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Active and passive air quality bio-monitoring in the tropics: Intra-urban and seasonal variation in atmospheric particles estimated by leaf saturated isothermal remanent magnetisation of *Ficus benjamina* L (Moraceae)

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Atmospheric pollutant emissions are likely to increase continously in developing cities like Abidjan (Ivory Coast) where air quality strategies are ineffective or not yet implemented. This could result in a big risk to human health. Local meteorological parameters can have both positive or negative effect on habitat quality depending on the biomonitoring approach used. This study investigates the sources and factors affecting the spatio-temporal variation in particulate pollution in a tropical area in Abidjan (Ivory Coast) using a passive and active biomonitoring approach. Leaf saturated isothermal remanent magnetisation (SIRM) of *Ficus benjamina* L. was monitored for 2-6 months over 2 consecutive years in four distinct urban land use classes (main roads, industrial zones, residential zones and parks) based on several meteorological parameters (wind speed, temperature, relative humidity and precipitation) and season. Results showed leaf SIRM varied among land use classes and season with main roads and industrial zones presenting higher leaf SIRM during the dry season. This suggests that vehicular exhaust emissions and industrial smokestacks were the main sources of particulate matter (PM) pollution in Abidjan. These results show also the contribution of natural particles from harmattan dust during the dry season. Leaf SIRM was negatively correlated with precipitation intensity, suggesting a wash-off effect of particles on leaves. Results, however, differed between the dry and wet season. During the dry season, leaf SIRM of young leaves was higher than that of old leaves. This trend was reversed during the raining season. This suggests combined effects of meteorology and plant growth/physiology.

Key words: Air pollution, saturated isothermal remnant magnetism, particulate matter, ficus benjamina, tropical humid area.

INTRODUCTION

Urbanization continues at a record pace all over the world, especially in emerging and developing economies. In these areas, cities are seen as destinations, especially for young people in search of employment, education, social contacts and cultural advantages (UN-Habitat, 2008). Indeed, large cities in developing countries contain the majority of the industries of this country, most of which are highly polluting manufacturing and mining industries, and the high proportion of motor vehicles. These factors lead to environmental damage, including air pollution like atmospheric particulate matter (PM) (WHO, 2006).

In general, sources of atmospheric PM are both natural (for example volcanic ash, wind-blown sand, etc.) and anthropogenic (for example industrial facilities, transportation, etc.). Both sources result in direct emission of PM (primary PM) and emission of gaseous aerosol precursors, leading to secondary PM. It is reported that at least 3400 million tons of PM is emitted on a global scale per year (Houghton et al., 2001; Gerasopoulos et al., 2006). Anthropogenic sources in urban areas include vehicular traffic by fossil fuel combustion, vehicle braking and industrial smokestacks (Petroff et al., 2008; Bukowiecki et al., 2010).

Epidemiological studies point to a causal association between population exposure to fine PM (diameter less than 2.5 µm) in air and cardiovascular and lung cancer mortality (Cachon et al., 2014; Goudie, 2014), and poor semen quality (Zhou et al., 2014). Several studies in West African countries like Ghana (Dionisio et al., 2010), Guinea (Weinstein et al., 2010), Senegal (Dieme et al., 2012), Benin (Cachon et al., 2014) and Cape Verde (Gonçalves et al., 2014) have shown that atmospheric PM concentration in these countries, and in the West African region in general, by far exceeded the WHO limits (25 $\mu g.m^{-3}$ daily for fine PM and 50 $\mu g.m^{-3}$ daily for PM diameter more than 10 µm) (WHO, 2006).

Most techniques used to study atmospheric PM pollution make use of electronic devices and physico-chemical processes. However, the majority of these methods are not able to estimate the integrated, biological exposition effects of the different and continuously changing concentrations of air pollutants, but instead provide only a physico-chemical indication about the exposition to a sole pollutant, or at most, to a combination of some pollutants (Falla et al., 2000). Moreover, most of the physico-chemical methods are expensive, limiting their use in developing countries, and making them impractical for assessing the pollution distribution with a high spatial resolution.

Biological monitoring or biomonitoring, that may be defined as the measurement of the response of living organisms to the state or to changes in their environment (Jakubowski and Trzcinka-Ochocka, 2005), could be an alternative or a complement to these physico-chemical methods. In general, plants are more sensitive (in terms of physiological reaction) to the most prevalent air pollutants than humans and animals. Biomonitoring with plants can be achieved through active and passive approaches. Passive biomonitoring may be performed through observation and analyses on native and cultivated vegetation already present in a given study area. Active biomonitoring can be carried out with selected test plants of standard genetic origin and developmental state, which are exposed to ambient air at the study site under standardized conditions (Nali and Lorenzini, 2007).

