_{2.5}$~~the contributions ~~of~~~~from~~ Domestic Fires (DF) ~~for~~ to women and Waste Burning (WB) ~~for~~ to students in Abidjan, Côte d'Ivoire, and Motorcycle Traffic (MT) ~~for~~ to drivers in Cotonou, Benin.

The average PE $PM_{2.5}$ mass concentrations were 331.7±190.7, 356.9±71.9 and 242.8±67.6 μg m^{-3} at DF, WB and MT for the women, students and drivers, which were 2.4, 10.3 and 6.4 times of the ambient $PM_{2.5}$ concentrations, respectively. Elevated ~~Mean concentrations of~~ PE $PM_{2.5}$ levels in dry season were found at ~~at~~ DF (358.8±100.5 μg m^{-3}), WB (494.3±15.8 μg m^{-3}) and MT (335.1±72.1 μg m^{-3})~~ were much elevated in dry season~~, on average 15% higher than that at DF and 55% higher at both WB and MT in ~~cold~~wet season. The ~~changes in PE $PM_{2.5}$~~seasonal variations ~~can be~~were attributed to ~~the source~~ emission sources, meteorological factors and personal activities. In addition, ~~T~~the results ~~also~~ show that geological material (35.8%, 46.0% and 42.4%) and organic matter (34.1%, 23.3% and 24.9%) were ~~always~~ the major components ~~in~~ of PE $PM_{2.5}$ at DF, WB and MT sites. It is worth noting that the contribution ~~to~~ of ~~PE $PM_{2.5}$ from~~ heavy metals was higher at WB (1.0%) than at DF (0.7%) and MT (0.4%), ~~which was~~ strongly influenced by the waste burning emission~~ strongly~~. This results in ~~, leading to~~ the highest ~~heavy metal~~ non-cancer risks on heavy metal ~~-~~for students~~, which are (~~5.1 and 4.8 times the values ~~of~~ for women and drivers, respectively~~' non-cancer risks)~~.

By ~~In~~ conducting organic ~~species~~speciation ~~of PE $PM_{2.5}$~~, ~~some~~ fingerprints were~~can be~~ used to ~~quantify~~ access the exposure ~~concentrations~~ and identify ~~trace~~ the source contributions from ~~local~~ typical local anthropogenic sources~~ to different samples~~. The ~~W~~women exposure concentration to particulate polycyclic aromatic hydrocarbons (PAHs) ~~in $PM_{2.5}$~~ at DF (77.4±47.9 ng m^{-3}) was 1.6 and 2.1 times, respectively, of that for students at WB (49.9±30.7 ng m^{-3}) and ~~2.1 times for~~ for drivers at MT (37.0±7.4 ng m^{-3}). This can be associated with the higher contributions from ~~, which is related to the~~ solid fuels burning and meat grilling ~~meat~~ activities to women, ~~,~~ resulting in 5 times ~~higher~~ exceed ~~of~~ the cancer risk safety threshold (1×10^{-6})~~ to women~~. Phthalate esters (PAEs), commonly used as plasticizers

in ~~many~~ products, were ~~observed to~~in ~~be~~ ~~extremely~~ high levels in the student exposure $PM_{2.5}$ samples (1380.4±335.2 ng m^{-3}) ~~at WB site,~~owing to ~~owing to the~~ obvious waste burning activities ~~emission~~ nearby~~obviously~~. The ~~D~~drivers' exposures to fossil fuel ~~emission~~ combustions ~~(especially traffic)~~ markers of ~~-~~hopanes in PE $PM_{2.5}$ at MT (50.9±7.9 ng m^{-3}) was ~~32~~.0-~~32~~.3 times ~~higher than~~of those for women at DF (17.1±6.4 ng m^{-3}) and students at WB (15.6±6.1 ng m^{-3})~~, correlating with the elevated exposure to traffic emissions for drivers~~.

Overall, the current study shows that wood combustion, waste burning, fugitive dust and motor vehicle emissions were the dominated sources ~~dominated~~ for the PE $PM_{2.5}$ ~~mass~~ and mainly contributed to its toxicities ~~mainly~~. The exposure to heavy metals of Pb and Mn had high non-cancer risks to students at WB, while severe cancer risk of PAHs was found for women at DF via inhalation ~~Heavy metals and organics chemicals in PE $PM_{2.5}$ in SWA brought about Pb and Mn non-cancer health risks for students at WB site and serious PAHs cancer risks for women at DF site via inhalation pathway.~~ The result of this~~is~~ study provides ~~basic~~original data, ~~and~~ initial perspective of $PM_{2.5}$ personal exposure, and health risk assessment in the ~~under~~developinged areas. The information ~~to~~ encourages the governments to improve the air quality and living standard of residents in this region.

Keywords: personal exposure to $PM_{2.5}$; domestic fires; waste burning; motorcycle traffic; southern West Africa

1. Introduction

The southern West Africa (~~SWA~~sWA) region ~~has~~ is experiencing~~experienced~~ an economic upturn. ~~and increasingly s~~ignificant a~~A~~nthropogenic ~~air pollutant~~ emissions of air pollutants ha~~ves~~ been increasing since ~~during t~~the last ~~last~~ few years, leading to~~-~~ poor air quality~~and causes serious air pollution~~ to the areas (IMF, 2017; Norman et al., 2007). Fine particulate matter ($PM_{2.5}$ with equivalent aerodynamic diameters ≤ 2.5 μm) is one of the major concerns ~~of~~ from international organizations and publics because of its high ~~the~~ health ~~effects~~ impacts by personal ~~associated with exposure levels, health of individuals and pollutant emission sources~~ exposures (Bruce et al., 2000; Chen et al., 2013; Owili et al., 2017). Owili et al. (2017) found that ~~the~~ four types of ambient $PM_{2.5}$, including mineral dust, anthropogenic pollutant, biomass burning and mixture aerosols are significantly associated with under-five and maternal mortality in Africa. However, studies on $PM_{2.5}$, especially direct personal exposure (PE) tests to $PM_{2.5}$ (no~~n-t~~ stationary sampling) and its health assessment,~~effects~~ are ~~still~~very limited in these low gross domestic product (~~income~~ GDP) countries ~~in this region~~.

Since the 1990s, several international campaigns have been performed in Africa. Some of them were mainly focused on the particles or aerosols, ~~for example~~such as DECAFE (Lacaux et al., 1995), EXPRESSO (Delmas et al. 1999; Ruellan et al., 1999), SAFARI-1992 (Lindesay et al., 1996), SAFARI-2000 (Swap et al., 2002), AMMA (Léon et al., 2009; Liousse et al., 2010; Marticorena et al., 2010) and INDAAF (Ouafo-Leumbe et al., 2017). ~~As we known, t~~In fact,~~he~~ Africa has ~~is~~ the largest production of ~~source of~~ mineral dust particles from the Sahara Desert and unpaved road surfaces (Laurent et al., 2008; Marticorena et al., 2010; Reeves et al., 2010), and carbonaceous aerosols originated from wild fires (mainly savannah fires) ~~as well~~ (Capes et al., 2008; Gaudichet et al., 1995) among the world. Therefore, these campaigns were more biased toward~~s~~ the natural sources of aerosols in Africa. ~~Liousse et al. (2014) have showed thatn the increase of the relative importance of particulate emissions from domestic fires and fossil fuel combustions in Africa.~~ In previous literature, the major contributions to the aerosol chemistry ~~in the dry season~~ in northern Benin in ~~the~~ dry season were dust (26~~%~~-59%), primary organic matters (POC, 30~~%~~-59%), elemental carbon (EC, 5~~%~~-9%) and water soluble inorganic ions (3~~%~~-5%) (Ouafo-Leumbe et al., 2017). Liousse et al. (2014) showed that the increase of relative importance of particulate emissions from domestic fires and fossil fuel combustions in Africa. Uncertainty has been raised by the residents who live in urban areas as they do concern on the health impact from air quality. ~~This poses serious health questions for people who frequent the city on a daily~~

basis. However, the there is still limited literatureworks on the health effects of personal exposurePE to $PM_{2.5}$ emitted from the typical anthropogenic sources in the emerging cities in Africa are still scarce.

The main anthropogenic emission sources of $PM_{2.5}$ in SWAsWA include domestic wood burning, fossil fuel combustion, unregulated traffic and industries, waste burning and road dust associated to human activities. An ongoing project in Africa-DACCIWA (Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa) (Africa-DACCIWA) aims at to quantifyquantifying the influences of anthropogenic and natural emissions on the atmospheric pollutant composition over South southern West Africa and to assessing their impacts on human health, ecosystem health and agricultural productivity,. The information which will be gathered and discussed communicated to with policy-makers, scientists, operational centrers, students and general publics. The current work involved in the framework of the Work Package 2 "Air Pollution and Health" of DACCIWA is tryingtends to link emission sources, air pollution and health impacts over representative differentiated urban sources: domestic fires and waste burning in Abidjan (Ivory Coast) and two-wheel vehicle traffic emission in Cotonou (Benin) for different target groups of populations.

Smoking meat (e.g., fish and pork) by biomass fuels (mainly woods) is an important diet pattern for residents of coastal countries in SWAsWA area. Many female workers without any personal health protection are engaged in roasting activities without any personal health protectiony. They are directly exposed to extremely the high $PM_{2.5}$ emissions pollution from wood burning and smoking meat, causing which could cause very serious health problemsissues. Besides, Uurbanization leads to explosive population growth and rural depopulation in SWAsWA, generating a huge amount resulting in a large amount of urban domestic wastes. The biggest landfill in Abidjan focused involved in this study receivesd more than 1,000,000 t waste per year (Adjiri et al., 2015). W A mass of garbage ithout lacks any processing capacity and reasonable appropriate treatment method, resulting in a large amount of air pollutants was thus emitted during from the combustion and stacking of waste,. Such which phenomenon damages the living environment and harm the residents' health (especially for children) condition of the populations in Abidjan, especially for children (UNEP, 2015). Moreover, in many most low-GDPincome countries, motorbike taxis areis a major mode of local transportation (Assamoi and Liousse, 2010). In Benin, motorbike taxi drivers (mainly male) represented almost ~2.5% of the total population of Benin in 2002 (Lawin et al., 2016). As Due to they spend many long working hours dailyin the middle of traffic every day, these drivers are highly exposed to traffic-related $PM_{2.5}$ pollution emissions

over years.

Major chemical components in $PM_{2.5}$ ~~,~~ ~~like~~like OC, EC, and ions ~~and EC mentioned above,~~ not only have strong impact on $PM_{2.5}$ physicochemical characteristics, but also cause~~affect~~ ~~its~~ health risks. Typical trace toxic chemicals, such as heavy metals and polycyclic aromatic hydrocarbons (PAHs), in ~~can be attached on~~ $PM_{2.5}$ ~~,~~ have ~~which would cause~~ various health damages to ~~problems for~~ humans (Cao et al., 2012; WHO, 1998; Xu et al., 2015). For instance,~~example,~~ Pb is a neuro-developmental metal which~~,~~ affect~~sing~~ children health and mental development ~~seriously~~ (USEPA, 2006; Xu et al., 2017). Several ~~Few~~ PAHs ~~can be~~are teratogenic and carcinogenic for humans ~~strongly~~ (Tang et al., 2008). Up to now, only few studies have investigated ~~$PM_{2.5}$~~ chemical compositions of ~~the personal exposure~~PE $PM_{2.5}$ samples, and little is known regarding the sources and health risks ~~of personal exposure $PM_{2.5}$~~ in ~~SWA~~sWA region. This poses a challenge ~~to~~ on formulation of strategies ~~aimed at~~to mitigat~~e~~ing $PM_{2.5}$ pollution and its health effects in this area.

Therefore, our study relies on the portative device sampling $PM_{2.5}$ ~~personal exposure~~ PE samples in ~~SWA~~sWA area in 2016. ~~Our~~Study objectives include ~~for the purpose of~~ 1) to characterize~~ing~~ the ~~the personal exposure~~PE to $PM_{2.5}$ ~~as variation of~~from different typical local ~~typical~~ anthropogenic ~~$PM_{2.5}$~~ sources by ~~the~~ chemical component ~~analysis~~ and $PM_{2.5}$ mass balance analysis; 2) to identify~~ing~~ potential pollution sources to different exposed populations ~~by~~ from fingerprint of organic markers; and 3) to evaluate the ~~ing~~ PE ~~the personal exposure~~ to $PM_{2.5}$ health risks by the United States Environmental Protection Agency (U.S. ~~–~~EPA) health risk assessment model. This information ~~will provide~~offers scientific understanding of the ~~personal exposure~~PE to $PM_{2.5}$ in ~~SWA~~sWA and ~~try to~~ arouses the government's attention to protect residents' health ~~there~~ from various anthropogenic sources.

2. Materials and methods

2.1. Site description and participants selection

~~Personal exposure~~PE to $PM_{2.5}$ (hereafter defined as PE $PM_{2.5}$) filter samples were collected using portative devices in ~~the polluted atmosphere of different~~unique source~~-~~dominated ~~-~~environments for different target groups of humans~~s~~, including Domestic Fires (DF) for women and~~,~~ Waste Burning (WB) for students ~~both~~ in Abidjan, Côte d'Ivoire, and Motorcycle Traffic (MT) for drivers in Cotonou, Benin (Figure 1). Abidjan (5°20′ N, 4°1′ W) is the economic capital of Côte d'Ivoire with 6.5 million inhabitants in 2016. It is characterized by a high level of industriali~~z~~s~~s~~ation and urbanization in ~~SWA~~sWA area.

Cotonou (6°21′ N, 2°26′ W) is the largest city and economic center of Benin, with about 1.5 million inhabitants in 2016. Both the cities experience a tropical wet and dry mixed climate, with relatively constant ambientair temperatures (in a range of 24-30 °C) and an average of relative humidity (RH) >above 80% throughout thea year.

DF site in Abidjan is located in the market of Yopougon-Lubafrique (5°19.7′ N, 4°6.4′ W) where in is a large courtyard with about 25 fireplaces (Figure 2). The major fuels used isare essentially hevea wood, which is a (one kind of local rubber trees) locally. Several adult female adult workers were employed to for grilling meat and/or roasting peanuts from 06:00 to 15:00 UTC (working time) in the working day. In this study, we selected two healthy, non-smoking female workers (an average age of 32.5 years old) to investigate conduct personal exposure to $PM_{2.5}$ from domestic fire and related sources, such as grilling (Figure 2). WB site in Abidjan is near the public landfill of Akouédo (5°21.2′ N, 3°56.3′ W), which has received all the wastes collected produced from Abidjan for the last past 50 years (Figure 2). We selected two healthy, and non-smoking primary school students (an average age of 11 years old) who live and study next to WB site (within 100 m straight-line distance) to determine the personal exposure features to $PM_{2.5}$ from waste burning (spontaneous combustion at high air ambient temperatures condition and irregular combustion by the landfill workers sometimes) emissions at landfill and other daily sources. Lastly, MT site in Cotonou is located in the Dantokpa area (6°22.1′ N, 2°25.9′ E), one of the biggest markets in western Africa (Figure 2). It is largely dominated by a mass of emissions from motorcycle traffic (two-wheel vehicles powered by petrol, also named zemidjan in local language) and a small quantity of other motor vehicles emissions. We chose two healthy, and non-smoking male motorcycle drivers (an average age of 50 years old) to survey $PM_{2.5}$ personal exposure from motorcycle emission and related sources (such as road dust).

