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BTEX air concentrations and self-reported common health problems in gasoline sellers from Cotonou, Benin

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To examine the relation between BTEX exposure levels and common self-reported health problems in 140 gasoline sellers in Cotonou, Benin, a questionnaire documenting their socioeconomic status and their health problems was used, whereas 18 of them went through semi-directed qualitative individual interviews and 17 had air samples taken on their workplace for BTEX analysis. Median concentrations for BTEX were significantly lower on official (range of medians: 54–207 μg/m³, $n = 9$) *vs* unofficial (148–1449 μg/m³, $n = 8$) gasoline-selling sites ($p < 0.05$). Self-reported health problems were less frequently reported in sellers from unofficial *vs* official selling sites ($p < 0.05$), because, as suggested by the semi-directed interviews, of their fear of losing their important, but illegal, source of income. Concluding, this study has combined quantitative and qualitative methodological approaches to account for the complex socioeconomic and environmental conditions of the investigated sellers, leading to their, in some cases, preoccupying BTEX exposure.

Keywords: BTEX; developing countries; gasoline sellers; human health; occupational exposure

Introduction

Air pollution is a major public health concern for every major city of the world. Thus, WHO regularly determines guidelines on the maximum environmental concentrations of many air pollutants (WHO 2000a). Benin is not exempted of this problem, which nowadays occurs acutely in its large cities, in particular in Cotonou, the economical capital and most populous city of the country (Ayi-Fanou et al. 2006; Satoguina & Alinsato 2010). High demographic concentration in this city has resulted in high mobility and various secondary economic activities including urban transport by two-wheeled vehicles (motorcycle taxis locally designated as "zémidjan") and the sale of poor quality gasoline on the streets sidewalks, hereafter referred to as "unofficial sites" (U), distinct from the "official" (O) gasoline retailers. Both of these sites reflect economical activities allowing many people to meet their basic needs, but also constitute important sources of air pollution.

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Previous studies addressing the problem of motorcycle taxis in Cotonou and their impact on the air quality and the health of the residents showed contamination with CO, NOx, and SO_2, particulate matters and volatile organic compounds (VOCs) (Bultynck & Reliquet 2003; Ayi-Fanou et al. 2006). In particular, benzene (B), toluene (T), ethylbenzene (E), and xylenes (X) are often detected in significant concentrations as a result of their presence in gasoline, fuels, and fuel additives (ATSDR 2000; Zdanevitch & Del Gratta 2004; Anand & Mehendale 2005; ATSDR 2007a, 2007b, 2007c). BTEX lipophilicity coupled with their small molecular size and lack of charge enables their fast absorption through biological membranes such as the alveoli, gastrointestinal wall, and the skin. These properties, combined with volatility at ambient temperature, makes inhalation the principal route of human exposure to these VOCs (Anand & Mehendale 2005). The main short-term effect on human health resulting from exposure to BTEX consists of neurotoxicity, but reproductive toxicity is also reported as medium- to long-term adverse effect (ATSDR 2000; WHO 2000b; ATSDR 2007a, 2007c). In addition, benzene is hematotoxic and a known human carcinogen (WHO 2000b; ATSDR 2007a).

The objectives of the present study were: (1) to compare the exposure concentrations of BTEX and the occurrence of self-reported health problems among gasoline sellers of official and unofficial gasoline-selling sites in Cotonou, Benin; and (2) to compare these concentrations with those measured in traffic and in the backyards of residences which are isolated from gasoline-selling sites and traffic.