In Abidjan (Ivory Coast), the magnetic leaf properties of *Amaranthus spinosus*, *Eleusine indica*, *Panicum maximum* and *Ficus benjamina* were used as passive bioindicators of habitat pollution by atmospheric PM (Barima et al., 2014). This study showed that atmospheric PM concentration in different land-use classes of this tropical urban environment can be best determined from leaf SIRM of *F. benjamina* and *A. spinosus*. Barima et al. (2014) recommended using the tree species (*F. benjamina*) for biomonitoring compared to grass because trees are generally more effective in capturing atmospheric particles than herbaceous plants (Fowler et al., 1989; Barima et al., 2014). Barima et al. (2014) conducted a study using passive biomonitoring and did not extend over a long period of the year. Therefore, this study did not determine the influence of meteorological parameters on leaf SIRM plants. Nevertheless, it is known that meteorological parameters can have a positive or negative effect on habitat quality (Kassomenos et al., 2014; Rodríguez-Germade et al., 2014).

Such information is necessary to determine the total PM deposition during a season or year, particularly in regions with high rainfall.

The main objective of this study is to determine the impact of season (dry vs rainy) and meteorological variables (rainfall, temperature, humidity and wind speed) on leaf SIRM of *F. benjamina*, obtained using passive and active biomonitoring. To achieve this goal, first, the influence of seasonal variation on leaf SIRM was examined, and the most important meteorological variables affecting leaf SIRM were identified. Next, the effect of exposure time to atmospheric PM on leaf SIRM was determined.

Rainfall and temperature heavily characterise seasons in tropical areas (Amara and Bouazza, 2016). Therefore, it is hypothesized that leaf SIRM of *F. benjamina* is influenced by these two meteorological variables.

MATERIALS AND METHODS

Test species

F. benjamina was chosen as a test species because it is

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widespread in the study area and across the different land use classes as a decorative plant. It is a tropical evergreen tree belonging to the *Moraceae*. This species reaches a height of 30 m in natural conditions; it has glossy, oval leaves of 6-13 cm long, waxy with an acuminate tip. Its roots are adventitious. *F. benjamina* is a popular tree worldwide cultivated for reforestation and ornamental purposes; in the latter case its height usually hardly exceeds 4 m.

Sampling area

The study was conducted in Abidjan, the largest city in Ivory Coast (5°00'- 5°30 N, 3°50'- 4°10'W) by its population size (> 4 million inhabitants) and economic importance in West Africa. The city was subdivided into 4 land use classes as comprehensively described in a former study (Barima et al., 2014): main roads (MR, 4 sites); industrial zones (IZ, 2 sites); residential zones (RZ, 2 sites) and parks (2 sites).

Its climate is tropical, hot and humid with a long dry season (November to April), a long rainy season (May-June-July), a short dry season (August) and a short rainy season (September-October). Passive biomonitoring was performed in February, March, April, May, June and July 2014. The first three months are in the dry season while the last is in the rainy season. Active biomonitoring was carried out in 2015 during the same months. The local climatic characteristics of this period are shown in Figure 1.

Biomonitoring methodology

Passive biomonitoring was carried out continuously from February to July 2014. For this passive approach *F. benjamina* trees planted by the Environment Service of the municipality were selected according to accessibility and geographical distribution criteria. Sites prohibited by civil protection as areas of gas storage of highly toxic waste and power stations have been avoided. Sampling locations were determined based on the availability of *F. benjamina*. Active biomonitoring was carried out from February to July 2015. Air layering techniques were performed for vegetative propagation of *F. benjamina* seedlings used in the passive biomonitoring. Three weeks later, the layerings are placed in pots (13 litres) filled with compost and soil, in which they were kept for three months. During this entire stage plants were kept in a municipal garden relatively far from any source of motor vehicle and industrial pollution. After three months of growth, two pots of *F. benjamina* which reached a height of about 1 m, were placed side-by-side in the selected sites in all considered land use classes. In each land use class, these plants have remained exposed to ambient air for three consecutive months during the dry season. The same process is carried out during the rainy season; new plants were placed at the beginning of the rainy season.

Leaf sampling

At each site, six mature and undamaged leaves were collected on the same plant and carefully placed in paper envelopes. The area of these six leaves was quantified with ImageJ (Version 1.43u) software after scanning the leaves in the laboratory soon after sampling. Leaves were dried at ambient temperature. After drying, all six dried leaves of each sampling location were tightly packed together by cling film, avoiding the movement of any leaf parts.