Two women (woman A and B) involved in this study at DF are were both in charge of cooking at home by charcoal and butane gas as fuel, (Figure S1abc) and daily household cleaning house in daily life (Figure S1abc). One of the student participators (student A, boy, 8 years old) at WB didoesn't not involve in cooking activities at home by himself [(energy sources for cooking energy isare charcoal and liquefied petroleum gas (LPG)]) (Figure S1ac), but the another student (student B, girl, 14 years old) is usually responsible for household cooking at home with burning by burning solid fuels (, i.e., wood) (Figure S1d). Two motorcycle drivers (driver A and B) focused in this study aat MT are both working for a local motorcycle operation company, whose working time is usually from 06:30 to 10:30, 12:00 to 17:00 and 18:30 to 21:00 UTC. They are drive ing on road almost all the working time and

~~go back~~returned home for meals. They d~~id~~ not participate ~~on't cook~~any cooking ~~-~~at home ~~by themselves~~ (energy source for cooking is charcoal) (Figure S1a).

2.2. Personal exposure to $PM_{2.5}$ samples collection and QA/QC

~~12~~Twelve-hour time integrated (daytime: 07:30 to 19:30 UTC; nighttime: 19:30 to 07:30 on the next day UTC) PE $PM_{2.5}$ samples were collected in two major southwestern African cities (Figure 1) during ~~the~~ dry season (from January 6th to 11th) and wet season (from July 5th to 10th) in~~,~~ 2016 ~~in two major southwestern African cities mentioned above (Figure 1)~~. PE $PM_{2.5}$ sampling was conducted ~~during~~ for three consecutive days ~~with the same type participants~~ synchronously~~,~~ using the PEM (Personal Environmental Monitor) sampling devices with SKC pump (SKC Inc., USA) at a flow rate of 10 liter per minute (lpm). The PEM $PM_{2.5}$ sampling head worn in the breathing zone of participants in this study. $PM_{2.5}$ ~~Samples~~ were collected on 37 mm pre-baked quartz filters (800 ~~–~~°C, 3 hours, QM/A®, Whatman Inc., UK). A total of 72 ~~personal exposure~~PE samples, including 24 samples (12 pairs of diurnal samples, the same as thereafter ~~daytime + 12 nighttime samples~~) for women at DF, 24 (12 ~~+ 12~~pairs) for students at WB and 24 (12~~+12~~ pairs) for drivers at MT, were collected in this study. Moreover, 12 PE $PM_{2.5}$ field blanks (one field blank for each participant in one season~~,~~ collected on the second day of the three consecutive sampling days) were ~~sampled~~ obtained ~~in this study~~ as well.

In order to verify the comparability of ~~personal exposure~~PE samples and data caused by not identical sampling devices, 10 pairs of $PM_{2.5}$ samples were synchronously collected by two sets of actual PEMs with SKC pumps. The comparison results ~~led~~ show~~to~~ a significant correlation between the $PM_{2.5}$ mass concentrations obtained from two sampling devices ($y=0.986x+0.189$, $R^2=0.974$, $P<0.0001$). Identical membrane type (quartz fiber) and analytical treatments were ~~used~~ applied in this study. After sampling, the filter samples were placed in Petri dishes, sealed with parafilm and stored in a freezer at -20 °C ~~freezer~~ to prevent loss of mass through volatilization prior to analysis. Blank values from blank filter samples were used to account for any artifacts caused by gas absorption and subtract the background $PM_{2.5}$ and chemical compositions concentrations in this area.

~~We report t~~The meteorological observations during the dry (December 2015 to March 2016) and wet (April to July 2016) seasons at the sampling ~~places~~sites were shown in Table 1. The ~~M~~meteorological data ~~are~~ were retrieved from the NOAA Global Surface Summary of the Day I (GSOD) at the airports of each cities, namely Felix Houphouet Boigny Airport (Abidjan) and Cardinal Bernadin Gantin International Airport (Benin). ~~We give t~~The daily

average air temperature, wind speed and rainfall accumulation are summarized in Table 1 as well.

2.3. $PM_{2.5}$ gravimetric and chemical analysis

PE $PM_{2.5}$ filter samples were analyzed gravimetrically for mass concentrations with a high-precision electronic microbalance (Sartorius MC21S, Germany) at Laboratoire d'Aérologie (Toulouse, France) before and after sampling in the weighing room after equilibration at 20-23 °C and the RH of 35%-45% for at least 24 hour. The absolute errors between replicate weights were less than 0.015 mg for blank filters and 0.020 mg for sampled filters.

Total carbon (TC) was determined on 0.5 cm^2 punch-out of the filters by a carbon analyzer (Ströhlein Coulomat 702C, Germany) at the Observatoire Midi-Pyrenees (OMP, Toulouse, France). The quartz filter samples were subjected to a thermal pretreatment step (kept at 60°C for 20 mins) in order to remove the volatile organic compounds (VOCs) and eliminate water vapor. Subsequently, the filters were combusted at 1200°C under O_2 and detected as CO_2 in the carbon analyzer. Elemental carbon (EC) was obtained using a two-step thermal method: step 1 consisted in a pre-combustion at 340 °C under O_2 for 2 h in order to remove organic carbon (OC); step 2 consisted in the oxidation of the remaining EC at 1200 °C under O_2. The difference (TC-EC) yielded OC concentration (Benchrif et al., 2018; Cachier et al., 2005).

To extract the water-soluble inorganic ions from the quartz filters, a quarter 1/4 of the filter was placed in a separate 15 mL vials containing 10 mL distilled-deionized water (18.2 MΩ resistivity). The vials were placed in an ultrasonic water bath and shaken with a mechanical shaker for 45 min (15 min × 3 times) to extract the ions. The extracts were filtered through 0.45 μm pore size microporous membranes. After that, three anions (Cl^-, NO_3^- and SO_4^{2-}) and five cations (Na^+, NH_4^+, K^+, Mg^{2+} and Ca^{2+}) in aqueous extracts of the filters were determined by an ion chromatograph (IC) analyzer (Dionex-600, Dionex, Sunnyvale, CA, USA), which was is equipped with an AS11-HC anion column and a CS12 cation column for separation. Details of the IC measurement method are are described in Bahino et al. (2018) and Cachier et al. (2005).

One element: of Fe (representing earth's crust emission) and ten heavy metals (i.e., : V, Cr, Mn, Co, Ni, Cu, Zn, Sb, Ba and Pb) in PE $PM_{2.5}$ samples were determined by Energy Dispersive X-Ray Fluorescence (ED-XRF) spectrometry (the PANalytical Epsilon 5 ED-XRF analyzer, the Netherlands) on with 1/4a quarter of filters in this study as well. The relative

errors for all measured elements were < 6% between the NIST Standard Reference Material (SRM) 2783 and our ED-XRF results, which is well within the required range of error, demonstrating the accuracy of ED-XRFmethod. Replicate analysis of one quartz-fiber filter sample (five times) yielded an analytical precision between 5.2%-13.9%. Details of the ED-XRF measurements are are showndescribed in Brouwer (2003) and Xu et al. (2012).

0.1-1.0 cm^2 punch-outs aAliquot punches (0.1-1.0 cm^2)s from the quartz filters were used to quantify the organic compounds, including polycyclic aromatic hydrocarbons (PAHs), phthalate esters (PAEs) and hopanes (see the specificdetails of target organic species and their abbreviations measured in this study shown in Table 5) by an in-injection port thermal desorption-gas chromatography/mass spectrometry (TD-GC/MS) method. The approach has the advantages of shorter sample preparation time (< 1 min), minimizing of contaminations from solvent impurities, and higher sensitivity, compared with the traditional solvent extraction-GC/MS method. The detail analytical procedures have been reported in previous publications (Ho and Yu, 2004; Ho et al., 2008, 2011; Xu et al., 2013, 2016a). The results of the blank analyses showed only trace contamination levels (<–5.0%) of PE $PM_{2.5}$ samples concentrations.

2.4. Health risk assessment model

A number of As we known, hhHeavy metals and toxic organic species are associated with negative personal exposurePE health effects (Škrbic et al., 2016; Val et al., 2013; Wang et al., 2017a; Xu et al., 2018a). In this study, four heavy metals (Mn, Ni, Zn and Pb) and all measured PAHs and PAEs species in PE $PM_{2.5}$ were selected to determine the personal exposurePE inhalation health risks (Xu et al., 2018a). The heavy metals non-carcinogenic risks and toxic organics carcinogenic and non-carcinogenic health risks of $PM_{2.5}$ via inhalation chemical species were calculated according to the U.S. EPA health risk assessment model (USEPA, 2004, 2011). The average daily exposure dose (D) via inhalation was estimated to assess the risk by the equations (1) as follows:

$$D = (C \times R \times EF \times ED \times cf) / (BW \times AT) \qquad (1)$$

the definitions and recommended values of parameters are shown in Table 2.

A hazard quotient (HQ) for non-cancer risk of heavy metals in PE $PM_{2.5}$ samples can be obtained from equation (2):

$$HQ = D / RfD \qquad (2)$$

the threshold value of RfD indicates whether there is an adverse health effect during a certain period. Hazard index (HI) can be obtained by summing up the individual HQ to estimate the

total non-cancer risks. If the HI < 1, then non-carcinogenic effect is impossible; HI ≥ 1, adverse health effect might likely appear (Hu et al., 2012).

The incremental lifetime cancer risk (ILCR) of PAHs and PAEs in ~~personal exposure~~PE $PM_{2.5}$ samples can be calculated by multiplying the cancer slope factor (CSF) of PAHs and PAEs with D as equation (3):

$$ILCR = D_{-} \times CSF \qquad (3)$$

for cancer risk, the value of 1×10^{-6} is an internationally accepted as the precautionary or threshold value above which the risk is unacceptable (Jedrychowski et al., 2015).

It is worth noting that, among the nineteen PAHs, BaP has been used as an indicator of PAHs carcinogenicity (Wang et al., 2006). The carcinogenic health risk of PAH species can be assessed by $[BaP]_{eq}$ instead (Yassaa et al., 2001) by equation (4):

$$\Sigma[BaP]_{eq} = \Sigma (C_i \times TEF_i) \qquad (4)$$

Additionally,~~Besides,~~ the carcinogenic risk for PAEs was assessed by DEHP, which is identified as a possible carcinogen to humans by the International Agency for Research on Cancer (IARC) (IARC, 1982; Li et al., 2016). The definitions and recommended values of the parameters in equations (2-4) are also shown in Table 2 and ~~Table~~ 3.

2.5. Questionnaire and time-activity diary

Questionnaire (Supporting information (SI)~~Appendix~~ A-C) and time-activity diary (SI~~Appendix~~ D) were collected from each participant during the sampling period, respectively, to fully grasp the basic information, potential personal exposure~~potential exposure~~PE sources and activities of participants. In the questionnaire, personal information, family status, dermatological, asthma symptoms, medical history, current health status and so on were first asked from each participant. Besides, the questions for women include: (1) living habits and environment (past and current living conditions, general living habits, cooking habits and domestic fuel type/usage); (2) work environment and travel habits (workplace, work nature, working hour~~time~~ and daily travel mode/time); and (3) affected by the burning of domestic solid fuels and roasting meat. The questions for students include: (1) living habits and environment (past and current living conditions, general living habits, participation in household duties, ~~the~~ family cooking habits and domestic fuel type/usage~~;~~, distance from home to WB site); (2) school environment and travel habits (school location and related environment and daily travel mode/time); and (3) affected by the burning of waste and household air pollution sources. The questions for drivers include: (1) living habits and environment (past and current living environments, general living habits, participation in

household duties, ~~the~~ family cooking habits and domestic fuel type/usage); (2) working environment and travel habits (motorcycle power type, driving conditions, working ~~time~~ hours and daily travel mode/time); and (3) affected by the motorcycle emission and household air pollution sources.

The time-activity diaries requested the participants to mark on half an hour basis (sleeping time excluded) to assess each microenvironment time spending and detailed activities.

3. Results and discussion

3.1. Personal exposure to $PM_{2.5}$ and its chemical compositions

3.1.1. PE $PM_{2.5}$ mass concentration

The average ~~personal exposure~~PE ~~to $PM_{2.5}$ (~~PE $PM_{2.5}$~~)~~ mass concentrations were 331.7±190.7, 356.9±71.9 and 242.8±67.6 μg m^{-3} for women at Domestic Fires (DF), students at Waste Burning (WB) and drivers at Motorcycle Traffic (MT), respectively, in this study ~~in 2016 in Southern West Africa (SWAsWA)in this study~~. Among these three types of subjects, the average concentrations of PE $PM_{2.5}$ for women and students were quite similar, ~40% higher than that of the drivers. PE $PM_{2.5}$ ranged from 106.2 μg m^{-3} (nighttime in dry season, January 7th) to 1164.7 μg m^{-3} (daytime in wet season, July 5th) for women at DF; from 37.8 μg m^{-3} (nighttime in wet season, July 8th) to 1137.0 μg m^{-3} (daytime in dry season, January 11th) for students at WB; and from 65.0 μg m^{-3} (nighttime in wet season, July 11th) to 648.5 μg m^{-3} (daytime in dry season, January 15th) for drivers at MT. The ranges and standard deviations of PE $PM_{2.5}$ concentrations were extremely large, especially for women, because ~~there are~~ the direct combustion sources were close to ~~around~~ the participants ~~women workers in this study~~. ~~Moreover, t~~The variations of ~~personal~~ physical ~~s~~ activities and intensities of air pollution sources potentially ~~intensities~~ lead to a drastic fluctuation for PE $PM_{2.5}$.

The average mass concentrations of PE $PM_{2.5}$ were 358.8±100.5, 494.3±15.8 and 335.1±72.1 μg m^{-3} in dry season (January), and 304.6±284.5, 219.5±71.3 and 150.6±10.4 μg m^{-3} in wet season (July) for women at DF, students at WB and drivers at MT, respectively (Table 4). Compared to dry season, the reduction rate of PE $PM_{2.5}$ for women at DF in wet season was approximately 15%, while the sharp reductions by more than 50% were observed for students and drivers ~~at a similar level by more than 50%~~. PE $PM_{2.5}$ concentrations reducing could be attributed to the occurrence of increased levels of rainfall in wet season in ~~SWA~~sWA (Table 1), which causes the large reduction of road dust exposed to drivers and limits the garbage spontaneous combustion significantly around students. Moreover, large

scale transport of mineral dust and combustion aerosols emitted by savannah wild fires contribute significantly to the aerosol load during the dry season (Djossou et al., 2018), which is more important at WB and MT than at DF (women worked in the crowded community environment).