Methods

This exploratory cross-sectional study was performed on a 7.7 km-long itinerary along the main road connecting Cotonou's neighborhoods of Mènontin, Kouhounou, Houenoussou, Vèdoko, Agontikon, Étoile Rouge, St Michel, and Aïdjèdo, in the Department of Littoral. This itinerary, rather flat and straight, was chosen since the two types of gasoline-selling sites (official and unofficial) are numerous along its way and that no database exists that lists the unofficial gasoline sellers due to the illegal nature of this activity. Also, given the absence of nearby industry or heating devices, as well as wood burning for cooking, in this essentially urban residential neighborhood, gasoline-selling sites, and traffic consist into the only sources of BTEX air pollution on this itinerary. Both types of gasoline-selling sites are located along the main road, or sometimes at its intersections with other secondary roads. Official sites correspond to common gas stations pertaining to branded companies and are equipped with fuel pump (gasoline or diesel) and indoor office fixed up for sellers. The gasoline is provided using a pistol exhibiting no system of vapors recovery. Some of these sites also offer other services: sale of brake oil and engine oil; vehicle cleaning. The clientele is varied (two-wheels or four-wheels (or more) motor vehicles). Conversely, on the unofficial sites that are opencast and situated on the sidewalk of the main road, gasoline is stored in large plastic containers disposed on the ground and is transferred into bottles of different capacities for its sale to passing-by customers. Most of the time, these bottles, sometimes without lid, are stored on a table. Gasoline is poured in the vehicle tanks using a plastic or metal funnel. Here, only gasoline, brake oil, and poor quality engine oil are sold, but no diesel.

Thus, on the basis of a formal oral consent, 140 sellers accepted to be included in the study for a quantitative survey. Among them, 18 have provided additional information during a subsequent individual semi-structured interview. Overall, occupational air sampling for BTEX analysis was performed for 25 subjects, i.e. nine in official selling

sites, nine in unofficial selling sites, four on motorcycle taxis circulating in traffic of the main road of the study's itinerary, and three in residential backyards isolated from gasoline-selling sites and traffic: Residence 1 (R1), distant of 800 m from the survey's itinerary; Residence 2 (R2), 500 m away; and Residence 3 (R3), 100 m away.

Quantitative survey

The administration, on the working site of each seller, of a questionnaire previously tested and validated in order to verify its intelligibility, allowed collecting information on the perceived health hazards associated to BTEX as well as common self-reported health problems. Meanwhile, this quantitative survey was completed by the collection of air samples for BTEX analysis, as described below.

Air sampling and analytical method

Air samples were performed in the breathing zone of the 25 subjects investigated using "radiello"®-type passive samplers. The sampling technique using radiello® is based on the principle of passive diffusion of gas molecules up to an adsorbent cartridge placed on the subject's chest (Fondazione Salvatore Maugeri 2007; Tera Environnement 2013). The cartridge, a solid support composed of Tenax®, is specifically adapted to the capture of gaseous pollutants. The amount of gas captured is proportional to its concentration in the environment. This sampling material was chosen following a pre-investigation during which four air samples were taken, two on unofficial sites and two in traffic, in order to validate and optimize the sampling technique. These two types of locations (unofficial sites and traffic) were chosen because of the high air concentrations of BTEX expected for it. Indeed, it was necessary to ensure that passive samplers would not reach saturation during the sampling periods, as this could have distorted the results. In fact, the normal sampling time of the radiellos® devices historically analyzed in the Laboratory of atmospheric chemistry of Brussels Environment (Brussels, Belgium), where the samples would further be analyzed, is 24 h (Bruxelles Environnement-IBGE 2009), as this laboratory usually focuses on local or European air samples in which BTEX air concentrations are generally rather low compared to what can be found in developing countries and to what the pre-investigation has revealed (Table 1). Therefore, the sampling durations in this study were determined based on expert judgment of the analytical chemists from this laboratory, with the purpose of preventing saturation of the radiellos® while allowing comparable amounts of analytes being collected. Using those criteria, the optimal sampling durations were thus determined as 20 min for the official gasoline-selling sites, 15 min for the unofficial selling sites, 13 min in the traffic, and 40 min in the three residential backyards.

Table 1. BTEX air concentrations measured during the pilot sampling.

