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IMPACT OF LOW-SEVERITY WILDFIRE ON LARGE WATER BODIES: WATER QUALITY AND DISINFECTION BY-PRODUCT PRECURSORS

Habibullah UZUN*

Department of Environmental Engineering, Istanbul Technical University, Türkiye

Anahtar Kelimeler

Low-severity Fire, Water Quality, DBP, Chlorination, Chloramination.

Abstract

Most studies have focused on evaluating the impact of moderate-to-high-severity wildfires on various water quality (WQ) parameters in riverine systems. In contrast, this study investigates the effects of low-severity wildfires on selected WQ parameters and the formation potentials of selected disinfection by-products (DBPs) in a reservoir characterized by relatively low dissolved organic carbon (DOC) content in its water located downstream of a fire-impacted watershed. The results showed that post-fire initial flushes had a detrimental effect (i.e., increased turbidity [up to 150%], aromatic DOC [up to 98%], ammonia [up to 10 times] and reactive phosphorus [up to 113%], concentrations) in the headwater collecting the post-fire runoff across the burned watershed. The concentrations of DBP FPs (Trihalomethanes [THMs], haloacetic acids [HAAs] and Halonitromethanes [HANs]) were governed mainly by the DOC content of the water samples, except for N-nitrosodimethylamine (NDMA), regardless of the sample collection point. However, the impact of the fire was limited or had no effect on the water quality parameters at the drainage point of the reservoir, which was located on the opposite side of the headwaters. Moreover, the deterioration in the WQ of the headwaters significantly improved over 2-3 months, eventually reaching levels like those observed at the reservoir drainage point. Consequently, the findings of this study demonstrate that watersheds subjected to low-severity burns do not present significant or long-term water quality degradation in large downstream water bodies adjacent to the affected areas.

DÜŞÜK ŞİDDETLİ ORMAN YANGINLARININ BÜYÜK SU KÜTLELERİ ÜZERİNDEKİ ETKİSİ: SU KALİTESİ VE DEZENFEKSİYON YAN ÜRÜNÜ ÖNCÜLLERİ

Anahtar Kelimeler

Düşük şiddetli yangınlar, Su kalitesi, DYU, Klorlama, Kloraminleme.

Öz

Literatürdeki çalışmalar, orta ve yüksek şiddetli orman yangınlarının akarsu sistemlerindeki çeşitli su kalitesi (SQ) parametreleri üzerindeki etkilerini değerlendirmeye odaklanmıştır. Buna karşılık, bu çalışma, yangından etkilenmiş bir havzanın aşağısında bulunan, nispeten düşük çözünmüş organik karbon (ÇOK) içeriğine sahip bir rezervuarda, düşük şiddetli orman yangınlarının seçili SQ parametreleri ve belirli dezenfeksiyon yan ürünleri (DYU) oluşum potansiyelleri üzerindeki etkilerini incelemektedir. Sonuçlar, yangın sonrası ilk yüzey suyu akışlarının, yanmış su toplama havzası boyunca gelen yüzey akışını toplayan derelerde su kalitesine olumsuz etki yaptığını göstermiştir. Özellikle bulanıklık (%150'ye kadar), aromatik ÇOK (%98'e kadar), amonyak (10 kata kadar) ve reaktif fosfor (%113'e kadar) konsantrasyonlarında belirgin artışlar gözlemlenmiştir. Çalışmada değerlendirilen DBP oluşum potansiyellerinin (trihalometanlar [THM'ler], haloasetik asitler [HAA'lar] ve halonitrometanlar [HAN'lar]) konsantrasyonlarının, numune toplama noktalarından bağımsız olarak, temel olarak su numunelerinin ÇOK içeriği tarafından kontrol edildiği tespit edilmiştir. Ancak N-nitrosaminler (NDMA) için farklı bir eğilim gözlenmiştir. Bununla birlikte, düşük şiddetli yangının etkisinin rezervuarın çıkış noktasında sınırlı olduğu ya da SQ parametreleri üzerinde herhangi bir etkisinin olmadığı belirlenmiştir. Ayrıca, su kaynağındaki su kalitesinde meydana gelen bozulmanın, 2-3 ay içinde önemli ölçüde iyileşerek nihayetinde rezervuarın tahliye noktasında gözlemlenen seviyelere ulaştığı tespit edilmiştir. Sonuç olarak, bu çalışmanın bulguları, düşük şiddetli yangınlara maruz kalan su toplama havzalarının, su sağladığı büyük su kütleli su toplama göletlerinde önemli bir su kalitesi değişimine yol açmadığını göstermiştir.

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* İlgili Yazar/Corresponding Author: uzunh@itu.edu.tr, +90 541 370 7748

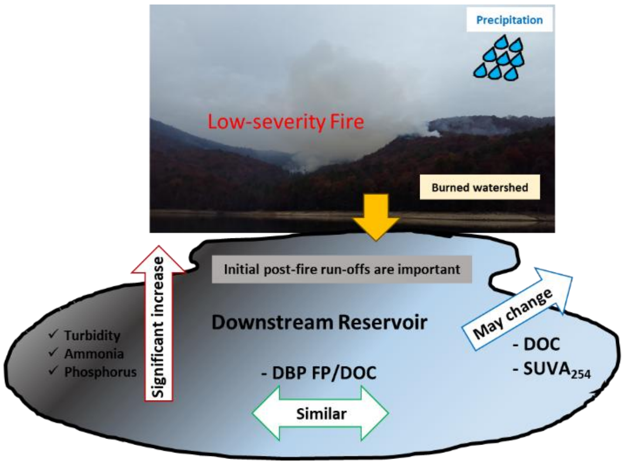
IMPACT OF LOW-SEVERITY WILDFIRE ON LARGE WATER BODIES: WATER QUALITY AND DISINFECTION BY-PRODUCT PRECURSORS

Habibullah UZUN †,
Department of Environmental Engineering, Istanbul Technical University, Türkiye

Highlights (At least three and a maximum of four sentences)

- Low-severity wildfires may affect water quality in streams, but the effects diminish quickly
- DOC mainly governs C-DBP precursor concentration fire-impacted water
- The release of ammonia, phosphorus and HAN precursors needs attention after wildfires
- Low-severity wildfires do not significantly affect water quality in large water reservoirs

Graphical Abstract (If applicable)



Purpose and Scope

The paper aims to enhance the understanding the responses of low-severity wildfires in large water bodies on water quality (WQ) and the precursors of DBPs.