The PE $PM_{2.5}$ mass concentrations in the daytime were much higher than those at ~~night~~nighttime~~, no matter~~ in ~~both~~ dry or wet seasons (Table 4 and Figure 3). The 12-hour averaged PE $PM_{2.5}$ concentrations showed day/night (D/N) ratios of 3.4 (3.8 in dry season and 3.1 in wet season, the same sequence thereafter), 2.7 (2.8 and 2.5) and 2.4 (1.5 and 3.3) for women at DF, students at WB and drivers at MT, respectively. Intensive human activities during the daytime, such as solid fuel combustion, waste combustion or motor vehicle emission ~~around~~ influenced the different group subjects, ~~enhance~~elevating ~~e~~ the exposure levels ~~of~~ of $PM_{2.5}$ ~~exposure in the daytime~~. ~~For example~~In the same case, lower PE $PM_{2.5}$ ~~personal exposure level~~ for students ~~at night~~ at WB in the nighttime can be explained ~~also~~ by the fact that the participants ~~in this study~~ usually spent~~d~~ most of their time indoors ~~at night~~ with limited physical activity, leading ~~them to be able~~ to stay away ~~a distance~~ and/or shelter from obvious emission sources (e.g., waste combustion) outdoors. ~~Besides,~~Moreover, ~~big~~ large fluctuations of D/N ratios for drivers were observed, with lower ~~value~~average in dry season ~~and~~ but higher in wet season. ~~Relatively lower D/N ratio probably attributes to nighttime driving (18:30 to 21:00 UTC) after dinner, which enhances their $PM_{2.5}$ exposed levels from vehicle emission and road dust.~~ ~~Much~~ Wet season high~~er~~ D/N ratios ~~in wet season~~ attribute to the increase in precipitation ~~in wet season~~ in Cotonou (Table 1), especially during~~at~~ nighttime (Sealy et al., 2003)~~.~~, This leads~~ing to~~ the lower PE $PM_{2.5}$ ~~exposure~~ for drivers at night after aerosol scavenging. ~~and the less~~Shorter driving time in wet season is another explanation for the phenomenon, because of ~~the~~ unfavorable weather occasionally (e.g., rain and storm).

The 5-h $PM_{2.5}$ average personal exposure concentration was 1574 μg m^{-3} (±287, n = 3) for open wood fires in households in the Njombe district of Tanzania (Titcombe and Simcik, 2011), and was comparable to the highest 12-h exposure level to $PM_{2.5}$ for women at DF site in this study (1164.7 μg m^{-3}, daytime in wet season, July 5th), and was 4.7 times of the daily average PE $PM_{2.5}$ concentration in dry and wet seasons (331.7±190.7 μg m^{-3}). ~~Besides, the lower D/N ratio probably attributes to the nighttime driving (18:30 to 21:00 UTC), when the drivers still exposed to vehicle emission and road dust.~~ Student (10-17 years old) $PM_{2.5}$ exposures ranged from less than 10 μg m^{-3} to more than 150 μg m^{-3} (mean 56 μg m^{-3}) in four neighborhoods in Accra, Ghana (Arku et al., 2014), much lower than that for students at WB

site (356.9±71.9 μg m^{-3}). It can be seen that the high exposure of students in this study is likely to be related to the waste burning emissions, while there was no obvious strong $PM_{2.5}$ emission source in the study of Arku et al. (2014).

T~~ T~~he average PE $PM_{2.5}$ levels are compared to the weekly ambient $PM_{2.5}$ concentrations (Djossou et al., 2018) ~~obtained~~ in the same area during ~~and~~ similar sampling period. The average PE $PM_{2.5}$ were 3.0 and 2.0 times of the ambient values ~~found~~ at DF, and 6.1 and 8.8 times at MT in dry and wet seasons, respectively. The highest PE $PM_{2.5}$ to ambient (A) (PE/A) ratios were found at WB, i.e., 10.3 in dry and 10.5 in wet seasons. Such large PE/A ratios are probably due to the impact of waste combustion affected ~~on t~~the respiratory exposure of residents ~~in this area~~, especially on children; on the other hand, high PE/A ratios can be attributed to the fact that WB site is located in the lowest living quality ~~poorest~~ region of Abidjan, where the ~~extremely~~ simplest ~~-~~stove and non-qualified wood as fuel used in house ~~at home~~ (Figure S1d). These~~,~~ lead~~ing~~ to an extremely ~~very~~ high ~~personal~~ PE $PM_{2.5}$ ~~exposure level~~ indoors during the cooking time ~~in this area~~ (especially for student B who was in charge of cooking, ~~at home sometimes~~ recorded in the activity logging and questionnaire). Meanwhile, the ambient $PM_{2.5}$ sampling equipment at WB was neither fixed very close to ~~(blue marker in Figure 1C)~~ nor ~~in~~ located at the downwind direction of the landfill (Djossou et al., 2018)~~,~~ that ~~which~~ cause ~~direct suggests~~ the ~~huge~~ differences between the ambient and ~~personal exposure~~PE $PM_{2.5}$ concentrations.

Moreover, ~~we also compare~~ the daytime PE and ambient $PM_{2.5}$ mass concentrations ~~with the~~on ~~daytime ambient $PM_{2.5}$, which collected in the same area and exactly~~ the same sampling dates ~~dates as the personal exposure sampling period~~were also compared. The average women daytime ~~women~~ PE $PM_{2.5}$ ~~for women~~ were 3.7 and 1.2 times of the ambient $PM_{2.5}$ at DF in dry and wet seasons, respectively, consistent ~~, which was similar as~~with ~~-~~the finding from the weekly compar~~at~~ison ~~with the weekly $PM_{2.5}$~~ mentioned above. ~~But~~ However, for the students at WB and drivers at MT, the PE/A ratios were both much lower ~~smaller~~ than those compared with the weekly ambient $PM_{2.5}$, with averages of 5.1 and 7.0 for the students at WB and~~,~~ 1.9 and 3.3 for the drivers at MT in dry and wet seasons, respectively. The PE/A ratios for students ~~were also showed~~had the highest values, which is consistent with the results found earlier.~~.~~ ~~In addition, t~~The PE/A ratios ~~observed~~ all above 1.0 and ~~the great~~large variability of $PM_{2.5}$ ~~mass concentrations~~ between ~~personal exposure~~PE and ambient concentrations ~~samples~~ imply that fix-point sampling is likely to underestimate the PE $PM_{2.5}$ ~~personal exposure~~~~PE~~ and consequent human health hazards~~,~~. The results ~~and~~ further

ceonfirm the importance of portative PE $PM_{2.5}$ sampling for ~~to $PM_{2.5}$~~ health risk assessment ~~again~~.

3.1.2. PE $PM_{2.5}$ chemical compositions

Table 4 summarizes the average ~~concentrations of~~ PE $PM_{2.5}$ chemical compositions, including carbon fractions (OC and EC), water-soluble inorganic ions and ~~several~~ target heavy metals. ~~Total carbon (~~TC~~)~~ ~~had~~was the highest composition ~~was the most important chemical species~~ in PE $PM_{2.5}$, accounting for 24.4~~%~~±4.5%, 16.6~~%~~±2.0% and 17.8~~%~~±4.9% of PE $PM_{2.5}$ ~~mass~~ for~~of~~ women, students and drivers, respectively. High ~~level of~~ OC values ~~proves~~ suggest the strong contribution of combustion sources to PE $PM_{2.5}$ in ~~SWA~~sWA ~~in this study~~ (Djossou et al., 2018; Ouafo-Leumbe et al., 2017). ~~The OC and EC concentrations varied significantly, ranging from 28.3 to 460.0, 8.0 to 189.9 and 14.7 to 65.1 μg m^{-3} for OC and 1.5 to 31.1, 0.8 to 35.1 and 1.9 to 18.2 μg m^{-3} for EC for the women, students and drivers, reseparatelypectively.~~ The average OC concentration (83.2 μg m^{-3}) and ~~percentage~~ composition (24.4%) in women PE $PM_{2.5}$ samples were the highest among the three types of ~~exposed~~ PE participants, due to their ~~close~~ direct contact with the ignition, and ~~the direct~~close to ~~burning of~~ the solid fuel~~s~~ (wood in this study) burning and meat roasting ~~meat~~ at the workplace~~,~~ and also~~even~~ their own residential units~~cooking at home, etc~~. However, the EC concentrations (8.4-10.5 μg m^{-3}) and ~~proportions~~ compositions (3.0-3.5%) were very ~~close betweensimilar among for~~ the~~se~~ three different PE groups~~targets were similar (8.4-10.5 μg m^{-3} and 3.0%-3.5%)~~, representing ~~meaning~~ that EC ~~is~~ was less affected by human activities related to combustion sources in this study.

The OC ~~and~~ to EC ratio (OC/EC) has been used to determine emission and transformation characteristics of carbonaceous aerosols (Cao et al., 2008). The OC/EC averaged 9.9±5.3 for women at DF, 6.1±0.7 for students at WB, and 5.8±2.7 for drivers at MT. ~~The p~~Previous studies (Cachier et al., 1989; Cao et al., 2005a; Cao et al., 2008; Li et al., 2009; Tian et al., 2017; Watson et al., 2001) ~~suggested~~summarized that average OC/EC characterizes 1.1 as motor vehicle exhaust, 2.7 as coal combustion and 9.0 as biomass burning f~~or~~rom their source samples (i.e., fresh emissions/plumes)~~The previous studies (Cao et al., 2008; Li et al., 2009; Tian et al., 2017) suggested that average OC/EC characterizes 1.1 as motor vehicle exhaust, 2.7 as coal combustion and 9.0 as biomass burning~~. In present study, ~~T~~the OC/EC ~~in the present study points~~suggests ~~out~~ that biomass burning ~~emission was~~was the main contributor to PE carbonaceous aerosols for women at DF, while ~~and~~ the mixed emissions ~~from~~ of biomass and coal burning~~,~~ ~~even~~ or/and motor vehicle exhaust were domina~~nt~~ ~~ted the carbonaceous aerosol sources~~ for students at WB and drivers at MT. The

OC/EC was ~~almost always~~mostly higher ~~during~~in wet season than dry season, ~~which may~~ascribed to ~~be related to the fact that~~ the fact that the higher RH~~relative humidity~~ in wet season favors the formation of secondary organic carbon (SOC) (Huang et al., 2014). ~~Drivers'~~The daytime OC/EC for drivers' PE samples ~~shows~~ were relatively low (an average~~:~~ of 3.7) and constant ~~stable ratios in~~between wet and dry seasons, ~~indicating~~ promising that motor vehicle exhaust was the most ~~important~~ dominant and stable pollution source ~~to drivers' OC and EC in the daytime~~ in~~, consistent with~~ their working environment ~~of motorcycle drivers in this study~~. P~~E~~ersonal exposure of women displays the higher (an average of~~:~~ 13.9) and more scattered OC/EC than those collected from students and drivers in wet season (Figure 4). This was induced by ~~, resulting from the~~ particularly high and dramatic changes in individual exposure to obvious carbonaceous aerosol sources (e.g., wood burning and grilling).

~~In~~With the data shown in ~~a previous study of~~ Djossou et al. (2018), the ~~about OC/EC at ambient (A) environment,~~PE OC/EC for the participants ~~in personal exposure samples~~ were ~~about ~~1.2 and 2.5 times of the ambient ~~values~~OC/EC in dry and wet seasons ~~for women~~ at DF, 1.7 and 2.8 times ~~for students~~ at WB, and 1.1 and 2.0 times ~~for drivers~~ at MT. ~~Therefore, the~~Such higher OC/EC values in ~~personal exposure~~PE samples can be resulted from ~~some~~ specific individual's activities and potentially contaminat~~ed~~ion ated microenvironments (Crist et al., 2008; Meng et al., 2009). In addition, ~~From the results we can also see that t~~the influences of precipitation and other meteorological factors on OC/EC in ambient samples ~~OC/EC of the ambient samples~~ were~~are~~ less than those on PE ~~personal exposure~~ samples (i.e., ~~D~~dry season OC/EC was more comparable between the ambient and PE~~personal exposure~~ samples ~~in this study~~).

The average concentrations of total ~~measured~~ quantified water~~-~~soluble inorganic ions were 23.6±12.8, 35.5±18.3 and 22.7±5.0 μg m^{-3} for women at DF, students at WB and drivers at MT, accounting for 8.5~~%~~±1.0%, 12.1~~%~~±2.7% and 11.9~~%~~±0.4% of PE $PM_{2.5}$ masses, respectively. ~~Unlike~~ Dissimilar with ~~of~~ the ~~ion~~ compositions in heavy polluted cities in~~of~~ China (SO_4^{2-}, NO_3^- and NH_4^+ were the most abundant ions in ambient or PE $PM_{2.5}$, accounting for 50~~%~~-90% of quantified ~~measured~~ ions and ~30% of $PM_{2.5}$ masses) (Xu et al., 2016b, 2018b; Zhang et al., 2013), Ca^{2+}, a marker of fugitive dust, was the most abundant ion, accounting for ~28% (in a range from~~from~~ 25.3% to 29.3%) of total quantified ions ~~in this study~~, following by Cl^-, SO_4^{2-} and K^+ for women at DF, Na^+, SO_4^{2-} and Cl^- for students at WB, and SO_4^{2-}, Na^+ and NO_3^- for drivers at MT. The profiles~~It~~ ~~can~~ thus indicate ~~be seen~~ that the particle resuspension by personal activities ~~is~~ was the main contributor to the PE $PM_{2.5}$ in

~~SWA~~sWA (Chen et al., 2017; Xu et al., 2015). The ~~day and night~~diurnal ~~-~~variations ~~of~~ on Ca^{2+} ~~contribution~~ composition of Ca^{2+} to total ions (i.e., daytime=30.6% and nighttime=22.8%) also illustrate this conclusion ~~(i.e., daytime=30.6% and nighttime=22.8%)~~. Moreover, SO_4^{2-} forms primarily through atmospheric oxidation of SO_2 emitted mainly from coal and diesel combustions (Seinfeld and Pandis, 2006~~;~~, Xu et al., 2016b). As the second most enriched ion, the average proportion of SO_4^{2-} was 17.7%, which implies that purification of raw coal and diesel (Wang et al., 2013) ~~can~~should be applied ~~in~~in this area for~~to lead to~~ lower~~ing~~ sulfur emissions and therefore decreasing ~~decrease the~~ PE~~personal exposure~~ to SO_4^{2-} in $PM_{2.5}$. The ~~Drivers'~~ SO_4^{2-} exposure levels for the drivers were 33% and 40% higher than the women and students respectively, indirect ~~which may indirectly~~ indicat~~inge~~ that the emission of SO_2 ~~SO_4^{2-} precursor SO_2~~ might be~~is~~ higher in Cotonou or ~~targeted drivers~~the participants ~~affected by vehicle emissions~~ are exposed to high~~er~~ SO_2 or SO_4^{2-}~~, especially~~ from the diesel vehicle emission~~s~~.