Type of site and duration of sampling	Benzene (μg/m³)	Toluene (μg/m³)	Ethylbenzene (μg/m³)	Xylene (μg/m³)
Unofficial 1 (2 h)	1896	1218	3927	9740
Unofficial 2 (4 h)	757	2878	3881	9705
Taxi-motorcycle 1 (2 h)	132	576	150	176
Taxi-motorcycle 2 (4 h)	101	748	207	600

The sampling conditions and specific data were noted for each sampling site: type of selling (i.e. official or unofficial), site position, sampling time and duration, types of selling-related activities on the site, quantity of gasoline sold, wind direction, and the seller's attitude. BTEX were extracted from the sampling cartridges by means of a nitrogen stream preceded by the injection of 0.5 µL of tetrafluorobenzene (10 µg/µL) as internal liquid standard. Samples then underwent thermal desorption (Markes Unity) at 250 °C, followed by a cryogenic step at −10 °C. BTEX were heated and then transferred to a gas chromatograph (Trace GC Ultra) equipped with a 60-m capillary column of 0.32 µm of internal diameter and a 3.0 µm-thick dimethylpolysiloxane film. The heating temperature of the column went from 35 to 180 °C following a gradient of 4 °C per minute, using helium as carrier gas under a flow rate of 1.9 mL/min. The chromatograph was coupled with a Fisons' Trace 250MS-type mass spectrometer. The spectrometer allowed automated BTEX identification on the basis of ions features and retention times; whereas, quantification of these ions is proportional to the intensity of their signal following a calibration curve prepared using standard ions.

Data processing and statistical analyses

Data on BTEX concentrations were subjected to a double entry in Epi Info software, version 3.5.1, and converted using Stata transfer software. Statistical analyses were realized by means of Stata 10 software.

For the purposes of this study, the sum of the concentrations measured for the three isomers of xylene (*m*-xylene, *p*-xylene, and *o*-xylene) was considered. Due to the small sample size, the median BTEX concentrations (total of 17 samples after excluding the results of the site U9 due to an incomplete sampling period) on the official ($n = 9$) and unofficial ($n = 8$) gasoline-selling sites were compared using the Wilcoxon–Mann–Whitney test. Again due to small sample size, descriptive statistics only (medians and ranges) were determined for BTEX concentrations in traffic ($n = 4$) and residential backyards ($n = 3$).

In view of the sample-specific information collected as describe above, BTEX concentrations results were then grouped based on three characteristics that may influence BTEX concentrations observed on the two types of gasoline-selling site. These are: (1) the type of activity usually conducted by the sellers on the site at the time of the sampling, (2) the wind direction on the basis of the most frequent spatial orientation of the seller while working, and (3) the moment of the day at which the sampling occurred or not (traffic rush hour or not). More specifically, the activity on the site informs on the type of manipulation of the gasoline devices that the seller was doing at the time of the air sampling (filling vehicle tank, fuel delivery, or filling empty bottles), and thus its potential exposure to BTEX. The wind direction informs on the influence of the wind on the diffusion of BTEXs in the radiello® samplers, as it may vary whether the seller faces the direction of the wind flow or not. The sampling time enables to assess whether an increased traffic at rush hours may have influenced the results obtained for the gasoline-selling sites.

As far as the data on the information collected by questionnaire are concerned, the normality condition of the quantitative variables was verified by visual inspection of Gaussian curves generated by means of the Epi Info software. Considering the absence of normality, the medians of these variables were compared using the Wilcoxon–Mann–Whitney test. To compare the qualitative variables, the χ^2 test or Fisher's exact probability test were used, depending of which conditions of application of these respective tests were fulfilled for each intended comparison of the qualitative variables. The level of significance of every statistical test was set at 5 % for bilateral assumptions.

Semi-structured interviews

All the interviews were conducted in the same spatio-temporal conditions and they enabled to qualitatively examine the socioeconomic conditions that could influence the different expression of health problems and the attitudes of the sellers working in each of the two types of gasoline-selling sites. The interviews were justified by the fact that the quantitative survey described above revealed that almost all unofficial sellers reported to be in good health and expressed less health difficulties than those of the official sites, contrary to what we expected.

The analysis of data collected through interviews was made by a longitudinal approach that follows the inductive method described by Lessard-Hébert et al. (1995) and which initially required the development of interview guidance and records. Thus, we first got familiarized with the collected information after several readings of the interview records. We then proceeded to the coding of the collected data. From this first-step analysis came out significant assumptions on the explanation of the discrepancies in the expressions of health problems on both types of sites. We finally turned back to our interviewees who confirmed these significant assumptions, which are reported hereafter in the discussion.

