Artificial Turf Football Fields: Environmental and Mutagenicity Assessment

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Artificial football turf fields: environmental and mutagenicity assessment.

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Abstract:	The public recently has raised concerns regarding potential human health and environmental risks associated with tire crumb constituents in artificial football turf fields. The aim of the present study was to develop an environmental analysis drawing a comparison between artificial football turf fields and urban areas relative to concentrations of particles PM10 and PM2,5 and related polycyclic aromatic hydrocarbons (PAHs); aromatic hydrocarbons (BTXs); and mutagenicity of the organic PM10 and PM2,5 extracts. No significant differences were found between PM10 concentrations at an urban site and at football turf fields, both in warm and in cold seasons, and neither with or without on-field activity; PM2,5 concentrations were significantly higher in the urban site in cold season as the PM2,5 and PM10 ratio. BTXs were significantly higher in urban sites than in football turf fields both in warm days and in cold ones; the toluene and benzene ratio was always related to normal urban conditions. The concentration of PAHs in the monitored football fields were comparable to urban levels in the two different periods of samplings and the contribution of PAHs released from the granulate was negligible. PM10 organic extract mutagenicity in artificial football turf fields was higher, while PM2,5 organic extract mutagenicity was lower compared to the considered urban site, however both comparable to that reported in literature for urban sites. On the basis of this environmental monitoring are not present more environmental risks on artificial football turf fields than on rest of the city.
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Dear Editor,

We are sending the manuscript
"*Artificial football turf fields: environmental and mutagenicity assessment"*
that we submit for possible publication on *Archives of Environmental Contamination and Toxicology*.

An environmental analysis was performed to determine the contamination levels due to the presence of tire crumb in artificial turf fields and to determine whether an artificial turf field can lead to an additional exposure on the normal exposure levels to pollutants in urban areas.
The aim of the present study was to compare data from artificial football turf fields with urban areas in relation to: 1) concentration of airborne particulates PM10 and PM2,5; 2) concentration of related PAHs; 3) concentration of aromatic hydrocarbons (benzene, toluene and xylenes); and 4) mutagenicity of the organic PM10 and PM2,5 extracts. These analyses were conducted both with or without activity in the turf fields and, in order to understand how natural weather conditions influence levels of chemicals released from turf fields, in two different seasons.
The samplings were conducted in Torino, an industrial north western Italian city, at six different football fields and at two meteorological–chemical control stations located in the urban centre, a background and a traffic one; five of the football fields contained artificial turf.
On the basis of this environmental monitoring there were not present more environmental risks on artificial football turf fields than on rest of the city.

Best regards
Tiziana Schilirò

Artificial football turf fields: environmental and mutagenicity assessment.

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ABSTRACT

The public recently has raised concerns regarding potential human health and environmental risks associated with tire crumb constituents in artificial football turf fields. The aim of the present study was to develop an environmental analysis drawing a comparison between artificial football turf fields and urban areas relative to concentrations of particles PM10 and PM2,5 and related polycyclic aromatic hydrocarbons (PAHs); aromatic hydrocarbons (BTXs); and mutagenicity of the organic PM10 and PM2,5 extracts.

No significant differences were found between PM10 concentrations at an urban site and at football turf fields, both in warm and in cold seasons, and neither with or without on-field activity; PM2,5 concentrations were significantly higher in the urban site in cold season as the PM2,5 and PM10 ratio. BTXs were significantly higher in urban sites than in football turf fields both in warm days and in cold ones; the toluene and benzene ratio was always related to normal urban conditions. The concentration of PAHs in the monitored football fields were comparable to urban levels in the two different periods of samplings and the contribution of PAHs released from the granulate was negligible. PM10 organic extract mutagenicity in artificial football turf fields was higher, while PM2,5 organic extract mutagenicity was lower compared to the considered urban site, however both comparable to that reported in literature for urban sites. On the basis of this environmental monitoring are not present more environmental risks on artificial football turf fields than on rest of the city.

INTRODUCTION

Recycled tire material or “tire crumb” is used as a component in many recreational fields, including artificial turf fields. These crumbs are as much as 90% by weight of the fields. The tire crumbs are roughly the size of grains of course sand. They are made by shredding and grinding used tires. Tire crumb materials are spread two to three inches thick over the field

surface and packed between ribbons of green plastic used to simulate green grass (EHHI, 2007). Tire rubber is composed of 40 - 60% rubber polymer, reinforcing agents such as carbon black (20 - 35%), aromatic extender oils (15 - 20%), vulcanization additives (4%, e.g., zinc oxide, benzothiazole and derivatives), antioxidants (1%) and processing aids (<1%, e.g., plasticizers and softeners) (Wik and Dave, 2009) . The use of tire crumbs in applications such as football fields provides several benefits, including reduced sports injury. Non-playground uses include as an asphalt additive in road building and as an aggregate in concrete; tire crumb contributes to the strength of concrete, and the product is reportedly lighter in weight than typical concrete (Pierce and Blackwell, 2003). The public recently has raised concerns regarding potential human health and environmental risks associated with the presence of and potential exposures to tire crumb constituents in recreational fields, especially with regard to children's exposures (US EPA, 2009). Adults, and especially children, playing on tire crumb could potentially be exposed by ingestion of the product directly, by ingestion of surface water runoff through the product, by inhalation of dust, or by skin contact with the material or surface water runoff. Public health analysis of the health risks from human exposures to the rubber tire crumbs has not been adequately addressed up to this point (Anderson et al., 2006). Concerns have been expressed that toxic chemicals derived from tire rubber could be transferred to the environment and to organisms having direct contact with these products. For example, chemical additives such as Zn and polycyclic aromatic hydrocarbons (PAHs) were widely detected in the leachate from tire rubber (Stephensen et al., 2003; Wik and Dave, 2005; Kanematsu et al., 2009; Menichini et al., 2011). Zhang and collaborators (2008) reported that the levels of PAHs and Zn in tire crumb used as infill for artificial turf were above health-based soil standards, and lead in the tire crumb was highly bioaccessible in synthetic gastric fluid at relatively low levels (Zhang et al., 2008).