Design/methodology/approach

The study effectively achieves its objectives by field sampling and laboratory analysis, considering both immediate and long-term impacts of water quality and DBP precursor concentration levels.

Findings

The findings suggest low-fire intensity fires may temporarily increase turbidity, DOC, ammonia and phosphorus in water bodies. However, such effects were short-lived and did not lead to a long-term deterioration of WQ in the larger reservoirs downstream. THMs, HAAs and HAN precursors are mainly driven by changes in DOC.

Research limitations/implications (if applicable)

Although the study contributed significantly to understanding the effects of low-severity fires on WQ and DBP precursors in large reservoirs, the results suggested further studies to improve knowledge in this critical field.

Practical implications (if applicable)

Research points to the need for adaptive water management practices, considering the temporary effects of low fire frequency on water quality.

Social Implications (if applicable)

This research can significantly impact society by shaping public attitudes toward fire management (i.e., prescribed [Rx] fires), informing policy decisions.

Originality

This paper provides new insights into the impacts of low-severity wildfires (LSWF) on WQ and DBP precursors`s concentration levels in large water bodies downstream. It gives valuable information to water managers, policymakers, and researchers.

† Corresponding author: uzunh@itu.edu.tr, +90 541 370 7748

1. Introduction

Forests cover over 30% of land worldwide (Perry et al., 1999; Shah et al., 2022). In addition to other benefits (i.e., biodiversity conservation, mitigating climate change, socioeconomic benefits), forested catchments, or forested watersheds, play a significant role in regulating water yield while maintaining its quality (Hampton et al., 2022; Matteo et al., 2006). Forest soil can filter pollutants, balance nutrient formation, and release from the system. Forested watersheds have been shown to reduce turbidity and suspended solids, nitrogen forms, and pathogens (Kalita and Harner, 1999; Mazumder et al., 2015; Singer and Brown, 2018). Consequently, keeping low turbidity and sediment and nutrient load can decrease the operational costs for water treatment. However, wildfires threaten forested catchments by altering land cover, hydrological balance and water quality (Chen and Chang, 2023; Hohner et al., 2019; Paul et al., 2022).

Wildfires can increase sediment transport and solids to nearby water sources. Additionally, wildfires can alter water quality (i.e., higher DOC, changing nitrogen balance, transport of PAHs, ash and mercury (Becker et al., 2018; Hohner et al., 2019; Ku et al., 2024; Rodríguez-Cardona et al., 2020; Uzun et al., 2020a), etc.) in streams impacted by wildfire. Furthermore, post-fire runoff events can enhance the transport of DBP precursors (THMs [Trihalomethanes], Haloacetic acids [HAAs], and haloacetonitriles [HANs]) from burned areas to regions downstream of the affected lands (Chen et al., 2021; Rodríguez et al., 2009; Uzun et al., 2020a). Such degradation can be more pronounced when the severity of fire is high, primarily due to loss of humus layer and ash formation during fires (McCullough et al., 2023; Schulze and Fischer, 2021).

Most studies examine wildfires' impact on water quality, and DBP precursors focus on moderate to high-severity fires, with samples collected from mostly river systems (Becker et al., 2018; Ferrer et al., 2021; Hauer and Spencer, 1998; Hickenbottom et al., 2023; Hohner et al., 2019, 2017, 2016; Uzun et al., 2020a; Writer et al., 2014). Consequently, to the best of my knowledge, research is needed about the effects of low-severity wildfires on both river systems and large water bodies that receive water from rivers flowing through affected areas. Therefore, the objectives of the study were (i) to evaluate the effect of low-severity wildfire on the post-fire runoff water (streams collecting runoff) and (ii) to assess the impact of runoff events on the water quality of a large reservoir located downstream of the burned areas.

Consequently, this study collected water samples from rivers and the large water bodies downstream following a low-severity wildfire that affected a part of the forested watershed—considering the limited and short-term detrimental impact of low-severity fires (i.e., prescribed (Rx) fires) on water quality (Battle and Golladay, 2003; Coates et al., 2017; Olivares et al., 2021, 2019; Orlova et al., 2020; Sakulich et al., 2022; Uzun et al., 2020; Wu et al., 2023). This study can guide water treatment plants, especially those using large water bodies as a source following low-intensity wildfires.