Results

Analysis of air sampling

A comparison of the respective BTEX concentrations of both types of gasoline-selling sites is depicted in Figure 1(a). It can be observed that benzene concentrations are generally higher on the unofficial sites (median = 478 μg/m^3) than on the official ones (79 μg/m³), and the observed difference is statistically significant ($p = 0.043$). The same observation is made for the concentrations of toluene (1449 vs. 207 μg/m^3, $p = 0.016$), ethylbenzene (148 vs. 54 μg/m^3, $p = 0.034$), and xylene (240 vs. 81 μg/m^3, $p = 0.012$).

Figure 1(b) suggests that the traffic may also contribute to the BTEX exposure of the two types of gasoline sellers, but to a lower extent as compared to the punctual source emissions that both types of gasoline-selling sites represent. Some BTEX were also found at lower concentrations in residential backyards isolated from the gasoline-selling sites as well as from the traffic. In all cases, toluene is present with the highest concentrations, followed by benzene (on gasoline-selling sites and in traffic) or xylene (in residences' backyards).

The impact of factors such as the activity of the seller during the sampling, the wind directions, and the daily moment of the sampling on the various BTEX concentrations observed between the two types of site is shown in Figure 2. Thus, the BTEX sampling data from both the official and unofficial selling sites are grouped according to four different combinations of exposure conditions of the gasoline workers investigated, including: filling the vehicle's tank without receiving the wind on the chest (therefore on the radiello® sampler), at moments of the day outside from rush hour (Group 1); filling the vehicle's tank without receiving the wind on the chest, at rush hour (Group 2); filling the vehicle's tank while receiving the wind on the chest, at rush hour (Group 3); and fuel delivery on official sites or exclusively filling of the empty bottles on unofficial sites, in both cases while receiving the wind on the chest, at moments of the day outside from rush hour (Group 4). Although the number of sites by groups does not allow significant statistical analysis, the visual inspection of the results from such categorization