To examine further the known risks to human from exposure to the playground product, Anderson and colleagues (2006) turned to traditional published scientific literature; one study, done by investigators working in Alberta (Birkholz et al., 2003), examined the human and ecosystem hazard presented by tire crumb using in vitro mutagenicity assays. The associated hazard analysis suggested that the risk associated with playground use was very low. Toxicity to all of the aquatic organisms tested was observed in the fresh aqueous extract, but activity disappeared with aging of the tire crumb for 3 months in place on the playground. The investigators concluded that the use of tire crumb in playgrounds results in minimal hazard to children and the receiving environment, assuming intended use of the product, such as exclusive outdoor use and the presence of no solvents other than water. Regarding the central question of potential harm to children, the published literature contained some information about the product, including *in vitro* toxicity models (Gualtieri et al., 2005; Wik and Dave, 2006; Mantecca et al., 2007; Gomes et al., 2010). Most previous work has focused on the toxic chemicals in the leachate of tire rubber material. Wik and Dave (2009) reviewed thoroughly the ecotoxicological effects of tire rubber leachate and indicated its potential risks to aquatic organisms in water and sediment (Wik and Dave, 2009). The report went onto indicate that the health aspects associated with the inhalation of rubber particles are largely unknown. Very limited work has been done on the characterization of volatile and semi-volatile organic compounds out-gassing from commercial tire crumbs on artificial turf fields (US EPA, 2009; Li et al., 2010; van Rooij and Jongeneelen, 2010), despite the fact that if tire crumb is used as infill for artificial turf, the inhalation zone over these installations could be a major human exposure source. Really, traditional published resources and networks of environmental health experts could not establish the product's safety in use with children or adults (Anderson et al., 2006). The possible danger for children or adults is from direct contact with chemical compounds contained in the crumbs, which could happen by ingestion

or as a result of contact. A qualitative assessment of these risks produced the following conclusions -ingestion on the ground is unlikely and the gastric juices of the digestive system are not powerful enough to extract the toxic products from the crumb; - dermatological contact presents a generally very low risk: a more effective solvent than water would be needed to extract toxic compound in quantity, and an adequate (non polar) carrier would be necessary to penetrate the skin and cause significant absorption; - inhalation is considered negligible as the crumbs do not contain volatile chemical compounds under pressure, although, as the wear of a tire, even the use of an artificial field could generate fine particles and related compounds (Birkholz et al. 2003; LRCCP, 2006).

An environmental analysis is needed to determine quantitatively the contamination levels due to the presence of tire crumb in artificial turf fields. It is also important to determine whether an artificial turf field can lead an additional exposure to the normal exposure levels to pollutants in urban areas. The aim of the present study was to develop an environmental analysis drawing a comparison between artificial football turf fields and urban areas in relation to 1) concentration of particles PM10 and PM2,5, 2) concentration of related PAHs, 3) concentration of aromatic hydrocarbons (benzene, toluene and xylenes) and 4) mutagenicity of the organic PM10 and PM2,5 extracts. These analysis were conducted both in presence and absence of use of the turf fields and, in order to understand how natural weathering conditions influence levels of chemicals released from turf fields, in two different seasons.

MATERIALS AND METHODS

Samplings sites

The samplings were carried in Torino, an industrial north western Italian city, in six different football fields and in two meteorological–chemical control stations located in the urban

centre, a background and a traffic one; five of the football fields were in artificial turf (Figure 1). The characteristics of the sampling sites are reported in Table 1. Two different courses of samplings were carried out: in June (from 12 to 26) without playing and in November (from 6 to 15) during the course of matches, in order to verify the influences of both meteorological and seasonal conditions and the presence of play.

PM analysis

PM10 and PM2,5 were sampled on glass microfiber filters (Type A/E, 8'' x 10'', Gelman Sciences, Michigan, USA), with Sierra Andersen High Volume Samplers 1200/VFC (Andersen Samplers, Atlanta, Georgia, USA) using a flow of approximately 1160 L/min. Sample duration was controlled by a timer accurate to ± 15 min over a 24 hr sample period. The exact flow was calculated daily, corrected for variation in atmospheric pressure and actual differential pressure across the filter.

The filters were pre- and post-conditioned by moving them to a dry and dark environment for 48 h, and they were weighed in a room with controlled temperature and humidity. Procedures were conducted according to the European Committee for Standardization (CEN, 1998). The PM10 and PM2,5 concentrations, C (µg/m3), in the air volume sampled, V (L), was calculated as follows:

$$C = [(W2 - W1) - (B2 - B1)] \times 10^3 / V$$

where W1 is the mean of three tare weights of the same filter before sampling (mg), W2 is mean of three post-sampling weights of the same sample-containing filter (mg), B1 is mean tare weight of blank filters (mg), B2 is mean post-sampling weight of blank filters (mg) and V is volume as sampled at the nominal flow rate. At all football field sampling sites the measurements were carried out at the summit of the penalty area while for urban sampling site the measurements were carried out at the meteorological–chemical stations.

Aromatic Hydrocarbons analysis

Measurements of benzene, toluene, and xylenes (BTX) levels were carried out at all sites using a sampling line (air flow =1L/min) consisting of a membrane pump (KNF Neuberger, N73 KN 18), a gas meter (SIMBRUNT "Ariete 1"), and a granular activated carbon (GAC) cartridge (SKC coconut shell charcoal adsorbent sample tubes, inc. catalog number 226-01). As reported in the SKC certificate of quality, these cartridges are calibrated at 25 °C. The factors of temperature and humidity are not significant except under the most extreme temperature conditions or over 90% of relative humidity, which did not occur at these sites during this period. Cold temperatures do not interfere with the collection of chemical substances onto solid sorbents (SKC, Inc.). At all football field sampling sites the measurements were carried out at approximately 2 m of height from street level and approximately at the summit of the penalty area while for urban sampling site the measurements were carried out at the meteorological–chemical stations.

Air monitor samples were analyzed using a gas chromatograph (GC) Carlo Erba 5300 Mega Series equipped with a flame ionization detector (FID) and capillary column DB-624 30m×0.318mm ID, film 1.8μm. Each sample was eluted using 3 mL ultrapure carbon disulfide (CS2 99.9% low benzene content, Aldrich 34.227-0). A calibration curve was prepared from known concentrations of benzene, toluene, and xylenes. GC thermal program was: 45 °C for 4min, increase of 10 °C/min, from 45 to 145 °C, then 145 °C for 2 min.