2. Materials and Methods

2.1. Wildfire Description. The study area is within the southern Appalachian Mountains, a physiographic province characterized by its remarkable biodiversity and vegetation (Lafon et al., 2017; Robbins et al., 2024). This area is characterized by a humid subtropical climate, receiving an average annual precipitation ranging from approximately 120 to 150 cm. This rainfall is relatively evenly distributed throughout the year, with peak amounts occurring in the spring and late summer (South Carolina Forestry Commission (SCFC), 2017; South Carolina State Climatology Office (SCSCO), 2017a). The elevation ranges from 300 to 1,000 meters above sea level, affecting orographic precipitation and resulting in complex hydrological patterns across the terrain (Reilly et al., 2022). In the early Fall of 2016, the combination of low humidity, strong winds, falling leaves, and abundant leaf litter created ideal conditions for the development of wildfires. On November 9, 2016, an escaped campfire became a wildfire called the Pinnacle Mountain Fire (Figure 1a). By November 12, the fire-affected area had exceeded 40 km². It continued to expand, ultimately encroaching upon Table Rock Reservoir—a primary drinking water source for one of the largest utilities in the southeastern United States (US). The authorities successfully contained the blaze on December 5, 2016 (SCFC, 2017). Following a post-fire assessment, it was observed that the areas affected by the fire were localized, influenced by varying wind directions and topographical features. Field observations and spatial analysis indicated that the fire predominantly exhibited low severity, primarily consuming surface litter and understory vegetation, while most overstory canopies remained largely unaffected (Lafon et al., 2017; Reilly et al., 2022). In areas subjected to more severe burning, there was a marked reduction in live vegetative cover and dead organic layers, particularly on exposed ridges and south-facing slopes, where fire intensity was locally intensified. In contrast, moist coves and north-facing slopes retained a significant amount of pre-fire litter and shrub structure. The burn coverage within the watershed was heterogeneous: approximately 70–80% of the northern watershed and 40–50% ([fire-affected area]/[total area] × 100) of the southern portion were burned, resulting in an average watershed burn coverage of 61%. This affected a 19 km² area, which experienced low-severity burning within the 31 km² watershed (Figure 2a)(Lafon et al., 2017; Reilly et al., 2022; Robbins et al., 2024; South Carolina Forestry Commission (SCFC), 2017; Trickett, 2018).

2.2. Water Sample Collection and Reservoir Evaluation. Sampling sites were carefully selected to investigate the streams that supply the reservoir and traverse regions impacted by wildfire. This methodology facilitates the comparison of water quality at the reservoir's opposite end, where the intake location of drinking water was operated. Therefore, three sampling locations were determined (Figure 2a) to assess the effects of the Pinnacle Mountain Fire on the reservoir's water quality. Following the containment of the fire, water samples were collected for six months from the mixing point of the reservoir, with two main headwaters (the South Saluda River [SSR] and Slicking Creek [SC]) receiving water from tributaries traversing the burned watershed. Coordinates of sampling points and the long-term flow conditions of streams are as follows: SSR: 35°03'41.3"N; 82°42'06.8" W (mean flow:1.03 m^3/s) and SC: 35°03'58.9"N: 82°41'51.1"W (mean flow: 0.34 m^3/s). In addition, another set of water samples was collected from the outlet of the reservoir (35°03'54.4"N 82°40'20.8" W), where the intake construction of the utility is located (Plant Intake [PI]). Water Evaluation and Planning (WEAP) software was used for watershed evaluation (Figure 1b). According to the assessment, the reservoir covers an area of approximately 40 km^2, reaches a depth of 38 m, and holds up to 36 million m^3 of water. Considering the headwater's average mean flows and the reservoir volume and neglecting all other hydrological factors, this reservoir can be filled by these two headwaters for 6–8 months.

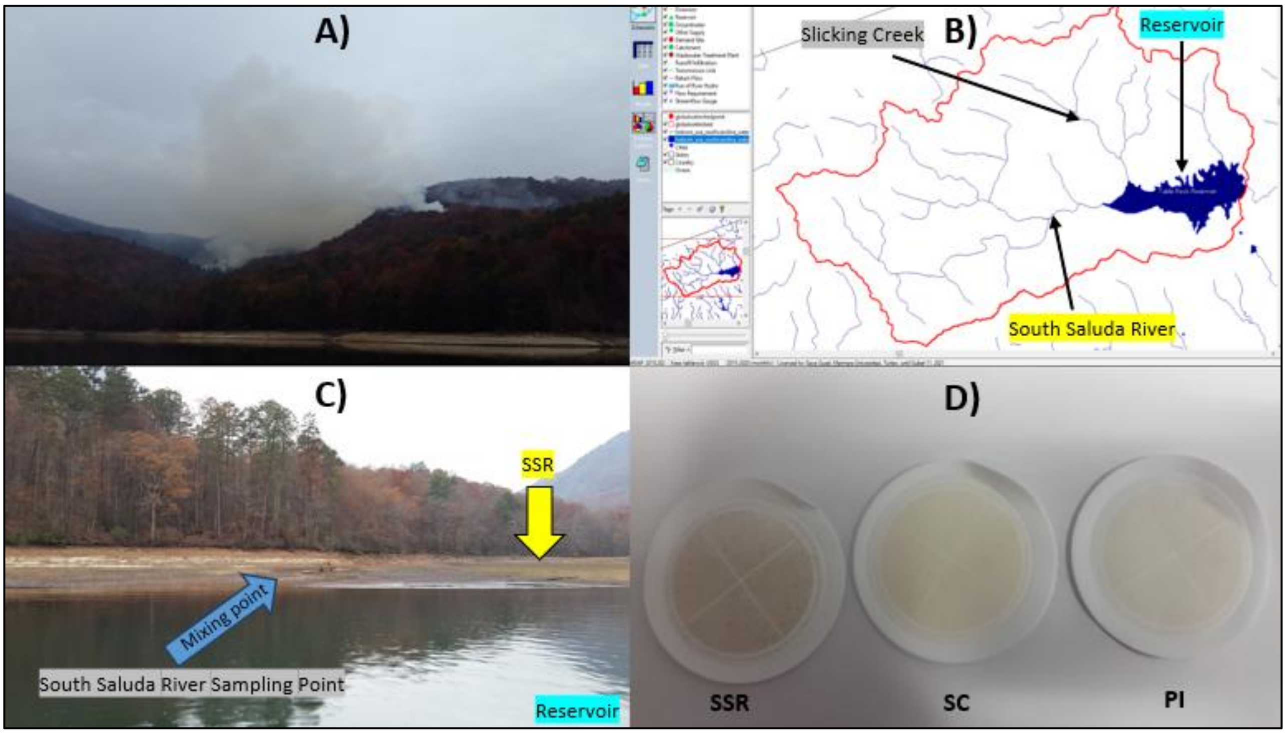


Figure 1. Image of the Watershed during a Fire Event (a), Image of the Reservoir Generated by Water Evaluation and Planning (WEAP) Software) (b) The sample collection point of South Saluda River (SSR) (c) and 0.45 µm PES filters were used to process initial flush samples obtained from SSR, Slicking Creek (SC) and Plant Intake (PI) (d).

