Environ Res Tec, Vol. 7, Issue. 2, pp. 233–255, June 2024

Environmental Research and Technology
https://ert.yildiz.edu.tr - https://dergipark.org.tr/tr/pub/ert
DOI: https://10.35208/ert.1383144

Review Article

Impact of dissolved organic nitrogen (DON) to the formation of disinfection byproducts (DBP) during water/wastewater treatment: A review

Ashik AHMED*[1], Sumaya TABASSUM[2], Debo Brata PAUL ARGHA[3], Pranta ROY[4]

[1]*Department of Nanoengineering, North Carolina A&T State University, Greensboro, North Carolina, USA*
[2]*Department of Water and Environment, Khulna University, Sher-E-Bangla Rd, Khulna, Bangladesh*
[3]*Department of Civil Engineering, Texas State University, Ingram School of Engineering, San Marcos, Texas USA*
[4]*Virginia Tech, Biological Systems Engineering, Blacksburg, Virginia, USA*

ARTICLE INFO

Article history
Received: 30 October 2023
Revised: 09 January 2024
Accepted: 05 February 2024

Key words:
DBPs mitigation; Disinfection byproducts (DBPs); Dissolved organic nitrogen (DON); DBPs precursors; Wastewater treatment

ABSTRACT

Disinfection byproduct (DBP) formation during water and wastewater treatment is a concern for public health and environmental preservation. Dissolved organic nitrogen (DON) serves as a recognized precursor to DBP formation, which can potentially jeopardize human health. This review article offers a comprehensive insight into DON's influence on DBP formation during water and wastewater treatment processes. It delves into DON's sources, properties, and concentrations in water and wastewater, underlining the variability dependent on water source and environmental conditions. The mechanisms of DBP formation from DON, encompassing formation pathways and influencing factors, are meticulously examined. Different treatment methods, like chlorination, ozonation, and UV disinfection, are carefully examined to see how they affect the formation of DON and DBP. Factors that sway DON's impact on DBP formation are also explored. The review also presents various DBP reduction techniques, spanning physical, chemical, and biological treatment methods, their efficacy in curtailing DON's influence, and their potential pros and cons. It addresses challenges, outlines future research directions, identifies knowledge gaps, and highlights the necessity for regulatory measures and policies, providing recommendations for prospective research avenues. It is clear from this in-depth review that more research is needed to understand how DON affects the formation of DBP entirely. It is also essential to protect human health and the environment and follow the rules first when treating wastewater. In conclusion, it analyzes DON's part in forming DBP in water and wastewater treatment. This emphasizes the need for ongoing research and mitigation strategies to protect public health and water quality.

Cite this article as: Ashik Ahmed, Sumaya Tabassum, Debo Brata Paul Argha, Pranta Roy. Impact of dissolved organic nitrogen (DON) to the formation of disinfection byproducts (DBP) during water/wastewater treatment: A review. Environ Res Tec 2024;7(2)233–255.

INTRODUCTION

Water is an indispensable and precious resource for human survival, and safeguarding its availability and quality is of utmost significance. Wastewater treatment is a pivotal measure in ensuring responsible water resource management. It effectively treats domestic, industrial, and municipal wastewater before it is released into the environment or reused for various applications [1]. Disinfection, as a vital step in the wastewater treatment process, is aimed at neutralizing or eliminating harmful microorganisms that may pose potential health hazards to human populations, animals, such as fish, amphibians, and aquatic invertebrates, can be adversely affected by exposure to disinfection compounds in water [2, 3].

***Corresponding author.**
*E-mail address: mahmed1@aggies.ncat.edu

Published by Yıldız Technical University Press, İstanbul, Türkiye

Water/wastewater disinfection is commonly accomplished using chemical or physical techniques, such as chlorination, ozonation, UV radiation, and other advanced oxidation processes [4–7]. These methods effectively eliminate or deactivate microorganisms, which helps reduce the spread of waterborne diseases and safeguard public health [4, 8]. However, one drawback is that disinfection can trigger reactions between disinfectants and organic matter in wastewater, forming DBPs [9].

DBPs encompass various chemical compounds that can arise from chemical reactions between disinfectants and organic matter in wastewater [10]. Examples of DBPs include trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), N-nitrosodimethylamine (NDMA), nitrosamines, aldehydes, and other halogenated and organic compounds [11]. DBPs have been recognized as potential carcinogens and mutagens, prompting concerns about their health risks to humans and the environment when present in treated water or wastewater.

Wastewater treatment plants (WWTPs) typically use chlorine or ultraviolet (UV) light for final disinfection before discharging treated wastewater. Research on the formation of DBPs in treated wastewater has involved various methods such as gas chromatography/mass spectrometry (GC/MS) for identifying unknown DBPs [12], target-compound analyses for specific known DBPs [13], and bulk parameters like total organic halogen (TOX) [14]. The types and amounts of DBPs formed from organic matter in wastewater effluent depend on factors such as the level of wastewater treatment and concentrations of ammonia (NH3) and DON [13, 15]. Well-nitrified WWTP effluents with low ammonia concentration (<0.5 mg/L as N) tend to produce large amounts of THMs, while poorly nitrified effluents (e.g., NH3–N >5 mg/L) generally inhibit THM production [16]. Chlorination (oxidation) of amino acids can result in the formation of aldehydes and nitriles, with subsequent chlorine substitution forming chloral hydrate (trichloroacetaldehyde) and dichloroacetonitrile [17]. Chlorinated wastewater from an extended aeration treatment plant has been found to produce chloroform, dichloroacetonitrile, and chloral hydrate at specific concentration levels (0.032–0.080, 0.007–0.014, and 0.020–0.038 mg/L respectively) [17]. Higher chlorine doses can destroy the aromatic ring and the formation of chloral hydrate and HAAs [16].

Certain methods exhibit varying degrees of effectiveness in treating DON in drinking water sources. Jar tests involving natural organic matter fractions showed the least removal (~10%) for hydrophobic neutrals, while hydrophobic bases (~30%), hydrophilic bases (~35%), and hydrophilic neutrals (~50%) demonstrated improved but still lower removal rates compared to fulvic (70%) or humic (80%) acids [18]. Alum coagulation in an Australian river achieved moderate DON removal for hydrophobic acid fractions (~50%), hydrophilic acid fractions (64%), and unfractionated material (~64%), but no removal for the neutral fraction [19]. Biofiltration holds the potential to either remove or generate DON in drinking water sources [20]. Powdered activated carbon has the capacity to eliminate up to 72% of DON, while the sole study employing the emerging metal organic framework adsorbent for DON removal demonstrated a 98.1% removal efficiency [21, 22].

Recently, DON, which refers to the portion of organic nitrogen that remains in solution after removing particulate organic nitrogen during wastewater treatment, has gained recognition as a significant factor in forming DBPs. A substantial portion of DON, up to 85%, is found in treated wastewater effluent [23]. This DON comprises various compounds such as proteins, amino acids, and humic substances, although a significant portion, approximately 50%, remains unidentified and uncharacterized [23]. DON can originate from diverse sources, such as human and animal waste, agricultural runoff, and industrial discharges [24], and its concentration in wastewater can vary depending on the composition of the wastewater and treatment processes employed [9, 25].

The presence of DON in wastewater can have noteworthy implications for DBP formation during disinfection [26]. The mechanisms by which DON influences DBP formation are intricate and may involve multiple pathways, including the formation of nitrogenous disinfection byproducts (N-DBPs), as well as interactions with other organic and inorganic constituents of effluent organic matters [27, 28]. The influence of DON on the formation of DBPs during wastewater treatment is an increasingly essential and researched area due to its potential impacts on water quality, human health, and environmental protection. A thorough understanding of the underlying mechanisms and factors that affect the role of DON in DBP formation is essential for optimizing disinfection processes and ensuring the safety of treated wastewater [29].

Hence, this review presents a comprehensive summary of the current knowledge on how DON affects the formation of DBPs during water/wastewater treatment. This review will explore the mechanisms through which DON impacts DBP formation, the factors that influence these mechanisms, and the strategies that can be utilized to mitigate DBP formation. Additionally, any gaps in knowledge and research needs in this field will be highlighted, and the regulatory and policy implications of the relationship between DON and DBPs will be discussed.

DISINFECTION BYPRODUCTS: HIDDEN THREAT IN WATER/WASTEWATER TREATMENT

Disinfection byproducts can silently jeopardize the effectiveness of wastewater treatment processes, as they can be generated during the disinfection stage and have the potential to impact water quality negatively. Various factors, such as the level of wastewater treatment, concentrations of ammonia and DON, and the amount of chlorine used, can all influence the formation of DBPs [30–32]. Therefore, it is essential to carefully manage and monitor DBP formation to guarantee the safety and quality of treated wastewater before it is discharged into the environment. By implementing effective strategies to minimize DBP formation, wastewater treatment plants can help protect the environment and pub-

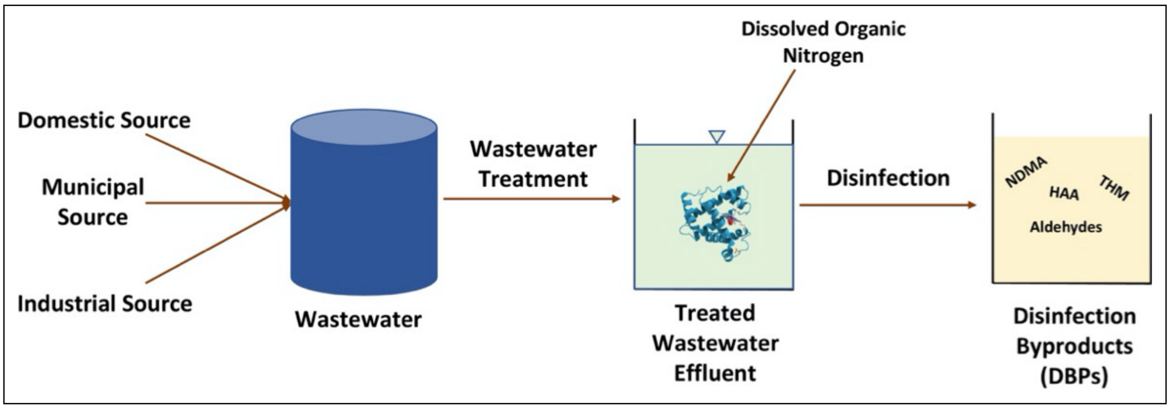


Figure 1. DBP formation in wastewater treatment and disinfection with DON presence.

lic health [28, 29]. The general procedure of DBP formation from wastewater through treatment and disinfection in the presence of DON is illustrated in Figure 1 [30–33].

Types and Properties of DBPs

DBPs can be classified into various types based on their chemical composition, including THMs, HAAs, HANs, NDMA, chlorate, chlorite, bromate, and among others [34–36]. Figure 2 represents the chemical formula of the different readily formed DBPs during disinfection. THMs can be produced during chlorination, chloramination, and ozonation, followed by chlorination [37]. Similarly, HAAs can form during chlorination and chloramination processes. NDMA can be formed through reactions between nitrogen-containing precursors, such as dimethylamine (DMA), and disinfectants, particularly chloramines (formed by the reaction of chlorine with ammonia) [38, 39]. Chlorite (ClO_2^-) and chlorate (ClO_3^-) can be produced during disinfection processes that involve the use of chlorine-based disinfectants, such as chlorine gas (Cl_2), sodium hypochlorite (NaClO), or chlorine dioxide (ClO_2) [40, 41]. Bromate (BrO_3^-) can be produced during disinfection processes that involve the use of bromide (Br-) ions and an oxidizing agent, such as ozone (O_3) or chlorine-based disinfectants, particularly in waters with high bromide concentrations [42, 43].

DBPs encompass several properties, including solubility, volatility, stability, reactivity, and toxicity, collectively contributing to their potential impact on water quality and human health. The solubility of DBPs can exhibit variability, with some being volatile and prone to evaporation from water due to low solubility, while others may possess a higher solubility and persist in water for longer durations. The stability of DBPs can also vary, ranging from relatively stable compounds to those that degrade or transform into other substances over time [44]. Furthermore, DBPs can display differing reactivity, influencing their interactions with other chemical compounds in water and the environment. Toxicity is another significant property of DBPs, as some may be associated with potential carcinogenic and adverse reproductive effects [10, 40]. It is important to note that the properties of DBPs can be influenced by various factors, such as the type and concentration of disinfectants used, water quality parameters, and environmental conditions[45].

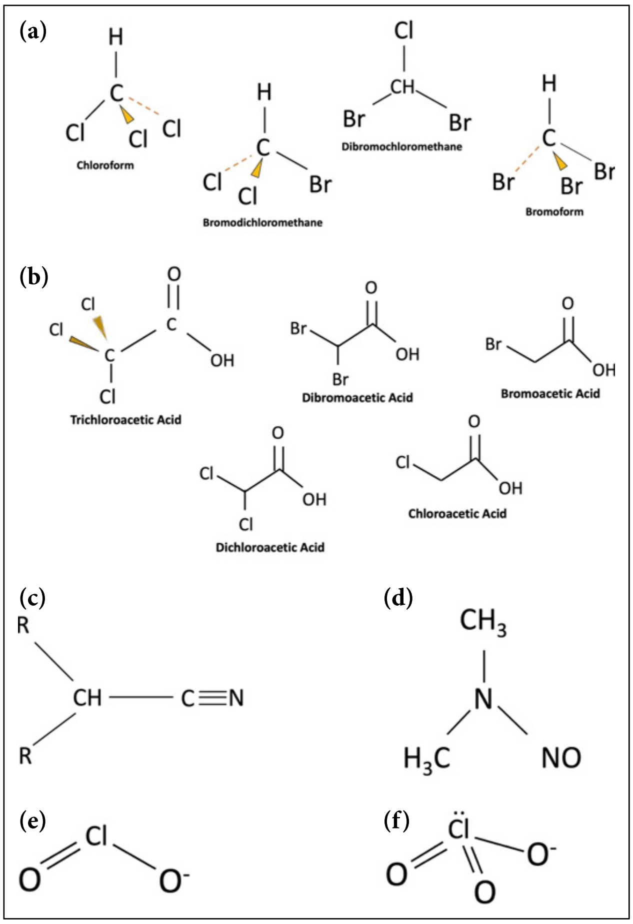


Figure 2. Chemical formula of the different types of DBPs; **(a)** THMs, **(b)** HAAs, **(c)** HANs, **(d)** NDMA, **(e)** chlorite **(f)** chlorate.