Sampling rates of SKC passive sampler 530-11 were supplied by the manufacturer: benzene = 10.26 mL/min, toluene 9.05 mL/min, m-xylene = 8.18 mL/min, o-xylene = 8.18, p-xylene = 8.2 mL/min. The detection limit of 0.2 μg/sampler was calculated for the 3 aromatics with a signal-to-noise ratio ranging from 5 to 1. The accuracy of the analysis was determined by repeated analysis of a sample for 20 times. The mean of the 20 injections into GC/FID recorded benzene as 9.4 $\mu g/m^{-3}$ (SD =0.5) with a coefficient of variation of 4.3%. Recovery

(95%) was determined using previously described techniques (Bono, 2003) . When the signal-to-noise ratio ranged from 5 to 1, there was no apparent benzene contamination of CS_2 bottles.

Polycyclic Aromatic Hydrocarbons analysis

The following PAHs were determined in this study and they were considered pollutants of priority interest as categorized by International Agency for Research on Cancer (IARC) as carcinogenic (Group 1), probable (Group 2A) and possible (Group 2B) carcinogenic to humans: Benzo[a]pyrene (1), Benzo[a]anthracene (2A), Benzo[b]fluoranthene (2B), Benzo[k]fluoranthene (2B), Dibenzo[a,h]anthracene (2A), Indeno[1,2,3-c,d]pyrene (2B), other PAHs determined were: Fluoranthene, Pyrene, Chrysene, Benzo[g,h,i]perylene, Phenanthrene, and Anthracene. The determination of PAHs was performed on each PM10 and PM2,5 half filters; they were cut in small pieces and placed in a 50-mL polypropylene sterile tube with 15mL of toluene. The tubes were placed in an ultrasonic water bath for 15 min, followed by 1 min of vortexing. This procedure was repeated 3 times. Toluene extracts were evaporated with a rotary evaporator until 2 mL, than evaporated to 150 µL under a stream of nitrogen. The adopted method consisted of HRGC/ LRMS analysis using the method UT2.M128 R01 2002 (Pereira et al., 2001; Gilli et al., 2007a).

Mutagenicity analysis

The PM10 and PM2,5 half filters were cut in small pieces with stainless steel scissors (about 0.5 cm×0.5 cm) and extracted with acetone using a Soxhlet apparatus for at least 85 cycles. Acetone was able to extract moderately polar and highly polar classes of compounds. This polar fraction consistently contributed to the highest percentage of mutagenicity, whereas the neutral non-polar fraction contributed the least (Claxton et al., 2004). Mixture solutions were evaporated with a rotary evaporator and redissolved in dimethyl-3-sulfoxide (DMSO) to obtain a concentration of 0.2 $m^3/\mu L$. The mutagenic activity of the PM10 extracts was

determined using the Salmonella microsome assay (*Ames test*) according to the standard plate method of Maron and Ames (1983). Each sample was evaluated with and without metabolic activation (10% S9 mix), using TA98 Salmonella typhimurium strain. Extracts containing an equivalent of 4, 8 or 16 m3 of sampled air were suspended in DMSO and 2 ml top-agar containing biotin was added and subsequently plated on histidine-free agar plates. Each tester strain was checked routinely to confirm genotypes for optimal response to known mutagens as follows: 2-nitrofluorene (2-NF), 1 μg/plate, were used as positive control for TA98 without S9; 2-aminofluorene (2-AF) at 2 μg/plate was used to assess microsomal fraction efficiency. The appropriate solvent controls were also included in each test to check sample preparation interferences. The plates were incubated for 48 h at 37 °C, before counting the number of revertant colonies.

The series of concentrations of PM10 organic extract were tested to generate a concentration-response curve (20, 40 or 80 μL of the DMSO 0.2 m^3/mL suspension). The slope of concentration- response curve (revertants/m3) was calculated by least-squares linear regression from the first linear portion of the concentration–response curve. The regression coefficients obtained ranged from 0.67 to 0.99, with mean values of 0.89 ± 0.11 for TA98, 0.87 ± 0.14 for TA98 +S9. All experiments were performed in triplicate with at least three concentrations. The results were expressed as net revertants (rev/m^3), subtracting the spontaneous revertants, calculated by the concentration–response curve (Buschini et al., 2001; Cassoni et al., 2004; Claxton et al., 2004).

Statistical analysis

Statistical analyses were performed using the SPSS Package, version 14.0 for Windows. Means were compared with the t-test, and the Spearman rank correlation coefficient (rS) was used to assess relationships between variables. The mean difference and correlation were considered significant at $p < 0.05$.

RESULTS and DISCUSSION

PM concentrations

A total of 24 PM10 and 24 PM2,5 filters were analysed during the two sampling courses. The temperatures registered during the sampling courses of June were between 16 and 34 °C, while during the sampling course of November between 0 and 18°C. Figure 2 and Figure 3 show PM10 and PM2,5 concentrations, respectively, in the sampling sites during the two sampling periods. During the first sampling, in June, the mean PM10 concentrations were 59 ± 13 $\mu g/m^3$ and 54 ± 15 $\mu g/m^3$ in urban site and in football turf fields respectively; while the mean PM2,5 concentrations were 21 ± 3 $\mu g/m^3$ and 20 ± 4 $\mu g/m^3$ in urban site and in football turf fields respectively. During the second sampling, in November, the mean PM10 concentrations were 110 ± 18 $\mu g/m^3$ and 103 ± 17 $\mu g/m^3$ in urban site and in football turf fields respectively; while the mean PM2,5 concentrations were 83 ± 13 $\mu g/m^3$ and 54 ± 7 $\mu g/m^3$ in urban site and in football turf fields respectively.

No significant differences were found between PM10 concentrations in urban site and in football turf fields both in warm days and in cold ones and neither with or without playing; while for PM2,5 concentrations were significantly higher in the urban site in cold days ($p< 0.01$) while in warm days there was no difference ($p= 0.31$). Significant differences were found between PM10 and PM2,5 concentrations in June and in November ($p< 0.01$).

The ratio PM2.5/PM10 concentrations in November were between 0.65 and 0.93 with a mean value of 0.76 ± 0.10 in urban sites and between 0.47 and 0.58 with a mean value of 0.53 ± 0.04 in football turf fields and the difference was significant ($p<0.01$); in June the ratios were between 0.27 and 0.43 with a mean value of 0.37 ± 0.06 in urban sites and between 0.29 and 0.49 with a mean value of 0.39 ± 0.07 and in football turf fields respectively and the difference was not significant.