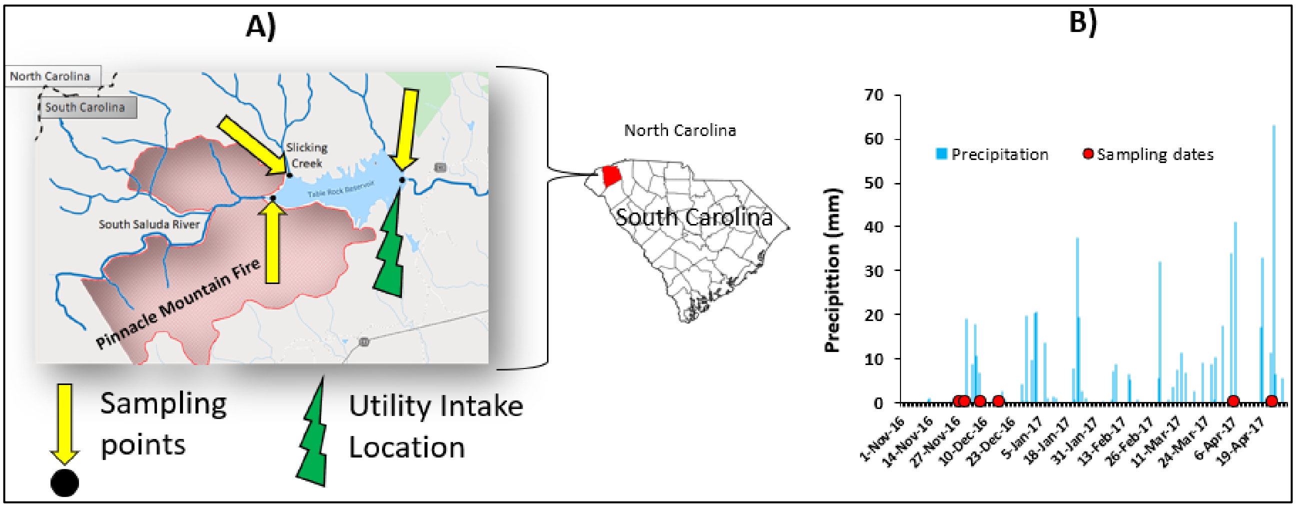


Figure 2. Pinnacle Mountain Fire boundaries (demarcated by reddish-colored areas) and location of Table Rock Reservoir South Carolina Map (a), and daily precipitation recorded in the area after the fire event and sampling dates (b).

The impact of the fire at the designated sampling points was compared with water samples collected (November 28, 2016) from the same sampling points (non-impacted reference samples under base-flow conditions) before the first major post-fire storm event. Recently, Uzun and colleagues (2020) indicated that wildfires could generate more aromatic and mobile organic carbon, which drained from burned areas for a relatively short period (<1 year), and that initial flushes are critical for evaluating such water quality changes in fire-impacted water sources. Therefore, grab water samples were collected over six months, encompassing the consecutive winter and spring seasons of 2016-2017. The total precipitation in the region was 2, 92, 137, 29, 116, and 213 mm in November 2016, December 2016, January 2017, February 2017, and March and April 2017, respectively (Figure 2b)(National Weather Service (NWS), 2017b). Samples were collected via boat (please refer to Figure 1c for a representative image of the SSR sample collection site) from pre-determined points after five rainfall events (three initial flushes [December 1, 8, and 17, 2016] and two delayed flushes [April 6 and 24, 2017]) in addition to base flow samples (Figure 2b)(National Weather Service (NWS), 2017b).

2.3. Water Quality Analysis. Duplicate grab water samples were collected in 1000 mL of pre-washed amber glass bottles and delivered to the laboratory in an ice-filled cooler. Immediately after arrival in the laboratory, samples were filtered with 0.45 µm polyethersulfone (PES) membranes (please refer to Figure 1d for illustrative example an illustrative image of PES filters after filtration of initial flushes from selected sampling locations) (all membranes were cleaned by passing ≥500 mL of distilled and deionized water [DDW] before use) except turbidity samples and stored in the refrigerator below 4 ºC in the dark until analysis and then, selected water quality (WQ) parameters: turbidity, conductivity, apparent color, pH, reactive phosphorus, dissolved organic carbon (DOC), and specific ultraviolet absorbance ($SUVA_{254,}$ which is used to describe the aromaticity of dissolved organic matter [DOM] were calculated using the following formula: $UV_{254}/DOC \times 100$ [L/mg-m]), total nitrogen [DN], inorganic nitrogen forms [ammonia, nitrate, nitrite], and dissolved organic nitrogen [DON][calculated]). All these WQ parameters, bromide ion and selected elements were quantified by using the same methods that have already been published elsewhere (Majidzadeh et al., 2020, 2019a, 2019b, 2017; Olivares et al., 2021; Uzun et al., 2019, 2018). Dissolved organic nitrogen (DON) was calculated using the following formula: DN - (Ammonia-N + Nitrate-N + Nitrite-N), and only the samples were used where DON/DN was ≥40% (Lee and Westerhoff, 2005; Majidzadeh et al., 2020, 2017; Ruecker et al., 2017; Uzun et al., 2019).