Formation Mechanisms of DBPs

Trihalomethane Formation

Trihalomethane formation is a chemical process that occurs during water disinfection when halogen-based disinfectants, such as chlorine, react with organic matter present in water. Chlorination involves oxidation and substitution [46]. Oxidized organic compounds are formed when chlorine reacts with organic matter [47]. In the substitution reaction, chlorine replaces hydrogen atoms in organic matter to form chlorinated organic compounds [48]. Chlorine further reacts with water to form chlorine radicals ($Cl^\bullet$), which react with organic matter to form halogenated organic compounds [49]. This step usually limits trihalomethane formation. The most common THMs are chloroform ($CHCl_3$), bromodichloromethane ($CHCl_2Br$), dibromochloromethane ($CHClBr_2$), and bromoform ($CHBr_3$) [50–52].

Haloacetic Acid Formation

Figure 3 represents the formation mechanisms of HAAs. Through chlorination and chloramination, haloorganic intermediate compounds are formed. The haloorganic intermediates can further react with chlorine or chloramines to form haloacetic acid intermediates through halogenation reactions. The haloacetic acid intermediates can then undergo hydrolysis or oxidation reactions to form HAAs as the final product [53].

Haloacetonitriles Formation

HANs can be formed by the presence of organic nitrogen compounds and through the Cl_2 and NH_2Cl disinfection processes [54]. Chlorine or chloramines can react with the organic nitrogen to form N-chloramines. The produced N-chloroamines can undergo hydrolysis, which involves the addition of water molecules, resulting in the formation of N-chloroimine. The N-chloroimine species can further react with other organic nitrogen compounds in the wastewater effluent, such as amino acids or other organic matter, through nucleophilic substitution or addition or rearrangement reactions, resulting in the formation of HANs [53, 54].

N-nitrosodimethylamine (NDMA) Formation

Dimethylamine (DMA) and amide are two common organic nitrogen compounds found in water, that can undergo nitrosation. Nitrite ions (NO_2^-) react with DMA to form NDMA as an intermediate and nitrosation of amide can form N-Nitrosamide intermediates [55]. N-Nitrosamine intermediates, formed through nitrosation of DMA or amides, can undergo dimethylation, where dimethylating agents, such as formaldehyde (HCHO) or other methylating agents, react with the intermediates to form NDMA [55]. Figure 4 shows the formation mechanisms of NDMA.

Chlorite and Chlorate Formation

Chlorite (ClO_2^-) and chlorate (ClO_3^-) formation can occur during water disinfection processes that involve the use of Cl_2 or NH2Cl [56]. Chlorine can react with natural organic matter (NOM) or other precursors in water, leading to the formation of chlorite through a series of oxidation reactions [57]. Chlorine can also oxidize chloride ions (Cl^-) in water to form hypochlorite (ClO^-), and further oxidation of hypochlorite can result in the formation of chlorate [57]. The specific mechanisms and pathways of chlorite and chlorate formation can vary depending on pH, temperature, and chlorine dosage.

Bromate Formation

Bromate (BrO_3^-) formation is involved with the use of O_3 for disinfection. O_3 reacts with bromide ions (Br^-) in water to form bromate through a series of oxidation reactions [43]. The formation of bromate is highly dependent on factors such as pH, temperature, ozone dosage, and bromide ion concentration [58].

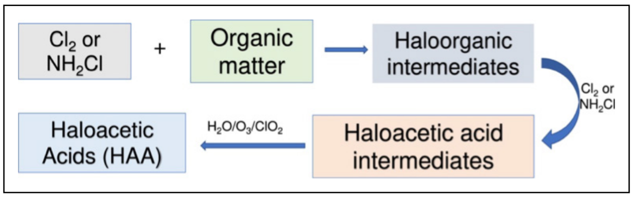


Figure 3. Formation mechanisms of the HAAs.

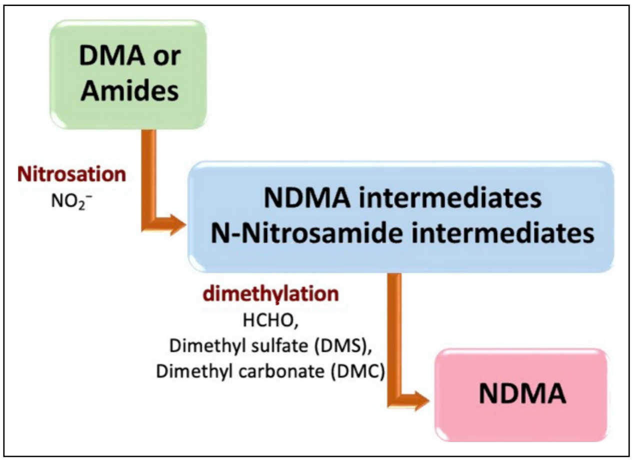


Figure 4. NDMA formation mechanisms.

$$\text{Br-} \xrightarrow{O_3} \text{HBrO or BrO-} \xrightarrow{O_3} BrO_3^- \quad [59]$$

Or,

$$\text{Br-} \xrightarrow{\cdot OH} \text{HBrO or BrO-} \xrightarrow{\cdot OH} BrO_3^- \quad [59]$$

Challenges in Controlling DBPs

Controlling DBPs poses several challenges due to their diverse nature and the complexities associated with their formation and control. Some of the specific challenges for controlling DBPs include formation variability, multiple DBP types, changing regulations, treatment trade-offs, cost implications, monitoring and optimization, public awareness, and communication, etc. DBP has a complex and multifaceted nature. Several factors, such as the type and concentration of disinfectants, water quality parameters, and environmental conditions, make it challenging to predict and mitigate the formation of specific DBPs [60]. Besides, reducing disinfectant dosages or changing disinfection methods, may have trade-offs with other treatment goals, such as pathogen removal or other water quality parameters. Balancing DBP control with other treatment objectives can be challenging.

The factors such as temperature, pH, and chlorine dosage make the DBP control more challenging. The concentrations of regulated DBPs can vary significantly in household tap water due to changes in water temperature [61]. Specifically, when water is heated for bathing or spa use at higher temperatures (e.g., 35–50 °C), there can be a rapid increase in the levels of THMs and HAAs within 0.5 h [62]. This highlights the potential for significant fluctuations in DBP levels in tap water in response to changes in water temperature, which may have implications for human exposure to these contaminants. Chuang et al. [28] stated that the concentrations of chloroform are 0.028, 0.057, 0.128, 0.171, and 0.304 mg/L for 4, 15, 25, 35, and 50 °C, respectively. He also found a similar pattern for dichloroacetic acid and trichloroacetic acid also got higher DBP concentrations when the temperature changes from 10 to 25 °C [63]. It is hard to control the DBPs with these varying concentrations for different temperatures.

The formation of chlorine DBPs is known to be influenced by pH, as most chlorine reactions are pH dependent. Lower, more acidic pH conditions typically result in less chloroform formation, with a corresponding increase in the concentration of HAAs [64]. This trend of reduced chloroform formation with decreasing pH was also observed in a study by Özbelge [65], where hypochlorite was adjusted to pH 4, 7, and 10 and added to resorcinol in different ratios. No chloroform was formed at pH 4, and a 1:3 ratio, but at pH 7 and 10, 50% and 95% of the resorcinol were converted to chloroform, respectively [65]. With varying pH, different controlling measures need to be taken to control DBPs.

Potential Effects on Human Health

Human exposure to DBPs can occur through three main pathways: dermal contact, ingestion, or inhalation [66, 67]. Several epidemiological studies have demonstrated associations between DBP exposure and increased risks of cancer development, liver and kidney defects, central nervous system issues, adverse reproductive outcomes, and endocrine disruption, causing concern for human health in areas where DBPs are present in drinking water [68–70]. Consistently linked to chlorination DBPs as one of the health risks associated with DBP exposure is urinary bladder cancer [70–73]. Another study discovered a potential association between high concentrations of DBPs and increased risks of colon and rectal cancer, especially with individual DBPs such as THMs and HAAs, with the most consistent association observed for rectal cancer. To better comprehend these associations, additional research is required [73].

Emerging DBPs formed in distribution systems during chlorination and chloramination, such as THMs, HAAs, and HANs, have been reported to cause symptoms related to liver, kidney, and nervous system diseases. Unregulated DBPs have been associated with spontaneous abortions, congenital disabilities, stillbirths, and other negative reproductive effects [74]. Recent research has focused on maternal exposure to emerging DBPs during pregnancy, particularly THMs and dichloroacetic acid, and some DNA anomalies have been observed in cord blood, leading to foetal growth restriction or other adverse reproductive outcomes [75–78]. Emerging DBPs may also be classified as carcinogenic substances or have other detrimental effects on human health, such as alterations in pregnancy duration, menstrual cycle, pregnancy loss, foetal development, and congenital malformations, as well as cancer risks, as reported in various studies [79–81].

According to López-Roldán et al. [82], the risk of developing cancer or diseases from ingesting THMs is higher compared to the risk from inhalation during showering or dermal exposure [83]. This highlights the significant danger posed to human health by drinking water contaminated with DBPs, particularly THMs and HAAs. The risks may be higher when the raw water source is surface water, but they may be lower when it is a mix of surface water and groundwater, or solely groundwater.

I-aldehydes, cyanides, halonitromethanes, haloketones, haloacetamides, iodinated-DBPs, and N-nitrosamines are just some of the DBPs that have been the subject of recent studies. Andersson et al., Chaukura et al., and Chen et al. [84–86] all report that these DBPs are more cytotoxic, genotoxic, and mutagenic than their brominated and chlorinated counterparts, suggesting they pose serious health risks. The N-nitrosamine NDMA (N-nitrosodimethylamine) has been the focus of much attention because even trace amounts (ng/L) have been linked to a 10-fold higher risk of cancer over a lifetime. Among the N-nitrosamines, NDMA (N-nitrosodimethylamine) has garnered significant attention due to its presence in drinking water at low levels of ng/L, which has been associated with a lifetime excess cancer risk of 10^{-6}.

DON: A KEY PLAYER IN DBP FORMATION

DON has been identified as a key player in the formation of DBPs such as THMs, HAAs, HANs, and NDMA in water treatment systems [87]. DON is a complex mixture of organic compounds that can originate from various sources, such as natural organic matter, wastewater, and agricultural runoff. During water treatment processes, disinfectants, such as chlorine, can react with DON, leading to the formation of DBPs, including THMs, HAAs, and other classes of DBPs. Amino acids, nitrogen-containing heterocyclic compounds found in nucleic acids (e.g., cytosine), cells of algae, and extracellular organic matter have been proposed as potential precursors for halogenated acetonitriles (HANs) when they react with chlorine or chloramines. This suggestion is supported by studies conducted by [63, 88, 89].

When free chlorine is present in organic fractions with a high concentration of DON, dichloroacetonitrile (DCAN) is more likely to form at higher concentrations, as reported by Lee et al. and Dotson et al. [87, 90] and Yang et al. [91] show that during chloramination in natural waters, the relationship between DCAN and DON is not well established. According to a hypothesis by Yang et al. [91] DCAN can be formed during chloramination via the hydrolysis of N-chloroimine, which is generated via the direct incorporation of chloramines into diketone moieties of DOM. DCAN is positively correlated with SUVA in chlorinated natural waters [91], suggesting that aromatic content within DOM may be related to the formation of diketone moieties for HAN formation.

Oftentimes, N-DBPs like halonitromethanes (HNMs), N-nitrosamines (NAs), and halonitromethanes (HANs) have been found in chloraminated or chlorinated wastewater effluent at concentrations ranging from nanograms per liter to micrograms per liter [15, 92, 93]. Compared to other disinfection byproducts that are regulated, like THMs and HAAs, these N-DBPs have been found to be more toxic and to pose more health risks [11, 94, 95].

DON Sources in WWTP

DON in WWTPs comes from both the wastewater that is being treated and the microorganisms that are already present at the site. Low DON concentrations, between 3 and 7 mg/L, are typical in raw municipal wastewater [96, 97]. Carbamate and pyrimidine compounds are major contributors to DON in wastewater from industries producing pesticides, textiles, dairy, fertilizer, leather, and pharmaceuticals, with concentrations ranging from 12 to 71 mg/L [98]. A study found that pproximately 88–91% of the TDN in the wastewater generated by the yoghurt production industry comprises DON [99]. A notable origin of DON in wastewater is the use of agricultural fertilizer [20]. An additional research finding revealed that the leather industry contributes 111.5 mg/L of total nitrogen (TN) in wastewater, with a notable portion being attributed to DON [100]. Prior to discharge into municipal wastewater collection systems, DON levels can be reduced to around 10–15 mg/L through industrial wastewater treatment processes [98]. The breakdown of organic materials in the waste material field can also increase the concentration of DON in landfill leachate and coincide with the WWTP influent [94–99], which in turn can react with DBPs precursors in drinking water treatment processes, potentially increasing the formation of DBPs[101–103]. Therefore, DON from municipal waste can play a significant role in forming DBPs in potable water [104, 105].

Microbially derived DON (mDON) is another source of DON at WWTPs. It is found in soluble microbial products (SMP) released during cell metabolism and biomass decay [15, 106]. Lab-scale aerobic bioreactors treating synthetic organic wastewater with ammonium chloride as the sole nitrogen source have been shown to produce up to 3.45 mg/L of DON in the effluent [107]. mDON is largely made up of bioavailable substances for algae, such as proteins, enzymes, nucleic acids, amino acids, and fulvic acid-like substances [108]. There is no chemical difference between DON from the influent and mDON in domestic WWTPs. Recent research, however, has suggested that model predictions indicate mDON may account for nearly 50% of the effluent DON in the activated sludge process [109]. Figure 5 represents the various sources that can generate DON in wastewater system.

Characteristics and Properties of DON

DON's unique properties can contribute to DBP formation, making it an important component of wastewater and natural water systems. DON's varied properties make it a key player in DBP formation. DON can form nitrogenous DBPs, for instance. The composition and concentration of DON in water, disinfectants used, and environmental conditions can affect DON's unique ability to form DBP.