BTX concentrations

A total of 24 GAC cartridges were analysed during the two sampling courses for the evaluation of BTX concentrations. In Table 2 are reported BTX concentrations in the sampling sites during the June and November courses respectively. During the first sampling, in June, the mean benzene concentrations were 2.9 ± 0.1 μg/m^3 and 1.9 ± 0.6 μg/m^3; the mean toluene concentrations were 12.5 ± 1.6 μg/m^3 and 6.2 ± 2.1 μg/m^3, the mean xilenes concentrations were 5.9 ± 0.4 μg/m^3 and 10.1 ± 5.2 μg/m^3 in urban site and in football turf fields respectively. During the second sampling, in November, the mean benzene concentrations were 6.7 ± 1.3 μg/m^3 and 5.1 ± 0.9 μg/m^3; the mean toluene concentrations were 33.0 ± 6.5 μg/m^3 and 20.4 ± 6.3 μg/m^3, the mean xilenes concentrations were 22.5 ± 7.3 μg/m^3 and 28.5 ± 5.5 μg/m^3 in urban site and in football turf fields respectively. Significant differences were found between BTXs concentrations in urban site and in football turf fields both in warm days and in cold ones, BTXs were mean higher in urban sites ($p<0.05$). Significant differences were also found between BTXs concentrations in June and in November ($p< 0.01$).

Table 2 also shows ratios between benzene and toluene in the two sampling periods. During the first sampling, in June, the mean Toluene/Benzene (T/B) ratios, were 4.3 ± 0.5 and 3.5 ± 1.2 in urban sites and in football turf fields respectively while during the second sampling, in November, the mean T/B ratios, were 4.9 ± 0.4 and 4.0 ± 0.8 in urban sites and in football turf fields respectively. The difference between the two sampling sites was significant (paired t-test, $p =0.04$).

PAH concentrations

A total of 12 PAHs were analysed from both PM10 and PM2,5 extract in each football fields and in urban sites, during the two sampling courses. In Table 3 are reported PAHs concentrations in the sampling sites during the June and November courses respectively.

These PAHs exhibited effects that were representative of the total PAHs; the health effects of individual PAHs are not exactly alike. (ATSDR, 1995; Torben, 1996). Benzo[a]pyrene is one of the PAHs with demonstrated carcinogenic properties in animals, including humans (Group 1 IARC) (Straif et al., 2005), and it is an excellent indicator of PAHs exposure since it highly correlates with the other major carcinogenic PAHs (Feilberg, 2002). PAHs are products of incomplete combustion and are widespread in the environment and they may contribute to human cancer; however, the association between PAH exposure and lung cancer is considered unproven (Nielsen et al., 1996; Farmer et al., 2003). During the first sampling, in June, being a summer period, concentrations of PAHs, when present, were very low. Among the analysed PAHs the Benzo[a]pyrene is the only ruled by law and it was never present. The only PAHs with values above the detection limit, although at low concentrations, were: Benzo[b]fluoranthene + Benzo[k]fluoranthene present in 4 football fields (including the clay field), at least in PM10 fraction, Benzo[ghi]perylene present in 3 football fields (including the clay field) and Chrysene in 2 football fields only in the PM10 fraction.

During the second sampling, in November, PAHs concentrations were higher than in summer period. Benzo[a]pyrene was always present with a mean value of 1.06 ± 0.51 ng/m^3 in the football fields, concentration comparable to those reported as annual average according to current regulation (1 ng/m^3). Except for Anthracene, the other PAHs were often present in every football fields and in urban site; the more abundant compounds are Benzo(b)fluoranthene + Benzo(k)fluoranthene, Chrysene and Benz[a]antracene, both in football fields and in urban site.

The percentage ratio between the amount of total PAHs and the amount of PM10 or PM2.5 on which they are adsorbed: 10.4 ± 5.1 % and 15.8 ± 7.6 % respectively, confirmed that in general, also for the football fields, the highest concentration of PAHs was on the PM 2.5.

Mutagenicity

Spontaneous reversion of the tester strains to histidine independence is measured in each Ames test and was expressed as the number of spontaneous revertants per plate. Spontaneous reversion is at a frequency that is characteristic of the strain. The data were expressed as the average revertants number per plate from the triplicates. Table 4 summarized the results obtained from the study tests. Extracts of airborne particulate matters collected in the football fields and in urban background site of Torino, showed low mean mutagenicity to Salmonella typhimurium strain TA98 with and without metabolic activation (S9 mix). In comparison with the spontaneous revertants, greater effect was recorded with TA98 without S9 both for PM10 and for PM2,5. The mutagenic characteristics show a seasonal trend and were found to be significantly different for the two sampling periods for both PM2,5 and PM10. In June, in the football fields, mean mutagenicity for PM2,5 was 111.4 ± 40.7 revertants/mg and 77.4 ±17.0 revertants/mg for TA98 and TA98+S9 respectively; mean mutagenicity for PM10 was 56.6 ± 10.8 revertants/mg and 39.5 ± 9.2 revertants/mg for TA98 and TA98+S9 respectively. While in the urban site mutagenicity for PM2,5 was 161.4 and 56.9 revertants/mg for TA98 and TA98+S9 respectively and for PM10 was 39.7 and 36.9 revertants/mg for TA98 and TA98+S9 respectively.

In November, in the football fields, mean mutagenicity for PM2,5 was 490.8 ± 91.9 revertants/mg and 328.6 ± 99.7 revertants/mg for TA98 and TA98+S9 respectively; mean mutagenicity for PM10 was 576.7 ± 268.5 revertants/mg and 333.6 ± 233.5 revertants/mg for TA98 and TA98+S9 respectively. While in the urban site mutagenicity for PM2,5 was 769.8 and 373.3 revertants/mg for TA98 and TA98+S9 respectively and for PM10 was 239.2 and 212.5 revertants/mg for TA98 and TA98+S9 respectively.

