

Table 4-7. Studies of 6PPD and 6PPD-q concentrations in outdoor air

Location	Information	Concentration (pg/m ³)	Lab Instrumentation	Detection Limit
Hong Kong Baptist University, Hong Kong (Cao et al. 2022)	Between September 2020 and August 2021, researchers collected 16 samples and analyzed them for a range of antioxidants and transformation products, including 6PPD and 6PPD-q.	The concentrations of 6PPD and 6PPD-q in air were found to be [median (range)]: 6PPD: 1.78 (0.82–6.30) 6PPD-q: 1.18 (0.54–13.8)	UPLC Orbitrap Mass Spectrometry and UHPLC Triple Quadrupole Mass Spectrometry	IQL (ng/mL): 6PPD: 0.035 6PPD-q: 0.023
Global megacities (Johannessen et al. 2022)	Researchers measured a range of antioxidants and transformation products, including 6PPD and 6PPD-q in archived extracts collected at representative sites (away from major roadways) on PUF disks from passive air samplers deployed across 18 major cities that compose the GAPS Network (GAPS-Megacities) during a three-month period in 2018.	The concentrations of 6PPD and 6PPD-q in ambient air were found to be [mean (range)]: 6PPD: (ND–<LOQ) 6PPD-q: 0.85 (ND–1.75)	UPLC Q-Exactive Orbitrap HRMS	IQL (ng/mL): 6PPD: 1.95 6PPD-q: 0.122 MQL (pg/m ³) 6PPD: 2.71 6PPD-q: 0.169
Guangzhou and Taiyuan, China (Wang et al. 2022)	Between May 2017 and April 2018, researchers collected 72 samples of PM _{2.5} from air at three sites. Each site was sampled 24 times, and samples were analyzed for a range of antioxidants and TPs, including 6PPD and 6PPD-q.	The concentrations of 6PPD and 6PPD-q in air (PM _{2.5} fraction) were found to be [median (range)]: 6PPD: Guangzhou: 1,820 (22.2–6,050) Roadside in Guangzhou: 4,040 (2.23–9,340) Taiyuan: 81 (1.02–3,190) 6PPD-q: Guangzhou: 1,100 (3.04–2,350) Roadside in Guangzhou: 2,810 (2.96–7,250) Taiyuan: 744 (2.44–1,780)	ESI / Ultrahigh-resolution Orbitrap MS / triple quadrupole MS	MQL (pg/m ³): 6PPD: 0.25 6PPD-q: 0.08 MDL (pg/m ³): 6PPD: 0.07 6PPD-q: 0.02
Guangzhou, Hangzhou, Nanjing, Shanghai, Taiyuan, and Zhengzhou, China (Zhang et al. 2022)	Researchers collected 81 samples of PM _{2.5} from ambient air in six megacities in China between 2018 and 2019 and analyzed them for a range of antioxidants and TPs, including 6PPD and 6PPD-q.	The concentrations of 6PPD and 6PPD-q in air (PM _{2.5} fraction) were found to be [median (range)]: 6PPD: Guangzhou: 0.9 (0.3–10) Hangzhou: 4.6 (0.1–6.0) Nanjing: 2.1 (0.4–75) Shanghai: 4.4 (0.5–135) Taiyuan: 6.9 (0.02–487) Zhengzhou: 8.4 (1.2–109) 6PPD-q: Guangzhou: 1.7 (0.1–15) Hangzhou: 6.7 (0.8–26) Nanjing: 2.3 (1.1–68) Shanghai: 5.9 (0.3–39) Taiyuan: 3.3 (1.1–84) Zhengzhou: 2.9 (0.3–32)	UHPLC-MS/MS	LOD (pg/mL): 6PPD: 1 6PPD-q: 5