2.4. DBP Formation Potential (FP) Tests. Formation potentials of selected disinfection by-products (DBP FPs) (regulated carbonaceous [C-DBPs]: THMs and HAAs, unregulated DBPs: haloacetonitriles [HANs], and N-nitrosodimethylamine [NDMA]) were determined for each sample as described in our previously published studies elsewhere (Chen et al., 2023; Majidzadeh et al., 2017; Olivares et al., 2021; Uzun et al., 2017, 2015). C-DBPs were quantified following excess chlorine addition, while nitrogenous-DBPs (N-DBPs) and THMs were quantified after excess chloramine addition to the 0.45 µm PES membrane-filtered samples. After a pre-determined oxidation period, the residual oxidants in the samples were quenched with slightly more ascorbic acid than the stoichiometric amount needed. Then, liquid-liquid extractions were performed following USEPA method 552.2 and USEPA method 551.1 for HAAs and other volatile DBPs, respectively. Subsequently, the DBPs were quantified using an Agilent GC-ECD. To analyze NDMAs, a predetermined amount of sodium thiosulfate ($Na_2S_2O_3$) (slightly higher than the $Na_2S_2O_3/NH_2Cl$ molar ratio of 4:1) was added to the samples to quench residual chloramine. After quenching, the samples were subjected to a solid phase extraction (SPE) process following the USEPA Method 521. Subsequently, an Agilent GC-MS/MS system was used to measure and quantify the target DBP.

3. Results and Discussions

3.1 Release of Suspended Solids and Aromatic Carbon. Before the rainy season after the fire (baseline or reference water [RW] sample), the turbidity and apparent color values at all sampling sites were ≤1.7 NTU and ≤30 Pt-Co (Figure 3a). Because SC was collecting water from mostly unburned or slightly burned portions of the watershed, the effect of fire was limited (turbidity = 2.2 NTU and color 45 Pt-Co) compared to PI (turbidity = 1.6 NTU and color 39 Pt-Co) and RW samples. However, the impact of fire was apparent in the SSR samples, which drain water from more extensively burned areas. During the first post-fire flush, higher values were measured in the SSR samples (turbidity = 4.8 NTU and color 71 Pt-Co). These higher values show that the first post-fire surface runoff started the release of more suspended eroded particles from the barren soils of the burned areas. This finding was consistent with those of other fire studies that showed substantial flushing of sediments during the first storm events following wildfires in riverine systems (Hohner et al., 2019; Paul et al., 2022; Raoelison et al., 2023; Tran et al., 2021). Nevertheless, these parameters did not show significant alterations during the later flushes at any sample collection point, and the low-severity fire (LSWF) did not significantly affect the water quality of the large reservoir located downstream of the fire-affected river.

In the RW sample, DOC concentrations were comparable in all samples (1.55±0.05 mg/L, Figure 3b). As with the solid releasing trends, the SSR sample had a 55% higher DOC content with 40% higher aromaticity during the first post-fire runoff. Except for the third flush (January 17, 2017), DOC concentrations and $SUVA_{254}$ values were not significantly different in any sample (SSR, SC vs. PI or SW) during the later flushes. This could be related to the delayed transport of DOC from the fire-impacted parts of the watershed. These observations confirm that fires can increase the release of more aromatic pyrogenic DOC (PyC), but this effect diminishes rapidly depending on the severity of the fire and hydrological conditions (Hickenbottom et al., 2023; Hohner et al., 2016; Li et al., 2023; Uzun et al., 2020a). The higher aromaticity in SSR water during the first flush of sampling may be related to the formation of newly generated aromatic/hydrophobic compounds during a fire (Jin et al., 2023; Kieta et al., 2023), the rapid removal of such compounds by erosion/leaching processes, or the mobilization of carbon pools in the system. This might be related to increased soil erosion, primarily due to the reduction of vegetation cover and alterations in soil composition (Girona-García, 2024). It is known that the movement of pyrogenic carbon (PyC) through erosion and leaching is important for spreading carbon across landscapes. This also affects how these new aromatic compounds move into water systems (Abney and Berhe, 2018). As this study does not aim to investigate aromatic PyC compounds directly, their presence can only be inferred through specific indicators such as turbidity and $SUVA_{254}$. Consequently, the findings suggest that the effects of low-severity wildfires diminished over time due to dilution within a large reservoir.

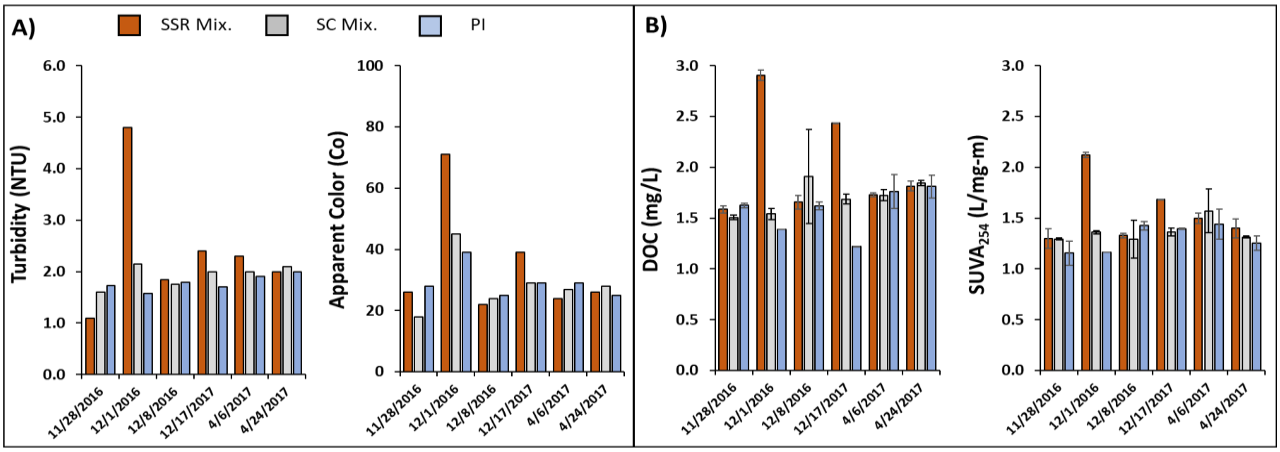


Figure 3. Changes in turbidity and apparent color (a), DOC and $SUVA_{254}$ (b) in SSR, SC, and PI point samples. Samples collected on 11/28, 2016, were used as a Reference Water (RW). The samples' turbidity and apparent color values were measured only once to conserve water for further DBP and WQ analysis, preventing standard deviation calculation.