CONCLUSIONS

This environmental analysis showed that the particulate matter fractions in artificial turfs often had concentrations equal to that found in background urban stations, both in warm and in cold periods. In general the monitoring of PM10 and of PM2.5 in Torino showed concentrations that were frequently higher than the daily (50µg/m^3 and 20 µg/m^3 respectively) quality targets (Air Quality Directive, 2008/50/CE) especially in winter times. The comparison between artificial field and clay one (P1 and P2) showed slightly higher for the latter especially in cold times, but this situation was also deferred in urban areas in the two different sampling days; probably the lifting of the clay during the game tends to raise the values of particulates. There were no differences in the concentration of particulate matter linked to seniority of the fields or the type of fields (black UT or thermoplastic) considering the different sampling days. The PM2.5 and PM10 ratio in football fields was comparable to urban sites, and it was between 0.4 and 0.8 (values closer to 0.8 indicate a situation where it is more important to the respirable fraction), especially in winter times, the situation becomes more critical in urban sites, reflecting the growing influence of the fine component.

The concentration of BTX in the monitored football fields were constant and were comparable to urban background levels or at least reflect a normal situation related to urban pollution source of motor vehicles (the only exception is the concentration of xylenes during the first sampling in P1, that was greater than in both the other fields and in urban stations probably because of in that field had been painted the gates during the days preceding the sampling), in general benzene and toluene values were much lower than the urban sites. There were no substantial differences in the concentrations of aromatic hydrocarbons related to seniority of the field or the type of fields (black UT or thermoplastic) considering the different sampling days even taking into account the few cases analyzed, the condition of "use" and the temperatures. The T/B ratio was always related to normal urban conditions in all sites

considered; some studies showed that when this ratio takes values greater than two can be assumed that the pollution comes from traffic (Valerio et al., 2005).

The concentration of PAH, both on PM10 and on PM2,5, in the monitored football fields were comparable to urban levels in the two different periods of samplings. About the warm sampling, B[b]f + B[k]f were regarded as characteristic of PAH emissions from combustion of gasoline vehicles, B[ghi]pe was considered (after Py) characteristic of emissions from tire wear and asphalt (Pengchai et al., 2005); these PAH were also present on the clay field so probably, since the fields were without on-field activity, these values could be attributable to traffic in surrounding streets. In the cold sampling, B[b]f + B[k]f were present in all fields and with the highest percentage compared to others; the same consideration was true for B[a]a (characteristic of PAH emissions from combustion of gasoline vehicles). Py and B[ghi]pe were also present on the clay field therefore, as the fields were used, these values colud be attributable to traffic in surrounding streets.

The concentration ratios of all PAHs vs. BaP lied in the respective ranges observed in urban areas (Menichini et al.,1999).

In Italy, in warm season, the total PAHs concentrations in a traffic site, range between 1 and 4 ng/m^3 while in a background one between 0.1 and 1 ng/m^3 (Menichini et al., 2006, ISPRA, 2010); in the monitored fields total PAHs values ranging from <0.1 to 0.6 ng/m^3. In cold season, the total PAHs concentrations in a traffic site, range between 3 and 13 ng/m^3 while in a background one between 1 and 5 ng/m^3; in the monitored fields total PAHs values ranging from 2.8 and 15.5 ng/m^3 (Menichini et al., 2006, ISPRA, 2010). Therefore also for what concerns the PAHs there was a normal urban profile in the considered periods. The highest PAHs concentrations were reported on PM2.5 (70 - 90%), in this regard, in our investigation, the concentration of PAHs could be worse at the city level by considering the relationship between PM10 and PM2,5 in football fields, which turns out to be lower than urban sites. The

concentrations measured in the field substantially equalled the urban background concentrations measured close to the field, and the contribution of PAHs released from the granulate was likely negligible. There were no differences in the concentration of PAH linked to seniority of the fields or the type of fields (black UT or thermoplastic) considering the different sampling days.

Since target PAHs were present in air as particle-bound, their highest concentrations were expected to occur close to the points where the turf is stressed causing particles to be released (Menichini et al., 2011). However, the hi-vol air sampler was located at the summit of the penalty area, which implies the measurements could underestimate the actual concentrations the athletes were exposed to. The use of personal air samplers seems to be a suitable procedure to estimate the actual concentrations the athletes are exposed to. However a recent study underline that the uptake of PAH by football players active on artificial grounds with rubber crumb infill is minimal. If there was any exposure, than the uptake is very limited and within the range of uptake of PAH from environmental sources and/or diet (van Rooij and Jongeneelen, 2010).

In the present monitoring the mutagenicity of football field PM10 was higher while the mutagenicity of football field PM2,5 was lower, compared to the urban site. In general in artificial football fields, both in June and in November, there were mean values comparable to that reported in other studies in urban sites (Gilli et al., 2007a; Gilli et al., 2007b).

In the present study, the concentrations of PM, BTX, PAHs and mutagenicity had a normal urban trend in the considered periods and there were no significant differences between football fields and urban sites; moreover no substatial differences were found between artificial football fields and “natural” football field. On the basis of this environmental monitoring there were not present more risks on artificial football turf fields than on rest of

the city, yet, further work will be necessary to assess the actual scenarios of exposure by inhalation and the corresponding risks.

Acknowledgements

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Table 1. Characteristics of the sampling sites.

Football Field (name)	**Age (years)**	**Material**	**Dimensions (m)**	**1st sampling**	**2nd sampling**
Pellerina 1 (**P1**)	3	black UT[1]	45 x 90	12 June	6 November
Pellerina 2 (**P2**)	3	clay	45 x 90	13 June	7 November
Carrara (**C**)	1.5	black UT[1]	40 x 65	14 June	8 November
Rivermosso (**R**)	3	black UT[1]	40 x 65	15 June	9 November
Passo Buole (**S**)	3	thermoplastic	45 x 90	21 June	14 November
Barracuda (**B**)	1.5	black UT[1]	40 x 65	26 June	15 November
Meteorological–chemical station (name)				**1st sampling**	**2nd sampling**
Background (**1a**) Environmental Protection Regional Agency (Piedmont A.R.P.A.)		6 m high, in the central limited traffic zone.		12-26 June	6-15 November
Traffic (**1b**) Environmental Protection Regional Agency (Piedmont A.R.P.A.)		2 m height, "sandwiched" between two busy streets and bordered with the central limited traffic zone.		12-26 June	6-15 November

[1]Used Tires

Table 2. Benzene (B), Toluene (T) and Xilenes (Xs: sum of m-xilene, o-xilene and p-xilene) concentrations (μg/m^3) and Toluene and Benzene (T/B) ratio in the sampling sites during the first period of samplings, 12-26 June (2A) and during the second period of samplings, 6-15 November (2B) (1a: meteorological–chemical background urban station; R: artificial turf, Rivermosso; C: artificial turf, Carrara; P1: artificial turf, Pellerina; P2: football field clay; B: artificial turf, Barracuda; S: artificial turf, Passo Buole).