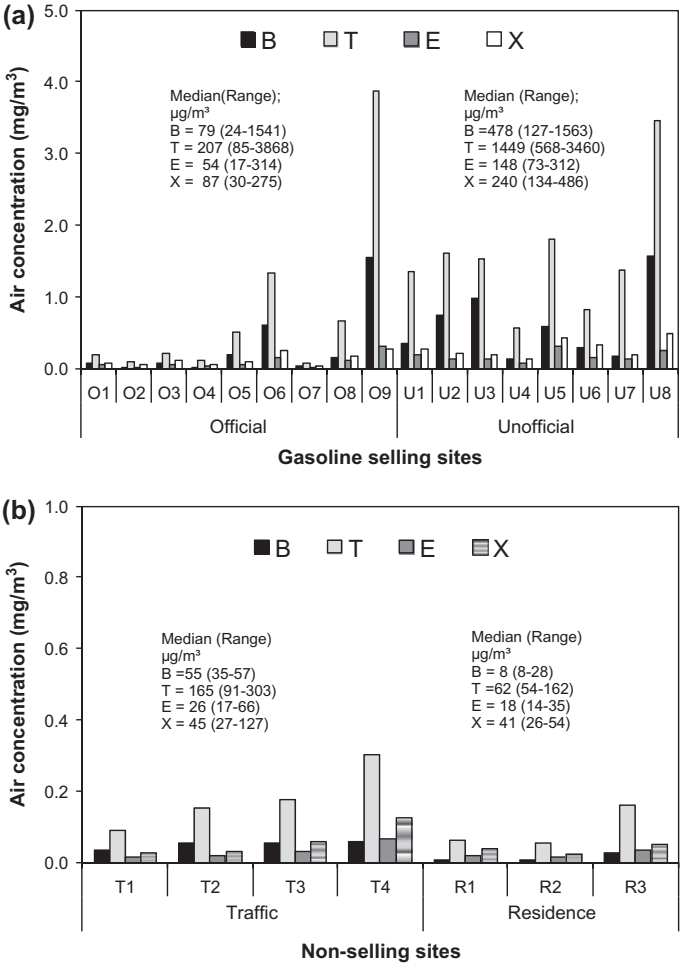

Figure 1. Median and range of BTEX concentrations (µg/m³) measured: (a) on the official (O) and unofficial (U) gasoline-selling sites (site-related difference in air concentrations was statistically significant for each COV ($p < 0.05$, Wilcoxon–Mann–Whitney test)); (b) in traffic (T) and isolated residential backyards (R), in Cotonou, Benin. The limit of detection based on a one-hour sampling duration were, respectively, 0.16 (B), 0.1 (T), 0.1 (E), 0.19 (m-X and p-X), and 0.1 (o-X) µg/m^3. Corresponding limits of quantifications were 0.3, 0.2, 0.2, 0.4, and 0.2 µg/m^3.

suggests that the differences in BTEX concentrations between official and unofficial sites, observed above in Figure 1(a), are maintained in Groups 1–3, but not in Group 4.

Quantitative survey

The questionnaire survey revealed significant differences between the two types of gasoline sellers regarding their sociodemographic and economic status (Table 2). Thus, informal sellers have a higher proportion of individuals who have not completed secondary school (34.3 %) than the official sellers (9.6 %). We also found a higher proportion of women working on the unofficial sites (27 %) than on the official ones (13.3 %).

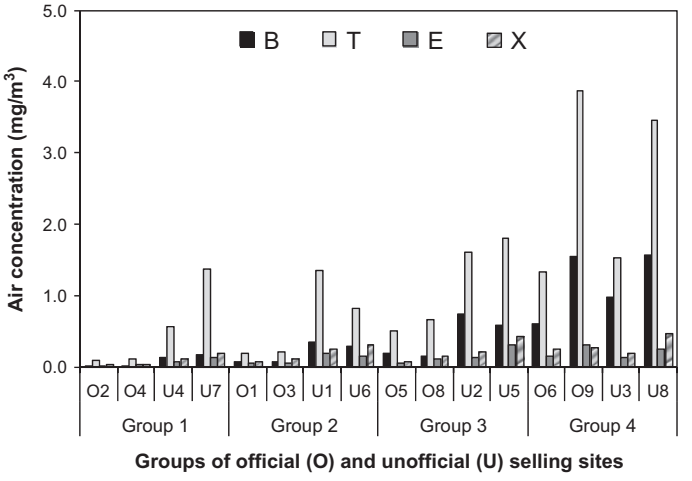

Figure 2. Impact of various combinations of exposure conditions (Groups 1–4, see results for details) on BTEX concentrations measured on official and unofficial gasoline-selling sites. The limit of detection based on a one-hour sampling duration were, respectively, 0.16 (B), 0.1 (T), 0.1 (E), 0.19 (*m*-X and *p*-X), and 0.1 (*o*-X) μg/m^3. Corresponding limits of quantifications were 0.3, 0.2, 0.2, 0.4, and 0.2 μg/m^3.

Moreover, informal sellers have lower monthly income than official sellers (30,000 vs. 35,000 francs CFA (F CFA)).

It also comes out from this survey that the official sellers express health problems related to the eyes, nose, throat, head, and in general, at a frequency that is significantly higher, statistically, than the unofficial sellers (Table 3). Eye problems raised by the sellers were itchy and watery eyes, problems with vision, irritation, and burns. Sneezing, stuffy nose, runny nose, and irritation were the nasal self-reported problems. The throat problems identified were cough, pain, dry throat or hoarseness, and irritation. Head-related problems that were reported consist into headaches, memory loss, heavyness, and concentration difficulties. The problems affecting the general condition were general fatigue, drowsiness, dizziness, and nausea.

Finally, it is noteworthy that the proportion of sellers that consider that gasoline handling and resulting BTEX exposure may affect negatively their health was greater on the official gasoline-selling sites than on the unofficial ones (90.4 vs. 70.1 %, $p = 0.003$ for the Fisher exact test, results not shown).

Discussion

This study explored the levels of BTEX exposure of gasoline sellers in Cotonou, Benin, and their common self-reported health problems. It did so by means of air measurements of these VOCs' levels on the gasoline-selling sites (official and unofficial) combined with a quantitative survey completed by a qualitative investigation on health matters, as self-reported by the gasoline sellers.