Figure 5. Some anthropogenic sources of DON in wastewater.

Studies from Bolyard and Reinhart and Liu et al. [110, 111] show that the bioavailability of DON is linked to its chemical properties. Effluent with a higher tryptophan to humic substances fluorescence ratio was found to have more bioavailable DON, which could promote algal growth, according to research by [111]. In addition, the bioavailability of effluent DON was shown to increase with molecular weight for DON molecules smaller than 1 KDa [107]. The varying bioavailability of DON in natural waters is likely due to differences in DON's chemical composition. Free amino acids [112–115], urea [116, 117], and nucleic acids [115, 116] are readily taken up by heterotrophic bacteria and/or marine and freshwater algae. The research of Carlsson and Granéli [118] shows that in N-limited systems, algae are less able to make use of humic substances and other forms of DON for growth. Photochemical reactions in natural waters may convert DON into more labile compounds like primary amines [119] or ammonia [120], although these reactions can also have a negative impact on the bioavailability of DON [120]. DON exhibits biodegradability over time, as evidenced by a study that observed variations in the biodegradation of DON among effluent samples from four examined plants before filtration. Specifically, a decline in DON was noted in prefiltration samples from two of the four plants, with these two plants experiencing a reduction of organic nitrogen ranging between one-quarter to one-third over a 20-day period [121].

As wastewater progresses through various treatment stages in a conventional biological nutrient removal (BNR) process, the concentration of DON typically decreases, with the majority of DON removal occurring in the anaerobic zone of the anaerobic/anoxic/oxic process [97]. In cases where the DON concentration in the influent is already low (between 1.1 and 3.9 mg/L), only a small amount of DON is removed during wastewater treatment, leaving concentrations of 0.5 to 1.3 mg/L in the effluent [122]. Studies by Sattayatewa et al. and Huo et al. [96, 97] show that the actual efficiency of DON removal can vary greatly between different wastewater treatment plants, from 30% to 90%. Furthermore, the composition of domestic wastewater typically consists of proteins, amino acids, and humic-like substances. However, in the effluent, the composition changes to include amino acids, EDTA, and specific proteins that are newly produced compounds, as reported in studies by [97, 123]. In addition, the low molecular weight dissolved organic nitrogen (LMW DON) concentration, which initially ranges from 4.2–4.4 mg/L, undergoes changes during treatment in the effluent, resulting in a range of 1.5–3.5 mg/L (LMW DON), accounting for 50–65% of the effluent DON [119, 120]. According to Huo et al. [97], more than 80% of the effluent DON are hydrophilic and these hydrophilic fractions are mostly bioavailable (almost 85% of the hydrophilic DON) [124, 125]. Secondary effluent DON is well-characterized, with abundant presence of proteins, amino acids, and EDTA [126], whereas DON in raw wastewater is poorly characterized. 60% of the DON in the effluent is made up of proteins, while only 13% is amino acids [126]. Huo et al. [97] also reported that between 50% and 66% of the total DON in WWTP effluent is made up of LMW compounds. Urea, amino acids, DNA, peptides, and synthetic nitrogenous compounds like pesticides and pharmaceuticals are all examples of LMW compounds. In contrast, Pagilla et al. [127] reported that fulvic acids, proteins, and humic acids make up the bulk of the HMW DON in the effluent.

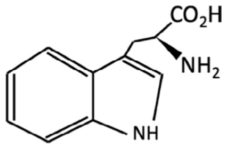
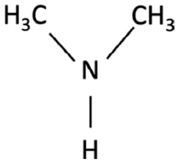
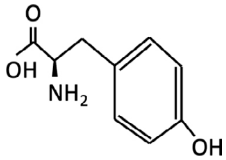
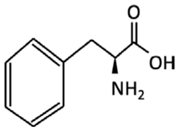
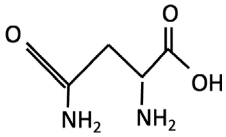
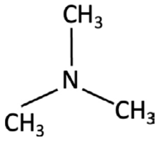
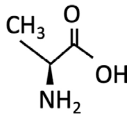
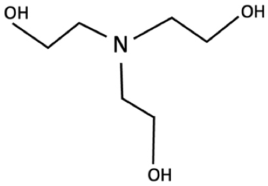
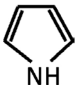
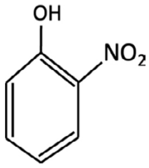
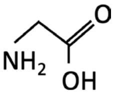
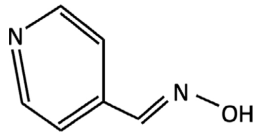
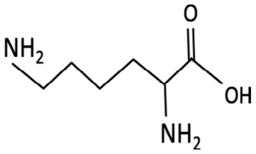
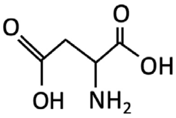
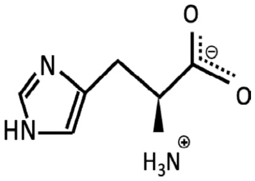
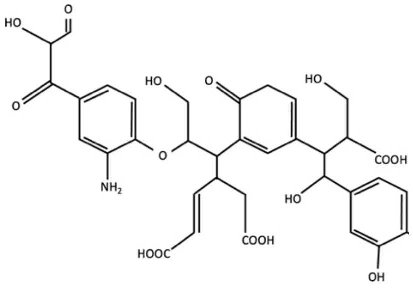
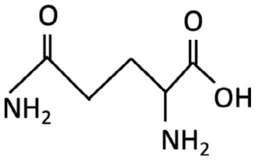
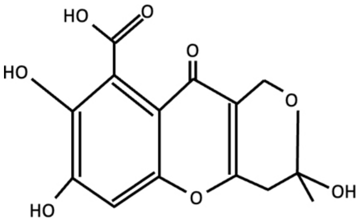
DON Species: Precursors of N-DBPs

N-DBPs were identified during the chlorination of natural water, which include haloacetonitriles, halonitromethanes, haloacetamides, and NDMA [128]. If excess disinfectants are added, the amount of N-DBP species formed can be used to estimate the formation potential of N-DBPs. This method neutralizes any residual chlorine or chloramine after disinfection reactions have concluded. After that, typical N-DBP species like dichloroacetonitrile and trichloronitromethane are extracted using liquid/liquid extraction (LLE) and analyzed using gas chromatography (GC) with electron capture detection. According to Hu et al. and Plumlee et al. [29, 129], the most frequently detected N-DBP is NDMA, which is concentrated using solid phase extraction (SPE) or LLE and measured using liquid chromatography-tandem mass spectrometry (LC-MS/MS) or GC coupled to an ion trap MS/MS. NDMA accounts for greater than 90% of the total proportion and can be found in wastewater effluent at concentrations greater than 0.0001 mg/L. Najm and Trussell [130] point out that the use of recycled water raises concerns due to the high levels of NDMA present in this water source. The formation of 2,2-dichloroacetamide is primarily attributed to amino acids such as aspartic acid, histidine, tyrosine, glutamine, asparagine, and phenylalanine [131]. Similarly, chloroacetonitrile is derived from nitriles, amino acids including tryptophan, tyrosine, asparagine, and alanine, as well as pyrrole, as reported by Yang et al. [132]. Trichloronitromethane shares similar amino acid precursors with chloroacetonitrile, including glycine [132]. On the other hand, NDMA is primarily formed from dimethylamine (DMA) and tertiary amines that contain DMA functional groups [133]. The formation of cyanogen chloride (CNCl), another type of N-DBP, is often attributed to the presence of glycine and fulvic/humic substances, as identified by [134]. Hydrophilic acids (HiA), hydrophilic bases (HiB), and hydrophobic acids (HoA) all have varying degrees of potential for dichloroacetamide (DCA) formation, but HiAs have the most [135]. DCA is most likely formed from protein-like substances made up of amino acids in the HiA fraction [135]. The amino acids aspartic acid, histidine, tyrosine, tryptophan, glutamine, asparagine, and phenylalanine are all candidates for DCA formation when exposed to chlorine [135]. The precursors capable of forming chloropicrin, with yield capacities ranging from 0.4% to 53%, include 2-nitrophenol, 3-nitrophenol, 4-pyridinealdoxime, trimethylamine, nitromethane, glycine, lysine, and triethanolamine [43, 136, 137]. Chlorination of certain free amino acids [138], heterocyclic nitrogen in nucleic acids [139], proteinaceous materials, and combined and bound amino acids in humic structures generates dihaloacetonitriles and other haloacetonitriles [140]. Table 1 shows the chemical structure of different precursor organic compounds. Compared to other naturally occurring organic compounds, the identified N-DBP precursors typically have a low molecular weight and electrostatic charge [53]. Because of this trait, common water treatment processes, such as coagulation, are ineffective against them. However, it is anticipated that many of these N-DBP precursors will be biodegradable, making them amenable to removal via nanofiltration [53].

IMPACTS OF DON ON DBP FORMATION

An extensive amount of literature has investigated the possible link between the transformation of DON in wastewater treatment plants and the formation of N-DBPs; this includes studies by Aitkenhead-Peterson et al. and Chang et al. [141, 142], among others. The proportion of amphiphilic bases to neutrals in DON has been found to be the most important factor in determining N-DBP formation potentials [143]. Tertiary amines with benzyl functional groups were also found to be associated with an increased likelihood of NDMA formation [144]. The majority of these analyses, however, have only looked at how DON and its N-DBP change before and after the disinfection process. According to research by Selbes et al. [145] and Ding et al. [54], N-DBPs can be roughly divided into two categories: non-halogenated N-DBPs (such as N-nitrosamines) and halogenated N-DBPs. According to previous studies, secondary amines are a major contributor to N-nitrosamine compounds formed during the chlorination process, especially NDMA, as demonstrated by [146]. Bond et al. [88] point out that the formation of halogenated N-DBPs is more complicated than that of non-halogenated ones. Another two study note that haloacetamides, halonitriles, and organic halamines have received a great deal of attention in the study of halogenated DON in wastewater [54, 147].

Table 1. Chemical structures of different DBPs precursors

Tryptophan		Dimethylamine	
Tyrosine		Phenylalanine	
Asparagine		Trimethylamine	
Alanine		Triethanolamine	
Pyrrole		2-nitrophenol	
Glycine		4-pyridinealdoxime	
Lysine		Aspartic acid	
Histidine		Humic acid	
Glutamine		Fulvic acid	

DON in Wastewater Treatment Produce DBP

The formation of N-DBPs from DOM is influenced by a number of DOM properties, including its nitrogen content, hydrophobicity, specific UV absorbance (SUVA), and molecular weight (MW) distribution. A study has shown that a lower ratio of DOC to DON in DOM indicates higher nitrogen contents in DOM, and thus a greater likelihood of the formation of N-DBPs like HANs, halonitromethanes (HNMs), and N-nitrosamines during chloramination [148]. Same study also shows that the LMW fractions of DOM with a size of less than 1 kDa tend to have a higher contribution to the formation of N-DBPs during chloramination compared to the high MW fractions (>3 kDa) [148]. Another study reports that hydrophilic DOM fractions have a higher propensity for the formation of HANs and N-nitrosamines than hydrophobic and transphilic DOM fractions [149]. However, they found that the hydrophobic fractions of DOM contribute more to the formation of HNMs during chloramination than the other fractions [149]. In addition to the natural organic matter in surface water, Chow et al. [150] notes that effluent organic matter from biological wastewater treatment plants can affect the formation of N-DBPs due to differences in physicochemical properties, such as molecular size distribution, and higher concentrations of DON (0.7–1.9 mg/L in effluent organic matter vs. a median value of 0.3 mg/L in NOM). Effluent organic matter contains a high concentration of microbially derived DON, which is rich in amines, peptides, and amino acids [151] and therefore has the potential to be converted into N-DBPs via chloramination [152]. It is expected that the yields of N-DBPs from reclaimed water will be greater than those from surface water in situations where wastewater is reused. This is because recycled water is chemically and physically distinct from surface water. In addition, organic matter from effluents is a major contributor to N-DBP precursors in drinking water supplies vulnerable to wastewater discharges [153].

Nitrosamines, halonitroalkanes, and nitriles are just some of the chemical compounds found in the N-DBPs [154]. The N-DBPs also have a wide range of $-NO_2$ and -CN derivatives. The genotoxicity of these chemicals toward mammalian cells is much higher than that of halogen-containing DBPs [155]. An increase in N-DBPs in drinking water supplies has been linked to increased contributions from wastewater discharge. This is why DON is getting so much interest in the wastewater treatment sector. DON is a precursor for the formation of carcinogenic N-DBPs during disinfection, making its presence in wastewater effluent significant in the context of indirect or direct potable wastewater reuse. Recent studies have highlighted the importance of determining the sources of N-DBPs in wastewater effluents, and have found that DON is a major precursor [143, 156]. The formation of N-DBPs can also be aided by organic nitrogen particulate matter in effluents, such as bacterial cells. To a greater extent than dissolved nitrogenous organic matter in secondary effluent, Chuang et al. [28] discovered that Gram-negative *Escherichia coli* and Gram-positive *Enterococcus faecalis* bacterial cells were capable of forming N-DBPs like dichloroacetonitrile, dichloroacetamide, and trichloroacetamide during chlorination.