Biomagnetic leaf properties

Magnetic properties were carried out using a protocol described by Mitchell et al. (2010) and Kardel et al. (2011). All six dried leaves of each sampling location, packed by cling film were pressed into a 10 cm^3 plastic tube. Each tube was magnetised in a direct current (DC) field of 1 mT with a Molspin pulse magnetiser (Molspin Ltd, UK). Saturation Isothermal Remanent Magnetisation (SIRM) of the samples ($A.m^2$) was measured using a Molspin Minispin magnetometer (Molspin Ltd, UK) with high sensitivity. Each sample was measured twice to avoid measurement errors. After every ten measurements, the magnetometer was calibrated using a magnetically-stable rock specimen. Measured SIRM values (mA/m) were normalized for plastique tube volume (10 cm^{-3}) and leaf area (m^2) which leads to a final SIRM expressed as A. Magnetic measurements were carried out at the Laboratory of Environmental and Urban Ecology of the University of Antwerp (Belgium).

Data analysis

Statistical analysis was performed using Statistica 7.1 (Stat Soft France). A significance level of 0.05 was used for all the tests. A regression was performed, by Pearson's method, between SIRM and monthly averages of air temperature, air humidity, and wind speed, and total monthly rainfall to determine the main seasonal parameters influencing leaf SIRM. These meteorological data were obtained from the archives of tutiempo Network (Data provided by the weather station: 655780 (DIAP)), SL (https://fr.tutiempo.net/climat/ws-655780.html).

To find the effect of exposure time on leaf SIRM, *F. benjamina* leaves from active biomonitoring were sampled after one and three months of exposure. The effect of exposure time was tested using a t-test intra season and between seasons. Differences in leaf SIRM between the four land use classes were tested for significance by using a one-way analysis of variance (ANOVA) procedure and a Tukey-HSD test.

RESULTS

Intra-urban variation in leaf SIRM

SIRM of *F. benjamina* leaves showed great variability within the different land use classes for both active and passive biomonitoring (Figure 2). Leaf SIRM obtained via passive biomonitoring can be grouped into two classes according to the land use classes. The first group consists of MR and IZ and displays a statistically higher SIRM ($p < 0.05$) than the second group (RZ and Park). For the first group, Leaf SIRM ranged between 70.31µA (IZ-2015) and 110.03 µA (MR-2015). The lower leaf SIRM was the second group whose values are below 22 µA (Figure 2), at least three times lower than in the first group. There were no significant differences between SIRM within each land-use class in 2014 and 2015 ($p > 0.05$).

Seasonal variation in leaf SIRM

Leaf SIRM varied significantly between and within seasons (Figure 3). This in-season variation differs among the considered land-use classes. Except for July (last rainy month), leaf SIRM values obtained during the dry season are higher than those obtained during the