The analytical results of air samples show very high levels of exposure to benzene and toluene on both types of gasoline-selling sites, with the higher concentrations being encountered on the unofficial sites. In view of the concentrations measured in traffic and in isolated residences backyards, which are substantially lower, local air contamination

Table 2. Sociodemographic and economic characteristics of the subjects investigated.

Variables	Official site, median (IQR) or %	Unofficial site, median (IQR) or %	*p*-value
n (number of seller)	73	67	
Age:			< 0.001[d]
≤ 35 years	24 (32.9 %)	48 (71.6 %)	
> 35 years	49 (67.1 %)	19 (28.4 %)	
Female subjects	9 (12.3 %)	18 (26.9 %)	0.029[d]
Matrimonial status			0.001[d]
Traditional marriage	57 (78.1 %)	35 (52.2 %)	
Bachelor	10 (13.7 %)	30 (44.8 %)	
Others[a]	6 (8.2 %)	2 (3 %)	
Number of children	3 (1–4)	1 (0–3)	< 0.001[e]
Education level completed			< 0.001[d]
Primary school	7 (9.6 %)	23 (34.3 %)	
Secondary school	54 (74 %)	26 (38.8 %)	
Others[b]	12 (16.4 %)	18 (26.9 %)	
Number of working years as gasoline seller	11 (7–16)	4 (2–8)	< 0.001[e]
Present every day on the site			< 0.001[d]
Yes	4 (5.5 %)	26 (38.8 %)	
No	69 (94.5 %)	41 (61.2 %)	
Frequencies of presence on the site if sometimes absent			< 0.001[d]
Selling for 24 h and free for 24 h	69 (100 %)	4 (9.8 %)	
No selling on Sunday	0	34 (82.9 %)	
Others[c]	0	3 (7.3 %)	
Vacation available			< 0.001[d]
Yes	61 (83.6 %)	3 (4.5 %)	
No	12 (16.4 %)	64 (95.5 %)	
Minimum daily of gasoline sold	500 (120–700)	150 (100–250)	< 0.001[e]
Maximum daily of gasoline sold	1000 (500–2000)	275 (200–500)	< 0.001[e]
Monthly income (in F CFA[f])	35,000 (32,000–42,000)	30,000 (21,000–30,000)	< 0.001[e]

Notes: IQR – interquartile range.
[a]Civil marriage, widow(er).
[b]University, any level.
[c]Selling for 2 days and free for 2 days, three days selling per week.
[d]Pearson's chi-square test.
[e]Mann–Whitney *U*-test.
[f]1 US$ ≈ 481 Francs CFA (F CFA).

on official and unofficial sites by the BTEX arising specifically from the activity of gasoline sale appears as the main contributory source to the sellers' total exposure. On these sites, the concentrations for benzene and toluene approach, or even exceed in some cases, the recommendations issued by WHO and raise concerns about potential adverse effects on the gasoline sellers' health. Indeed, benzene, a Group 1 carcinogen by WHO, presumably acts via non-threshold mechanisms of action and presents a cancer slope factor that varies between 2.2 E-6 and 7.8 E-6 $(\mu g/m^3)^{-3}$ according to the US EPA (WHO 2000b; ATSDR 2007a). Thus, the observed concentrations on gasoline-selling sites, both official and unofficial, would correspond to a risk of about 10^{-4} for a lifetime exposure. Considering the non-carcinogenic effects, the RfC for chronic exposure is 30 µg/m³ (US EPA 2013), a value lower than the concentration found on the gasoline-selling sites and in the traffic during this study. These two estimates consist however into overestimation of the

Table 3. Self-reported health problems depending on the type of gasoline-selling site.

Variables	Official site	Unofficial site	*p*-value
n (number of sellers)	73	67	
Eye irritations	49 (67.1 %)	34 (50.7 %)	0.049[b]
Nose irritations	65 (89 %)	51 (76.1 %)	0.035[c]
Throat irritations and cough	56 (76.7 %)	33 (49.2 %)	0.001[b]
Respiratory problems	26 (35.6 %)	20 (29.8 %)	0.468[b]
Skin irritations	22 (30.1 %)	22 (32.8 %)	0.731[b]
Headaches	64 (87.7 %)	42 (62.7 %)	0.001[c]
General state	71 (97.3 %)	58 (86.6 %)	0.019[c]
Common diseases[a]	67 (91.8 %)	57 (85.1 %)	0.164[c]

[a]Malaria, fever, flu, cold.
[b]Pearson's chi-square test.
[c]Fisher's exact probability test.

true risk since the investigated workers are not continuously exposed to such levels in their day-to-day life, but rather solely when they are working.