Effect of DON on DBP Formation

Significant precursors to the formation of nitrogenous N-DBPs are thought to be DON compounds. Dichloroacetonitrile is one N-DBP that can be formed from DON; it is extremely toxic and has an LC50 value that is orders of magnitude higher than carbonaceous DBPs [157]. This indicates that highly toxic by-products may be present in water due to the formation of N-DBPs from DON during disinfection processes, highlighting the need for effective monitoring and mitigation strategies to ensure water safety. A study reports that several DBPs, including dichloroacetonitrile (DCAN), dsorbed organic chlorine (AOCl), and three nitrosamines (N-nitrosodibutylamine (NDBA), N-nitrosodiethylamine, and N-nitrosodipropylamine), were formed during the chlorination of mDON that accumulated during denitrification with various carbon sources and C/N ratios [158]. Sodium acetate as a carbon source and relatively high C/N ratios generally increased the formation potentials of NDBA, DCAN, and AOCl. This indicates that the formation of particular DBPs during the chlorination of mDON can be affected by the carbon source and C/N ratio used during denitrification. Upon chloramination, THMs, dichloroacetic acids, and dihaloacetonitrile originate from similar precursors, and HANs, HAAs, and THMs originate from similar structures within DOM [28]. Also, the precursor of HANs was only about 10% (on a molar basis) of that of THMs and HAAs [28]. DON/DOC in hydrophilic and transphilic fractions correlates with the potential for NDMA formation. The HAA showed a clear trend of increasing concentration only with storage time of long-term DBP changes across storage times (up to 20 days) and temperatures (5 to 20 °C) [159]. Chen et al. [160] took into account the effect of temperature and found that as the temperature was raised (from 250 to 600 °C), there was a decrease in the formation of the four DBP categories that were being studied (THMs, HAAs, HANs, and NDMA). Hua et al. [161] developed a model for the role of lignin phenols in NOM product DBP formation based on concentrations and DBP yields. Trichloroacetic acid is the most formed DBP, followed by dichloroacetic acid and chloroform in terms of the contribution of lignin phenols to the formation of DBP during chlorination. Trichloroacetic acid > dichloroacetic acid & DCAN > chloroform is the formation order of these DBPs due to the lignin phenols in the chloramination [161]. Table 2 shows some potential DBPs formation during the disinfection process by using chlorine, chloramines, chlorine dioxide, and the combined UV and chlorine due to the different complex structured emerging organic micropollutants (EOMPs). Industrial wastewater discharge, municipal sewage discharge, and agricultural runoff are all major contributors to EOMPs in aquatic environments. Toxins from pharmaceuticals and personal care products (PPCPs), endocrine-disrupting chemicals (EDCs), and brominated flame retardants (BFRs) are just a few examples [162].

Factors Influencing the Impact of DON on DBP Formation

The impact of DON on DBP formation can be influenced by several factors.

Concentration and Composition of DON

The concentration and composition of DON in water are key factors that can influence its impact on DBP formation. DON is a complex mixture of organic nitrogen-containing compounds. The concentration of DON in water can vary widely depending on the source of water, season, and oth-

Table 2. Different EOMPs with their chemical structures and the respective DBPs formation with the disinfection process

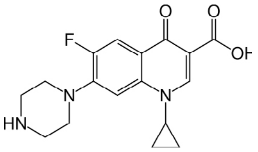
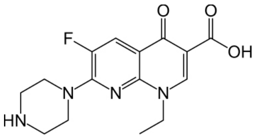
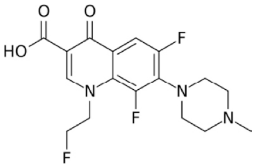
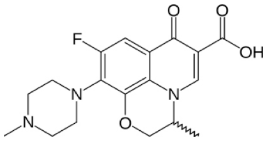
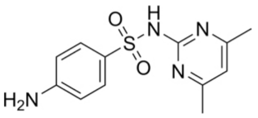
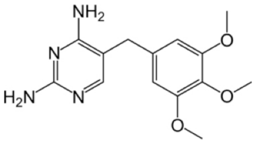
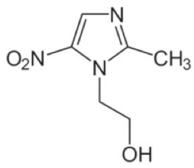
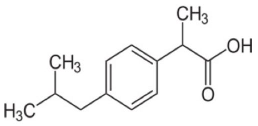
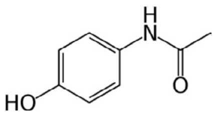
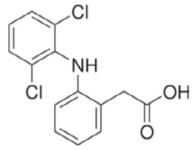
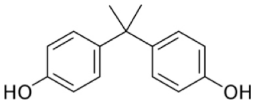
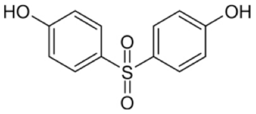
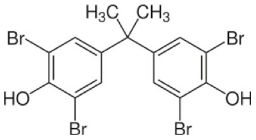
Different EOMPs (PPCPs, EDCs, BFRs)	**EOMP structure**	**Disinfectant use**	**Potential DBPs formation**	**Ref**
1. Ciprofloxacin		Chlorine	Antibiotic transformation products (TP305, TP262, TP262, TP290, TP292, TP 296, ETC.)	[163]
2. Enoxacin		Chlorine dioxide	THMs, HAAs, HANs, HKs (Haloketones), HAL (Haloacetaldehydes)	[164]
3. Fleroxacin		Chlorine or Chlorine dioxide	Haloacetonitriles, Trihalomethanes, Haloaceticacids	[165]
4. Ofloxacin		Chlorine	Antibiotic transformation products (TP305, TP262, TP262, TP290, TP292, TP 296, ETC.)	[73]
5. Sulfamethazine		Chlorine	Transformation products (TP305, TP262, TP292, TP 296, ETC.)	[166]
6. Trimethoprim		UV and Chlorine	Trichloromethane, Chloral hydrate, Dichloroacetonitrile, Trichloronitromethane	[167]
7. Metronidazole		Chloramine	Dichloroacetonitrile, Tricholoacetamide, Dicholoacetamide, Trichloromethane	[168]
8. Ibuprofen		UV and Chlorine	Trichloromethane, Chloral hydrate; 1,1-dichloro-2-propanone; 1,1,1-trichloropropanone; Dichloroacetic acid, Trichloroacetic acid	[169]
9. Acetaminophen/ Paracetamol		Chloramines	Trichloromethane, Dichloroacetonitrile, Dicholoacetamide, Tricholoacetamide	[54]
10. Diclofenac		Chlorine dioxide	Enhanced-hazardousness transformation products	[170]

Table 2 (cont). Different EOMPs with their chemical structures and the respective DBPs formation with the disinfection process

Different EOMPs (PPCPs, EDCs, BFRs)	EOMP structure	Disinfectant use	Potential DBPs formation	Ref
11. Bisphenol A		Chloramine	Halogenated bisphenol A, Trihalomethane, Haloaceticacids, Haloacetonitriles	[171]
12. Bisphenol S		Chlorine	Monochloro-, dichloro-, trichloro-, tetrachloro-bisphenol; biphenyl ether dimer and trimers	[172]
13. Tetrabromobisphenol A		Chlorine	Transformation products (TP305, TP262, TP292, TP 296, ETC.)	[173]

er environmental factors [174]. Higher concentrations of DON, as well as specific types of organic nitrogen-containing compounds, may increase the potential for DBP formation during disinfection processes. When using sludge alkaline fermentation liquid (SAFL) as the carbon source, the DON concentration in the effluent (1.52 mg/L DON) was higher when compared to when using sodium acetate (0.56 mg/L DON) [175]. However, compared to sodium acetate, SAFL resulted in effluent formation potentials that were 43% and 55% lower for dichloroacetonitrile (7.63 g/mg DON) and nitrosamines (1.57 g/mg DON), respectively. Alanine, glycine, and tyrosine were found to be important precursors to N-DBPs [175]. Protein- and lignin-like compounds made up the bulk of the DON molecules in the effluent [175].

Type and Dosage of Disinfectants

The type and dosage of disinfectants used during water treatment can significantly influence the formation of DBPs from DON. Different disinfectants, such as chlorine, chloramines, chlorine dioxide, and ozone, may react differently with DON and result in varying levels of DBP formation. For instance, chlorine is known to react with DON to form various DBPs, such as trihalomethanes and haloacetic acids, while chloramines can also react with DON to form nitrosamines, another type of DBP [37]. As an example, the amount of chlorine added to reclaimed water during the chlorination process can affect the production of chlorinated DBPs [176]. Slightly oxidized unsaturated aliphatic compounds and polycyclic aromatic compounds have been discovered to be produced during chlorination [177]. In addition, the proportion of polycyclic aromatic chlorinated DBPs with one chlorine atom and highly oxidized unsaturated aliphatic chlorinated DBPs with two chlorine atoms was found to increase with increasing chlorine dosage [177].

Co-occurring Water Constituents

Other naturally occurring water constituents, such as bromide, iodide, and NOM, are also capable of having an impact on the relationship between DON and DBP formation. For example, during the process of disinfection, bromide can react with chlorine to produce brominated DBPs [178]. These brominated DBPs, which include bromoform and bromodichloromethane, are known to have a higher level of toxicity in comparison to their chlorinated counterparts [178]. Bromoform and bromodichloromethane are both classified as Group 2B, possibly carcinogenic to humans [179]. Studies have shown that long-term exposure to elevated levels of bromoform and bromodichloromethane in drinking water may be associated with an increased risk of certain adverse health effects, including bladder cancer, reproductive and developmental effects, and liver and kidney damage [180]. The toxicity of bromoform and bromodichloromethane is primarily attributed to their potential to induce genotoxicity, oxidative stress, and disruption of cellular functions. These DBPs can bind to DNA and proteins, causing DNA damage and impairing cellular processes [181]. During the disinfection process, NOM, which is a complex mixture of organic compounds derived from decaying plant and animal materials, can interact with DON, and affect the formation of DBP. NOM is a byproduct of decomposition of plant and animal matter [182].

Water Treatment Processes

The specific water treatment processes employed, such as pre-oxidation, coagulation, and filtration, can also affect the impact of DON on DBP formation [183]. These processes can modify the concentration and composition of DON, as well as other water constituents, which can subsequently influence DBP formation during disinfection. For example, pre-oxidation processes, such as ozonation or chlorination, can alter the reactivity and characteristics of DON, affecting its potential to form DBPs during subsequent disinfection processes [184].

Reaction Time and Conditions

The reaction time and conditions during disinfection, including contact time, temperature, and pH, can impact the extent of DBP formation from DON. The reaction time refers to the duration for which the disinfectant and water are in contact during the disinfection process. Longer contact times can lead to increased DBP formation as more time allows for greater interaction between the disinfectant and organic or inorganic precursors in water [185]. For example, higher levels of THMs and HAAs have been observed with longer chlorine contact times during water treatment processes [186]. Higher temperatures can accelerate the rate of DBP formation as reactions are generally more rapid at elevated temperatures [187]. For instance, warm water used in hot tubs, spas, or showers can lead to higher levels of DBPs due to increased reaction rates. The pH of the water can also affect DBP formation, as some DBPs are more likely to form under acidic or basic conditions [187].

Water Quality Regulations

Water quality regulations play a significant role in managing DBP formation, including the impact of DON. Compliance with regulatory standards may necessitate adjustments in water treatment processes, disinfection practices, and monitoring strategies to mitigate DBP formation from DON. Regulatory guidelines, such as maximum contaminant levels (MCLs) established by regulatory agencies, dictate the permissible levels of DBPs in drinking water, and are typically based on extensive research and risk assessments to safeguard public health [188]. Ensuring compliance with these regulations may require utilities to implement additional treatment steps or optimize existing treatment processes to control DBP formation, including addressing the contribution of DON [189]. To prevent harmful effects on the environment, it is essential that industrial wastewater discharge standards do not include nitrogen species, especially when dealing with situations where DON levels are high. Strict compliance with regulations helps protect aquatic ecosystems, lessens the likelihood of eutrophication, and promotes ecological harmony in the receiving environment. Hence, understanding and adhering to water quality regulations are critical factors in effectively managing DBP formation, including the role of DON, in drinking water supplies [190].

DBP MITIGATION TECHNIQUES FOR WASTEWATER TREATMENT

DBP mitigation is important due to the potential health risks associated with DBPs, such as carcinogenicity, genotoxicity, and reproductive and developmental effects. Compliance with regulatory standards for DBP levels in drinking water is necessary to ensure the safety of the water supply and protect public health. Different countries have different regulatory standards for DBPs [191]. For example, the maximum allowable limits for THMs, HAAs, bromate, and inorganic DBPs are 0.08, 0.06, 0.01, and 1 mg/L respectively whereas there has no set limit for NDMA [27]. Therefore, effective DBP mitigation strategies are essential in wastewater treatment to reduce the formation of DBPs and ensure compliance with regulatory requirements.

Techniques for DBP Control

Physical treatment methods are employed to decrease the formation of DBPs in wastewater by physically removing or altering wastewater constituents. Sedimentation [192], filtration [193], and membrane processes [194] are some examples of physical treatment techniques. Sedimentation facilitates the settling of suspended particles in wastewater, reducing the availability of precursor materials for DBP formation [192]. Filtration, on the other hand, involves passing wastewater through filters to remove particulate matter, organic matter, and other contaminants that can contribute to DBP formation [193]. Membrane processes utilize semipermeable membranes to selectively eliminate particles, dissolved substances, and microorganisms from wastewater [194].

Chemical treatment methods involve the utilization of chemicals to modify or eliminate DBP precursors in wastewater. Coagulation [195], oxidation [196], and advanced oxidation processes [197] are examples of chemical treatment techniques. Coagulation entails the addition of chemicals that form flocs, aiding in the removal of suspended particles and dissolved organic matter from wastewater [195]. Oxidation processes employ chemicals like chlorine or ozone to oxidize DBP precursors, reducing their reactivity toward DBP formation [198]. Advanced oxidation processes, such as UV irradiation in combination with hydrogen peroxide, generate highly reactive hydroxyl radicals that can effectively degrade DBP precursors [191, 199].

Biological treatment methods, on the other hand, employ microorganisms to transform or remove DBP precursors in wastewater. Activated sludge processes [200], biofiltration [201], and biological nutrient removal [202], are examples of biological treatment techniques. Activated sludge processes utilize microorganisms in the presence of oxygen to biodegrade organic matter and remove it from wastewater. Biofiltration involves the use of microorganisms attached to a solid support medium to biologically degrade organic matter [201]. Biological nutrient removal processes use microorganisms to remove nutrients, such as nitrogen and phosphorus, from wastewater, which can also indirectly reduce DBP formation by limiting the availability of DBP precursors [203].

Effectiveness of Physical, Chemical, and Biological Treatments in Reducing the Impact of DON on DBP Formation

The effectiveness of these treatments in mitigating the impact of DON on DBP formation is contingent upon several factors, including the specific treatment technique employed, the characteristics of the wastewater being treated, and the concentration and reactivity of DON. Physical treatment methods, such as sedimentation and filtration, can be successful in removing particulate and organic matter, including DON, from wastewater, thereby reducing the availability of DON for DBP formation [192, 201]. Chemical treatment methods, such as coagulation and oxidation, can also be effective in modifying or eliminating

DON from wastewater, thus mitigating its contribution to DBP formation [195, 198]. Biological treatment methods, such as activated sludge processes and biological nutrient removal, employ microbial processes to transform or remove DON, which can also diminish its impact on DBP formation [200, 202].