3.2. Nitrogen Forms and Phosphorus. Studies have shown that DN and DON concentrations can decrease ash- and fire-affected soil leachates. This decrease can be attributed to several factors associated with the chemical and physical alterations in soils post-fire. These alterations include changes in soil pH (Buts et al., 2023), nutrient availability (Agbeshie et al., 2022), and the presence of adsorptive materials such as charcoal and ash (Faridullah et al., 2017; Fernandez-Marcos, 2022), which can influence the leaching behavior of nitrogen compounds. The interaction of these factors diminishes the leachability of nitrogen, resulting in lower DN and DON concentrations in soil leachates. However, other studies have reported higher DN, DON, and NH_4^+ concentrations in stream water following wildfires (Bladon et al., 2008; Hickenbottom et al., 2023; Paul et al., 2022; Rodríguez et al., 2009; Uzun et al., 2020). In this study, TDN concentrations were comparable (0.19-0.23 ±0.04 mg/L) (Figure 4a) and consisted of DON (DON/DN ratio was 0.64-0.77 mg/mg) in RW samples (DON =0.12-0.17 mg/L) (Figure 4a and b). Concentrations of other inorganic nitrogen were also comparable (nitrate [NO_3^- = 0.03 ±0.01 mg/L as nitrogen] and nitrite [NO_2^- =0.005 ±0.001 mg/L as nitrogen]) (data not shown), showing similar nitrogen content in RW samples. As shown in previous studies, the DON/DN ratio decreased due to an increase in organic nitrogen concentration in samples (Näthe et al., 2018; Rodríguez-Cardona et al., 2020); in this study, the higher DON concentration was observed during the initial flush, exclusively in SSR samples. However, there was no clear trend in the content of DON during the later flushes. Similarly, during the post-fire initial flushes, the DN value (0.41 mg/L vs. 0.19 mg/L and 0.18 mg/L for SSR, SC and PI, respectively) increased significantly; however, this was primarily due to a substantial increase in ammonia-N concentration in SSR samples only (0.18 vs. 0.015 and 0.010 mg/L for SSR, SC and PI, respectively) (Figure 4c) rather than DON change. Nonetheless, the effect of fire on the different forms of nitrogen diminished rapidly and the nitrogen content of the samples was comparable, with a couple of exceptions in all samples during later flushes. These results further confirm that NH_4^+ accumulates in ashy materials following fires, is quickly mobilized, and is transported via surface run-off/erosion (Bladon et al., 2008; Paul et al., 2022; Raoelison et al., 2023; Uzun et al., 2020). In addition, DON concentration was comparable in RW samples (0.12-0.17 mg/L). Therefore, nitrogen content can increase due to ammonia in fire-impacted waters. However, the degree of increase and its effect are related to the severity of the fire. Finally, concentrations of reactive phosphorus exhibited an increase exceeding 100% during initial flushes (Figure 4d) exclusively in SSR samples, indicating that fire events can facilitate phosphorus release during post-fire runoff (Emelko et al., 2016; Ijaz et al., 2022; McCullough et al., 2023). Due to the evidence of the rise in ammonia and reactive phosphorus during post-fire runoff, possible algal blooms and oxygen depletion may impact aquatic life and water quality (Bertani et al., 2016; Ho and Michalak, 2017). Therefore, it is essential to understand these dynamics to create efficient water management plans, particularly after high-severity wildfires impact water sources.

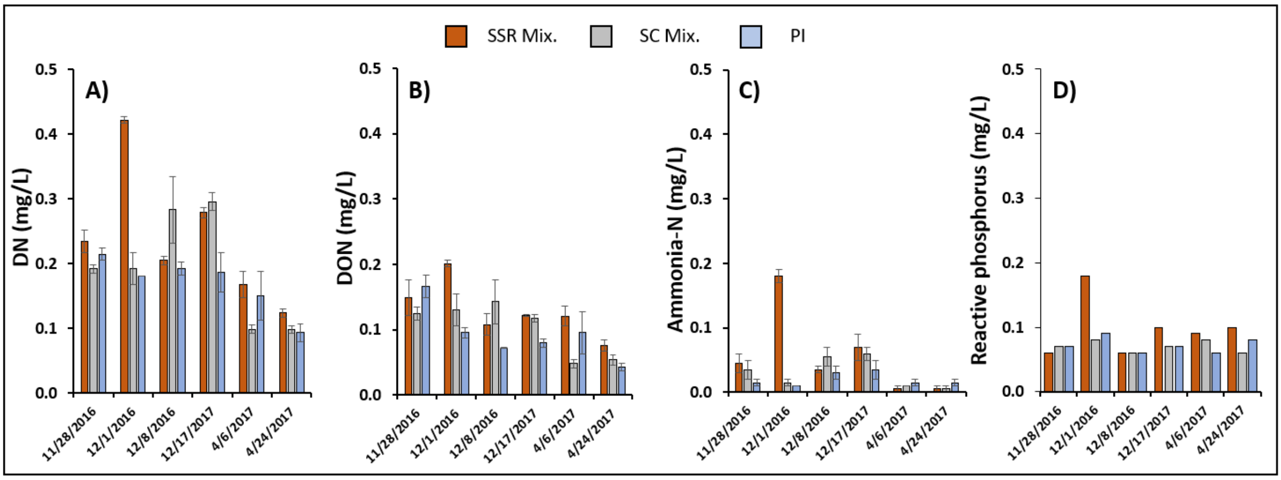


Figure 4. Changes in TDN (a), DON (b), ammonia as N (c) and reactive phosphorus (d) in SSR, SC, and PI point samples. Samples collected on 11/28, 2016, were used as a RW.