(2A)	**Urban control site (1a)**				**Football fileds**				
	B	**T**	**Xs**	**T/B**		**B**	**T**	**Xs**	**T/B**
12 Jun	2.7	10.4	5.5	3.9	**P1**	1.8	10.2	20.9	5.7
13 Jun	3.0	11.5	5.8	4.0	**P2**	1.4	5.1	7.4	3.6
14 Jun	3.0	12.5	6.0	4.2	**C**	1.3	5.6	7.9	4.3
15 Jun	3.0	12.9	6.4	4.2	**R**	1.4	4.2	7.2	3.1
21 Jun	3.1	15.3	5.9	5.1	**S**	3.0	6.9	8.3	2.3
26 Jun	2.7	13.0	6.0	4.2	**B**	2.2	5.3	8.8	2.4
(2B)									
Date	**B**	**T**	**Xs**	**T/B**		**B**	**T**	**Xs**	**T/B**
6 Nov	8.8	41.8	34.4	4.7	**P1**	6.0	18.9	25.7	3.1
7 Nov	7.4	38.4	25.8	5.2	**P2**	5.8	23.1	34.7	4.0
8 Nov	5.6	28.2	16.5	5.0	**C**	4.7	15.4	26.0	3.3
9 Nov	6.2	32.6	22.8	5.2	**R**	5.7	31.2	33.7	5.5
14 Nov	6.4	33.0	21.6	5.1	**S**	4.9	20.3	31.1	4.2
15 Nov	5.5	24.0	13.7	4.3	**B**	3.4	13.6	20.3	4.0

Table 3. Polycyclic Aromatic Hydrocarbons concentrations, from both PM10 and PM2,5 extraction, in the sampling sites during the first period of samplings, 12-26 June (3A) and during the second period of samplings, 6-15 November (3B) (1a: meteorological–chemical background urban station; R: artificial turf, Rivermosso; C: artificial turf, Carrara; P1: artificial turf, Pellerina; P2: football field clay; B: artificial turf, Barracuda; S: artificial turf, Passo Buole). PAH: Benzo[a]pyrene (B[a]p), Benzo[a]anthracene (B[a]a), Benzo[b]fluoranthene (B[b]f), Benzo[k]fluoranthene (B[k]f), Dibenzo[a,h]anthracene (Db[ah]a), Indeno[1,2,3-c,d]pyrene (I[cd]p), Fluoranthene (Fl), Pyrene (Py), Chrysene (Ch), Benzo[g,h,i]perylene (B[ghi]pe), Phenanthrene (Fe), Anthracene (A). LOD (limit of detection) = 0.09 ng/m^3.

(3A)	**PAH ng/m^3**	**B[a]p**	**B[a]a**	**B[b]f + B[k]f**	**Db[ah]a**	**I[cd]p**	**Fl**	**Py**	**Ch**	**B[ghi]pe**	**Phe**	**A**
12 June	**PM10**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
1a	**PM2,5**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
12 June	**PM10**	<LOD	<LOD	0.17	<LOD	<LOD	<LOD	<LOD	0.10	0.12	<LOD	<LOD
P1	**PM2,5**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.10	<LOD	<LOD
13 June	**PM10**	<LOD	<LOD	0.15	<LOD	<LOD	<LOD	<LOD	<LOD	0.10	<LOD	<LOD
P2	**PM2,5**	<LOD	<LOD	0.13	<LOD	<LOD	<LOD	<LOD	<LOD	0.09	<LOD	<LOD
14 June	**PM10**	<LOD	<LOD	0.12	<LOD	<LOD	<LOD	<LOD	<LOD	0.09	<LOD	<LOD
C	**PM2,5**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
15 June	**PM10**	<LOD	<LOD	0.12	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
R	**PM2,5**	<LOD	<LOD	0.10	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
21 June	**PM10**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.10	<LOD	<LOD	<LOD
S	**PM2,5**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
26 June	**PM10**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
B	**PM2,5**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
(3B)	**PAH ng/m^3**											
15 November	**PM10**	0.78	0.62	1.98	<LOD	0.70	0.34	0.48	0.62	0.78	<LOD	<LOD
1a	**PM2,5**	0.70	na	na	na	na	na	na	na	na	na	na
6 November	**PM10**	0.77	0.76	1.81	<LOD	0.50	0.57	0.69	1.00	0.65	0.17	<LOD
P1	**PM2,5**	0.70	0.57	1.61	<LOD	0.49	0.43	0.55	0.77	0.64	0.14	<LOD
7 November	**PM10**	0.34	0.44	1.06	<LOD	0.26	0.25	0.32	0.57	0.29	0.10	<LOD
P2	**PM2,5**	0.29	0.26	0.78	<LOD	0.23	0.15	0.19	0.31	0.27	<LOD	<LOD

8 November C	**PM10**	1.19	1.20	2.53	0.12	0.69	0.45	0.62	1.53	0.87	0.12	<LOD
	PM2,5	1.09	1.04	2.37	0.11	0.64	0.35	0.44	1.33	0.81	0.11	<LOD
9 November R	**PM10**	1.75	2.13	3.98	0.19	1.03	0.56	0.71	2.24	1.22	0.15	<LOD
	PM2,5	1.64	1.79	4.00	0.18	0.98	0.40	0.54	2.11	1.16	0.14	<LOD
14 November S	**PM10**	1.49	1.53	3.18	0.25	1.01	0.94	1.32	1.98	1.31	0.24	<LOD
	PM2,5	1.04	1.1	2.23	0.14	0.67	0.54	0.71	1.37	0.88	0.16	<LOD
15 November B	**PM10**	0.82	0.95	2.08	<LOD	0.56	0.55	0.79	1.31	0.71	0.17	<LOD
	PM2,5	0.72	0.62	1.70	<LOD	0.49	0.31	0.39	0.82	0.67	0.12	<LOD

Table 4. Mutagenicity of PM10 (4A) and PM2,5 (4B) organic extracts. Summary of the *Ames test* results: mean spontaneous Salmonella revertants and mean net revertants *per* m^3 of sampled air and *per* µg of particles; (1a: meteorological–chemical background urban station; 1b: meteorological–chemical traffic urban station; R: artificial turf, Rivermosso; C: artificial turf, Carrara; P1: artificial turf, Pellerina; P2: football field clay; B: artificial turf, Barracuda; S: artificial turf, Passo Buole).