Potential Benefits and Drawbacks of Using These Treatments

The utilization of physical, chemical, and biological treatment methods in wastewater treatment for controlling DBP formation has both advantages and disadvantages. These treatments have the potential to reduce DBP formation, improve water quality, and comply with regulatory standards. Physical methods, chemical methods, and biological methods can selectively modify or remove DBP precursors through transformation via chemical reaction and microbials, all of which can lead to improved water quality and reduced health risks associated with DBPs [23].

However, there are also drawbacks to consider. Physical and chemical methods may require additional equipment, chemicals, and operational costs, which can increase the overall cost of wastewater treatment [204]. Chemical methods may also generate residuals or by-products that need proper handling and disposal [205]. Moreover, some physical and chemical methods may not effectively remove all types of DBP precursors, and additional treatment steps may be needed. Biological methods may require careful control of environmental conditions, such as temperature, pH, and nutrient levels, to optimize microbial activity and DBP precursor removal [206]. Additionally, biological methods may have longer treatment times and may not be suitable for all types of wastewater or treatment plant configurations [207]. While physical, chemical, and biological treatment methods offer potential benefits in mitigating DBP formation in wastewater treatment, it is important to also consider their drawbacks.

CHALLENGES AND FUTURE DIRECTIONS

The field of DBPs control in wastewater treatment has several knowledge gaps and research requirements. Further investigation is needed in key areas such as identifying and characterizing DBP precursors, understanding the mechanisms of DBP formation, optimizing treatment efficacy, and assessing the toxicity and health risks of DBPs. Comprehensive research is necessary to identify and characterize different types of DBP precursors in wastewater, including their sources, reactivity, and fate during treatment processes.

The complex mechanisms of DBP formation, including pathways and reaction kinetics, require further understanding. While various treatment methods have been proposed for DBP control, their efficacy and optimization in different wastewater treatment scenarios need more investigation. Limited information is available on the toxicity and health risks associated with different types of DBPs, including genotoxicity, carcinogenicity, and potential adverse effects on human health and the environment. Further research is necessary to better understand the toxicological properties of DBPs and their impacts on public health and the environment. Long-term monitoring and assessment of DBP precursors, formation, and treatment efficacy in full-scale wastewater treatment plants are needed to understand the effectiveness of different treatment methods under real-world conditions, aiding in the identification of suitable treatment strategies for different wastewater treatment scenarios.

CONCLUSION

In conclusion, the formation of DBPs in wastewater treatment is a complex issue that requires careful consideration of the impacts of DON, health effects of DBPs, and mitigation strategies. DON has been found to influence DBP formation in wastewater treatment, which has potential implications for water quality and public health. The health effects of DBPs, including genotoxicity and carcinogenicity, underscore the need for further research and understanding of their toxicological properties. Various mitigation strategies, such as physical, chemical, and biological treatment methods, offer potential benefits in reducing DBP formation, improving water quality, and complying with regulatory standards. However, it's important to note that these methods also have drawbacks, including additional costs and the potential generation of chemical residuals or by-products.

To address the knowledge gaps and research requirements in this field, future investigations should prioritize identifying and characterizing DBP precursors, understanding mechanisms of DBP formation, optimizing treatment efficacy, and assessing toxicity and health risks of DBPs. Long-term monitoring and assessment of DBP precursors, formation, and treatment efficacy in real-world wastewater treatment plants would provide valuable insights for effective mitigation strategies. Regulatory and policy measures should also be considered to ensure appropriate guidelines and standards are in place to mitigate DBP formation and protect public health.

In summary, it is crucial to carefully balance the benefits and drawbacks of DBP control methods and continue research efforts to advance our understanding of DBP formation, health effects, and mitigation strategies in wastewater treatment. This will enable the development of sustainable and effective approaches to minimize DBP formation, ensure safe water quality, and protect public health and the environment. By addressing the challenges and knowledge gaps in this field, we can work towards achieving efficient wastewater treatment practices that prioritize human health, environmental sustainability, and regulatory compliance.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] D.Niat [1] A. Voulgaropoulos, "Mitigation of PFAS in U.S. public water systems future steps for ensuring safer drinking water," Environmental Progress & Sustainable Energy, Vol. 41(2), Article e13800, 2022. [CrossRef]

[2] S. Albolafio, A. Marín, A. Allende, F. H. García, P. J. Simón-Andreu, M. A. Soler, and M. I. Gil, "Strategies for mitigating chlorinated disinfection byproducts in wastewater treatment plants," Chemosphere, Vol. 288(2), Article 132583, 2021. [CrossRef]

[3] C. Casado, J. Moreno-SanSegundo, I. D. la Obra, B. E. García, J. A. S. Pérez, and J. Marugán, "Mechanistic modelling of wastewater disinfection by the photo-Fenton process at circumneutral pH," Chemical Engineering Journal, Vol. 403(1), Article 126335, 2021. [CrossRef]

[4] J. Wang and H. Chen, "Catalytic ozonation for water and wastewater treatment: Recent advances and perspective," Science of The Total Environment, Vol. 704, Article 135249, 2020. [CrossRef]

[5] S.-S. Liu, H. Qu, D. Yang, H. Hu, W. Liu, Z. Qiu, A. Hou, J. Guo, J.-W. Li, Z. Shen, and M. Jin, "Chlorine disinfection increases both intracellular and extracellular antibiotic resistance genes in a full-scale wastewater treatment plant," Water Research, Vol. 136, pp. 131–136, 2018. [CrossRef]

[6] A. C. Mecha, M. S. Onyango, A. Ochieng, C. J. S. Fourie, and M. N. B. Momba, "Synergistic effect of UV–vis and solar photocatalytic ozonation on the degradation of phenol in municipal wastewater: A comparative study," Journal of Catalysis, Vol. 341, pp. 116–125, 2016. [CrossRef]

[7] F. J. Beltrán, J. Encinar, and J. F. G. González, "Industrial wastewater advanced oxidation. Part 2. Ozone combined with hydrogen peroxide or UV radiation," Water Research, Vol. 31(10), pp. 2415–2428, 1997. [CrossRef]

[8] T. Bond, M. R. Templeton, and N. Graham, "Precursors of nitrogenous disinfection by-products in drinking water––A critical review and analysis," Journal of Hazardous Materials, Vol. 235–236, pp. 1–16, 2012. [CrossRef]

[9] Y. Huang, Y. Zhang, Q. Zhou, A. Li, P. Shi, J. Qiu, and Y. Pan, "Detection, identification and control of polar iodinated disinfection byproducts in chlor(am)inated secondary wastewater effluents," Environmental Science, Vol. 5, 397–405, 2019. [CrossRef]

[10] T. Manasfi, B. Coulomb, and J.-L. Boudenne, "Occurrence, origin, and toxicity of disinfection byproducts in chlorinated swimming pools: An overview," International Journal of Hygiene and Environmental Health, Vol. 220(3), pp. 591–603, 2017. [CrossRef]

[11] S. D. Richardson, M. J. Plewa, E. D. Wagner, R. Schoeny, and D. M. DeMarini, "Occurrence, genotoxicity, and carcinogenicity of regulated and emerging disinfection by-products in drinking water: a review and roadmap for research," Mutation Research-Reviews in Mutation Research, Vol. 636(1–3), pp. 178–242, 2007. [CrossRef]

[12] W. H. Glaze and J. E. Henderson IV, "Formation of organochlorine compounds from the chlorination of a municipal secondary effluent," Water Pollution Control Federation, pp. 2511–2515, 1975.

[13] S. Krasner, P. Westerhoff, B. Chen, G. L. Amy, S. Nam, S. R. Chowdhury, S. Sinha, and B. E. Rittmann, "Contribution of wastewater to DBP formation," International Water Association (IWA), 2008.

[14] M. R. Jekel, and P. V. Roberts, "Total organic halogen as a parameter for the characterization of reclaimed waters: measurement, occurrence, formation, and removal," Environmental Science & Technology, Vol. 14, pp. 970–975, 1980. [CrossRef]

[15] S. W. Krasner, P. Westerhoff, B. Chen, B. E. Rittmann, S.-N. Nam, and G. Amy, "Impact of wastewater treatment processes on organic carbon, organic nitrogen, and DBP precursors in effluent organic matter," Environmental Science & Technology, Vol. 43, pp. 2911–2918, 2009. [CrossRef]

[16] R. L. Jolley, Water chlorination: chemistry, environmental impact and health effects, Lewis Publishers, 1990.

[17] M. L. Trehy, R. A. Yost, and C. J. Miles, "Chlorination byproducts of amino acids in natural waters," Environmental Science & Technology, Vol. 20, pp. 1117–1122, 1986. [CrossRef]

[18] P. Bose, "Selected physico-chemical properties of natural organic matter and their changes due to ozone treatment: Implications for coagulation using alum," [Master Thesis]. University of Massachusetts Amherst, 1995.

[19] T. Carroll, S. King, S. R. Gray, B. A. Bolto, and N. A. Booker, "The fouling of microfiltration membranes by NOM after coagulation treatment," Water Research, Vol. 34, pp. 2861–2868, 2000. [CrossRef]

[20] P. Westerhoff and H. Mash, "Dissolved organic nitrogen in drinking water supplies: a review," Journal of Water Supply: Research and Technology-Aqua, Vol. 51, pp. 415–448, 2002. [CrossRef]

[21] M. Pishnamazi, S. Koushkbaghi, S. S. Hosseini, M. Darabi, A. Yousefi, and M. Irani, "Metal organic framework nanoparticles loaded-PVDF/chitosan nanofibrous ultrafiltration membranes for the removal of BSA protein and Cr(VI) ions," Journal of Molecular Liquids, Vol. 317, Article 113934, 2020. [CrossRef]

[22] G. F. Parkin, and P. L. McCarty, "A comparison of the characteristics of soluble organic nitrogen in untreated and activated sludge treated wastewaters," Water Research, Vol. 15, pp. 139–149, 1981. [CrossRef]

[23] F. Zheng, J. Wang, R. Xiao, W. Chai, D. Xing, and H. Lu, "Dissolved organic nitrogen in wastewater treatment processes: Transformation, biosynthesis and ecological impacts," Environmental Pollution, Vol. 273, Article 116436, 2021. [CrossRef]

[24] J. D. Rouse, C. A. Bishop, and J. Struger, "Nitrogen pollution: an assessment of its threat to amphibian survival," Environmental Health Perspectives, Vol. 107(10), pp. 799–803, 1999. [CrossRef]

[25] N.-B. Chang, D. Wen, A. M. McKenna, and M. P. Wanielista, "The Impact of Carbon Source as Electron Donor on Composition and Concentration of Dissolved Organic Nitrogen in Biosorption-Activated Media for Stormwater and Groundwater Co-Treatment," Environmental Science & Technology, Vol. 52(16), pp. 9380–9390, 2018. [CrossRef]

[26] S. M. Iskander, T. Zeng, E. Smiley, S. C. Bolyard, J. T. Novak, and Z. He, "Formation of disinfection byproducts during Fenton's oxidation of chloride-rich landfill leachate," Journal of Hazardous Materials, Vol. 382(15), 2020, Article 121213, 2020. [CrossRef]

[27] X.-X. Wang, L. Baoming, M.-F. Lu, L. Yuping, Y.-Y. Jiang, M. Zhao, Z.-X. Huang, Y. Pan, M. Hengfeng, and W.-Q. Ruan, "Characterization of algal organic matter as precursors for carbonaceous and nitrogenous disinfection byproducts formation: Comparison with natural organic matter," Journal of Environmental Management, Vol. 282, Article 111951, 2021. [CrossRef]

[28] Y.-H. Chuang, A. Y.-C. Lin, X. H. Wang, and H. H. Tung, "The contribution of dissolved organic nitrogen and chloramines to nitrogenous disinfection byproduct formation from natural organic matter," Water Research, Vol. 47(3), pp. 1308–1316, 2013. [CrossRef]

[29] H. Hu, C. Jiang, H. Ma, L. Ding, J. Geng, K. Xu, H. Huang, and H. Ren, "Removal characteristics of DON in pharmaceutical wastewater and its influence on the N-nitrosodimethylamine formation potential and acute toxicity of DOM," Water Research, Vol. 109, pp. 114–121, 2017. [CrossRef]

[30] L.-S. Wang, D. Wei, J. Wei, and H.-Y. Hu, "Screening and estimating of toxicity formation with photobacterium bioassay during chlorine disinfection of wastewater," Journal of Hazardous Materials, Vol. 141(1), pp. 289–294, 2007. [CrossRef]

[31] H. Zhang, J. Qu, H. Liu, and X. Zhao, "Isolation of dissolved organic matter in effluents from sewage treatment plant and evaluation of the influences on its DBPs formation," Separation and Purification Technology, Vol. 64(1), pp. 31–37, 2008. [CrossRef]

[32] J. L. Roux, H. Gallard, and J.-P. Croué, "Chloramination of nitrogenous contaminants (pharmaceuticals and pesticides): NDMA and halogenated DBPs formation," Water Research, Vol. 45, pp. 3164–3174, 2011. [CrossRef]

[33] P. Roy, M. A. Ahmed, S. Islam, A. K. Azad, S. Islam, and R. Islam, "Water Supply, Sanitation System and Water-borne Diseases of Slum Dwellers of Bastuhara Colony," Khulna, Department of Civil Engineering, KUET, Khulna, Bangladesh, 2020. [CrossRef]

[34] J. L. Roux, M. J. Plewa, E. D. Wagner, M. Nihemaiti, A. Dad, and J.-P. Croué, "Chloramination of wastewater effluent: Toxicity and formation of disinfection byproducts," Journal of Environmental Sciences, Vol. 58, pp. 135–145, 2017. [CrossRef]

[35] G. Ding, X. Zhang, M. Yang, and Y. Pan, "Formation of new brominated disinfection byproducts during chlorination of saline sewage effluents," Water Research, Vol. 47, pp. 2710–2718, 2013. [CrossRef]