Generally, Na^+ and Cl^- ranked the ~~were the~~ third and fourth ~~ranked~~abundant ions in the PE samples. The sampling sites in ~~SWA~~sWA cities in this study are all close to the sea and ~~are~~ were affected by sea salt particles ~~strongly~~. It~~'s~~ is also worth noting that biomass burning marker-K^+ (Kang et al., 2004; Zhang et al., 2014b) display~~ed~~s a high absolute average concentration of ~~(~~3.4 μg m^{-3}~~)~~ and composition ~~percentage (~~of 14.5%~~)~~ in women' PE $PM_{2.5}$ samples, confirming their distinct exposure from biomass burning during the roasting at the workplace. ~~As we know~~To the best knowledge, NO_3^- derives from NO_x emitted mainly from motor vehicle exhaust (especially gasoline vehicle), industry and power plants (Seinfeld and Pandis, 2006; Xu et al., 2016b). Additional consideration ~~here:~~includes that the industry is not well-developed in this area (i.e., much less industry in Cotonou than Abidjan) and thus is not the main contributor to ~~source of~~ $PM_{2.5}$ (Ouafo-Leumbe et al., 2017). In comparison with the findings ~~for~~from the other two sites, ~~It suggests that~~ motor vehicle emission obviously contributed to drivers' ~~exposure~~ PE concentrations~~obviously in this study, comparing with women at DF and students at WB~~, consistent with the conclusion for~~about~~ SO_4^{2-} as discussed above.

The concentrations of 10 targeted heavy metals, including V, Cr, Mn, Co, Ni, Cu, Zn, Sb, Ba and Pb, ~~can be found~~are also shown in Table 4. The total concentrations ~~of these 10 elements~~ were 1.4±0.3, 3.9±6.5 and 0.8±0.2 μg m^{-3} for women at DF, students at WB and drivers at MT ~~during the sampling period~~, accounting for 0.7~~%~~±0.4%, 1.0~~%~~±1.2% and 0.4~~%~~±0.1% of the PE $PM_{2.5}$~~,~~ respectively~~correspondingly~~. The PE heavy metal for the ~~exposed concentration of~~ students was 1.8 and 3.9 times ~~higher than~~of ~~-~~those for the women

and drivers,~~, resulting~~ mainly due to ~~from~~ the emissions from garbage combustion at landfill ~~which emit extremely high level of heavy metals as we known~~ (Wang et al., 2017b). The D/N ratios ranged from 0.8 to 2.1 for women and drivers~~,~~ but averaged 4.0 ~~in dry season~~ and 7.0 in dry and wet seasons respectively ~~–~~for students. The~~re~~is can be explained by ~~the~~ ~~are~~ two reasons~~:~~. ~~for this phenomenon: t~~The first is that ~~reason could be related with~~ there were intense physical activities from the students and strong disturbances from landfill workers ~~in the daytime at landfill;~~. Another ~~the second~~ reason is ~~that~~ spontaneous combustion of waste occurring ~~s~~ frequently during the day due to ~~, because of~~ less precipitation and higher ambient~~air~~ temperature in the ~~at~~ daytime. Ba, Zn and Mn were found to be the dominant heavy metals, accounting of ~73% of total quantified elemental concentration in all samples. ~~It is worth mentioning that~~ Ba t~~oo~~ook~~k~~ up a decisive advantage over other elements, ~~accounting~~ having a contribution of >50% for ~~for more than half of all the elements for~~ students. ~~Because Ba~~It is usually added ~~to~~ in rubber and plastic products to improve acid and alkali resistance. S~~However, , at the same time these~~such products were~~are~~ main fractions ~~are the main components~~ of the garbage at landfill in this area (Feng et al., 2006). Zn and Mn ranked the first and second ~~PE~~personal exposure elements ~~places~~ for drivers at MT~~,~~ which are mainly derived from the motor oil additive, tyre wear and brake pads worn (Zhao and Hopke, 2006).

3.2. Mass balance of personal exposure to $PM_{2.5}$

Calculation of mass balance ~~for~~ of the PE $PM_{2.5}$ is an effective method to figure out the principal components in $PM_{2.5}$ and ~~for its~~distinguish the ~~–~~pollution source~~s discrimination~~ (Gokhale et al., 2008). PE $PM_{2.5}$ mass in this study can be classified into six parts: organic matter (OM), EC, water-soluble inorganic ions, geological material (GM), heavy metals and ~~unknown~~ unresolved ~~part~~fraction (Figure 5). The first five main resolved ~~parts~~fractions can explain 78.3%~~%~~ to 90.6% of total PE $PM_{2.5}$ mass concentrations in this study. Unresolved fraction ~~Unknown part~~ may include water and other undetected substances ~~in PE $PM_{2.5}$~~. For OM, since there is no ~~the~~ full ~~chemical~~organic composition ~~–~~profiles ~~composition of the aerosol organic fraction~~ for the PE $PM_{2.5}$~~is largely unknown~~, a conversion factor 1.4 (1.4 corrects the organic carbon mass for other constituent associated with the organic carbon molecule) is generally used (Turpin and Lim, 2001) to ~~shift~~ quantify ~~OC to~~ OM by the equation (5):

$$OM = 1.4 \times OC \qquad (5)$$

~~based on the equation (5),~~ OM accounted for 34.1%~~%~~±6.3%, 23.3%~~%~~±2.8% and 24.9%~~%~~±6.9% of

the PE $PM_{2.5}$ mass for women at DF, students at WB and drivers at MT, respectively. The results show , indicating that there are distinct sources to for PE $PM_{2.5}$ OC for women at DF. According to the information gathering from the questionnaires, the combustion sources, such as roasting meat/peanuts and burning wood, should beare the major contributors the sources toto PE OC for for women personalwomen in this study exposure samples,. which consistent with the results mentioned above.

In addition, Fe has been widely used to estimate the upper limit of GM in previous studies (Taylor and McLennan, 1985). Fe constitutes about ~4.0% of the Earth's crust in dust of the earth's crust (Cao et al., 2005Cao et al., 2005b; Hao et al., 2007; Kabata-Pendias and Mukherjee, 2007; Sun et al., 2014; Wu et al., 2012; Xu et al., 2016b). The amount of GM is calculated by equation (6):

$$GM = (1/4.0\%) \times Fe \qquad (6)$$

based on this equation, iIt is found that GM contributed 35.8%±2.1%, 46.0%±3.7% and 42.4%±4.7% of PE $PM_{2.5}$ mass concentrations for women at DF, students at WB and drivers at MT, respectively. Fugitive dusts, including road dust resuspension from disturbance of motor vehicles and human activitiess, construction dust from uncovered construction sites, and the dusts generated related to from burning activities, could be the dominination inant sources to PE $PM_{2.5}$ in this study. OM and GM showed the almost identicalsimilar proportions (34.1% and 35.8%, respectively) of PE $PM_{2.5}$ mass for women at DF. The fractions of GM in PE samples percentages for students and drivers were approximately 10% and 7% higher than that for women. Therefore, Therefore, ttThe fugitive dust related contributions wasissare the most important sources for PE $PM_{2.5}$ in this less developed area, shown by meaning that there are nearly half 50% PE $PM_{2.5}$ contribution sources offor students and drivers, attributable to human physical activities and a large amount of covered land. As mentioned above, iIt is surprising to note that the secondary formed ions (i.e., SO_4^{2-}, NO_3^- and NH_4^+), and the even total measured quantified water-soluble inorganic ions show wereare the in exceedingly low proportions in to PE $PM_{2.5}$ for all subjectsgroups. This reconfirms the limited contribution to PE $PM_{2.5}$ from secondary ionic formation again ionic sources.

From In Figure 5, evident diurnal distinguishes are can be observed in on the two major chemical compositions of (OM and GM) in this study. We can see that GM exhibiteds the lower proportion at nighttime (35.3%) than daytime (47.5%), indicating suggesting its close relationship with human activities. For different seasons, we find the hHigher GM was found for bothall each type of groupsparticipant in dry season, because of the harmattan haze

introduced~~bringing~~ mineral dusts and the la~~k~~cke of precipitation increasing road dust resuspension. Moreover, OM showed~~s~~ the equal or lower proportions ~~in PE $PM_{2.5}$~~in the~~between~~ ~~at~~ daytime (25.0%) that nighttime (30.0%), relative to ~~which is mainly related with~~ the meteorological parameters (i.e., factor ~~they~~ affected the formation of secondary organic carbonaceous aerosol) and diurnal changes of combustion sources around subjects ~~variations between day and night~~. ~~There is a~~An exception is ~~found~~ that ~~in the last case, i.e.,~~ OM proportion ~~at daytime~~ of women PE $PM_{2.5}$ at daytime (50.8%) was much higher ~~(50.8%)~~ than nighttime (38.2%) in wet season, due to the influences from the damp wood burning at the working time. ~~As we know, b~~Burning biomass fuel with high moisture often results in lowe~~r~~ combustion efficiency, longe~~r~~ smoldering period and high air pollutant emissions (Grandesso et al., 2011; Shen et al., 2012, 2013). The emission factor of OC usually increases with the fuel moisture content (Chen et al., 2010; Keita et al., 2018). Therefore, burning the damp wood led to ~~more~~higher OC emission than dry wood, in-line with the observation for ~~to~~ women PE results in this study~~There is an exception in the last case, i.e., OM proportion at daytime women PE $PM_{2.5}$ was much higher (50.8%) than nighttime (38.2%) in wet season, due to the influence from the damp wood burning at the working time. As we know, the damp wood burning emits more smoke (PM) than dry wood (Shen et al., 2013) or change in emission factors (Keita et al., 2018)~~.

4. ~~Fingerprint o~~Organic species fingerprint ~~in~~ of personal exposure to $PM_{2.5}$

O~~In this section, we use o~~rganic fingerprint markers can be used to ~~that~~ indicate specific emission sources and ~~to~~ further characterize ~~investigate~~ the ~~sources and detailed characteristics of PE $PM_{2.5}$~~ pollutions impacted on ~~for~~ different populations. ~~Unlike PE $PM_{2.5}$ mass concentration variations (students > women > drivers), organic fingerprint measured in this study, such as PAHs, PAEs and hopanes (Table 5), show different concentration orders in this study.~~ The average PE concentrations of $PM_{2.5}$-bound PAHs, PAEs and hopanes ~~PE mass concentrations~~ were 54.8±20.3, 986.8±82.2 and 27.9±1.0 ng m^{-3} ~~in this study~~, respectively, representing ~~showing a~~ high ~~very serious $PM_{2.5}$~~ organic pollutions in ~~SWA~~sWA region (Table 5). Dissimilar with the trend on $PM_{2.5}$ masses (students > women > drivers), the PE to target organic compounds for different groups were varied, ~~The~~with a descending ~~following~~ order~~s~~ of ~~were~~ women > students > drivers for PAHs, students > women > drivers for PAEs, and drivers > women > students for hopanes (Table 5 and Figure 6).

4.1. PAHs

~~The total quantified PAHs concentration (ΣPAHs) accounted for 0.12‰-0.21‰% of PE $PM_{2.5}$ mass concentration.~~ Benzo[b]fluoranthene (BbF) was the most abundant PAH for women at DF, followed by benzo[a]pyrene (BaP) and indeno[1,2,3-cd]pyrene (IcdP). The average ~~BbF~~ concentration of BbF (~~a~~the maker of low temperature combustion, such as wood burning) was 11.6±19.2 ng m^{-3}, accounting for ~~up to~~ approximately 15.0% of the ΣPAHs for women ~~PE samples (Table 5)~~ (Wang et al., 2006) (Table 5). ~~While t~~The most abundant PAH species~~s~~ for students at WB and drivers at MT were IcdP (6.4±4.5 ng m^{-3}) and benzo[ghi]perylene (BghiP) (6.4±0.5 ng m^{-3}), respectively, ~~which~~ indicat~~inge~~ the contributions from the waste incineration and/or high temperature ~~fuel~~ combustion of fuel (e.g., gasoline vehicle emission) (Baek et al., 1991; Wang et al., 2006). The average ΣPAHs ~~average concentrations in wet season increased 326% and 52% for~~of women at DF (125.4±54.8 ng m^{-3}) and drivers at MT (44.6±10.8 ng m^{-3}) in wet season were 326% and 52% higher than those in dry season (29.4±5.6 and 29.4±4.4 ng m^{-3} respectively), while ~~the~~ ΣPAHs ~~decreased 42%~~ in wet season (36.8±15.7 ng m^{-3}) was ~~reversibly~~ 42% lower than that dry season (62.9±45.0 ng m^{-3}) ~~compared with dry season (62.9±45.0 ng m^{-3})~~ for students at WB. The dramatic increase in ~~women's~~ PE~~exposure~~ to PAHs for women is mainly due to raise ~~the increase in~~of ~~humidity (~~moisture content~~) of~~ in the wood used for grilling meat in wet season, promoting more ~~resulting in~~ PAHs ~~formation~~emission from ~~emissions sharp raising from~~ wood combustion processes (Shen et al., 2013). The restraint of waste combustion in wet season is the main factor ~~in the~~for the ~~decrease~~ lower of ~~students' exposure~~PE to $PM_{2.5}$-bound PAHs at landfill, in accordance with seasonal pattern on PE $PM_{2.5}$ mass ~~seasonal change pattern~~. Fanou et al. (2006) measured the PE PAHs concentrations ~~were measured~~ in Cotonou ~~in the previous study (Fanou et al., 2006), the resu~~ and found ~~It showed~~ that the PAHs level ~~of total PAHs~~ associated with particles ranged from 76.21 to 103.23 ng m^{-3} for 35 taxi-moto drivers in March 2001. Our values ~~The PAH levels determined in this study~~ for drivers at MT site was 50%-64% lower than their values ~~in Fanou et al. (2006) study~~, suggesting that the exposure to~~on~~ PAHs for the motorbike driver ~~exposure to PAHs~~ in this region has been improved ~~has improved~~.

