

Table 4-1. Studies of 6PPD and 6PPD-q concentrations in surface water

Location	Information	Concentration (varies by study)	Lab Instrumentation	Detection Limit
Canada (Challis et al. 2021)	Sampling was conducted in the City of Saskatoon in Canada. Snowmelt samples were collected in 2019 and 2020 from the city's snow dumps. Stormwater samples were collected at seven outfalls representing residential, industrial, and retail developments. Nine surface-water samples were collected from the South Saskatchewan River. Samples were analyzed for 6PPD-q.	The concentrations of 6PPD-q were found to be [mean (range), ng/L]: Surface water—2020: not detected	UHPLC-MS	LOD: 1.2 ng/mL LOQ: 3.3 ng/mL
Canada (Monaghan et al. 2021)	Surface-water (n=2) and stormwater (n=4) samples were collected in May and June of 2021 in Nanaimo, British Columbia, Canada, and analyzed for 6PPD-q. The analytical method provides semiquantitative results of 6PPD-q.	The concentrations of 6PPD-q were found to be [range, ng/L]: Surface water: 96–112	direct sampling tandem mass spectrometry method for <i>semiquantitative</i> 6PPD-q determinations using CP-MIMS with a thin PDMS capillary hollow fiber membrane	LOD: 8 ng/mL
Seattle, Los Angeles, San Francisco (Tian et al. 2022)	Roadway runoff and roadway runoff-impacted receiving water samples were reanalyzed for 6PPD-q using a commercial standard. Concentrations were visually approximated from the boxplots provided in the publication.	The concentrations of 6PPD-q in stormwater were found to be [μ g/L]: Surface water (receiving water): approximately 0.02 to 0.3	UHPLC-MS with SPE	LOQ: 5.1 ng/L
Pearl River Delta, China (H.-Y. Zhang et al. 2023)	Surface runoff samples (courtyard [n=2], road [n=3], and farmland [n=2]) were collected in Dongguan and Huizhou across multiple events in 2015. Three Guangzhou WWTP influents and effluents were sampled in 2016. Surface-water samples from the Zhujiang (n=13) and Dongjiang (n=13) rivers were collected in 2015. Six samples were collected from a DWTP in Guangzhou in 2020. All samples were analyzed for 23 tire additives and their transformation products, including 6PPD-q and 6PPD.	The concentrations of 6PPD and 6PPD-q were found to be [median (range), ng/L]: 6PPD: Zhujiang River: 0.48 (0.31–1.07) Dongjiang River: 0.36 (0.27–1.29) 6PPD-q: Zhujiang River: 1.51 (0.26–11.3) Dongjiang River: 0.91 (0.29–8.12)	UHPLC-MS	6PPD: LOD: 0.04 ng/L LOQ: 0.12 ng/L 6PPD-q: LOD: 0.05 ng/L LOQ: 0.17 ng/L
Guangzhou, China (R. Zhang et al. 2023)	Surface-water (n=19), groundwater (n=43), and stormwater (n=10) samples were collected along the Liuxi River and analyzed for p-phenylenediamines, including 6PPD and 6PPD-q. Suspended particles from stormwater samples were also analyzed. As expected, 6PPD was only detected in the particle phase.	The concentrations of 6PPD and 6PPD-q were found to be [median (range), ng/L]: 6PPD: Surface water: ND 6PPD-q: Surface water: 0.18 (ND–0.75)	UHPLC-MS/MS	6PPD: MDL: 0.048 ng/L MQL: 0.160 ng/L 6PPD-q: MDL: 0.029 ng/L MQL: 0.098 ng/L
Seattle Area (Zhao et al. 2023)	Samples from roadway runoff (n=4; grab samples) and roadway-impacted creek water (n=5; composite samples) were collected and analyzed for 6PPD and 6PPD-q. Both compounds were detected in 100% of the samples. 6PPD measurements were considered semiquantitative given the compound's instability in water.	The concentrations of 6PPD and 6PPD-q in stormwater were found to be [mean \pm SD, ng/L]: 6PPD: Surface water: 99 \pm 64 6PPD-q: Surface water: 90 \pm 20	LC-MS/MS	6PPD: LOD—Creek: 3.3 ng/L LOQ—Creek: 4.9 ng/L LOD—Runoff: 2.4 ng/L LOQ—Runoff: 3.9 ng/L 6PPD-q: LOD—Creek: 1.2 ng/L LOQ—Creek: 3.1 ng/L LOD—Runoff: 2.1 ng/L LOQ—Runoff: 5.7 ng/L