3.3. Regulated emerging DBP FPs under Chlorination and Chloramination. THM FP and HAA FPs were investigated under chlorination conditions. The results showed that THM and HAA precursor concentrations were 49, 46, and 51 µg/L and 38, 41, and 44 µg/L SSR, SC, and PI, respectively. The average THM and HAA concentrations in the SC and PI samples were comparable during the first flush. However, the SSR samples had higher average THM and HAA FP values (102 and 97 µg/L, respectively) (Figure 5a and b). THM FP and HAA FP values were not significantly different in any sample (*p>0.05*) (SSR, SC vs. PI or SW) during the later flushes except for the third flush. Furthermore, DOC vs. THM FP and HAA FP correlations were strongly positive ($R^2 \geq 0.7$), particularly in SSR samples (data not shown). Therefore, increased THM FP and HAA FP were associated with higher DOC concentrations in the SSR samples. DOC normalized concentrations were calculated to examine the reactivity of DBP precursors per unit of carbon (Figure 5c and d). The results showed that the carbon-normalized average reactivity and variability of the THM and HAA precursors were within a similar range for all samples except for the third flush. As shown previously, this can be related to the delayed transport of DOC from more extensively burned areas. These data are consistent with earlier studies showing that low to medium-severity wildfires do not significantly affect the carbon-normalized reactivity of C-DBP precursors. Therefore, the increase in THM and HAA precursor concentrations was due to the enhanced mobility of DOC, particularly during the first post-fire runoff event (Hickenbottom et al., 2023; Hohner et al., 2016; Uzun et al., 2020; Writer et al., 2014).

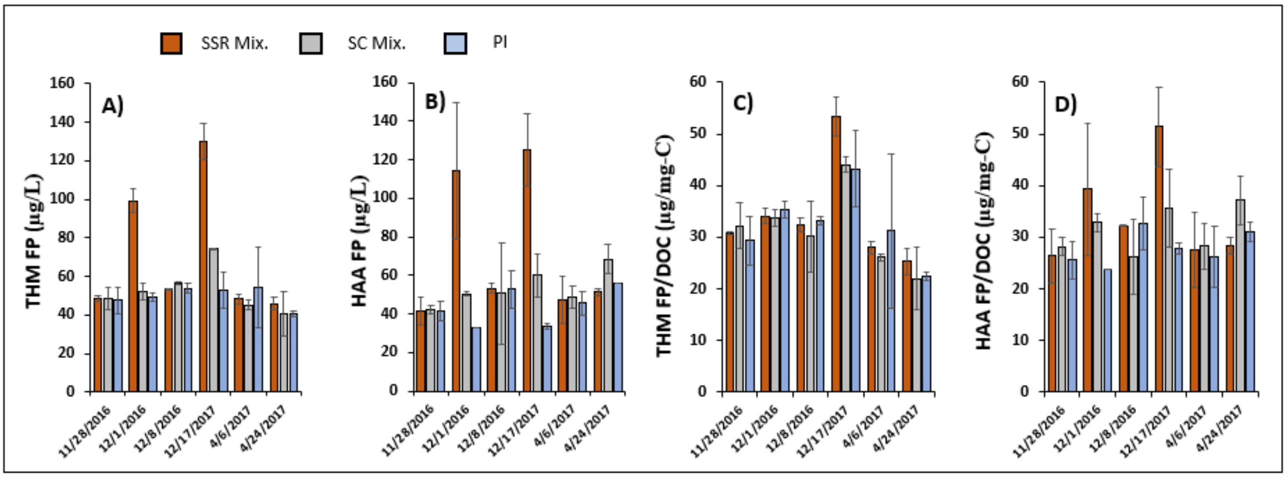


Figure 5. Changes in regulated DBPs (THM FP [a] and HAA FP [b]) and carbon-normalized THM FPs (c) and THM FPs (d) values for SSR, SC and PI point samples under chlorination.

THMs FP, HANs FP and NDMA FPs were also investigated under chloramination conditions (Figure 6). In general, the results showed: i) the THM FP levels were significantly lower than the chlorination THM FP levels (chloramination THM FP/ chlorination THM FP were between 5-16 %), ii) the DOC concentration mainly governed the precursor concentration levels of THM FP and HANs (Figure 6a and b), and iii) carbon-normalized values were generally comparable for all types of tested DBPs (Figure 6d and e). Therefore, given the significantly lower THM FP, chloramination is a practical choice for treating fire-impacted waters. However, considering the possible formation of HANs and significantly higher cytotoxicity of HANs compared to THMs (Lau et al., 2020; Liu et al., 2022; Richardson et al., 2007; Wagner and Plewa, 2017). These findings suggest that when fire-impacted water undergoes treatment for potable use under chloramination conditions, further optimization of oxidation conditions may be needed to minimize HAN formation in treated waters (Chen et al., 2020).

A recently published study showed that NDMA FP levels could be higher in fire-impacted samples, and this increase may be explained by using anthropogenic fire suppressants during the fire (Uzun et al., 2020). Moreover, it is well known that NDMA FP does not correlate with DOC or DON (Uzun et al., 2015; Yang et al., 2015) and several known precursors are anthropogenically derived (Ruecker et al., 2017). In this study, NDMA FP values (Figure 6c) were comparable in all samples and did not correlate strongly with water quality parameters, including DOC and DON. This finding also proves that low-severity fires do not induce significant alterations in DBP precursors (Majidzadeh et al., 2015a, 2015b; Olivares et al., 2019; Uzun et al., 2020).