~~As shown i~~In Figure 6A, ~~differing from the almost unchanged diurnal variation (daytime > nighttime) of PE $PM_{2.5}$ and its major chemical components discussed above,~~ PE PAHs showed ~~unstable~~ fluctuating diurnal variations for these three ~~types of target populations~~kinds of subjects. For ~~: 1) W~~the women at DF~~:~~, ~~the~~ the daytime concentrations ~~during~~ in ~~the~~ wet and dry seasons were both higher than those at nighttime due to ~~, suggesting that women's~~the intensive ~~combustion activities at daytime (~~roasting meat and burning wood~~)~~

~~strongly impacted the PE PAHs~~during working hours. ~~The average D/N ratios were 1.7 in dry season with the 12-hour average ΣPAHs of 37.4±25.1 ng m^{-3} for daytime and 21.4±17.2 ng m^{-3} for nighttime and 3.5 in wet season with 195.6±121.9 ng m^{-3} for daytime and 55.3±44.3 ng m^{-3} for nighttime; 2)~~ For the s~~S~~tudents at WB, ~~: nighttime~~ PE PAHs at night ~~time~~ were higher in dry season but ~~and~~ lower in wet season ~~compared with daytime levels, with the average D/N ratios of 0.7 and 1.8, respectively~~. Both ~~of~~ the PAH profiles ~~in the day and night~~ were ~~with the~~ feature~~d~~s with ~~of~~ high~~er~~ combustion markers of ~~-~~BbF and benzo[e]pyrene (BeP), and high gasoline vehicle emission markers of dibenzo[a,h]anthracene (~~-~~DahA) and BghiP (Baek et al., 1991; Wang et al., 2006). For ~~;~~ ~~The higher concentrations of combustion markers BbF and BeP were observed during the day, while the higher concentrations of gasoline vehicle emission markers DahA and BghiP were found at night (Baek et al., 1991; Wang et al., 2006), which was related to the garbage truck for waste transportation from city to the landfill during night. Moreover, we should also note that the impact of garbage truck emission was offset by PM$_{2.5}$ wet deposition during the wet season; 3) D~~the drivers at MT, ~~: we are surprised to see that~~ the average ~~dry season~~ D/N ratio in dry and wet seasons were~~as~~ 0.8 and ~~with the ΣPAHs of 26.3±7.6 ng m^{-3} for daytime and 32.5±13.8 ng m^{-3} for nighttime, and the average wet season D/N ratio was~~ 0.3~~, with 21.9±8.4 ng m^{-3} for daytime and 67.3±23.7 ng m^{-3} for nighttime,~~ respectively. The high~~er PE ~~nighttime~~ ΣPAHs concentrations at night~~time~~ and low~~er~~ D/N ratios for drivers ~~in this study~~ may be explained by the ~~possibility that there are~~ potential combustion sources ~~(P~~for PA~~A~~Hs ~~sources)~~ ~~around~~close to the participant~~s drivers~~ (e.g., ~~especially~~ sources nearby ~~around~~the drivers' home~~s at night~~) in Cotonou, Benin ~~at night rather than the motor vehicle exhaust,~~ especially in wet season. This can be deduced by the ~~(~~combustion ~~emission~~ marker of BaP which was the highest PAH species at night in wet season~~)~~, even though ~~although~~ the drivers exposed to the traffic emissions during the night working time (18:30 to 21:00 UTC). Further studies are thus required to confirm the findings and figure out the reasons.

In the study of Titcombe and Simcik (2011), the authors found that the 5-h average total PAH personal exposure concentration was 5040 ng m^{-3} (±909, n = 3) for open wood fires in households in the Njombe district of Tanzania, which was much higher (~65 times) than the women exposure PAHs at DF site in the current research. The highest 12-h exposure PAHs for women at DF site in this study was 469.7 ng m^{-3} (daytime in wet season, July 6th), approximately one-tenth of the PAHs concentration from open wood fires in Tanzania mentioned above. The large PE PAH concentrations difference between these two studies

may be influenced by many factors such as wood type, combustion state, stove structure and

Diagnostic ratios of PAHs with similar molecular weights have been widely used in source identification (Tobiszewski and Namiesnik, 2012; Yunker et al., 2002). In our study, the average values of BeP/(BeP+BaP) and IcdP/(IcdP+BghiP) were 0.47 and 0.52 for women at DF, 0.51 and 0.52 for students at WB, and 0.64 and 0.34 for drivers at MT, respectively (Figure 7), showing indicating that the unique impacts on the PE $PM_{2.5}$ fromof different atmospheric pollution sources on the different type participants are very significant, and that the diagnostic ratios of PAHs can be applied to identify the source of PAHs in PE $PM_{2.5}$ effectively. The average BeP/(BeP+BaP) ratios ranged from 0.47 to 0.64, comparable with those reported in Chinese megacities of Guangzhou (0.41-0.72) and Xi'an (0.59-0.73) of China (Li et al., 2005; Xu et al., 2018cb), and but lower than the value measured at reported in Shanghai (all samples > 0.70), China (Feng et al., 2006). This, implies ying the low oxidability of the PAHs in the less-developed cities in SWAsWA cities (less developed than Chinese cities). PAHs in drivers' PE samples wereare more prone to aging (i.e., the average ratio was 1.3-1.4 times of those for women and students) because of their re-suspension ofonto road dusts where PAHs are attached to (i.e., longer residence lifetime) and longer outdoor activity time (i.e., exposure to more sunlight). ; and mFore fine and ultra-fine particles-bound PAHs are emitted infrom high-temperature combustion in from motor vehicular engine, which are more easily photochemically oxidized oxidation in the atmosphereir (Baek et al., 1991; Lima et al., 2005). The differences of BeP/(BeP+BaP) ratios in between dry and wet seasons is arewere not obvious, and without general patternno fixed rule. However, thise ratio exhibiteds a significant day-night changevariation, with the valuesan average of 0.59 and a0.49t in theat daytime and 0.49 at nighttime, respectively. It This represents means that more favorable more beneficial meteorological conditions at daytime (suchi.e., as more sunlighthigher light intensity) and stronger more individual physical activities y (i.e., time extending for increasing the time of particulate re-suspension) at daytime are more conducive to the aging of $PM_{2.5}$ and its bounded PAHs. Moreover, IcdP/(BghiP+IcdP) of < 0.2, 0.2-0.5 and > 0.5 were used to identify represent petrogenic, petroleum combustion and a mix of grass, wood, and coal combustions, respectively (Yunker et al., 2002). The quite relatively low ratios for drivers at MT (0.34) demonstratesindicates that the PAHs in those samples were mainly produced from motor vehicles emissions (petroleum combustion), while grass, wood and coal combustions were more dominant for women at DF (0.52) and students at WB (0.52) (Figure 7). However, IcdP/(IcdP+BghiP) ratio dide not in all samples from our study show snot significant seasonal

761 variation.

762

763 *4.2. Phthalate esters (PAEs)*

764 Phthalate esters are widely used as plasticizers in ~~plastic~~ materials and can be released
765 into the air from the matrix evaporation and ~~plastics~~ combustion (Gu et al., 2010; Wang et al.,
766 2017a). The ~~personal exposure~~PE levels of PAEs could be mainly attributed to the usage of
767 the household products, painting material ~~at home~~, plastic waste incineration and municipal
768 sewage release (Zhang et al., 2014a). The total concentrations of six phthalate esters (the first
769 six species of PAEs in Table 5~~i.e., DMP, DEP, DBP, BBP, DEHP and DNOP~~) and one
770 plasticizer (bis(2-ethylhexyl)adipate, DEHA) (abbreviated as ~~named~~ ΣPAEs for the total ~~all~~
771 ~~these~~ seven species) were 882.0±193.3, 1380.4±335.2 and 698.1±192.4 ng m^{-3}, respectively,
772 for women at DF, students at WB and drivers at MT (Table 5). Bis(2-ethylhexyl)phthalate
773 (DEHP) was the most dominant PAE species, followed by di-n-butyl phthalate (DBP) ~~in this~~
774 ~~study~~ for all the three groups ~~kinds~~ of participants. DEHP is mainly used as a plasticizer for
775 manufacture of polyvinyl chloride (PVC); and ~~. And~~ together with DBP, they are the most
776 widely used ~~phthalate esters~~PAEs globally (Meng et al., 2014). The average DEHP and DBP
777 concentrations were 543.6 and 304.6 ng m^{-3}, accounting for ~~up to~~ approximately 55.1% and
778 30.9% of the ΣPAEs, respectively (Figure 6B). The elevated ΣPAEs for students ~~at WB in~~
779 ~~this study are mostly result from~~can be ascribed to the combustion of ~~the~~ plastic products at
780 landfill nearby. ~~The~~ Our results ~~in this study~~ are similar to ~~as~~ the previous studies conducted
781 ~~carried out~~ in Xi'an and~~,~~ Tianjin, ~~of~~ China (Kong et al., 2013; Wang et al., 2017a). The
782 ΣPAEs ranged from 376.6 to 1074 ng m^{-3} ~~in~~ outdoors, and from 469.2 to 1537 ng m^{-3} in
783 ~~student~~ classrooms ~~in Xi'an~~ (Wang et al., 2017a), where~~in which~~ DEHP and DBP were also
784 the most abundant PAEs ~~dominant species,~~with a sum of composition of ~~totally accounting~~
785 ~~for~~ 68% and 73% of the ΣPAEs ~~in~~ outdoor and indoor ~~environments~~, respectively.

786 The average concentrations of the ΣPAEs for women at DF, students at WB and drivers
787 at MT were comparable in dry season. ~~But~~However, the average concentrations were
788 927.2±154.9, 1929.8±340.4 and 594.6±16.6 ng m^{-3} in wet season ~~in this study~~, 1.1, 2.3 and
789 0.7 times of the ΣPAEs ~~values~~ in dry season (Figure 6B). A significant increase in ~~students~~
790 PE ΣPAEs for student at WB ~~in wet season~~ can be attributed to the enhanced PAEs emission
791 in the daytime with high RH (3173.6±1028.3 ng m^{-3}), consistent with the findings on PE
792 $PM_{2.5}$ ~~above~~. Dry and wet seasons ~~led to almost~~had similar PAEs profiles with different
793 diurnal ~~day and night~~ variations (Figure 6B). The average D/N ratios of the ΣPAEs in dry season
794 demonstrate constant concentrations~~show limited changes~~, with an average of ~~the values of~~ 1.0, 1.0 and 1.3, respectively, for

women, students and drivers,; while a much larger variations of 1.1, 4.6 and 0.7 were found for in wet season. Noticeably different diurnal D/N ratios between two seasons observed in this study for students at WB is interrelated with the human activities (specially related to the emissions from plastic materials emissions) and the subdued waste spontaneous combustion resulting led by from diurnal variations of meteorological conditionsparameters (i.e., more precipitation at night in wet season), which had been mentioned in Section. 3.1.1.

4.3. Hopanes

Hopanes have been used asare markers for fossil fuels (e.g., petroleum) combustion, especially for petroleum combustion (Simoneit, 1999; Wang et al., 2009). The average PE to concentration of drivers who exposed to the sum of eight quantified hopanes (Σhopanes) in this study for the drivers was 50.9±7.9 ng m^{-3}, 2.0 and 2.3 times higher than for the women at DF (17.1±6.4 ng m^{-3}) and students at WB (15.6±6.1 ng m^{-3}) (Table 5), respectively (Table 5),. The results which pindicateroves thean extremely high driver personal respiratory exposure contribution from the motor vehicle emissions (e.g., gasoline combustion) for the driversin this study. Then, iIt is important to note that numbers of automobiles areis rapidly increasing in SWAsWA cities, which further exacerbating es the air pollution and consequencerelated health issuesproblems there. The Σhopanes showed the unobvious seasonal variations for three kinds types of PEexposure participants. The , i.e., 0.9, 1.8 and 0.7 times Σhopane concentrations were observed in dry season were 0.9, 1.8 and 0.7 times of those in wet season. Even thoughAlthough the Σhopane concentrations were changeable in this studyvaried among three sites, their profiles distribution of ion individuall species of species hopanes were similar for each participant. 17α(H)-21β(H),30-norhopane (αβ-NH) and 17α(H)-21β(H)-hopane (αβ-HH) were two most dominant abundant hopanes in all PE $PM_{2.5}$ samples, with the the average concentrations of 6.0 and 6.5 ng m^{-3} and the percentages compositions of 21.4% and 23.3% of the Σhopanes, respectively (Table 5 and Figure 6C).

Compared with D/N ratios of the ΣPAHs and ΣPAEs, Σhopanes exhibited a more stable diurnal trend in this study, which namely, the daytime concentrations were higher in the daytime always greater than nighttime due to, owing to the obvious heavier traffic emissions during the day. For women at DF, D/N ratio was both 2.0 in dry and wet seasons, with the Σhopanes of 24.0±11.1 and 12.2±5.0 ng m^{-3} for daytime and nighttime in dry season, and 21.4±17.5 and 10.9±3.6 ng m^{-3} in wet season. Emphasize that The D/N ratio of the Σhopane for drivers at MT presthadthehighestvalue of(11.5)foralldetectedchemicalspeciesinthisstudy,withtheconcentrationsof780±191and449±164ngm^{-3}fordaytimeand nighttime in dry season, and 74.2±16.3 and 6.5±1.7 ng m^{-3} in wet season. It is notable We notice that the

daytime concentrations for drivers were comparable ~~for drivers~~ between the two seasons, while the nighttime hopanes in wet season were mostly washed away by rainfall ~~mostly~~, resulting in a very large ~~drop~~ decline in its concentrations ~~levels~~.

~~Therefore, although~~Even though these organic groups~~PAHs, PAEs and hopanes~~ are not major fractions~~abundant components~~ in PE $PM_{2.5}$, theirs~~e~~ fingerprints ~~organics~~ can more accurately illustrate ~~trace~~ the contributions of air pollution sources to $PM_{2.5}$. PAHs, PAEs and hopanes ~~The PAHs, PAEs and hopanes~~ are source markers for ~~representing~~ the ~~emissions from~~ combustion activities~~sources~~, plastics emissions and fossil fuel ~~combustion~~ emissions (e.g., from gasoline vehicles), ~~,~~ respectively, ~~are very~~ well match~~inged~~ to the potential air pollution sources impacted on ~~around these~~ th~~re~~e PE $PM_{2.5}$ for ~~type~~ participants in this study. ~~The~~ Our results not only indicate that the $PM_{2.5}$ respiratory exposure ~~was~~ can be strongly contributed from the environmental pollution sources and individual activities, but also prove reliable ~~the successful~~ application of organic tracers ~~in~~on characterization of ~~human~~ personal exposure study.

5. Health risk assessment of personal exposure to $PM_{2.5}$

Non-cancer risks of four heavy metals (i.e., Mn, Ni, Zn and Pb) and cancer risks of PAHs and PAEs via inhalation exposure way for women at DF, students at WB and drivers at MT are shown in Table 6. In general, the non-carcinogenic risks of Mn and Pb were relatively higher than those of Ni and Zn, but still well below ~~behind~~ the international threshold value of ~~(~~1.0~~)~~. Among those four metals, Hazard Quotient (HQ) of Pb in wet season for students at WB was the highest (2.95~~-x~~×~~-~~10^{-2}~~E-02~~), which suggests that Pb non-carcinogenic risk to children is more ~~obvious~~severe ~~-~~in that area compared with other participants and metals. ~~Except that Ni shows the stable wet season greater non-carcinogenic risk than dry season for all three kinds targets, t~~There was no ~~stable~~ consistent ~~change~~difference on the risks between ~~in~~ dry and ~~/~~wet season~~s risks of other components~~, except Ni which showed~~s~~ much greater value in wet than dry season for both participants. Counting ~~Summing up~~ the~~se four me~~ total of four toxic heavy metals~~tals~~, Hazard Index (HI) ~~values~~ for ~~women at DF, students at WB and drivers at MT in dry and wet seasons~~participants ~~were also~~are also ~~represented~~ shown in Table 6. The ~~D~~dry/wet season ratios of HI were 0.9, 0.5 and 2.3 for women, students and drivers, respectively, ~~-~~suggesting that the non-cancer risk of ~~personal~~ PE~~exposure~~ to metals in $PM_{2.5}$ for drivers ~~in dry season~~ was ~~much~~ significantly higher in dry than ~~that in~~ wet season~~s for drivers~~, owing to a mass of fugitive dust on the road at low RH~~in dry season~~. Moreover, the ~~yearly~~ average HI levels were 8.06~~-x~~×~~-~~10^{E-03}, 4.13~~-x~~×~~-~~10^{E-02} and 8.68~~-x~~×~~-~~10^{E-03} for the women ~~at DF~~, students ~~at WB~~ and drivers ~~at MT~~, respectively. ~~, showing t~~The highest non-

cancer health risks ~~from~~ of the heavy metals in PE $PM_{2.5}$ for students ~~are~~were~~,~~ 5.1 and 4.8 times of those for women and drivers. Overall, Mn, Zn, Ni, Pb and HI were all ~~within~~ below the safety limit for the ~~all~~ populations involved in this study, ~~pointing out~~representing ~~the~~ negligible non-cancer ~~health~~ risks of heavy metals in PE $PM_{2.5}$ in ~~SWA~~sWA region.