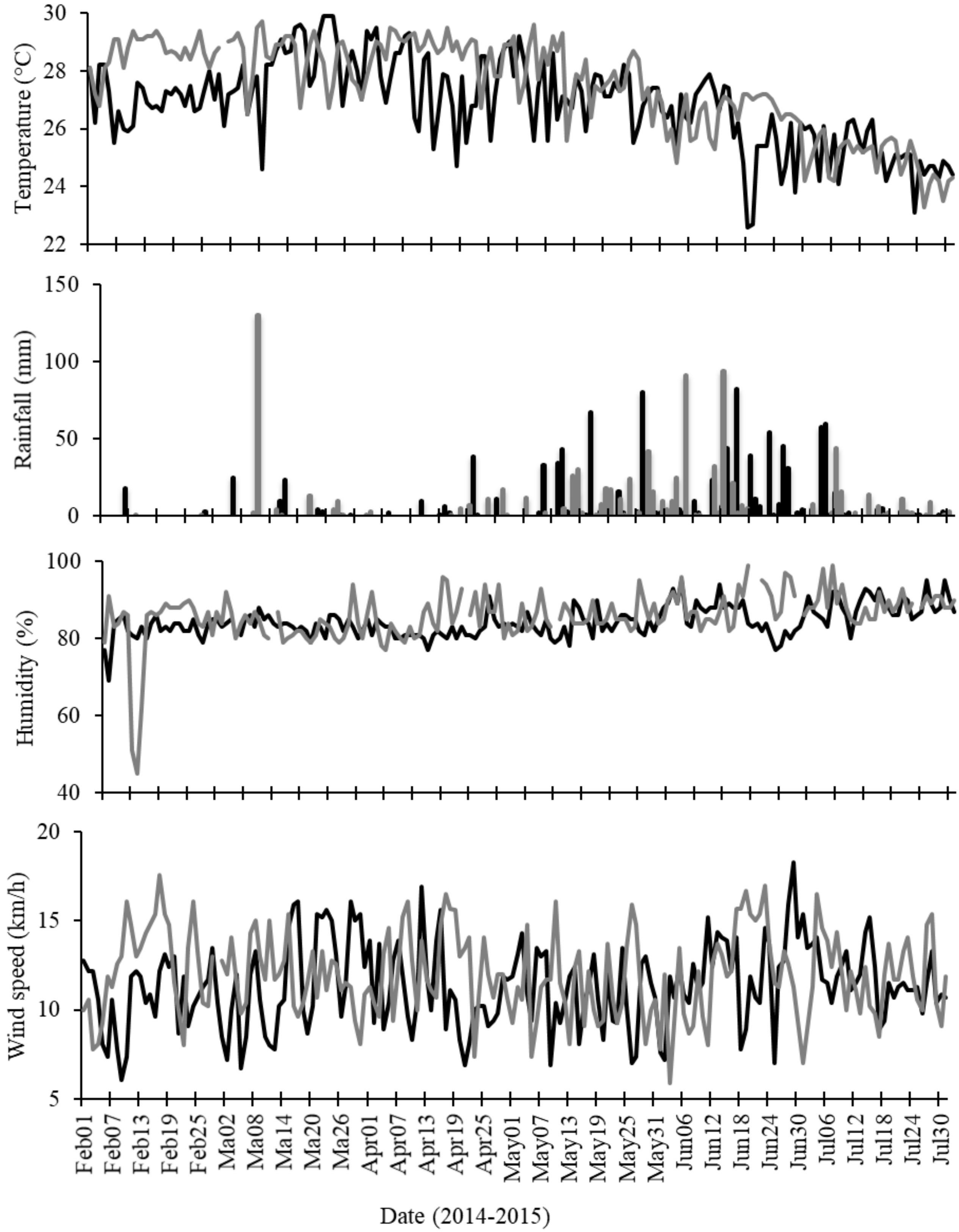

Figure 1. The daily mean of temperature, rainfall, humidity and wind speed during the experimental period from February to July 2014 (black line) and February to July 2015 (grey line). Values were taken each week for the following months: Feb: February, Ma: March, Apr: April, May: May, Jun: Jun, Jul: July. Data source: www.tutiempo.net or https://fr.tutiempo.net/madrid.html.

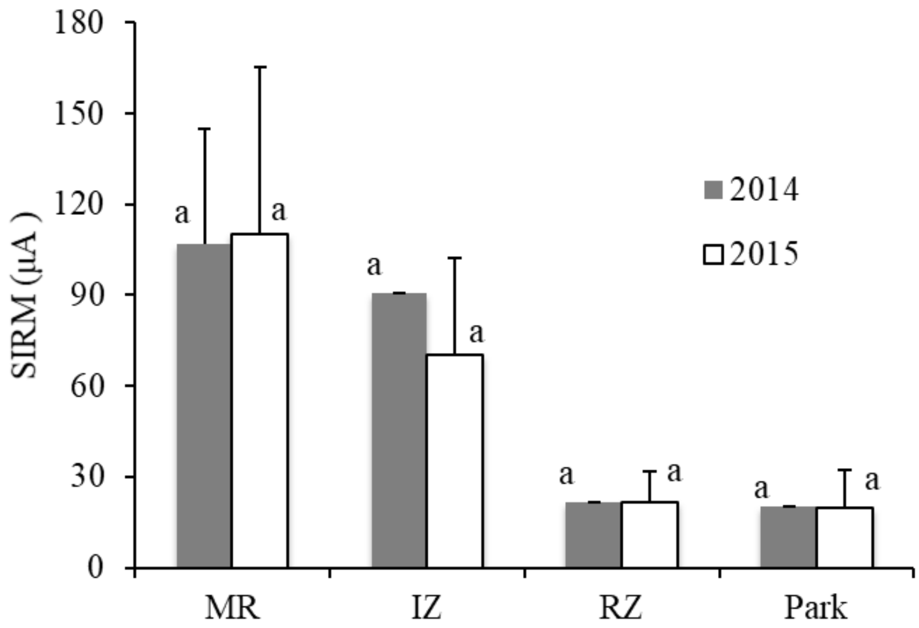

Figure 2. Leaf SIRM for *Ficus benjamina* as observed in main roads (MR), industrial zones (IZ), residential zones (RZ) and parks). Different letters indicate significant differences between land use classes for each considered period.