[36] Y. Zhong, W. Gan, Y. Du, H. Huang, Q. Wu, Y. Xiang, C. Shang, and X. Yang, "Disinfection byproducts and their toxicity in wastewater effluents treated by the mixing oxidant of ClO_2/Cl_2," Water Research, Vol. 162, pp. 471–481, 2019. [CrossRef]

[37] G. Hua, and D. A. Reckhow, "Comparison of disinfection byproduct formation from chlorine and alternative disinfectants," Water Research, Vol. 41, pp. 1667–1678, 2007. [CrossRef]

[38] W. A. Mitch, and D. L. Sedlak, "Formation of N-nitrosodimethylamine (NDMA) from dimethylamine during chlorination," Environmental Science & Technology, Vol. 36, pp. 588–595, 2002. [CrossRef]

[39] W.-H. Chen, and T. M. Young, "Influence of nitrogen source on NDMA formation during chlorination of diuron," Water Research, Vol. 43, pp. 3047-3056, 2009. [CrossRef]

[40] B. Ye, Y. Cang, J. Li, and X. Zhang, "Advantages of a ClO_2/NaClO combination process for controlling the disinfection by-products (DBPs) for high algae-laden water," Environmental Geochemistry and Health, Vol. 41, pp. 1545–1557, 2019. [CrossRef]

[41] S. Sorlini, F. Gialdini, M. Biasibetti, and C. Collivignarelli, "Influence of drinking water treatments on chlorine dioxide consumption and chlorite/chlorate formation," Water Research, Vol. 54, pp. 44–52, 2014. [CrossRef]

[42] J.-Y. Fang and C. Shang, "Bromate Formation from Bromide Oxidation by the UV/Persulfate Process," Environmental Science & Technology, Vol. 46, pp. 8976–8983, 2012. [CrossRef]

[43] T. Lin, S. Wu, and W. Chen, "Formation potentials of bromate and brominated disinfection by-products in bromide-containing water by ozonation," Environmental Science and Pollution Research International, Vol. 21, pp. 13987–14003, 2014. [CrossRef]

[44] L. Li, Y. Jeon, H. Ryu, J. W. Santo Domingo, and Y. Seo, "Assessing the chemical compositions and disinfection byproduct formation of biofilms: Application of fluorescence excitation-emission

spectroscopy coupled with parallel factor analysis," Chemosphere, Vol. 246, Article 125745, 2020. [CrossRef]

[45] P. Roy, M. A. Ahmed, and A. Kumer, "An overview of hygiene practices and health risks related to street foods and drinking water from roadside restaurants of Khulna city of Bangladesh," Eurasian Journal of Environmental Research, Vol. 3, pp. 47–55, 2019.

[46] B. Li, X. Ma, Q. Li, W. Chen, J. Deng, G. Li, G. Chen, and W. Liao, "Factor affecting the role of radicals contribution at different wavelengths, degradation pathways and toxicity during UV-LED/chlorine process," Chemical Engineering Journal, vol. 392, Article 124552, 2020. [CrossRef]

[47] S. Onodera, "Formation mechanism and chemical safety of nonintentional chemical substances present in chlorinated drinking water and wastewater," Yakugaku Zasshi, Vol. 130, pp. 1157–1174, 2010. [CrossRef]

[48] N. Clarke, K. Fuksová, M. Gryndler, Z. Lachmanová, H.-H. Liste, J. Rohlenová, R. Schroll, P. Schröder, and M. Matucha, "The formation and fate of chlorinated organic substances in temperate and boreal forest soils," Environmental Science and Pollution Research, Vol. 16, pp. 127–143, 2009. [CrossRef]

[49] T. Li, Y. Jiang, X. An, H. Liu, C. Hu, and J. Qu, "Transformation of humic acid and halogenated byproduct formation in UV-chlorine processes," Water Research, Vol. 102, pp. 421–427, 2016. [CrossRef]

[50] R. Loyola-Sepulveda, G. Lopez-Leal, J. Munoz, C. Bravo-Linares, and S. M. Mudge, "Trihalomethanes in the drinking water of Concepción and Talcahuano, Chile," Water and Environment Journal, Vol. 23, pp. 286–292, 2009. [CrossRef]

[51] M. Panyakapo, S. Soontornchai, and P. Paopuree, "Cancer risk assessment from exposure to trihalomethanes in tap water and swimming pool water," Journal of Environmental Sciences, Vol. 20, pp. 372–378, 2008. [CrossRef]

[52] A. M. Abdullah, "Assessment of potential risks from trihalomethanes in water supply at Alexandria Governorate," Journal of Pollution Effects & Control, Vol. 2, pp. 1–4, 2014.

[53] T. Bond, E. H. Goslan, S. A. Parsons, and B. Jefferson, "A critical review of trihalomethane and haloacetic acid formation from natural organic matter surrogates," Environmental Technology Reviews, Vol. 1, pp. 93–113, 2012. [CrossRef]

[54] S. Ding, W. Chu, T. Bond, Q. Wang, N. Gao, B. Xu, and E. Du, "Formation and estimated toxicity of trihalomethanes, haloacetonitriles, and haloacetamides from the chlor(am)ination of acetaminophen," Journal of Hazardous Materials, Vol. 341, pp. 112–119, 2018. [CrossRef]

[55] J. C. Beard, and T. M. Swager, "An organic chemist's guide to n-nitrosamines: their structure, reactivity, and role as contaminants," The Journal of Organic Chemistry, Vol. 86, pp. 2037–2057, 2021. [CrossRef]

[56] M. S. Abdel-Rahman, D. Couri, and R. J. Bull, "Metabolism and pharmacokinetics of alternate drinking water disinfectants," Environmental Health Perspectives, Vol. 46, pp. 19–23, 1982. [CrossRef]

[57] V. Uyak, and I. Toroz, "Enhanced coagulation of disinfection by-products precursors in Istanbul water supply," Environmental Technology, Vol. 26, pp. 261–266, 2005. [CrossRef]

[58] I. H. Aljundi, "Bromate formation during ozonation of drinking water: A response surface methodology study," Desalination, Vol. 277, pp. 24–28, 2011. [CrossRef]

[59] A. N. Gounden, and S. B. Jonnalagadda, "Advances in treatment of brominated hydrocarbons by heterogeneous catalytic ozonation and bromate minimization," Molecules, Vol. 24, Article 3450, 2019. [CrossRef]

[60] R. A. Li, J. A. McDonald, A. Sathasivan, and S. J. Khan, "A multivariate Bayesian network analysis of water quality factors influencing trihalomethanes formation in drinking water distribution systems," Water Research, Vol. 190, Article 116712, 2021. [CrossRef]

[61] B. Liu, and D. A. Reckhow, "Disparity in disinfection byproducts concentration between hot and cold tap water," Water Research, Vol. 70, pp. 196–204, 2015. [CrossRef]

[62] P. Roccaro, H.-S. Chang, F. G. Vagliasindi, and G. V. Korshin, "Differential absorbance study of effects of temperature on chlorine consumption and formation of disinfection by-products in chlorinated water," Water Research, Vol. 42, pp. 1879–1888, 2008. [CrossRef]

[63] J. Fang, J. Ma, X. Yang, and C. Shang, "Formation of carbonaceous and nitrogenous disinfection by-products from the chlorination of Microcystis aeruginosa," Water Research, Vol. 44, pp. 1934–1940, 2010. [CrossRef]

[64] Y.-C. Hung, B. W. Waters, V. K. Yemmireddy, and C.-H. Huang, "pH effect on the formation of THM and HAA disinfection byproducts and potential control strategies for food processing," Journal of Integrative Agriculture, Vol. 16, pp. 2914–2923, 2017. [CrossRef]

[65] T. Özbelge, "A study for chloroform formation in chlorination of resorcinol," Turkish Journal of Engineering and Environmental Sciences, Vol. 25, pp. 289–298, 2001.

[66] S. Chowdhury, M. J. Rodriguez, and R. Sadiq, "Disinfection byproducts in Canadian provinces: associated cancer risks and medical expenses," Journal of Hazardous Materials, Vol. 187, pp. 574–584, 2011. [CrossRef]

[67] A. Gonsioroski, V. E. Mourikes, and J. A. Flaws, "Endocrine disruptors in water and their effects on the reproductive system," International Journal of Molecular Sciences, Vol. 21, Article 1929, 2020. [CrossRef]

[68] Y. Chen, T. Xu, X. Yang, W. Chu, S. Hu, and D. Yin, "The toxic potentials and focus of disinfection byproducts based on the human embryonic kidney (HEK293) cell model," Science of the Total Environment, Vol. 664, pp. 948–957, 2019. [CrossRef]

[69] C. Legay, M. J. Rodriguez, J. B. Sérodes, and P. Levallois, “Estimation of chlorination by-products presence in drinking water in epidemiological studies on adverse reproductive outcomes: a review,” Science of the Total Environment, Vol. 408, pp. 456–472, 2010. [CrossRef]

[70] R. S. Chaves, C. S. Guerreiro, V. V. Cardoso, M. J. Benoliel, and M. M. Santos, “Hazard and mode of action of disinfection by-products (DBPs) in water for human consumption: Evidences and research priorities,” Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, Vol. 223, pp. 53–61, 2019. [CrossRef]

[71] M. Diana, M. Felipe-Sotelo, and T. Bond, “Disinfection byproducts potentially responsible for the association between chlorinated drinking water and bladder cancer: a review,” Water Research, Vol. 162, pp. 492–504, 2019. [CrossRef]

[72] S. Regli, J. Chen, M. Messner, M. S. Elovitz, F. J. Letkiewicz, R. A. Pegram, T. J. Pepping, S. D. Richardson, and J. M. Wright, “Estimating potential increased bladder cancer risk due to increased bromide concentrations in sources of disinfected drinking waters,” Environmental Science & Technology, Vol. 49, pp. 13094–13102, 2015. [CrossRef]

[73] R. R. Jones, C. T. DellaValle, P. J. Weyer, K. Robien, K. P. Cantor, S. Krasner, L. E. B. Freeman, and M. H. Ward, “Ingested nitrate, disinfection by-products, and risk of colon and rectal cancers in the Iowa Women’s Health Study cohort,” Environment International, Vol. 126, pp. 242–251, 2019. [CrossRef]

[74] C. Quintiliani, C. Di Cristo, and A. Leopardi, “Vulnerability assessment to trihalomethane exposure in water distribution systems,” Water, Vol. 10, Article 912, 2018. [CrossRef]

[75] L. A. Salas, M. Bustamante, J. R. Gonzalez, E. Gracia-Lavedan, V. Moreno, M. Kogevinas, and C. M. Villanueva, “DNA methylation levels and long-term trihalomethane exposure in drinking water: an epigenome-wide association study,” Epigenetics, Vol(7), pp. 650–661, 2015. [CrossRef]

[76] P. Yang, B. Zhou, W.-C. Cao, Y.-X. Wang, Z. Huang, J. Li, W.-Q. Lu, and Q. Zeng, "Prenatal exposure to drinking water disinfection by-products and DNA methylation in cord blood," Science of the Total Environment, Vol. 586, pp. 313–318, 2017. [CrossRef]

[77] W.-C. Cao, Q. Zeng, Y. Luo, H.-X. Chen, D.-Y. Miao, L. Li, Y.-H. Cheng, M. Li, F. Wang, and L. You, "Blood biomarkers of late pregnancy exposure to trihalomethanes in drinking water and fetal growth measures and gestational age in a Chinese cohort," Environmental Health Perspectives, Vol. 124(4), pp. 536–541, 2016. [CrossRef]

[78] B. E. Holmes, L. Smeester, R. C. Fry, and H. S. Weinberg, "Identification of endocrine active disinfection by-products (DBPs) that bind to the androgen receptor," Chemosphere, Vol. 187, pp. 114–122, 2017. [CrossRef]

[79] C. Di Cristo, A. Leopardi, C. Quintiliani, and G. de Marinis, "Drinking water vulnerability assessment after disinfection through chlorine," Procedia Engineering, Vol. 119, pp. 389–397, 2015. [CrossRef]

[80] T. W. Ng, B. Li, A. Chow, and P. K. Wong, "Effects of bromide on inactivation efficacy and disinfection byproduct formation in photocatalytic inactivation," Journal of Photochemistry and Photobiology A: Chemistry, Vol. 324, pp. 145–151, 2016. [CrossRef]

[81] C. M. Villanueva, S. Cordier, L. Font-Ribera, L. A. Salas, and P. Levallois, "Overview of Disinfection By-products and Associated Health Effects," Current Environmental Health Reports, Vol. 2(1), pp. 107–115, 2015. [CrossRef]

[82] R. López-Roldán, A. Rubalcaba, J. Martin-Alonso, S. González, V. Martí, and J. L. Cortina, "Assessment of the water chemical quality improvement based on human health risk indexes: Application to a drinking water treatment plant incorporating membrane technologies," Science of the Total Environment, Vol. 540, pp. 334–343, 2016. [CrossRef]

[83] R. Dyck, G. Cool, M. Rodriguez, and R. Sadiq, "Treatment, residual chlorine and season as factors affecting variability of trihalomethanes in small drinking water systems," Frontiers of Environmental Science & Engineering, Vol. 9(1), pp. 171–179, 2015. [CrossRef]

[84] A. Andersson, M. J. Ashiq, M. Shoeb, S. Karlsson, D. Bastviken, and H. Kylin, "Evaluating gas chromatography with a halogen-specific detector for the determination of disinfection by-products in drinking water," Environmental Science and Pollution Research, Vol. 26(8), pp. 7305–7314, 2019. [CrossRef]

[85] N. Chaukura, S. S. Marais, W. Moyo, N. Mbali, L. C. Thakalekoala, T. Ingwani, B. B. Mamba, P. Jarvis, and T. T. I. Nkambule, "Contemporary issues on the occurrence and removal of disinfection byproducts in drinking water - A review," Journal of Environmental Chemical Engineering, Vol. 8(4), Article 103659, 2020. [CrossRef]

[86] S. Chen, J. Deng, L. Li, and N. Gao, "Evaluation of disinfection by-product formation during chlor(am) ination from algal organic matter after UV irradiation," Environmental Science and Pollution Research, Vol. 25(6), pp. 5994–6002, 2018. [CrossRef]