Furthermore, inhalation of a toluene concentration greater than 260 µg/m³ over a period of one week could lead to nervous system disorders (WHO 2000c). Due to the rather occupational nature of the BTEX exposure of the investigated subject in the current study, even though occurring in outdoors environmental setting, a comparison of the measured levels with occupational criteria of air quality may be better indicated in order to assess the incurred risk. In this context, the concentrations measured for benzene and toluene are below OSHA's exposure limits of, respectively, 3.19 and 754 mg/m³ (Han et al. 2005). Whereas regarding ethylbenzene and xylene, exposure concentrations measured herein are also below the available guidelines. These comparisons therefore suggest a rather low health risk for both types of sellers investigated here on the basis of occupational guidelines (OSHA 1996; US EPA 2000; Zdanevitch & Del Gratta 2004). Note that neither environmental nor occupational standards have been determined for BTEX in Benin.

In light of the results presented in Figure 2, the high concentrations of benzene and toluene found on both official and unofficial gasoline-selling sites appears to stem from the type of activity leading to the sellers' exposure rather than the type of site *per se*. Indeed, the difference in concentrations between the official and unofficial sites are maintained in Groups 1–3, but not in Group 4, which is characterized by air sampling conducted while proceeding to the delivery of gasoline on the official sites and filling empty bottles on unofficial sites. This observation suggests that it is the activity of gasoline storage on the sale sites which is the determining factor of the workers' exposure. Since this activity is less frequent or is likely taking place under more controlled and standardized conditions in regular service stations than on the unofficial selling sites, it may result in the observed differences in BTEX concentrations, regardless of the other factors considered. These results are consistent with those obtained by Correa et al. (2012) in a Brazilian study.

High concentrations of benzene and toluene measured during this study also raise the question of the quality of the gasoline sold in Cotonou so as of the seller's safety on their working places. In United States, the US EPA recommends maximum fractions of 5 % of benzene, 2 % of ethylbenzene, and 11–12 % of toluene and xylene in gasoline (US EPA 2010). Since January 2000, the quantity of benzene in gasoline in Europe is limited to a maximum of 1 % (de Brouwer 2011). In developing countries, this type of

recommendation, as well as those concerning the protection of workers and the monitoring of BTEX concentrations in the air of the working space or in ambient air, is often nonexistent. Corrective measures in this regard should be taken. Indeed, the case of Benin is not unique: an Indian study showed that benzene exposure of gas station sellers was thoroughly greater than that of office workers as the measured air concentrations on the corresponding working sites were, respectively, 1100 and 70 μg/m³ over a 2-h sampling periods (Raghavan & Basavaia 2005).

It is also clear from this work that both types of sellers are familiar with air pollution that may result from gasoline-selling and handling. Besides, unofficial sellers feel healthier and express less common health problems, generally, than the official sellers (Table 3). Also, they are significantly fewer on unofficial sites to consider that gasoline can have negative effects on their health. Although counter-intuitive (given the acceptable sample size of the quantitative survey and the very high levels of benzene and toluene encountered on unofficial sites), this trend can be explained by the results of the individual semi-structured interviews that were further realized, and which thus confirmed the results obtained in first analysis. Indeed, the workers' perception of the unofficial gasoline-selling sites may be biased towards less severe health effects because of their fear of losing their job, having often already been given notice several times by the public security authorities to stop their illegal activity. Considering the data in Table 2 on the level of education and the average income, which suggest a lower average socioeconomic status for sellers of unofficial gasoline-selling sites as compared to official sites, the unlawful activity of smuggling gasoline sale along the streets of Cotonou appears as a source of income that those who practice it can hardly afford to lose. Finally, the self-reported health effects indicated in the current study are consistent with the sanitary hazards associated with BTEX as reported elsewhere in the scientific literature, both in environmentally or occupationally exposed populations (OSHA 1996; US EPA 2000; Hideaki et al. 2002; IPCS 2003; Saillenfait et al. 2003; ATSDR 2007a; Henderson et al. 2007; Mirkin 2007; de Brouwer 2011; CDC/NIOSH 2011).