~~In~~As shown in Table 6, the ILCRs of PAHs were all ~~beyond~~exceed the international acceptable level of ~~-~~1×10^{-6} ~~(international acceptable level), suggesting non-negligible cancer risks of PAHs for women at DF, students at WB and drivers at MT whenever~~either in dry or wet season. Meanwhile, the ILCRs of PAEs were all below 1×10^{-6}, well within the safety limit of cancer risk. For all ~~types of~~ target participants~~s~~, higher cancer risks of PE $PM_{2.5}$-bound PAHs and PAEs were ~~shown~~found in wet ~~season were more likely to cause cancer risks than dry~~ season~~. ; thus, t~~The seasonal ~~changes~~variations such as increase of ~~, mainly due to increased humidity~~RH could lead ~~, result in~~ raise of PE ~~an increased personal exposure~~ cancer risks to toxic organics ~~species~~ in $PM_{2.5}$. In dry season, the average ILCR values of PAHs for women and drivers were comparable ~~for women and drivers~~, both ~50% lower than those for students, implying the high toxicity originated from the waste burning ~~sources~~ and high sensitivity to juveniles. In wet season, PAHs exhibited the highest ILCR for women at DF, 2.5 and 2.7 times of those for students and drivers, respectively. ~~It can be seen that t~~The domestic wood burning and meat grilling ~~meat~~ can trigger nearly ten times the safety limit for PAHs ~~of cancer risks to target women in this study~~. The cancer risks of PAEs showed the similar ~~pattern~~ trend in dry and wet seasons (Yang et al., 2011), with the descending order of students ~~at WB~~ > women ~~at DF~~ > drivers ~~at MT (Yang et al., 2011)~~. The carcinogenic risks of PAEs for the drivers ~~in traffic environment~~ was the lowest, much lower (45% and 76% ~~lower for in~~ dry and wet seasons) than those ~~PAEs~~ for students who live~~d~~are close to ~~the source of~~ waste incineration. In a word, the ILCRs of PAHs exceeded the threshold value of 1×10^{-6} for all the participants, indicating that the carcinogenic PAHs are a threat to the individual's health and subsequently alerting a need of effective emission control in ~~SWA~~sWA. ~~However,~~Even though PAEs had ~~show limited~~low carcinogenic risks ~~in this study~~, ~~but~~ the effects from ~~of~~ waste burning ~~source~~ to students ~~is needed to~~should not be ignored ~~pay more attention~~ and proper ~~reasonable~~ control measures ~~s~~ for both $PM_{2.5}$-bound heavy metals and toxic organic must be established~~compounds~~.

In addition, it should be noted that ~~the~~ both non-cancer and cancer risks could be potentially underestimated since many toxic chemical components ~~could not be detected~~were not involved in this study. ~~It is concluded b~~Based on the current, there are ~~data tha~~a variety of~~t~~ ~~-~~emission sources impacted on the ~~different~~different degrees of impacts on the population

groups in sWA region ~~targets present different levels of risks from different chemical species in PE $PM_{2.5}$ from various air pollution sources~~. ~~We must pay a~~Attention should be paid on ~~to heavy metal non-cancer~~ health risks for chemicals via inhalation way, especially Pb and Mn for students at WB site as well as PAHs ~~cancer risks~~ for women at DF ~~site~~ in wet season ~~in SWAsWA region~~.

6. Conclusions

~~We explore the chemical characteristics and health risks of personal exposure to $PM_{2.5}$ (PE $PM_{2.5}$) from different typical anthropogenic air pollution sources in sSouthern West Africa. Our study finds that organic matter and geological material are the almost identical proportions (34.1% and 35.8%) for women at domestic fire site. Nearly half contribution to PE $PM_{2.5}$ for students at waste burning site and drivers at motorcycle traffic site comes from fugitive dust. Therefore, the primary source (mainly dust) is the most important source for PE $PM_{2.5}$ in these undeveloped regions. The contribution to PE $PM_{2.5}$ from heavy metals was higher for students (1.0%), owing to the waste burning emissions strongly, leading to the highest non-cancer risk among these three kinds of participants, as well as the extremely high PAEs concentrations (indicator of plastic emissions). PE $PM_{2.5}$-bound PAHs concentration for women at domestic fire site was 1.6 times for students and 2.1 times for drivers, which is mainly attributed to the wood burning and grilling meat activities, resulting in approximately five times higher of international cancer risk safe limit (nearly ten time of threshold value in wet season). Drivers' exposure to hopanes in PE $PM_{2.5}$ was 2.0-2.3 times higher than women and students, correlating with the elevated traffic emissions on road environment well.~~

~~This work can be regarded as the first attempt for health assessment in underdeveloped country of Africa at the current condition, even though, although there are some few drawbacks, such as relatively short sampling period and a limited number of participants. More investigations on personal exposurePE and related potential health effects by cohort study method will be considered in the futurefurther. The policy implication of our findings is that developing and implementing appropriate preventive and control measures on different $PM_{2.5}$ anthropogenic pollution sources in different regions are appropriate, such as using dry wood for barbecues for the female workers and improving waste treatment equipment at landfill as soon as possible to reduce waste inorganized waste stack and open combustion.~~

This work can be regarded as a first attempt for the assessment of personal exposure to particulate matter originating from main sources of combustion aerosols in representative cities of southern West Africa. We targeted in this study different groups of people exposed

to domestic fires, traffic and waste burning. Even though there are few drawbacks such as relatively short sampling period and limited number of participants, our findings provide a new insight on the health risk due to $PM_{2.5}$ exposure in areas with scarce observations. Developing countries of southern West Africa are facing a great challenge regarding air pollution mitigation strategy and more investigations on personal exposure and related potential health effects by cohort method will be considered in the future. In the short terms, developing and implementing appropriate preventive and control measures on anthropogenic combustion sources downtown such improving waste treatment equipment at landfill or efficient smoking equipment for domestic use, are appropriate.

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Author Contributions

H.X. and C.L. conceived and designed the study. H.X., J.-F.L., C.L. and B.G. contributed to the literature search, data analysis/interpretation and manuscript writing. J.-F.L., C.L., B.G., V.Y., A.A., K.H., S.H., Z.S. and J.C. contributed to manuscript revision. H.X., J.-F.L., E.G., J.A and L.L. carried outconducteed the particulate samples collection and chemical experiments, analyzed the experimental data.

Additional Information

Fig. S1 and SI A-D accompany this manuscript can be found in Supplementary Information.

Competing financial interests

The authors declare no competing financial interests.

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Figure Caption:

Figure 1. Location~~s~~ of the sampling sites (white square) within the cities. A: Domestic Fires (DF) site at the Yopougon-Lubafrique market in Abidjan; B: Waste Burning (WB) site at the landfill of Akeoudo in Abidjan~~, the location of the long-term sampling site is given by the blue marker~~; and C: Motorcycle Traffic (MT) site at Dantokpa area in Cotonou.

Figure 2. Pictures showing the sampling sites and corresponding participants: (a) women at DF; (b) students at WB; (c) drivers at MT.

Figure 3. Personal exposure to $PM_{2.5}$ mass concentrations of woman at DF, student at WB and driver at MT in dry season (January) and wet season (July) of 2016 in ~~SWA~~sWA area.

Figure 4. Variations of OC/EC ratios in personal exposure to $PM_{2.5}$ samples for women at DF, students at WB and drivers at MT (The box plots indicate the average concentration and the min, 1^{st}, 25^{th}, 50^{th}, 75^{th}, 99^{th} and max percentiles).

Figure 5. Personal exposure to $PM_{2.5}$ mass concentration closures for women at DF, students at WB and drivers at MT in different sampling seasons.

Figure 6. Distributions of A: PAHs; B: PAEs; and C: hopanes in $PM_{2.5}$ personal exposure samples for women at DF, students at WB and drivers at MT in dry and wet seasons of 2016.

Figure 7. Correlations between PAHs diagnostic ratios (average ratio points of each type participant indicate day and night value respectively).

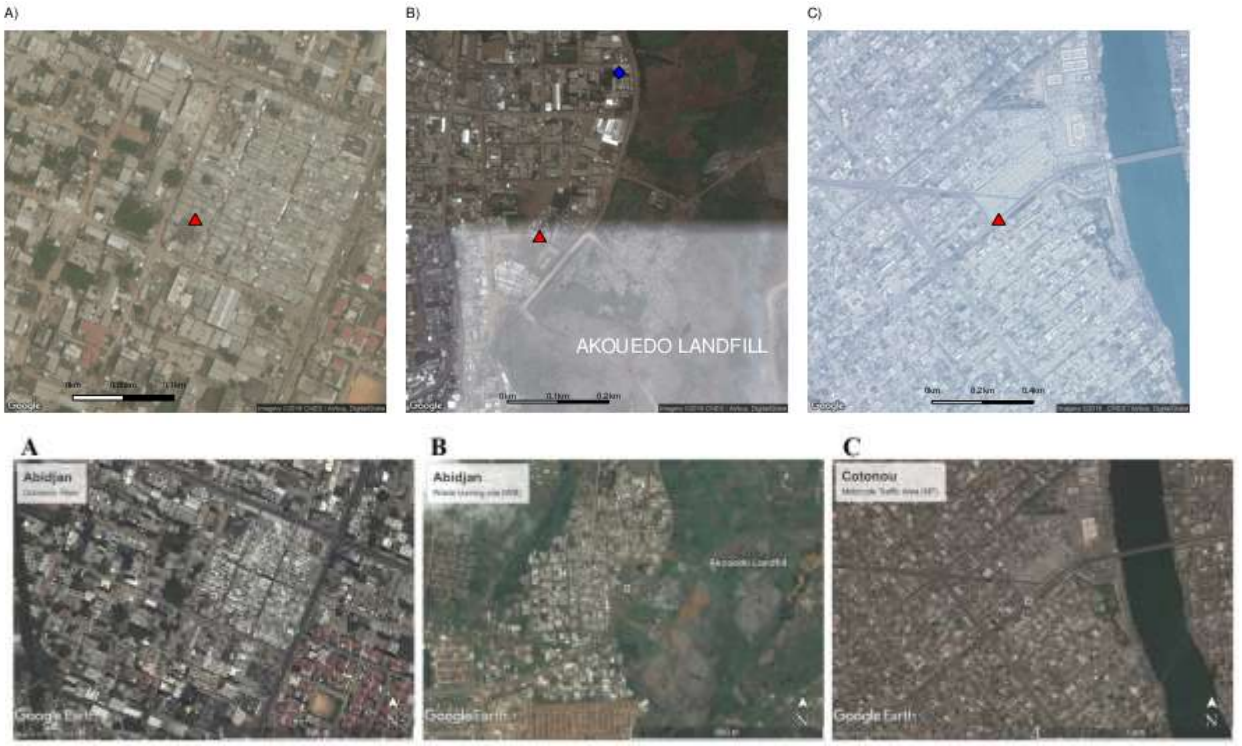


Figure 1.

1316

Figure 2.

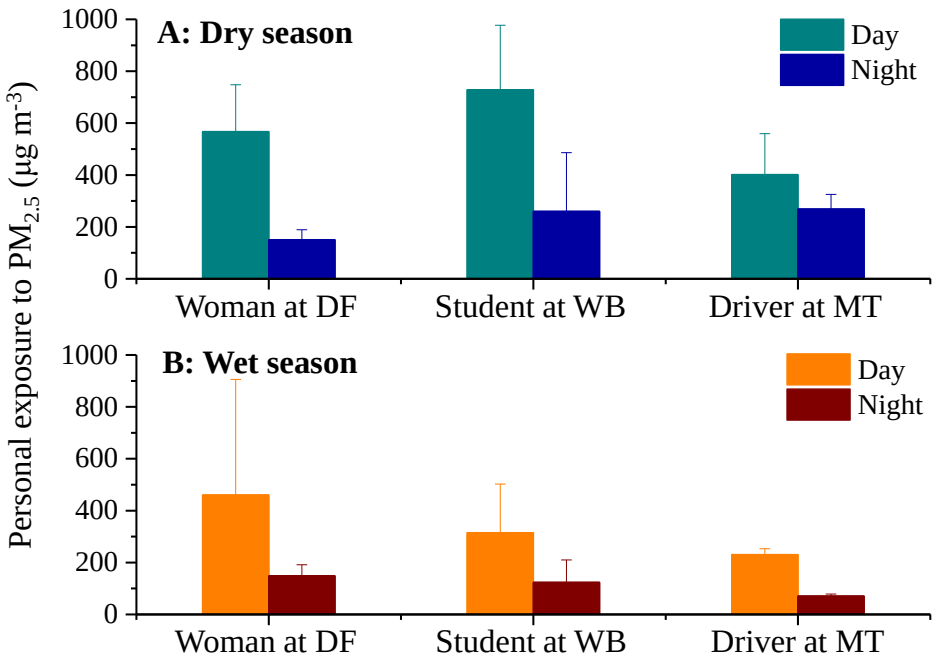

A: Dry season
Day
Night
Personal exposure to PM2.5 (μg m-3)
1000
800
600
400
200
0
Woman at DF
Student at WB
Driver at MT
B: Wet season
Day
Night
1000
800
600
400
200
0
Woman at DF
Student at WB
Driver at MT

Figure 3.

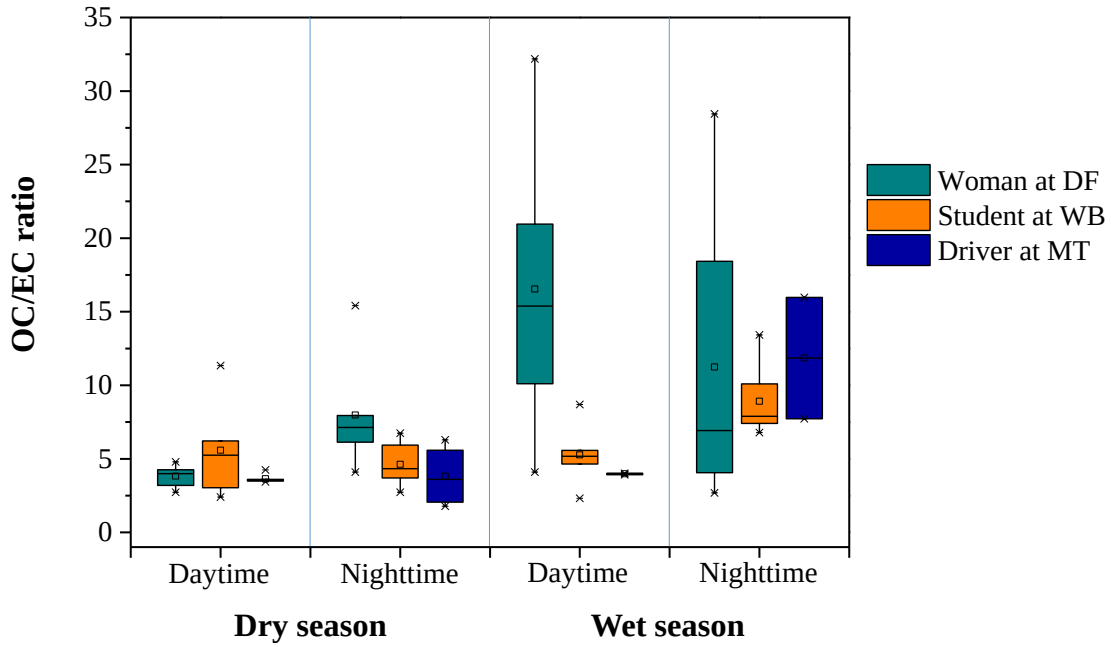

OC/EC ratio
35
30
25
20
15
10
5
0
Daytime
Nighttime
Daytime
Nighttime
Dry season
Wet season
Woman at DF
Student at WB
Driver at MT

Figure 4.