[87] W. Lee, P. Westerhoff, and J.-P. Croué, "Dissolved organic nitrogen as a precursor for chloroform, dichloroacetonitrile, N-nitrosodimethylamine, and trichloronitromethane," Environmental Science & Technology, Vol. 41(15), pp. 5485–5490, 2007. [CrossRef]

[88] T. Bond, O. Henriet, E. H. Goslan, S. A. Parsons, and B. Jefferson, "Disinfection byproduct formation and fractionation behavior of natural organic matter surrogates," Environmental Science & Technology, Vol. 43(15), pp. 5982–5989, 2009. [CrossRef]

[89] X. Yang, W. Guo, and Q. Shen, "Formation of disinfection byproducts from chlor(am)ination of algal

organic matter," Journal of Hazardous Materials, Vol. 197, pp. 378–388, 2011. [CrossRef]

[90] A. Dotson, P. Westerhoff, and S. W. Krasner, "Nitrogen enriched dissolved organic matter (DOM) isolates and their affinity to form emerging disinfection by-products," Water Science and Technology, Vol. 60(5), pp. 135–143, 2009. [CrossRef]

[91] X. Yang, C. Shang, W. Lee, P. Westerhoff, and C. Fan, "Correlations between organic matter properties and DBP formation during chloramination," Water Research, Vol. 42(8-9), pp. 2329–2339, 2008. [CrossRef]

[92] K. E. Furst, B. M. Pecson, B. D. Webber, and W. A. Mitch, "Tradeoffs between pathogen inactivation and disinfection byproduct formation during sequential chlorine and chloramine disinfection for wastewater reuse," Water Research, Vol. 143, pp. 579–588, 2018. [CrossRef]

[93] Z. Li, X. Liu, Z. Huang, S. Hu, J. Wang, Z. Qian, J. Feng, Q. Xian, and T. Gong, "Occurrence and ecological risk assessment of disinfection byproducts from chlorination of wastewater effluents in East China," Water Research, Vol. 157, pp. 247–257, 2019. [CrossRef]

[94] M. J. Plewa, Y. Kargalioglu, D. Vankerk, R. A. Minear, and E. D. Wagner, "Mammalian cell cytotoxicity and genotoxicity analysis of drinking water disinfection by-products," Environmental and Molecular Mutagenesis, Vol. 40(2), pp. 134–142, 2002. [CrossRef]

[95] E. D. Wagner, and M. J. Plewa, "CHO cell cytotoxicity and genotoxicity analyses of disinfection by-products: an updated review," Journal of Environmental Sciences, Vol. 58, pp. 64–76, 2017.

[96] C. Sattayatewa, K. Pagilla, R. Sharp, and P. Pitt, "Fate of organic nitrogen in four biological nutrient removal wastewater treatment plants," Water Environment Research, Vol. 82(11), pp. 2306–2315, 2010. [CrossRef]

[97] S. Huo, B. Xi, H. Yu, Y. Qin, F. Zan, and J. Zhang, "Characteristics and transformations of dissolved organic nitrogen in municipal biological nitrogen removal wastewater treatment plants," Environmental Research Letters, Vol. 8(4), Article 044005, 2013. [CrossRef]

[98] Y. Lester, H. Mamane, I. Zucker, and D. Avisar, "Treating wastewater from a pharmaceutical formulation facility by biological process and ozone," Water Research, Vol. 47(13), pp. 4349–4356, 2013. [CrossRef]

[99] S. Kucukcongar, Z. Gok, M. K. Oden, and S. Dursun, "Biodegradability of dissolved organic nitrogen in yoghurt and cheese production wastewaters," International Journal of Environmental Science and Technology, Vol. 20, pp. 4031–4040, 2023. [CrossRef]

[100] X. X. Gao, Y. W. Wang, Y. C. An, R. Y. Ren, Y. H. Lin, N. Wang…, and N. Q. Ren, "Molecular insights into the dissolved organic matter of leather wastewater in leather industrial park wastewater treatment plant," Science of the Total Environment, Vol. 882, Article 163174, 2023. [CrossRef]

[101] T. Khan, D. B. P. Argha, and M. S. Anita, "An analysis of existing medical waste management and possible health hazards in Jhenaidah municipality. Proceedings of International Conference on Engineering Research, Innovation and Education. Bandung, Indonesia: University of Pendidikan Indonesia," 2021.

[102] M. A. Ahmed, and M. Redowan, "Fate and transport of the biologically treated landfill leachate induced Dissolved Organic Nitrogen (DON)," 2023. https://par.nsf.gov/biblio/10431230-fate-transport-biologically-treated-landfill-leachate-induced-dissolved-organic-nitrogen-don. Accessed on May 2, 2024.

[103] M. R. Rashid, and M. Ashik, "Evaluation of physicochemical treatment technologies for landfill leachate induced Dissolved Organic Nitrogen (DON)," 2023. https://par.nsf.gov/biblio/10431232-evaluation-physicochemical-treatment-technologies-landfill-leachate-induced-dissolved-organic-nitrogen-don. Accessed on May 2, 2024.

[104] A. Ahmed, and S. M. Moniruzzaman, "A study on plastic waste recycling process in Khulna City," Proceedings of 4th International Conference on Civil Engineering for Sustainable Development (ICCESD). Khulna, Bangladesh, 2018.

[105] A. Ahmed, and S. Chakrabarti, "Analysis on solid waste management practices and development of integrated solid waste management model for developing country with special reference to Jhenaidah municipal area, Bangladesh," Proceedings of 4th International Conference on Civil Engineering for Sustainable Development (ICCESD). Khulna, Bangladesh, 2018.

[106] Y. N. A. Soh, C. Kunacheva, R. D. Webster, and D. C. Stuckey, "Identification of the production and biotransformational changes of soluble microbial products (SMP) in wastewater treatment processes: A short review," Chemosphere, Vol. 251, Article 126391, 2020. [CrossRef]

[107] S. He, L. Ding, K. Li, H. Hu, L. Ye, and H. Ren, "Comparative study of activated sludge with different individual nitrogen sources at a low temperature: Effluent dissolved organic nitrogen compositions, metagenomic and microbial community," Bioresource Technology, Vol. 247, pp. 915–923, 2018. [CrossRef]

[108] W. M. Xie, B. J. Ni, G. P. Sheng, T. Seviour, and H. Q. Yu, "Quantification and kinetic characterization of soluble microbial products from municipal wastewater treatment plants," Water Research, Vol. 88, pp. 703–710, 2016. [CrossRef]

[109] H. Hu, K. Liao, W. Xie, J. Wang, B. Wu, and H. Ren, "Modeling the formation of microorganism-derived dissolved organic nitrogen (mDON) in the activated sludge system," Water Research, Vol. 174, Article 115604, 2020. [CrossRef]

[110] S. C. Bolyard, and D. R. Reinhart, "Evaluation of leachate dissolved organic nitrogen discharge effect on wastewater effluent quality," Waste Management, Vol. 65, pp. 47–53, 2017. [CrossRef]

[111] H. Liu, J. Jeong, H. Gray, S. Smith, and D. L. Sedlak, "Algal uptake of hydrophobic and hydrophilic dissolved organic nitrogen in effluent from biological nutrient removal municipal wastewater treatment systems," Environmental Science & Technology, Vol. 46(2), pp. 713–721, 2012. [CrossRef]

[112] S. Pantoja, C. Lee, "Cell-surface oxidation of amino acids in seawater," Limnology and Oceanography, Vol. 39(7), pp. 1718–1726, 1994. [CrossRef]

[113] M. Middelboe, N. H. Borch, and D. L. Kirchman, "Bacterial utilization of dissolved free amino acids, dissolved combined amino acids and ammonium in the Delaware Bay estuary: effects of carbon and nitrogen limitation," Marine Ecology Progress Series, Vol. 128(1–3), pp. 109–120, 1995. [CrossRef]

[114] J. D. Thomas, "The role of dissolved organic matter, particularly free amino acids and humic substances, in freshwater ecosystems," Freshwater Biology, Vol. 38(1), pp. 1–36, 1997. [CrossRef]

[115] T. Berman, and D. A. Bronk, "Dissolved organic nitrogen: A dynamic participant in aquatic ecosystems," Aquatic Microbial Ecology, Vol. 31(3), pp. 279-305, 2003. [CrossRef]

[116] N. O. Jørgensen, L. Tranvik, H. Edling, W. Granéli, and M. Lindell, "Effects of sunlight on occurrence and bacterial turnover of specific carbon and nitrogen compounds in lake water," FEMS Microbiology Ecology, Vol. 25(3), pp. 217–227, 1998. [CrossRef]

[117] J. B. Rondell, K. W. Finster, and B. A. Lomstein, "Urea and DON uptake by a Lyngbya gracialis dominated microbial mat: A controlled laboratory experiment," Aquatic Microbial Ecology, Vol. 21, pp. 169–175, 2000. [CrossRef]

[118] P. Carlsson, and E. Granéli, Availability of humic bound nitrogen for coastal phytoplankton," Estuarine, Coastal and Shelf Science, Vol. 36, pp. 433–447, 1993. [CrossRef]

[119] K. L. Bushaw-Newton, and M. A. Moran, "Photochemical formation of biologically available nitrogen from dissolved humic substances in coastal marine systems," Aquatic Microbial Ecology, Vol. 18, pp. 285–292, 1999. [CrossRef]

[120] A. V. Vähätalo, and R. G. Zepp, "Photochemical mineralization of dissolved organic nitrogen to ammonium in the Baltic Sea," Environmental Science & Technology, Vol. 39(18), pp. 6985–6992, 2005. [CrossRef]

[121] S. Murthy, K. Jones, S. Baidoo, and K. Pagilla, "Biodegradability of dissolved organic nitrogen: Adaptation of the BOD test," Proceedings of the Water Environment Federation 2006 (pp. 1550–1559). Chicago, Illinois, USA, 2006. [CrossRef]

[122] K. Czerwionka, J. Makinia, K. R. Pagilla, and H. D. Stensel, "Characteristics and fate of organic nitrogen in municipal biological nutrient removal wastewater treatment plants," Water Research, Vol. 46(7), pp. 2057–2066, 2012. [CrossRef]

[123] P. J. Westgate, and C. Park, "Evaluation of proteins and organic nitrogen in wastewater treatment effluents," Environmental Science & Technology, Vol. 44, pp. 5352–5357, 2010. [CrossRef]

[124] H. Eom, D. Borgatti, H. W. Paerl, and C. Park, "Formation of low-molecular-weight dissolved organic nitrogen in predenitrification biological nutrient removal systems and its impact on eutrophication in coastal waters," Environmental Science & Technology, Vol. 51(7), pp. 3776–3783, 2017. [CrossRef]

[125] K. Lu, "Biogeochemical Processes of Dissolved Organic Nitrogen in Aquatic Environments," 2018. https://repositories.lib.utexas.edu/items/4a45560b-5c6f-42e8-90bd-700c0bf6b946. Accessed on May 2, 2024.

[126] E. Pehlivanoglu-Mantas, and D. L. Sedlak, "Measurement of dissolved organic nitrogen forms in wastewater effluents: concentrations, size distribution and NDMA formation potential," Water Research, Vol. 42(14), pp. 3890–3898, 2008. [CrossRef]

[127] K. R. Pagilla, M. Urgun-Demirtas, K. Czerwionka, and J. Makinia, "Nitrogen speciation in wastewater treatment plant influents and effluents - The US and Polish case studies," Water Science and Technology, Vol. 57(10), pp. 1511–1517, 2008. [CrossRef]

[128] H. V. M. Nguyen, S. Tak, J. Hur, and H. S. Shin, "Fluorescence spectroscopy in the detection and management of disinfection by-product precursors in drinking water treatment processes: A review," Chemosphere, Vol. 343, Article 140269, 2023. [CrossRef]

[129] M. H. Plumlee, M. López-Mesas, A. Heidlberger, K. P. Ishida, and M. Reinhard, "N-nitrosodimethylamine (NDMA) removal by reverse osmosis and UV treatment and analysis via LC–MS/MS," Water Research, Vol. 42(1–2), pp. 347–355, 2008. [CrossRef]

[130] I. Najm, and R. R. Trussell, "NDMA formation in water and wastewater," Journal-American Water Works Association, Vol. 93(2), pp. 92–99, 2001. [CrossRef]

[131] K. O. Kusk, A. M. Christensen, and N. Nyholm, "Algal growth inhibition test results of 425 organic chemical substances," Chemosphere, Vol. 204, pp. 405–412, 2018. [CrossRef]

[132] X. Yang, Q. Shen, W. Guo, J. Peng, and Y. Liang, "Precursors and nitrogen origins of trichloronitromethane and dichloroacetonitrile during chlorination/chloramination," Chemosphere, Vol. 88(1), pp. 25–32, 2012. [CrossRef]

[133] W. A. Mitch, and D. L. Sedlak, "Characterization and fate of N-nitrosodimethylamine precursors in municipal wastewater treatment plants," Environmental Science & Technology, Vol. 38(5), pp. 1445–1454, 2004. [CrossRef]

[134] J. H. Lee, C. Na, R. L. Ramirez, and T. M. Olson, "Cyanogen chloride precursor analysis in chlorinated

river water," Environmental Science & Technology, Vol. 40(5), pp. 1478–1484, 2006. [CrossRef]

[135] W. H. Chu, N. Y. Gao, Y. Deng, and S. W. Krasner, "Precursors of dichloroacetamide, an emerging nitrogenous DBP formed during chlorination or chloramination," Environmental Science & Technology, Vol. 44(10), pp. 3908–3912, 2010. [CrossRef]

[136] W. A. Mitch, and I. M. Schreiber, "Degradation of tertiary alkylamines during chlorination/chloramination: Implications for formation of aldehydes, nitriles, halonitroalkanes, and nitrosamines," Environmental Science & Technology, Vol. 42(13), pp. 4811–4817, 2008. [CrossRef]

[137] N. Merlet, H. Thibaud, and M. Dore, "Chloropicrin formation during oxidative treatments in the preparation of drinking water," The Science of the Total Environment, Vol. 47, pp. 223–228, 1985. [CrossRef]

[138] T. I. Bieber, "Dihaloacetonitriles in chlorinated natural water," Water Chlorination Environmental Impact and Health Effects, Vol. 4, pp. 85–96, 1983.