(4A) PM10	**TA 98 revertants/m^3**	**TA 98 +S9 revertants/m^3**	**TA 98 revertants/mg**	**TA 98 +S9 revertants/mg**	***Sampling sites***
Spontaneous	19	24	19	24	
12 June	1.2	1.0	39.7	36.9	**1a**
15 November	56.0	42.0	239.2	212.5	
12 June	2.7	1.8	59.3	39.3	**P1**
6 November	28.8	18.7	261.9	169.8	
13 June	3.0	1.9	62.0	39.0	**P2**
7 November	73.7	21.7	562.4	165.5	
14 June	2.7	.2	45.1	37.4	**C**
8 November	29.7	13.9	312.1	146.1	
15 June	3.2	3.0	56.8	53.6	**R**
9 November	60.6	38.1	555.9	349.2	
21 June	3.5	3.4	44.0	42.8	**S**
14 November	76.0	62.4	1036.1	751.8	
26 June	4.7	1.6	72.7	25.1	**B**
15 November	75.8	37.3	852.1	419.1	
(4B) PM2,5					
12 June	3.4	0.6	161.4	56.9	**1b**
15 November	63.9	31.0	769.8	373.3	
12 June	1.4	1.5	77.8	80.7	**P1**
6 November	25.0	15.6	480.8	300.4	
13 June	2.2	1.5	111.7	77.4	**P2**
7 November	27.5	10.9	416.1	165.7	
14 June	2.2	2.1	100.0	95.36	**C**
8 November	22.1	17.9	401.7	325.8	
15 June	3.9	1.7	164.0	69.1	**R**
9 November	36.1	24.9	645.1	443.9	
21 June	1.5	2.3	61.6	93.0	**S**
14 November	24.7	19.0	548.5	422.6	
26 June	2.6	0.8	153.6	49.0	**B**
15 November	22.1	15.3	452.6	313.2	

FIGURE CAPTIONS

Figure 1. Sampling sites are placed in north-western Italy, in Piedmont Region, in the chief town: Torino. Seven different sampling sites, two urban control sites and six football field sites (1a: meteorological–chemical background station; 1b: meteorological–chemical traffic station; R: artificial turf, Rivermosso; C: artificial turf, Carrara; P1: artificial turf, Pellerina; P2: football field clay; B: artificial turf, Barracuda; S: artificial turf, Passo Buole).

Figure 2. PM10 concentrations in the sampling sites during the two sampling periods, 12 – 26 June (grey bars and striped bars) and 6-15 November (black bars and dotted bars). 1a: meteorological–chemical background urban station; R: artificial turf, Rivermosso; C: artificial turf, Carrara; P1: artificial turf, Pellerina; P2: football field clay; B: artificial turf, Barracuda; S: artificial turf, Passo Buole.

Figure 3. PM2.5 concentrations in the sampling sites during the two sampling periods, 12 – 26 June (grey bars and striped bars) and 6-15 November (black bars and dotted bars). 1b: meteorological–chemical traffic urban station; R: artificial turf, Rivermosso; C: artificial turf, Carrara; P1: artificial turf, Pellerina; P2: football field clay; B: artificial turf, Barracuda; S: artificial turf, Passo Buole.

Figure 1.