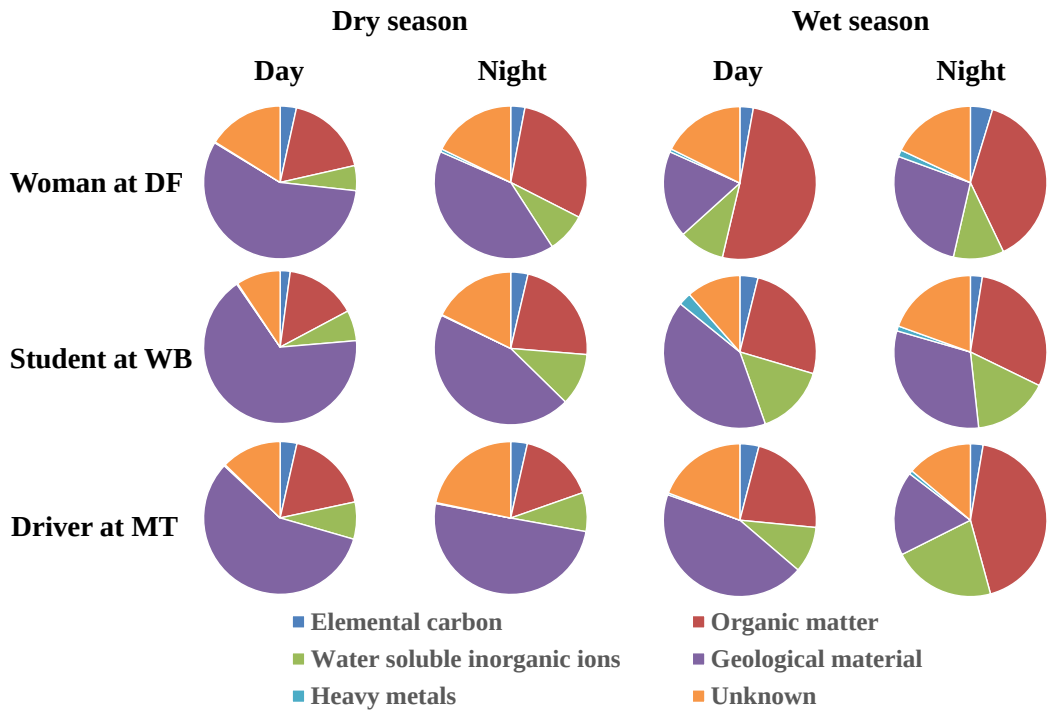
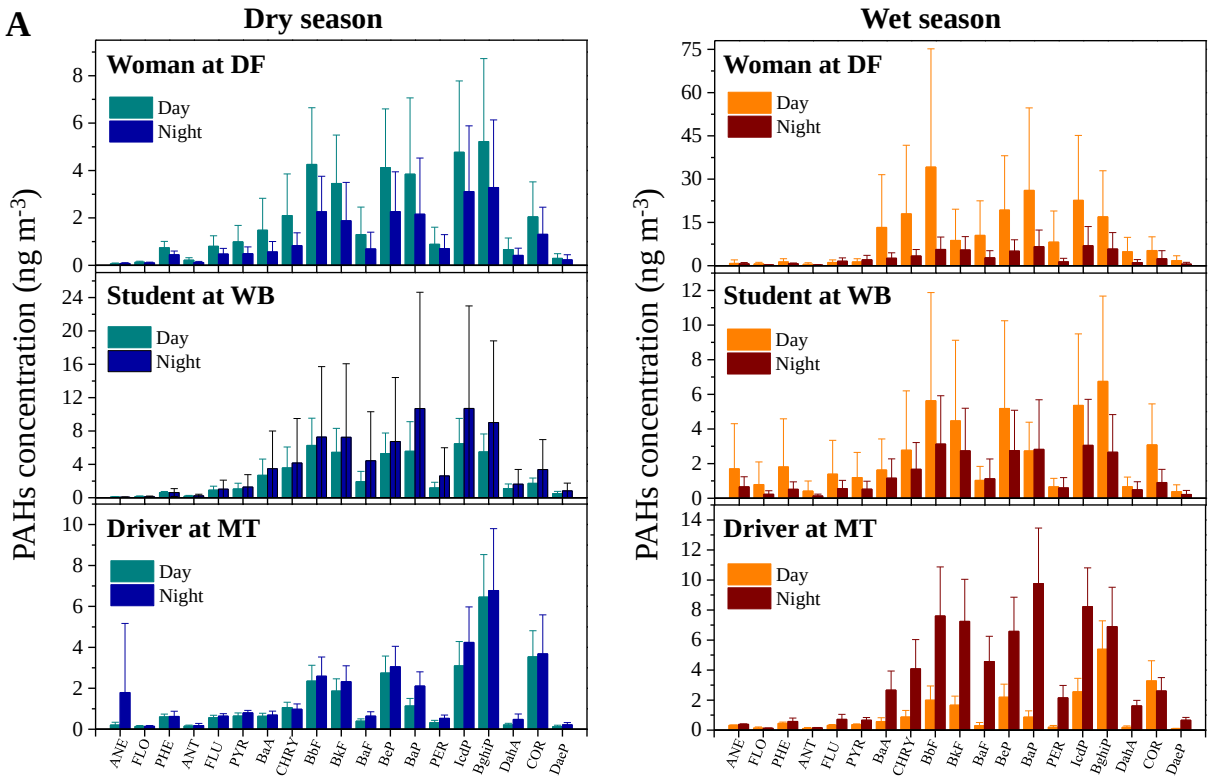

Dry season
Wet season
Day
Night
Day
Night
Woman at DF
Student at WB
Driver at MT
Elemental carbon
Organic matter
Water soluble inorganic ions
Geological material
Heavy metals
Unknown

Figure 5.



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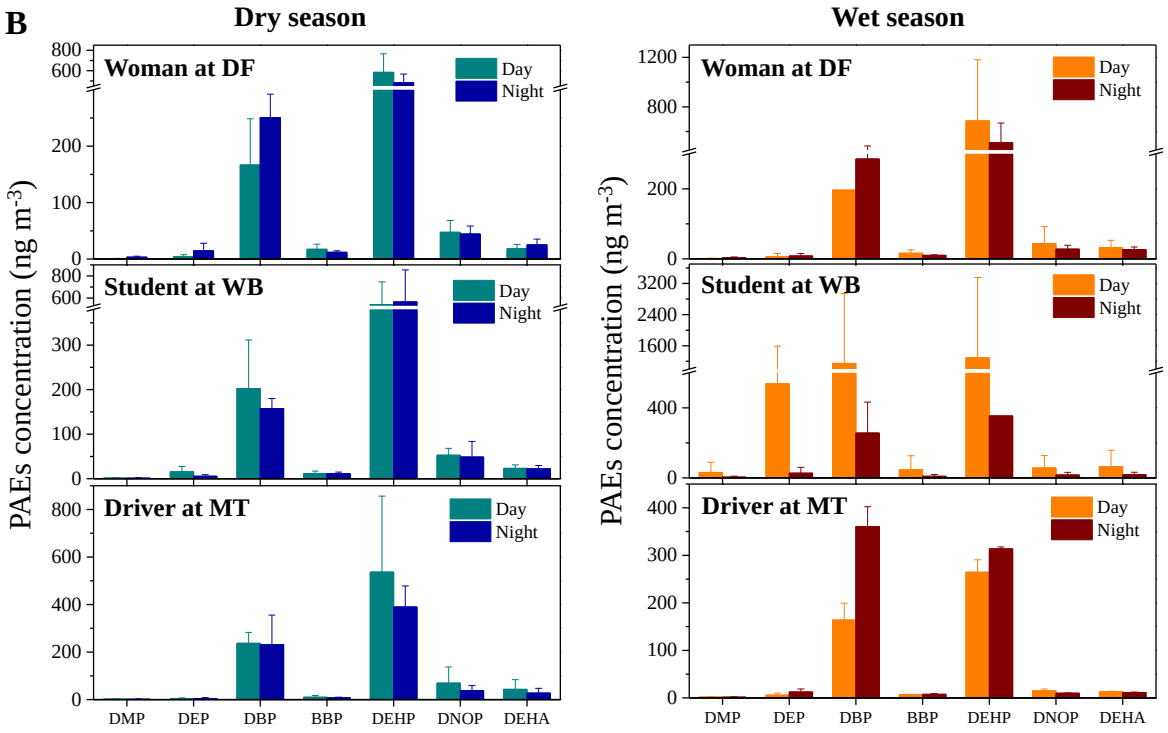

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C

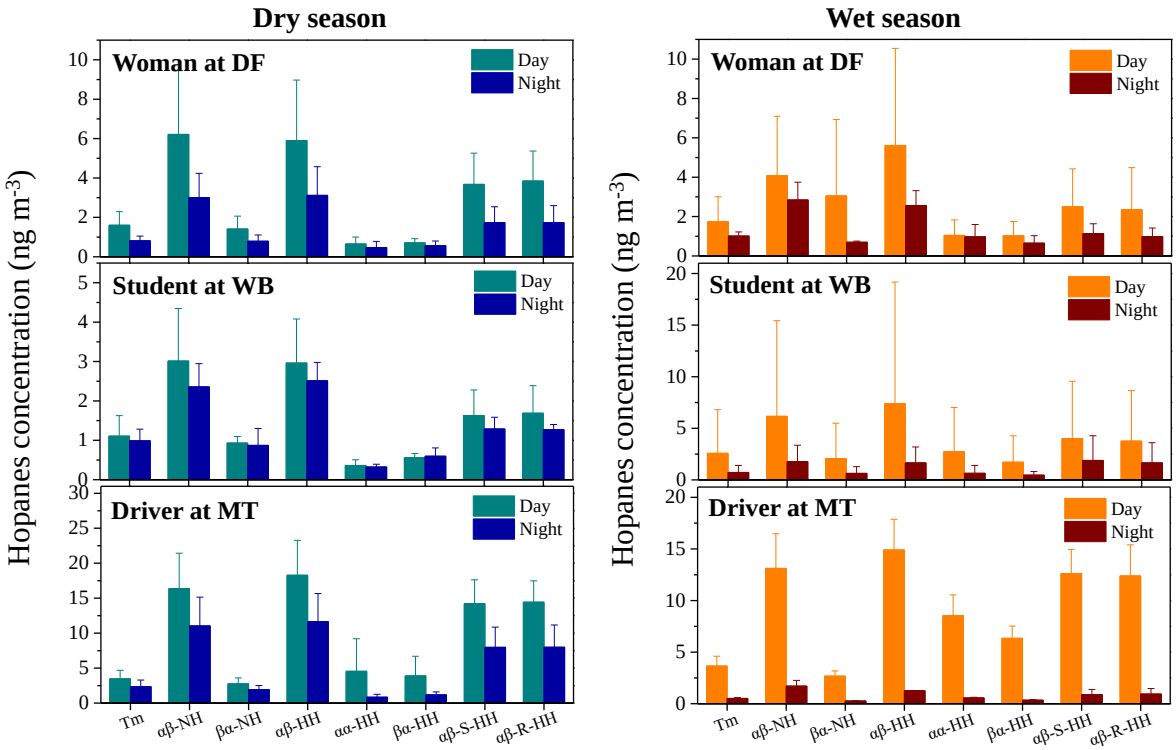
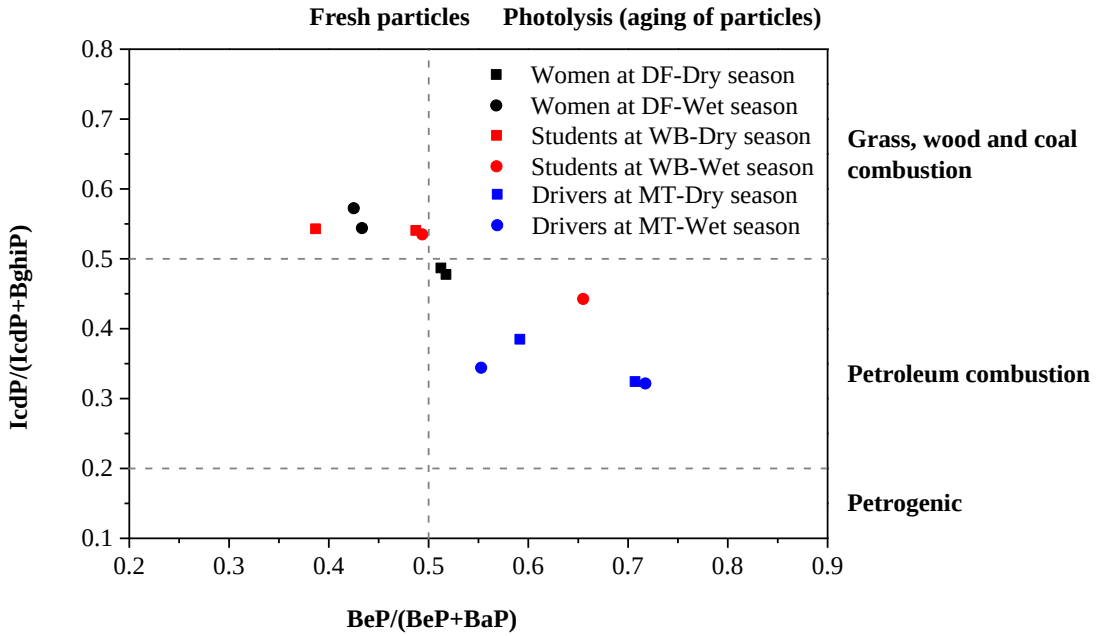

Dry season
Wet season
Woman at DF
Student at WB
Driver at MT
Day
Night
Hopanes concentration (ng m-3)
Tm
αβ-NH
βα-NH
αβ-HH
αα-HH
βα-HH
αβ-S-HH
αβ-R-HH

Figure 6.