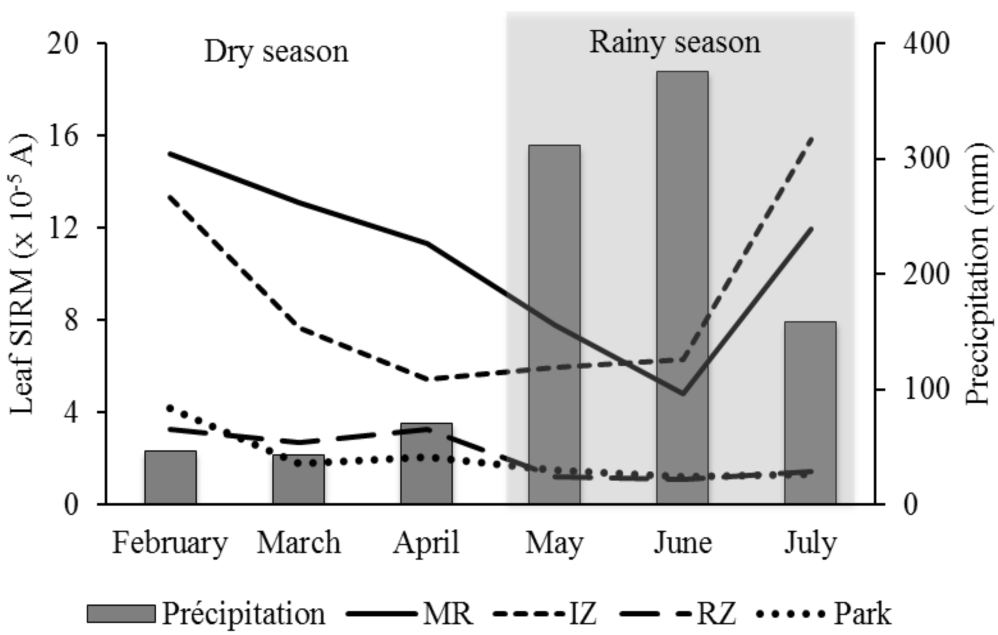

Figure 3. Leaf SIRM of *Ficus benjamina* and monthly rainfall from February to July 2014 for the passive biomonitoring.

rainy season. For MR and IZ, respectively, leaf SIRM decreased from 152.10 µA to 47.90 µA and from 133.0 µA to 62.70 x 10^{-5} A from February to June ($p < 0.05$). However, at the end of the rainy season (July), leaf SIRM rose to tend towards the value obtained during the end of the dry season. The same trends were observed for the active biomonitoring approach (Figure 4). In sum, whatever the month and season, leaf SIRM was higher