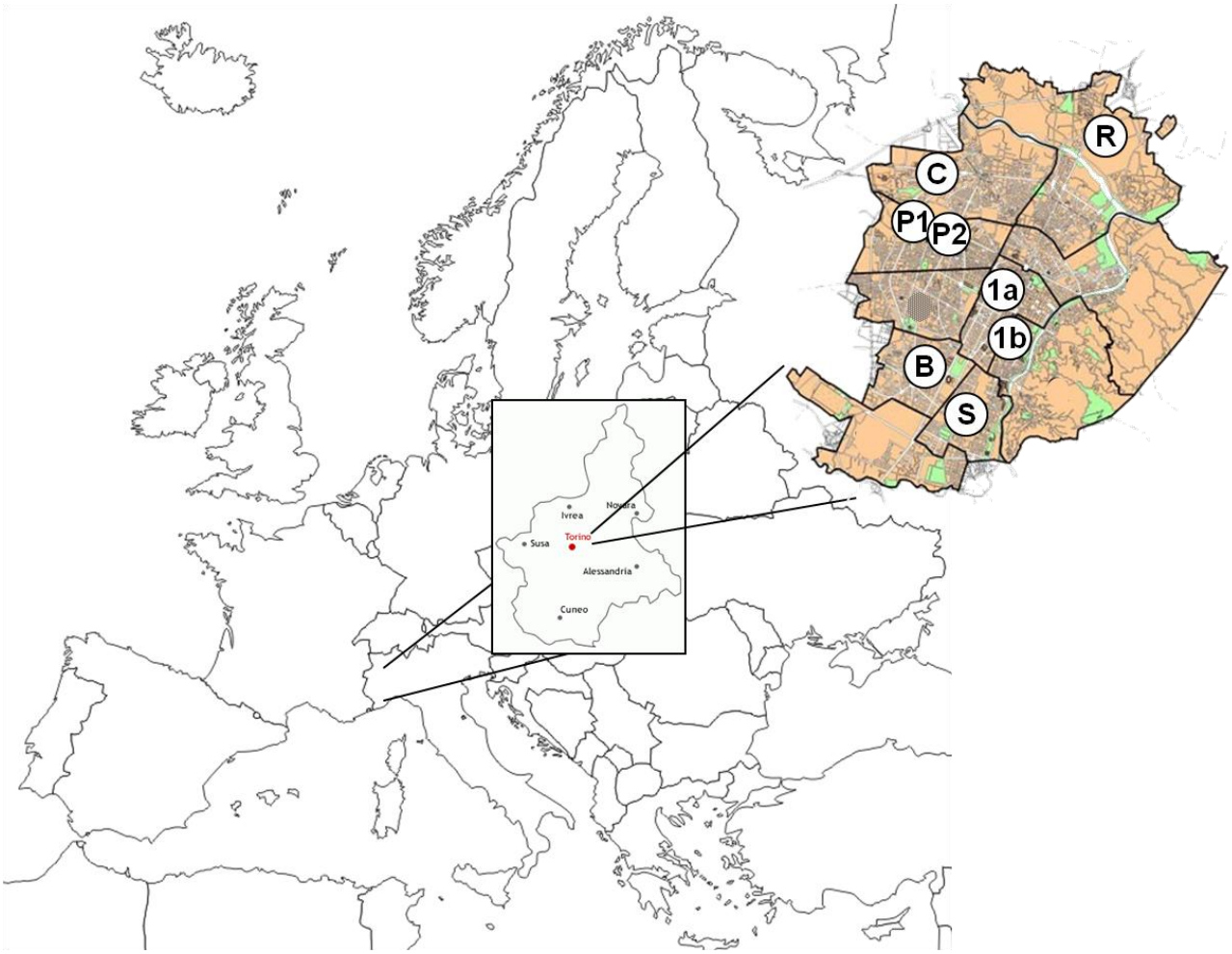


Figure 2.

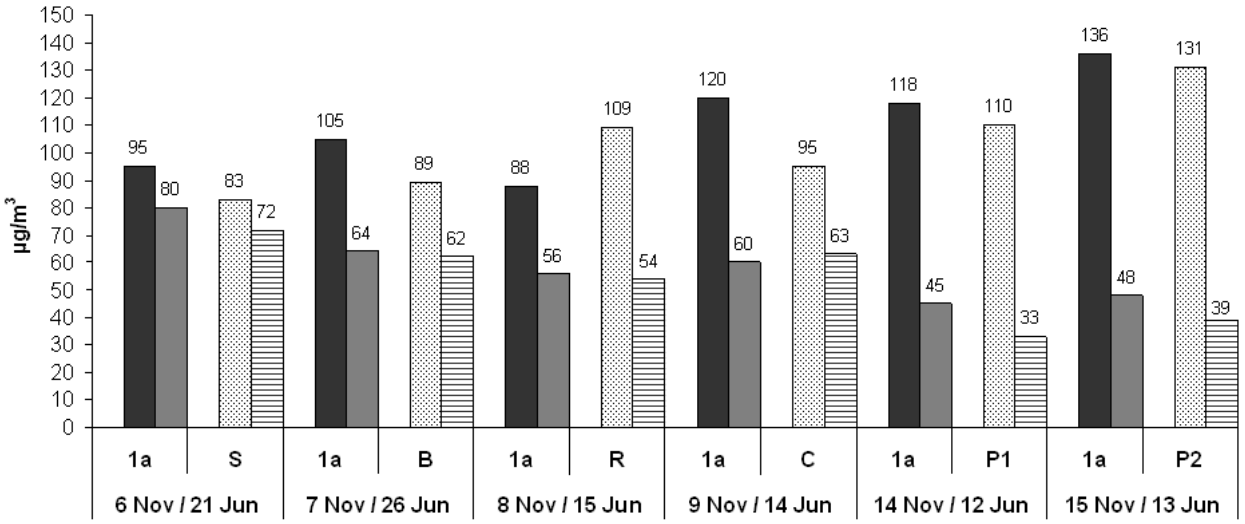
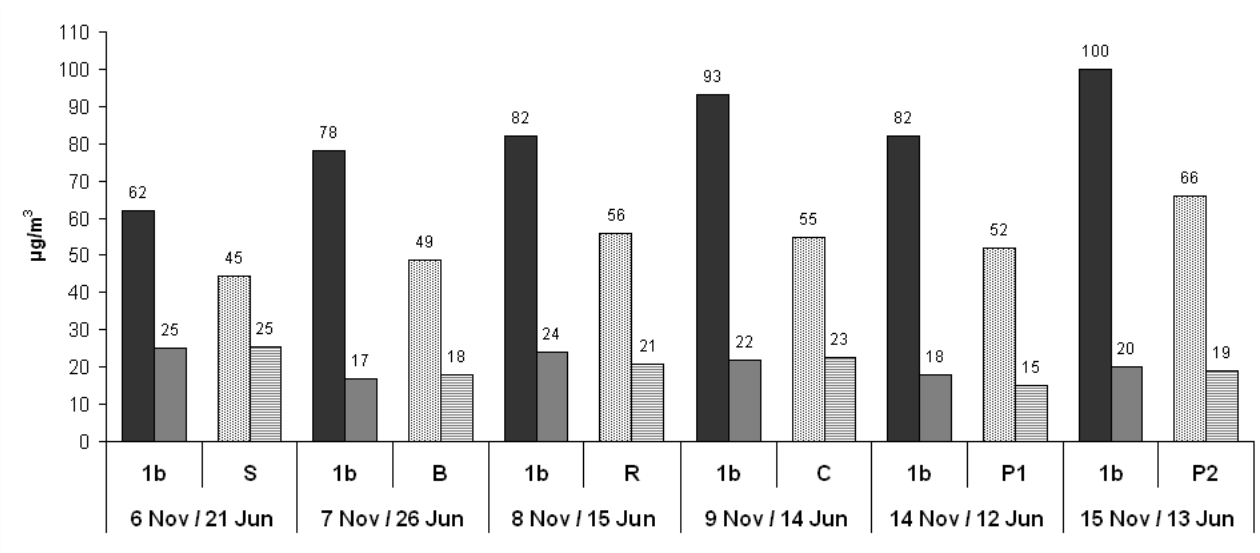

µg/m³
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
95
80
83
72
105
64
89
62
88
56
109
54
120
60
95
63
118
45
110
33
136
48
131
39
1a
S
1a
B
1a
R
1a
C
1a
P1
1a
P2
6 Nov / 21 Jun
7 Nov / 26 Jun
8 Nov / 15 Jun
9 Nov / 14 Jun
14 Nov / 12 Jun
15 Nov / 13 Jun

Figure 3.


µg/m3
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6 Nov / 21 Jun
7 Nov / 26 Jun
8 Nov / 15 Jun
9 Nov / 14 Jun
14 Nov / 12 Jun
15 Nov / 13 Jun