1336

1337 **Figure 7.**

1338

Table 1 Meteorological parameters of the studied two cities during the dry (December 2015 to March 2016) and wet (April to July 2016) seasons.

	Season	Abidjan	Cotonou
Mean daily air temperature (°C)	Dry	28.0	28.3
	Wet	27.5	27.7
Total rainfall (mm)	Dry	268	92
	Wet	626	558
Mean wind speed (m s^{-1})	Dry	3.0	3.0
	Wet	3.4	4.3

Table 2 Definitions and recommended values of the parameters in equations (1-4) in this study.

Parameter	Definition (unit)	Value used in this study (reference)
D	average daily exposure dose (mg kg^{-1} day^{-1})	/
C	heavy metals concentrations in equations (ng m^{-3})	/
R	inhalation rate, air volume a child inhaled each day (m^3 day^{-1})	16.0 for women and drivers; 15.2 for students (USEPA, 2011)
EF	exposure frequency (day $year^{-1}$)	130 for women and drivers (half working days); 182 for students (half year)
ED	exposure duration (year)	30 for women and drivers (working years); 15 for students (before going to high school)
BW	body weight (kg)	62.5 for women[a]; 37.5 for students[a]; 85.0 for drivers[a]
AT	averaging time (day)	30 or 15 × 365 (non-cancer); 70 × 365 (cancer)
cf	conversion factor (kg mg^{-1})	10^{-6}
HQ	hazard quotient	/
RfD	reference dose, estimated as the maximum permissible risk on human by daily exposure (mg kg^{-1} day^{-1})	Table 3
HI	hazard index	/
ILCR	incremental lifetime cancer risk (ILCR)	/
CSF	cancer slope factor (mg kg^{-1} $day^{-1})^{-1}$	Table 3
$[BaP]_{eq}$	equivalent BaP toxicity concentration (ng m^{-3})	/
C_i	individual PAH species concentration (ng m^{-3}) (i means target PAH species)	/
TEF_i	toxicity equivalency factor of each target PAH compound (i means target PAH species)	(Nisbet and Lagoy, 1992)

a: Measured in this study.

Table 3 Reference dose (RfD) (mg kg^{-1} day^{-1}) and cancer slope factor (CSF) (mg kg^{-1} $day^{-1})^{-1}$ via inhalation exposure way used in this study.

	RfD	CSF	Reference
Mn	1.8×10^{-3}	/	Liu et al., 2015
Ni	5.4×10^{-3}	/	Zhou et al., 2014; Liu et al., 2015
Zn	3.0×10^{-1}	/	Zhou et al., 2014
Pb	3.5×10^{-3}	/	Zhou et al., 2014; Hu et al., 2012
BaP	/	3.140	USEPA, 2011
DEHP	/	0.014	USEPA, 1997; Wang et al., 2017a

Table 4 Statistical analysis (arithmetic mean±standard deviation) of personal exposure to $PM_{2.5}$ mass concentrations and the chemical compositions (units: μg m^{-3}) during the sampling period in ~~SWA~~sWA region.

	Dry season						Wet season					
	Women at DF		**Students at WB**		**Drivers at MT**		**Women at DF**		**Students at WB**		**Drivers at MT**	
	Daytime	**Nighttime**	**Daytime**	**Nighttime**	**Daytime**	**Nighttime**	**Daytime**	**Nighttime**	**Daytime**	**Nighttime**	**Daytime**	**Nighttime**
PE $PM_{2.5}$	**567.0±180.6**	**150.6±38.5**	**728.5±248.5**	**260±226.1**	**401.3±158.0**	**269.0±56.1**	**460.5±445.2**	**148.6±42.9**	**315.2±186.9**	**123.7±86.1**	**230.4±22.8**	**70.7±8.1**
OC	72.4±24.6	31±5.0	85.0±57.4	40.9±34.4	49.5±12.5	31.8±14.2	189.3±197.8	40.1±9.3	65.2±65.2	28.5±26.8	37.0±3.5	22.2±10.6
EC	19.5±7.3	4.7±2.2	15.0±4.7	8.6±5.7	13.6±3.6	9.0±2.3	11.5±10.8	6.3±3.7	12.3±11.4	3.6±3.6	9.3±0.8	1.9±0.0
Total carbon	**91.9±31.1**	**35.7±6.8**	**100.0±60.1**	**49.5±39.5**	**63.1±16.0**	**40.8±13.6**	**200.8±207.1**	**46.3±7.2**	**77.4±76.2**	**32.1±30.3**	**46.3±4.2**	**24.1±10.6**
Cl^-	4.4±1.3	1.6±0.6	6.5±3.6	6.4±9.4	2.4±0.8	2.2±0.6	8.6±8.4	1.9±1.0	4.6±5.4	1.9±0.7	3.1±0.2	2.3±0.2
NO_3^-	2.7±0.7	2.2±1.4	5.5±1.3	3.0±0.7	3.7±1.3	2.7±0.5	2.2±0.8	1.6±0.7	5.0±6.0	1.8±1.3	1.6±0.2	1.2±0.1
SO_4^{2-}	4.0±1.1	1.8±0.6	7.5±2.5	3.6±0.9	7.5±2.5	5.3±0.6	6.8±5.2	2.3±0.8	6.4±5.9	2.3±0.4	5.2±0.3	3.2±0.5
Na^+	2.9±0.4	1.6±0.3	4.1±1.1	1.9±0.8	3.3±1.1	2.4±0.3	4.2±2.2	4.4±1.7	16.2±17.3	3.3±3.1	3.6±0.2	2.6±0.1
NH_4^+	0.6±0.2	0.4±0.5	1.4±0.4	3.0±4.1	1.1±0.2	0.9±0.2	0.6±0.5	0.1±0.0	0.6±0.2	0.4±0.3	0.7±0.0	0.1±0.0
K^+	3.2±0.6	1.7±0.6	5.8±4.0	2.2±0.8	1.9±0.4	2.1±0.9	7.6±8.0	1.3±0.8	3.3±4.4	1.3±0.6	1.1±0.0	3.6±1.5
Mg^{2+}	0.6±0.2	0.2±0.1	0.8±0.3	0.3±0.2	0.4±0.2	0.3±0.1	1.1±1.2	0.3±0.1	1.0±0.9	0.3±0.2	0.3±0.0	0.2±0.0
Ca^{2+}	11.0±3.2	3.1±0.9	14.9±4.5	4.9±3.2	10.6±5.5	6.0±1.2	6.6±4.3	3.2±0.8	17.3±13.9	4.5±3.8	6.8±0.3	2.3±0.1
Total ions	**29.3±6.6**	**12.5±3.7**	**46.6±15.4**	**25.2±18.8**	**30.9±11.9**	**21.9±3.2**	**37.6±29.5**	**15.1±2.2**	**54.4±50.0**	**15.8±8.8**	**22.3±1.0**	**15.5±1.9**
Fe	14.61±5.25	2.64±0.36	21.17±4.64	4.85±3.30	10.99±6.50	5.90±0.37	3.37±3.34	1.87±0.96	5.07±1.74	1.76±1.24	4.56±0.64	0.57±0.05
V	0.04±0.02	0.00±0.00	0.07±0.02	0.02±0.01	0.03±0.02	0.01±0.01	0.01±0.01	0.00±0.00	0.03±0.03	0.01±0.01	0.01±0.00	0.01±0.00
Cr	0.04±0.02	0.01±0.00	0.06±0.02	0.01±0.01	0.03±0.03	0.01±0.01	0.05±0.02	0.06±0.03	0.31±0.35	0.04±0.05	0.03±0.00	0.03±0.00
Mn	0.18±0.06	0.04±0.03	0.29±0.08	0.07±0.04	0.35±0.12	0.21±0.11	0.14±0.16	0.04±0.00	0.37±0.36	0.06±0.06	0.17±0.02	0.04±0.00
Co	0.05±0.02	0.01±0.01	0.09±0.02	0.01±0.01	0.05±0.03	0.02±0.02	0.02±0.02	0.02±0.02	0.04±0.05	0.02±0.02	0.02±0.01	0.01±0.00
Ni	0.02±0.01	0.00±0.00	0.02±0.01	0.01±0.01	0.02±0.01	0.01±0.01	0.02±0.02	0.03±0.02	0.12±0.14	0.02±0.03	0.02±0.00	0.01±0.00
Cu	0.04±0.01	0.02±0.01	0.14±0.03	0.02±0.01	0.05±0.03	0.03±0.01	0.13±0.07	0.13±0.07	0.67±0.81	0.10±0.09	0.07±0.02	0.06±0.01
Zn	0.40±0.22	0.55±0.73	0.49±0.19	0.15±0.12	0.33±0.16	0.19±0.07	0.51±0.32	0.32±0.17	1.41±1.55	0.26±0.27	0.29±0.04	0.12±0.00

Sb	0.02±0.01	0.05±0.02	0.02±0.02	0.00±0.00	0.02±0.04	0.01±0.01	0.12±0.08	0.21±0.18	1.16±1.38	0.22±0.29	0.07±0.04	0.08±0.09
Ba	0.19±0.09	0.16±0.12	0.25±0.11	0.07±0.09	0.22±0.18	0.05±0.07	0.47±0.39	1.02±0.60	6.80±8.30	0.84±1.41	0.18±0.18	0.14±0.01
Pb	0.07±0.03	0.07±0.07	0.17±0.07	0.04±0.03	0.07±0.05	0.02±0.03	0.14±0.02	0.09±0.03	0.92±1.01	0.13±0.18	0.05±0.02	0.03±0.01
Heavy metals	**1.05±0.28**	**0.91±0.80**	**1.59±0.51**	**0.40±0.31**	**1.16±0.66**	**0.56±0.28**	**1.62±0.65**	**1.93±1.10**	**11.80±13.91**	**1.69±2.38**	**0.90±0.26**	**0.53±0.09**

Table 5 Mass concentrations of PE $PM_{2.5}$-bound PAHs, PAEs and hopanes species for women at DF, students at WB and drivers at MT (ng m^{-3}).

Specific species (abbreviation)	Women at DF		Students at WB		Drivers at MT	
	Average	**Stdev***	**Average**	**Stdev***	**Average**	**Stdev***
acenaphthene (ACE)	0.4	0.5	0.6	1.2	0.7	1.7
fluorene (FLO)	0.3	0.3	0.3	0.6	0.1	0.0
phenanthrene (PHE)	0.8	0.4	0.9	1.2	0.6	0.1
anthracene (ANT)	0.3	0.2	0.2	0.2	0.2	0.0
fluoranthene (FLU)	1.0	0.4	1.0	0.7	0.6	0.1
pyrene (PYR)	1.2	0.5	1.0	0.5	0.6	0.1
benzo[a]anthracene (BaA)	4.5	8.5	2.2	1.5	1.1	0.5
chrysene (CHR)	6.1	11.2	3.0	1.6	1.8	0.8
benzo[b]fluoranthene (BbF)	11.6	19.2	5.6	2.7	3.6	1.2
benzo[k]fluoranthene (BkF)	4.9	4.2	5.0	2.9	3.3	1.1
benzo[a]fluoranthene (BaF)	3.8	5.3	2.1	2.4	1.5	0.8
benzo[e]pyrene (BeP)	7.7	8.1	5.0	2.5	3.6	0.7
benzo[a]pyrene (BaP)	9.7	12.5	5.5	5.7	3.5	1.6
perylene (PER)	2.8	5.0	1.3	1.4	0.8	0.4
indeno[1,2,3-cd]pyrene (IcdP)	9.4	9.3	6.4	4.5	4.5	0.7
benzo[ghi]perylene (BghiP)	7.8	6.1	6.0	3.6	6.4	0.5
dibenzo[a,h]anthracene (DahA)	1.8	2.2	1.0	0.6	0.6	0.1
coronene (COR)	2.8	1.6	2.3	1.4	3.3	0.4
dibenzo[a,e]pyrene (DaeP)	0.7	0.7	0.5	0.3	0.3	0.1
ΣPAHs	**77.4**	**47.9**	**49.9**	**30.7**	**37.0**	**7.4**
dimethyl phthalate (DMP)	2.2	1.0	9.6	27.9	1.9	0.5
diethyl phthalate (DEP)	8.3	4.1	146.5	517.0	6.8	1.4
di-n-butyl phthalate (DBP)	224.8	90.6	440.7	848.4	248.2	42.1
benzyl butyl phthalate (BBP)	13.8	4.3	19.7	37.3	8.1	2.9
bis(2-ethylhexyl)phthalate (DEHP)	566.4	181.4	688.0	899.1	376.3	144.5
di-n-octyl phthalate (DNOP)	40.9	16.9	43.8	26.2	33.0	31.0
bis(2-ethylhexyl)adipate (DEHA)	25.6	6.0	32.0	41.8	23.8	19.0
ΣPAEs	**882.0**	**193.3**	**1380.4**	**335.2**	**698.1**	**192.4**
17α(H)-22,29,30-trisnorhopane (Tm)	1.3	0.5	1.3	1.9	2.5	0.5
17α(H)-21β(H),30-norhopane (αβ-NH)	4.0	1.2	3.3	4.1	10.6	1.9
17β(H)-21α(H),30-norhopane (βα-NH)	1.5	1.8	1.1	1.5	1.9	0.3
17α(H)-21β(H)-hopane (αβ- HH)	4.3	1.9	3.6	5.4	11.5	2.2
17α(H)-21α(H)-hopane (αα-HH)	0.8	0.2	1.0	2.0	3.6	2.1
17β(H)-21α(H)-hopane (βα-HH)	0.7	0.2	0.8	1.2	2.9	1.2
17α(H)-21β(H),(22S)-homohopane (αβ-S-HH)	2.3	0.7	2.2	2.4	8.9	1.3
17α(H)-21β(H),(22R)-homohopane (αβ-R-HH)	2.2	0.8	2.1	2.1	8.9	1.3
Σhopanes	**17.1**	**6.4**	**15.6**	**6.1**	**50.9**	**7.9**

*: standard deviation

Table 6 Non-cancer risks of heavy metals and cancer risks of PAHs and PAEs via inhalation exposure way in PE $PM_{2.5}$ of women at DF, students at WB and drivers at MT in dry and wet seasons.

	Dry season			Wet season		
	Women	**Students**	**Drivers**	**Women**	**Students**	**Drivers**
Non-cancer risk						
Mn	5.71E-03	2.02E-02	1.09E-02	4.83E-03	2.31E-02	4.26E-03
Ni	1.44E-04	5.60E-04	1.77E-04	4.49E-04	2.59E-03	2.00E-04
Zn	1.45E-04	2.15E-04	6.16E-05	1.24E-04	5.45E-04	5.05E-05
Pb	1.75E-03	5.98E-03	9.33E-04	2.97E-03	2.95E-02	7.75E-04
HI	**7.74E-03**	**2.70E-02**	**1.21E-02**	**8.37E-03**	**5.57E-02**	**5.29E-03**
Cancer risk (ILCR)						
PAHs ($[BaP]_{eq}$)	3.13E-06	6.43E-06	3.22E-06	9.33E-06	3.68E-06	3.42E-06
PAEs (DEHP)	2.92E-07	3.36E-07	1.86E-07	3.15E-07	4.86E-07	1.16E-07