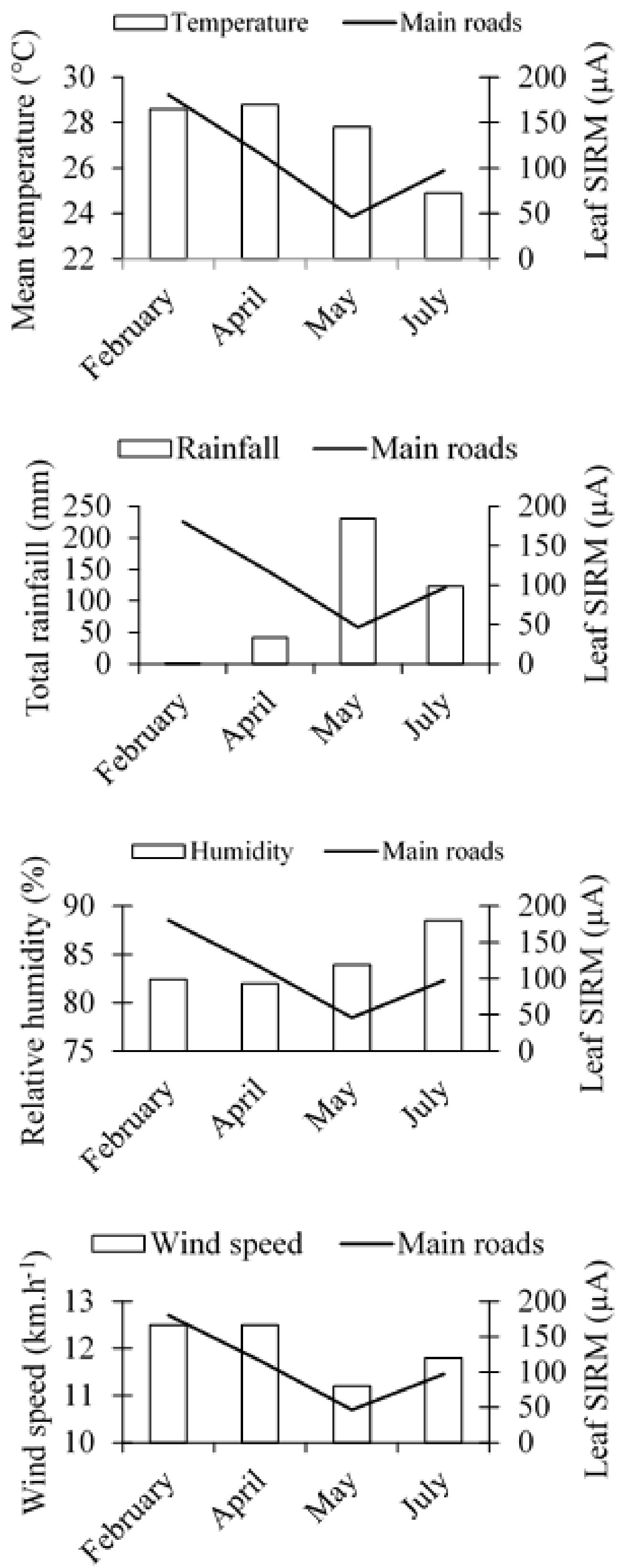

Figure 4. Leaf SIRM of *Ficus benjamina* near the main roads derived from active biomonitoring during the dry season (February to April) and the rainy season (May to July).

during the dry season than the rainy season ($p <0.05$).

Effects of meteorological variables on leaf SIRM in a passive biomonitoring approach

Among the meteorological studies, precipitation seems to be best correlated to changes in leaf SIRM ($p < 0.05$). This negative correlation is observed in all land use classes (Table 1, Figure 3). The highest correlations were obtained from monthly rainfall in MR ($r = -0.94$; $p = 0.004$) and RZ ($r = -89$; $p = 0.010$).

Effect of plant exposure duration to air on leaf SIRM – Seasonal effect

The comparison of leaf SIRM derived from active biomonitoring in the dry (April to May) and rainy season showed a statistical difference near the MR ($t = 3.038$; $p = 0.003$) and in IZ ($t = 2.546$; $p = 0.043$). Mean leaf SIRM is higher in dry season (148.3 µA for MR and 80.07 µA for IZ) than in rainy season (71.75 µA for MR and 98.40 µA for IZ). During the dry season (February to April), SIRM of leaves subjected to one-month exposure ("young leaves"; 180.50 µA) is important than those subjected to three months exposure ("old leaves"; 116.10 µA) ($t = 2.98$; $p = 0.013$). A reversed trend was observed, during the raining season (May to July), SIRM of "old leaves" (97.10 µA) was higher than that of the "younger" leaves (46.40 µA) ($t = -3.29$; $p = 0.007$) (Table 2). No clear statistical difference was found in the intra seasonal variations of the other land use classes (Table 2).

Monthly rainfall events could have had an influence on the observed variation in leaf SIRM in MR, with an increase in rain event resulting in a decrease in leaf SIRM (Figure 3). During the dry season in February leaf SIRM amounted > 180.0 µA, while when rainfall during the whole month exceeded 130 mm in July, leaf SIRM fell down to 100.0 µA. The other parameters, that is, air humidity, air temperature and wind speed did not appear to affect leaf SIRM in MR.

DISCUSSION

Intra-urban variation in leaf SIRM between land use classes

No significant differences in *F. benjamina* leaf SIRM were observed between the land use classes with both passive and active biomonitoring. The highest values were observed in MR and IZ (Figures 2 and 3). These results confirm that these sites were potentially more polluted than RZ and Park as it has been already demonstrated in a previous study in Abidjan (Barima et al., 2014). In other countries, similar classifications in these two groups have been found, e.g. Belgium (Kardel et al., 2012), India (Deshmukh et al., 2013), United Kingdom (Mitchell et al., 2010), Portugal (Sant'Ovaia et al., 2012), Greece (Kassomenos et al, 2014), China (Li et al., 2014), Korea (Yoo et al., 2014). Parks are particularly known to have better air quality than other urban land use classes (Serbula et al., 2010; Dias et al., 2012). Indeed, air quality was better within parks (urban background) due to the absence of motorised traffic, and worsened when approaching roads (Barima et al., 2014). These results confirm that the major urban pollution source determined with leaf SIRM is caused by fuel driven traffic (Bukowiecki et al., 2010; Kardel et al., 2012). However, Kardel et al. (2012) and Hofman et al. (2014a) showed that in addition to fuel-driven traffic, the railway is a major source of pollution in the urban area. But transportation from trains is not developed and tram being inexistent in Ivory Coast, we have not targeted these classes. In IZ sources of particles can be dual, partly from the ferromagnetic industry, partly from the local traffic.