The main limitation of this study is its small sample size and the possible measurement errors that could have stemmed from the sampling conditions, which exhibit sometimes very high air concentrations of the VOCs studied. Indeed, the small sample size does not allow drawing definitive conclusions on the BTEX exposure that may result from the activity of gasoline sale in this city. Thus, a larger scale study could include analysis of liquid gasoline with regard to its BTEX content and the correlation, or not, with the BTEX air concentration that could be encountered on the different selling sites simultaneously at the time of the filling of the various types of reservoirs and vehicles. Besides, a larger scale study could likely exhibit sufficient statistical power in order to perform a multivariate statistical analyses as cluster between BTEX and other variables as wind speed, hour of the day, weather, etc., an analysis that the small sample size of the current study precludes from realizing. Furthermore, although the advantage of using radiello® lies in its ease of use (portability, no need of power source), its drawback remains the loss of accuracy for very high concentrations, as such concentrations can lead to air sample that do not meet the specified speed of diffusion of BTEX in the radiello® or during the laboratory analysis. Although this may have happened in view of the concentrations measured herein (see Table 1), we tried to address this issue by diminishing the sampling time period. In turn, unequal sampling period may have underestimated the difference of BTEX concentration between the official (20 min sampling duration) and unofficial (15 min) gasoline-selling sites, whereas it may have increased the difference observed with the samples taken in traffic (13 min). But as

explained in method, we had no choice but to do accordingly, based on expert judgment, in order to prevent saturation of the samplers. Other possible errors related to the dilutions of highly concentrated air samples for the purpose of the analytical procedure cannot be ignored. These errors could be a source of uncertainty on the measurements made on the selling sites as well as in traffic. Moreover, a selection bias cannot be excluded for our quantitative survey (i.e. non-randomization of the sample), a bias which we intended to reduce by increasing as much as possible the sample size. An information bias may have also been introduced. Indeed, it is conceivable that unofficial sellers have provided inaccurate information in the questionnaire due to the fear of losing their job, as explained above. We tried to correct this bias by performing semi-structured individual interviews.

Conclusion

This exploratory study has originally combined quantitative and qualitative investigating approaches to accurately account for the complex socioeconomic and environmental context in order to understand the causes of a BTEX exposure that can be judged as of concern, for the investigated gasoline sellers. This combination reminds the eco-health approach to assess human health concerns in situations of exposure to environmental contaminants, an approach that has proven its effectiveness in particular in situations encountered in developing countries (Rappaport & Mergler 2004; Webb et al. 2010). In particular, the current study revealed a worrying exposure of gasoline sellers to benzene on the two types of gasoline-selling sites in Cotonou, and to toluene on the unofficial ones only. In this sense, the results are consistent with those reported in previous studies that focused on air pollutants in this city and their corresponding impact on human health (Bultynck & Reliquet 2003; Ayi-Fanou et al. 2006; Avogbe et al. 2011). In particular, this study highlighted the type of activity related to the sale of gasoline as the main risk factor for exposure to BTEX. Exposure levels observed could lead to significant health problems in the longer term. For now, the common health problems expressed should be interpreted as a signal for the need to address this problem by implementing corrective measures in order to reduce BTEX exposure of gasoline sellers, in particular the unofficial ones. In this regard, regulation of gasoline's maximum BTEX content as well as education campaigns destined to the unofficial sellers that would focus on personal protection measures can be pointed out. In doing so, the socioeconomic importance of this informal sector of economic activity for numerous Beninese families needs to be kept in mind. Thus, strictly enforcing regulation would unlikely contribute to solve the problem. Rather, multiple, global actions towards the long-term improvement of the economic conditions of those people making a living of unofficial selling of gasoline may lead them to eventually abandon this potentially harmful activity.

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