Table 4-7. Studies of 6PPD and 6PPD-q concentrations in outdoor air

Location	Information	Concentration (pg/m ³)	Lab Instrumentation	Detection Limit
United States and Canada (Wu, Venier, and Hites 2020)	In 2016, researchers collected 21 e-waste dust samples in an e-waste dismantling facility in Ontario, Canada. Residential samples were collected in Ontario, Canada in 2015 (n=20) and in Indiana, United States, in 2013 (n=12). In 2013, 10 sediment samples were collected in the Chicago Sanitary and Ship Canal. From 2018 to 2019, 20 air samples were collected in Chicago. Samples were tested for various antioxidants and ultraviolet filters, including 6PPD. 6PPD was detected in 100% of the e-waste dust samples, and in 70%–75% of all other sampled media.	The concentrations of 6PPD were found to be [median (range)]: Air particles (particle size not specified): 0.06 (<MDL–0.41)	LC-MS/MS	MDL: Air: 0.02 pg/m ³ Dust and sediment: 0.06 ng/g
Oxford, Mississippi (Olubusoye et al. 2023)	Researchers used passive samplers for 10 days along U.S. Highway 278. The abundance of airborne TWPs increased with proximity to the road with deposition rates (TWPs cm ² /day) of 23, 47, and 63 at 30 m, 15 m, and 5 m from the highway, respectively. Two common TWP compounds (6PPD-q and 4-ADPA) were detected in all samples, except the field blank, at levels above their limits of detection, estimated at 2.90 and 1.14 ng/L–1, respectively.	6PPD-q detected in all samples above the limit of detection	UHPLC-HRMS	LOD: 6PPD: 2.13 6PPD-q: 2.90

Notes: 4-ADPA=4-aminodiphenylamine, ESI= electrospray ionization, GAPS=Global Atmospheric Passive Sampling, HRMS=high-resolution mass spectrometry, IQL=instrument quantification limit, LC-MS/MS=liquid chromatography / tandem mass spectrometry, LOD=limit of detection, LOQ=limit of quantitation, MDL=method detection limit, MQL=method quantification limit, ND=nondetect, ng/g=nanogram per gram, MS=mass spectrometry, ng/L=nanograms per liter, ng/mL=nanogram per milliliter, pg/m³=picograms per cubic meter, PM_{2.5}=fine particulate matter; inhalable particles with diameters generally 2.5 micrometers and smaller, pg/m³=picograms per cubic meter, PUF=polyurethane foam, TWP=tire-wear particles, UHPLC=ultra-high-performance liquid chromatography, UHPLC=ultra-high-performance liquid chromatography–tandem mass spectrometry, UPLC=ultra-performance liquid chromatography

References

- Cao, Guodong, Wei Wang, Jing Zhang, Pengfei Wu, Xingchen Zhao, Zhu Yang, Di Hu, and Zongwei Cai. 2022. “New Evidence of Rubber-Derived Quinones in Water, Air, and Soil.” *Environmental Science & Technology* 56 (7): 4142–50. <https://doi.org/10.1021/acs.est.1c07376>.
- Johannessen, Cassandra, Amandeep Saini, Xianming Zhang, and Tom Harner. 2022. “Air Monitoring of Tire-Derived Chemicals in Global Megacities Using Passive Samplers.” *Environmental Pollution* 314 (December):120206. <https://doi.org/10.1016/j.envpol.2022.120206>.
- Olubusoye, Boluwatife S., James V. Cizdziel, Matthew Bee, Matthew T. Moore, Marco Pineda, Viviane Yargeau, and Erin R. Bennett. 2023. “Toxic Tire Wear Compounds (6PPD-Q and 4-ADPA) Detected in Airborne Particulate Matter Along a Highway in Mississippi, USA.” *Bulletin of Environmental Contamination and Toxicology* 111 (6): 68. <https://doi.org/10.1007/s00128-023-03820-7>.
- Wang, Wei, Guodong Cao, Jing Zhang, Pengfei Wu, Yanyan Chen, Zhifeng Chen, Zenghua Qi, Ruijin Li, Chuan Dong, and Zongwei Cai. 2022. “Beyond Substituted *p*-Phenylenediamine Antioxidants: Prevalence of Their Quinone Derivatives in PM_{2.5}.” *Environmental Science & Technology*, July, acs.est.2c02463. <https://doi.org/10.1021/acs.est.2c02463>.
- Wu, Yan, Marta Venier, and Ronald A. Hites. 2020. “Broad Exposure of the North American Environment to Phenolic and Amino Antioxidants and to Ultraviolet Filters.” *Environmental Science & Technology* 54 (15): 9345–55. <https://doi.org/10.1021/acs.est.0c04114>.
- Zhang, Yanhao, Caihong Xu, Wenfen Zhang, Zenghua Qi, Yuanyuan Song, Lin Zhu, Chuan Dong, Jianmin Chen, and Zongwei Cai. 2022. “*p*-Phenylenediamine Antioxidants in PM_{2.5}: The Underestimated Urban Air Pollutants.” *Environmental Science & Technology* 56 (11): 6914–21. <https://doi.org/10.1021/acs.est.1c04500>.