Seasonal variation in leaf SIRM from passive and active biomonitoring

Leaf SIRM of *F. benjamina* varied, both in the wet and dry season and within the same season on MR and IZ (Figures 3 and 4). This variation was not similar to the different land use classes. In general, leaf SIRM during the dry season was higher than during the rainy season. In temperate climatic regions and for deciduous species, several authors like Mitchell et al. (2010), Kardel et al. (2011) and Hofman et al. (2014b) also found a seasonal effect of leaf SIRM, but they observed an increase of leaf SIRM with increasing exposure time. Using PM sensors, other authors found similar trends. Instead, authors like Kassomenos et al. (2014) obtained in Greece and Spain, higher PM concentrations during the warm period. These variations of leaf SIRM or PM content in the atmosphere showed that the concentration of these pollutants is influenced by weather or meteorological conditions (Kassomenos et al., 2014).

In this study area, and in the West African tropical zone in general, PM prevalence in the atmosphere during the dry season could be explained by the harmattan dust. Indeed, in the dry season, from December to March, the West African region is subject to a dry dust-laden wind, the harmattan, blowing from the Sahara Desert. The harmattan wind carries the Sahara mineral dust to long distances (Gonçalves et al., 2014). Transport of particles by these winds has already been demonstrated in Mediterranean countries including Greece (Kassomenos et al., 2014), Portugal (Wagner et al., 2009) and Spain (Sagnotti and Winkler, 2012; Rodríguez-Germade et al., 2014).

In drier atmospheric conditions, PM concentrations are higher. Moreover, due to the lack of rain, there is little wash-off, which is observed during the rainy season and which is in contrast with the findings of Kardel et al.

Table 1. Results of simple regressions performed with *Ficus benjamina* leaf SIRM in a land-use class and meteorological variables (temperature, humidity, monthly rainfall and wind speed. *r*: Pearson coefficient of correlation. The number of samples per month = 109. Significant correlations ($p < 0.05$) are given in bold.

Parameter		Temperature (°C)	Humidity (%)	Monthly rainfall (mm)	Wind speed ($km.h^{-1}$)
Main roads	r	0.29	-0.69	-0.94	0.38
	p	0.570	0.128	0.004	0.450
Industrial zones	r	-0.57	0.07	-0.34	0.13
	p	0.234	0.896	0.040	0.804
Residential zones	r	0.60	-0.79	-0.89	0.57
	p	0.202	0.062	0.010	0.232
Parks	r	0.27	-0.71	-0.59	-0.68
	p	0.604	0.116	0.221	0.134

Table 2. Student T-test results of the seasonal evolution of mean leaf SIRM (µA ± standard deviation) derived from active biomonitoring in the dry (April-May) and rainy season (May-July). Significant effects are shown in bold ($p < 0.05$). Values assigned by the same letter are not statistically different (ANOVA, Turkey test).

Paramater		Main roads	Industrial zones	Residential zones	Parks
February		180.50[a]	69.76[ab]	35.80	38.60[a]
April		116.10[a]	11.31[a]	17.90	14.10
	t	2.98	-4.87	1.29	7.52
	p	**0.013**	0.128	0.418	0.084
May		46.40	36.80[a]	11.50	11.20
July		97.10	61.60[a]	21.50	15.20
	t	-3.29	-1.87	-1.83	-0.84
	p	**0.007**	0.312	0.318	0.554
Seasonal mean	t	3.038	2.546	1.214	1.123
	p	**0.003**	**0.043**	0.270	0.123

(2011) and Hofman et al. (2014b).

Rainfall effect on leaf SIRM

It is well known that atmospheric PM and dust concentrations vary due to variation in meteorological conditions, even with constant emissions to the environment, as meteorological conditions play a vital role in governing the fate of air pollutants (Deshmukh et al., 2013). Among the considered meteorological variables, rainfall is statistically and negatively correlated with leaf SIRM (Table 1, Figures 3 and 4). It seems that the heavy rain events wash off the intercepted dust from the leaves. This wash-off effect was also found by other authors (Matzka and Maher, 1999; Sant'Ovaia et al., 2012; Li et al., 2014), while others did not observe such an effect (Kardel et al., 2011; Hofman et al., 2014c).

Studies showed that leaf surface characteristics have a strong influence on the retention of particles by the leaf surfaces, and therefore on the intensity of wash off effect. Thus, leaves with complex shapes, waxy cuticles, ridged surface fine hairs or emitting sticky substances may accumulate particles efficiently (Freer-Smith et al., 1997; Kardel et al., 2011; Freer-Smith et al., 2004; Wang et al., 2013). However, within these characteristics, atmospheric PM amount, a species with ridged leaf surfaces, was significantly higher than species with waxy leaf surfaces (Wang et al., 2013). Furthermore, plants accumulated atmospheric PM both on foliage surfaces and waxes. In terms of quantity, atmospheric PM on leaf surface generally exceeded wax PM, with variable rates depending on the species and land use clases (Przybysz et al., 2014). In nature, atmospheric PM on leaf surface can easily be washed off from foliage by rain, as also pointed out by other authors (Beckett et al., 2000; Van Heerden et al., 2007). Moreover, increased direct exposure to rain event conditions might cause a more intensive mechanical and chemical abrasion of the wax layer (Wang et al., 2013) like *F. benjamina* (simple and waxy leaves) in our study case.