Location	Information	Concentration (varies by study)	Lab Instrumentation	Detection Limit
Canada (Johannessen et al. 2022)	Archived extracts of surface-water composite samples originally collected in 2019 and 2020 from the Don River were analyzed for 6PPD-q. The composite samples consisted of 3-hour flow-weighted composites collected over 42 hours.	The concentrations of 6PPD-q were found to be [$\mu\text{g/L}$]: 42-hour composite sample: 2.30 ± 0.05 (maximum) 3-hour composites of one rain event: 0.93–2.85	HRMS-UPLC	LOQ: 0.0098 $\mu\text{g/L}$
Canada (Johannessen, Helm, and Metcalfe 2021)	Surface-water samples were collected from the Don River and Highland Creek during 2020 and included grab and composite samples. Samples were also collected upstream, downstream, and immediately below the effluent outfall of a WWTP. Samples were analyzed in triplicate for tire-related compounds, including 6PPD and 6PPD-q.	The concentrations of 6PPD and 6PPD-q were found to be [mean \pm SD, $\mu\text{g/L}$]: 6PPD: Surface water (grab samples): ND Surface water (composite samples): Not applicable 6PPD-q: Surface water (grab samples): 0.72 ± 0.26 (Highland Creek; maximum triplicate 0.91) and 0.54 ± 0.04 (Don River) Surface water (composite samples): 0.21 ± 0.02 (Highland Creek) and 0.11 ± 0.02 (Don River)	UHPLC-HRMS	6PPD: LOD: not reported LOQ: not reported 6PPD-q: LOD: not reported LOQ: 0.0065 $\mu\text{g/L}$
Michigan (Nedrich 2022)	The Michigan Department of Environment performed a preliminary investigation of 6PPD-q occurrence. Seventeen surface-water samples were collected in rivers or creeks adjacent to roadways, and five samples were collected from roadway puddles. Surface-water samples included two from known salmon spawning rivers and two from locations downstream of industrial crumb-rubber storage facilities. Samples were collected within 35 hours of a significant rain event. Two of the 17 surface-water samples had detections of 6PPD-q, whereas 100% of puddle samples had detectable levels of 6PPD-q.	The concentrations of 6PPD-q were found to be [range, ng/L]: Surface water: ND–37	LC-MS	MDL: 3 ng/L
Australia (Rauert, Charlton, et al. 2022)	Thirty-two surface-water grab samples were collected in a tributary to the Brisbane River during storm events in 2020 and analyzed for tire-related compounds, including 6PPD-q. 6PPD was not included in this study because of its instability. 6PPD-q was detected in 100% of the grab samples.	The concentrations of 6PPD-q were found to be [median (range), ng/L]: Surface water: 17.5 (0.38–88)	LC-MS/MS	MDL: 0.1 ng/L
Australia [Brisbane River] (Rauert, Vardy, et al. 2022)	Surface-water grab samples from 21 sites, including one marine and two estuary sites, were collected in 2021 in Queensland and Brisbane. Samples were analyzed for tire-related chemicals, including 6PPD-q. 6PPD was not included in this study. 6PPD-q was detected in 18 of the 21 sites.	The concentrations of 6PPD-q were found to be [range, ng/L]: Surface water: <0.05–24 Estuary: <0.05–0.28 (two sites) Marine water: 0.10 (one site)	LC-MS/MS	MDL: 0.05 ng/L
China [Jiaojiang River] (Zhu et al. 2024)	In October 2022, researchers collected paired surface-water (n=30) and sediment samples (n=30) from the Jiaojiang River in the southeastern region of China. The Jiaojiang River is the largest river in Taizhou City. Surface-water samples were collected from the top 5–25 cm, extracted, and tested for nine PPD and seven PPD-q. In surface water, 6PPD and 6PPD-q were more frequently detected than the other PPD and PPD-q congeners analyzed, with detection frequencies of 100% and 93%, respectively. Concentrations of 6PPD-q in surface water were significantly correlated with 6PPD in surface water ($r_s=0.78$; $p < 0.01$).	The concentrations of 6PPD and 6PPD-q were found to be [median (range), ng/L]: 6PPD: 10 (4.0–72) 6PPD-q: 6.1 (<LOD–21)	LC-MS/MS	LOD (ng/L) 6PPD: 0.038 6PPD-q: 0.017

Notes: $\mu\text{g/L}$ =micrograms per liter, CP-MIMS=condensed phase membrane introduction mass spectrometry, DWTP=drinking water treatment plant, HRMS-UPLC=high-resolution mass spectrometry–ultra-performance liquid chromatography, LC-MS=liquid chromatography / mass spectrometry, 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=non-detect, ng/L=nanograms per liter, PDMS=polydimethylsiloxane, PPD=para-phenylenediamines, PPD-q=para-phenylenediamines-quinones, SPE=solid-phase extraction, UHPLC-HRMS=ultra-high-performance liquid chromatography–high-resolution mass spectrometry, UHPLC-MS=ultra-high-performance liquid chromatography–mass spectrometry, UHPLC-MS/MS=ultra-high-performance liquid chromatography–tandem mass spectrometry, WWTP=wastewater treatment plant

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