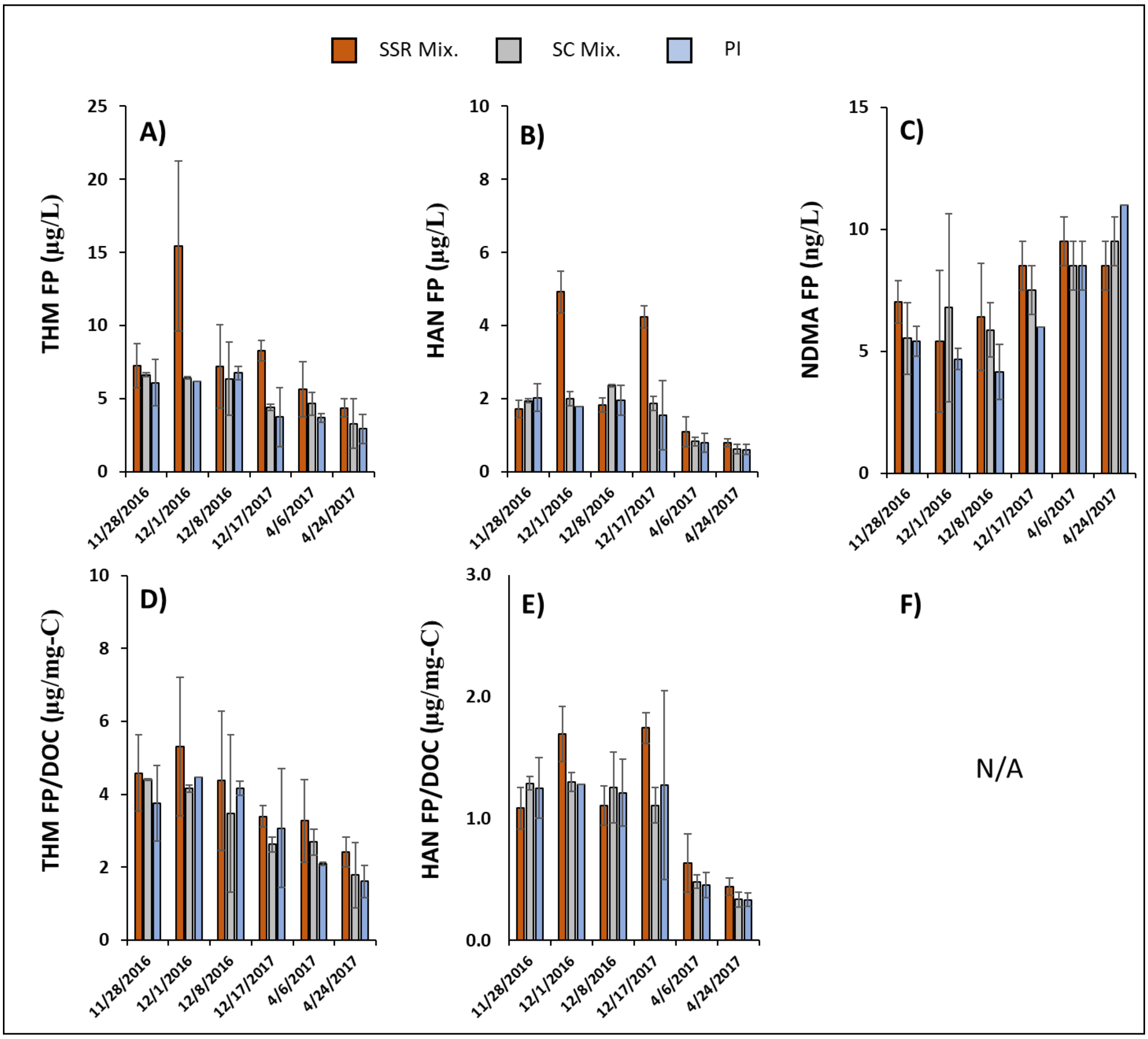


Figure 6. Changes in DBPs (THM FP [a] and HAN FP [b]), NDMA FP (c) and carbon-normalized THM FPs (d), HAN FPs (e) values for SSR, SC and PI point samples under chloramination. N/A= Not applicable.

4. Conclusion and Implications

Wildlife is among the most noteworthy events that can alter the water quality of forested watersheds. Increased fire severity and proportion of affected watersheds can adversely impact downstream aquatic ecosystems. Consequently, changes in water quality are a substantial concern for most water utilities. This study showed that LSWF can cause short-term increases in turbidity, DOC, ammonia and phosphorus levels in fire-impacted waters. Consequently, it can be inferred that there is a short-term risk of eutrophication due to promoted algae development and reduced light penetration in the lake (Ginger et al., 2017; Hauer and Spencer, 1998; Son et al., 2015; Wang et al., 2020). However, this depends on the lake's size and water temperature. Therefore, lake users must remain vigilant regarding the potential for algal proliferation, notoriously following the initial wet period of spring months. The study does not address sediment accumulation and the potential consequences of deposited sediments, as these aspects fall outside its scope. Nonetheless, the WQ results above can be ascribed to large water bodies capable of mitigating the detrimental effects of low-severity fires. Regarding DBP precursors, post-fire runoff can increase the concentration of THM, HAA, and HAN precursors, which are primarily governed by DOC changes with insignificant changes in DOC-normalized DBP FP values. Nevertheless, water utilities must be prepared for elevated levels of suspended solids, higher DOC, altered nitrogen forms, and treatability challenges if the proportion of burned watersheds is high and the severity of the fire is medium to high. Considering these observations and potential additional benefits of prescribed (Rx) fires (such as increased watershed resilience against wildfires, lower DOC and DN concentrations in source waters [Battle and Golladay, 2003; Clay et al., 2010; Coates et al., 2017; Olivares et al., 2021, 2019; Orlova et al., 2020; Uzun et al., 2020]), water utilities may consider implementing low-severity Rx fires to manage fuel accumulation in their watersheds without changing their water quality significantly.

Çıkar Çatışması (Conflict of Interest)

No conflict of interest was declared by the authors.

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