Effect of exposure duration on leaf SIRM

During the dry season, the mean values of leaf SIRM decreased significantly ($p < 0.05$) from February to April in MR (Table 2). However, during the rainy season (May to July), this trend changed ($p < 0.05$); SIRM increased after a longer exposure time. This decrease in SIRM with time during the dry season is in contrast with the results of Kardel et al. (2011) and Rodriguez-Germade et al. (2014), while it is in agreement with their conclusions during the rainy season. The first authors showed that SIRM of *Tilia platyphyllos* and *Carpinus betulus* leaves increased during the season with a limited effect of rain-induced wash off. A similar trend was also reported for *Platanus hispanica* (Rodríguez-Germade et al., 2014). Some authors have proposed that part of the particulate material responsible for the magnetic signal is not found on the leaves' surface but rather is incorporated into their structure through the stomata cavities or their cuticle waxy protective layer (Sagnotti and Winkler, 2012; Burkhardt and Pariyar, 2014; Przybysz et al., 2014).

F. benjamina, an evergreen tree, showed an increase in leaf SIRM with time during the rainy season. This result suggests that the encapsulation of magnetic particles into the leaf tissue mainly occurs during the rainy season (growth phase) compared to the dry season probably due to a higher wax regeneration or formation activity during this growth season (Mitchell et al., 2010; Kardel et al., 2011). Mitchell et al. (2010) showed the evergreen trees may incorporate a larger proportion of particles within the leaf structure.

However, lower leaf SIRM after three months of exposure to air during the dry season could be explained, in a tropical humid area, during this season, by the severity of drought and harmattan is more rigorous (Weinstein et al., 2010). Plant adaptation to drought stress (high temperature and low rainfall) and harmattan leads to stomata closure (Koffi et al., 2014) and a reduction of epicuticular wax production; it reduces the encapsulation of particles by leaf and thus a subsequent SIRM decline (Hofman et al., 2014b). In any event, rain-induced wash off of magnetic particles from tree leaves is likely to vary according to species and leaf characteristics, in addition to rain intensity, canopy position and degree of shelter (Mitchell et al., 2010; Hofman et al., 2014b).

Active biomonitoring versus passive biomonitoring

The choice of a biomonitoring method will depend on season (dry and rainy). Given the harsh environmental conditions of the dry season *F. benjamina* used with active biomonitoring could reduce their encapsulation of atmospheric particles because of their response to environmental stress (Hofman et al., 2014b) as explained in the previous section. Thus, a passive biomonitoring approach may be advisable in a dry season because the plant in an urban environment has already adapted to drought conditions compared to those from active biomonitoring that are spending there in the dry season for the first time.

During the rainy season, active biomonitoring would be useful since plants are in their growth phase. Moreover, sampling of leaves in late growth phase may optimise magnetic differentiation between sites with differing urban habitat quality differences in leaf SIRM; thus the atmospheric PM between sites became more pronounced later during the growing season (Kardel et al., 2011), especially for high spatial resolution biomonitoring studies (Kardel et al., 2010). However, a disadvantage of measurements in the rainy season is the wash-off effect caused by intense rain events. Using passive biomonitoring approach, differences in soil parameters, plant age and treatment, and even study plants availability in urban area are practical constraints.

In total, passive biomonitoring methods seem more appropriate than active biomonitoring approach to study PM deposition via leaf SIRM of *F. benjamina* in an African tropical urban environment like Ivory Coast.

Conclusion

There are no significant differences between the leaf SIRM of *F. benjamina* near main roads and industrial zones. Industrial smokestacks and vehicle exhausts seem the main sources of pollution in the city. Leaf SIRM varied between and within seasons. Leaf SIRM was higher during the dry season compared to the rainy season, suggesting a rain-induced wash-off effect of leaf deposited PM. The effect of exposure time on leaf SIRM showed contrasting results based on seasons. Leaf SIRM was the highest at the beginning of the dry season and lowest at the end of this season. In contrast, leaf SIRM was higher at the end of the rainy season than in the beginning but these values are lower than those obtained during the dry season. PM deposition process on the leaf surface and its encapsulation during the plant growth period could explain these results.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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