[139] M. S. Young, and P. C. Uden, "Byproducts of the aqueous chlorination of purines and pyrimidines," Environmental Science & Technology, Vol. 28(9), pp. 1755–1758, 1994. [CrossRef]

[140] H. Ueno, T. Moto, Y. Sayato, and K. Nakamuro, "Disinfection by-products in the chlorination of organic nitrogen compounds: By-products from kynurenine," Chemosphere, Vol. 33(8), pp. 1425–1433, 1996. [CrossRef]

[141] J. A. Aitkenhead-Peterson, M. K. Steele, N. Nahar, and K. Santhy, "Dissolved organic carbon and nitrogen in urban and rural watersheds of south-central Texas: land use and land management influences," Biogeochemistry, Vol. 96, pp. 119–129, 2009. [CrossRef]

[142] H. Chang, C. Chen, and G. Wang, "Identification of potential nitrogenous organic precursors for C-, N-DBPs and characterization of their DBPs formation," Water Research, Vol. 45(12), pp. 3753–3764, 2011. [CrossRef]

[143] H. Chang, C. Chen, and G. Wang, "Characteristics of C-, N-DBPs formation from nitrogen-enriched dissolved organic matter in raw water and treated wastewater effluent," Water Research, Vol. 47(8), pp. 2729–2741, 2013. [CrossRef]

[144] A. Piazzoli, F. Breider, C.G. Aquillon, M. Antonelli, and U. von Gunten, "Specific and total N-nitrosamines formation potentials of nitrogenous micropollutants during chloramination," Water Research, Vol. 135, pp. 311–321, 2018. [CrossRef]

[145] M. Selbes, W. Beita-Sandí, D. Kim, and T. Karanfil, "The role of chloramine species in NDMA formation," Water Research, Vol. 140, pp.100–109, 2018. [CrossRef]

[146] W. Wang, S. Ren, H. Zhang, J. Yu, W. An, J. Hu, and M. Yang, "Occurrence of nine nitrosamines and secondary amines in source water and drinking water: Potential of secondary amines as nitrosamine precursors," Water Research, Vol. 45(16), pp. 4930–4938, 2011. [CrossRef]

[147] Z. T. How, K. L. Linge, F. Busetti, and C. A. Joll, "Formation of odorous and hazardous by-products from the chlorination of amino acids," Water Research, Vol. 146, pp. 10–18, 2018. [CrossRef]

[148] H. Han, H. Miao, Y. Zhang, M. Lu, Z. Huang, and W. Ruan, "Carbonaceous and nitrogenous disinfection byproduct precursor variation during the reversed anaerobic–anoxic–oxic process of a sewage treatment plant," Journal of Environmental Sciences, Vol. 65, pp. 335–346, 2018. [CrossRef]

[149] C. Fang, X. Yang, S. Ding, X. Luan, R. Xiao, Z. Du…, and W. Chu, "Characterization of Dissolved Organic Matter and Its Derived Disinfection Byproduct Formation along the Yangtze River," Environmental Science & Technology, Vol. 55(18), pp. 12326–12336, 2021. [CrossRef]

[150] C. W. K. Chow, R. Fabris, J. van Leeuwen, D. Wang, and M. Drikas, "Assessing natural organic matter treatability using high performance size exclusion chromatography," Environmental Science & Technology, Vol. 42(17), pp. 6683–6689, 2008. [CrossRef]

[151] J. A. Leenheer, A. Dotson, and P. Westerhoff, "Dissolved organic nitrogen fractionation," Annals of Environmental Science, Vol. 1, pp. 45-56, 2007.

[152] J. K. Choe, L. C. Hua, Y. Komaki, A. M. A. Simpson, D. L. McCurry, and W. A. Mitch, "Evaluation of histidine reactivity and byproduct formation during peptide chlorination," Environmental Science & Technology, Vol. 55(3), pp. 1790–1799, 2021. [CrossRef]

[153] T. Bond, J. Huang, M. R. Templeton, and N. Graham, "Occurrence and control of nitrogenous disinfection by-products in drinking water – A review," Water Research, Vol. 45(15), pp. 4341–4354, 2011. [CrossRef]

[154] S. W. Krasner, H. S. Weinberg, S. D. Richardson, S. J. Pastor, R. Chinn, M. J. Sclimenti…, and A. D. Thruston, "Occurrence of a new generation of disinfection byproducts," Environmental Science & Technology, Vol. 40(23), pp. 7175–7185, 2006. [CrossRef]

[155] S. Brosillon, M. Lemasle, E. Renault, D. Tozza, V. Heim, and A. Laplanche, "Analysis and occurrence of odorous disinfection by-products from chlorination of amino acids in three different drinking water treatment plants and corresponding distribution networks," Chemosphere, Vol. 77(8), pp. 1035–1042, 2009. [CrossRef]

[156] W. Qi, L. Fang Yee, and H. Jiangyong, "Relationship between organic precursors and N-nitrosodimethylamine (NDMA) formation in tropical water sources," Journal of Water and Health, Vol. 12(4), pp. 736–746, 2014. [CrossRef]

[157] P. Jutaporn, M. D. Armstrong, and O. Coronell, "Assessment of C-DBP and N-DBP formation potential and its reduction by MIEX® DOC and MIEX® GOLD resins using fluorescence spectroscopy and parallel factor analysis," Water Research, Vol. 72, Article 115460, 2020. [CrossRef]

[158] J. Wang, F. Zheng, Z. Yu, J. Chen, and H. Lu, "Dissolved organic nitrogen derived from wastewater denitrification: Composition and nitrogenous disinfection byproduct formation," Journal of Hazardous Materials, Vol. 440, Article 129775, 2022. [CrossRef]

[159] P. G. Jang, H. G. Cha, "Long-term changes of disinfection byproducts in treatment of simulated ballast water," Ocean Science Journal, Vol. 55(2), pp. 265–277, 2020. [CrossRef]

[160] H. Chen, M. S. Ersan, N. Tolić, R. K. Chu, T. Karanfil, and A. T. Chow, "Chemical characterization of dissolved organic matter as disinfection byproduct precursors by UV/fluorescence and ESI FT-ICR MS after smoldering combustion of leaf needles and woody trunks of pine (Pinus jeffreyi)," Water Research, Vol. 209, Article 117962, 2022. [CrossRef]

[161] G. Hua, J. Kim, and D. A. Reckhow, "Disinfection byproduct formation from lignin precursors," Water Research, Vol. 63, pp. 285–295, 2014. [CrossRef]

[162] M. Altarawneh, A. Saeed, M. Al-Harahsheh, and B.Z. Dlugogorski, "Thermal decomposition of brominated flame retardants (BFRs): Products and mechanisms," Progress in Energy and Combustion Science, Vol. 70, pp. 212–259, 2019. [CrossRef]

[163] G. He, T. Zhang, Q. Zhang, F. Dong, and Y. Wang, "Characterization of enoxacin (ENO) during ClO2 disinfection in water distribution system: Kinetics, byproducts, toxicity evaluation and halogenated disinfection byproducts (DBPs) formation potential," Chemosphere, Vol. 283, Article 131251, 2021. [CrossRef]

[164] G. He, T. Zhang, F. Zheng, C. Li, Q. Zhang, F. Dong, and Y. Huang, "Reaction of fleroxacin with chlorine and chlorine dioxide in drinking water distribution systems: Kinetics, transformation mechanisms and toxicity evaluations," Chemical Engineering Journal, Vol. 374, pp. 1191–1203, 2019. [CrossRef]

[165] G. He, T. Zhang, Y. Li, J. Li, F. Chen, J. Hu, and F. Dong, "Comparison of fleroxacin oxidation by chlorine and chlorine dioxide: Kinetics, mechanism and halogenated DBPs formation," Chemosphere, Vol. 286(Part 1), Article 131585, 2022. [CrossRef]

[166] Y. Yang, J. Shi, Y. Yang, J. Yin, J. Zhang, and B. Shao, "Transformation of sulfamethazine during the chlorination disinfection process: Transformation, kinetics, and toxicology assessment," Journal of Environmental Sciences, Vol. 76, pp. 48–56, 2019. [CrossRef]

[167] Z. Wu, J. Fang, Y. Xiang, C. Shang, X. Li, F. Meng, and X. Yang, "Roles of reactive chlorine species in trimethoprim degradation in the UV/chlorine process: Kinetics and transformation pathways," Water Research, Vol. 104, pp. 272–282, 2016. [CrossRef]

[168] S. Zhang, T. Lin, W. Chen, H. Xu, and H. Tao, "Degradation kinetics, byproducts formation and estimated toxicity of metronidazole (MNZ) during chlor(am)ination," Chemosphere, Vol. 235, pp. 21–31, 2019. [CrossRef]

[169] E. Aghdam, Y. Xiang, J. Sun, C. Shang, X. Yang, and J. Fang, "DBP formation from degradation of DEET and ibuprofen by UV/chlorine process and subsequent post-chlorination," Journal of Environmental Sciences, Vol. 58, pp. 146–154, 2017. [CrossRef]

[170] Y. Wang, H. Liu, G. Liu, and Y. Xie, "Oxidation of diclofenac by aqueous chlorine dioxide: Identification of major disinfection byproducts and toxicity evaluation," Science of The Total Environment Vol. 473–474, pp. 437–445, 2014. [CrossRef]

[171] J. Li, J. He, Md. T. Aziz, X. Song, Y. Zhang, and Z. Niu, "Iodide promotes bisphenol A (BPA) halogenation during chlorination: Evidence from 30 X-BPAs (X = Cl, Br, and I)," Journal of Hazardous Materials, Vol. 414, Article 125461, 2021. [CrossRef]

[172] S. Zheng, J. Shi, J. Zhang, Y. Yang, J. Hu, and B. Shao, "Identification of the disinfection byproducts of bisphenol S and the disrupting effect on peroxisome proliferator-activated receptor gamma (PPARγ) induced by chlorination," Water Research, Vol. 132, pp. 167–176, 2018. [CrossRef]

[173] Y. Gao, S. Y. Pang, J. Jiang, J. Ma, Y. Zhou, J. Li…, and L. P. Yuan, "Transformation of flame retardant tetrabromobisphenol a by aqueous chlorine and the effect of humic acid," Environmental Science & Technology, Vol. 50(17), pp. 9608–9618, 2016. [CrossRef]

[174] P. Durand, L. Breuer, P. J. Johnes, G. Billen, A. Butturini, G. Pinay…, and R. Wright, "Nitrogen processes in aquatic ecosystems," 2011. https://centaur.reading.ac.uk/20855/8/Chapter%25207%2520ENA%2520Durand%2520Breuer%2520Johnes%25202011.pdf. Accessed on May 3, 2024.

[175] F. Zheng, S. Xu, W. Chai, D. Liu, and H. Lu, "Fermentation liquid as a carbon source for wastewater nitrogen removal reduced nitrogenous disinfection byproduct formation potentials of the effluent," Science of The Total Environment, Vol. 832, Article 155115, 2022. [CrossRef]

[176] Y. Du, X. T. Lv, Q. Y. Wu, D. Y. Zhang, Y. T. Zhou, L. Peng, and H. Y. Hu, "Formation and control of disinfection byproducts and toxicity during reclaimed water chlorination: A review," Journal of Environmental Sciences, Vol. 58, pp. 51–63, 2017. [CrossRef]

[177] J. K. Liang, Y. Lu, Z. M. Song, B. Ye, Q. Y. Wu, and H. Y. Hu, "Effects of chlorine dose on the composition and characteristics of chlorinated disinfection byproducts in reclaimed water," Science of the Total Environment, Vol. 824, Article 153739, 2022. [CrossRef]

[178] H. Zhai, X. Zhang, X. Zhu, J. Liu, and M. Ji, "Formation of brominated disinfection byproducts during chloramination of drinking water: New polar species and overall kinetics," Environmental Science & Technology, Vol. 48, pp. 2579–2588, 2014. [CrossRef]

[179] H. Komulainen, "Experimental cancer studies of chlorinated by-products," Toxicology, Vol. 198(1–3), pp. 239–248, 2004. [CrossRef]

[180] D. Baytak, A. Sofuoglu, F. Inal, S. C. Sofuoglu, "Seasonal variation in drinking water concentrations of

disinfection by-products in IZMIR and associated human health risks," Science of The Total Environment, Vol. 407(1), pp. 286–296, 2008. [CrossRef]

[181] M. Khallef, R. Liman, M. Konuk, İ. H. Ciğerci, D. Benouareth, M. Tabet, A. Abda, "Genotoxicity of drinking water disinfection by-products (bromoform and chloroform) by using both Allium anaphase-telophase and comet tests," Cytotechnology, Vol. 67(2), pp. 207–213, 2015. [CrossRef]

[182] T. I. T. Nkambule, "Natural Organic Matter (NOM) in South African waters : Characterization of NOM, treatability and method development for effective NOM removal from water," 2012. https://www.proquest.com/docview/2566004979/abstract/FB-5C4113E93B43BAPQ/1. Accessed on May 3, 2024.

[183] F. Dong, Q. Lin, C. Li, G. He, and Y. Deng, "Impacts of pre-oxidation on the formation of disinfection byproducts from algal organic matter in subsequent chlor(am)ination: A review," Science of The Total Environment, Vol. 754, Article 141955, 2021. [CrossRef]

[184] B. Sun, Y. Wang, Y. Xiang, and C. Shang, "Influence of pre-ozonation of DOM on micropollutant abatement by UV-based advanced oxidation processes," Journal of Hazardous Materials, Vol. 391, Article 122201, 2020. [CrossRef]

[185] K. Doederer, W. Gernjak, H. S. Weinberg, and M. J. Farré, "Factors affecting the formation of disinfection by-products during chlorination and chloramination of secondary effluent for the production of high quality recycled water," Water Research, Vol. 48, pp. 218–228, 2014. [CrossRef]

[186] X. Yang, C. Shang, and J. C. Huang, "DBP formation in breakpoint chlorination of wastewater," Water Research, Vol. 39(19), pp. 4755–4767, 2005. [CrossRef]

[187] G. Hua, and D. A. Reckhow, "DBP formation during chlorination and chloramination: Effect of reaction time, pH, dosage, and temperature," Journal AWWA, Vol. 100(8), pp. 82–95, 2008. [CrossRef]

[188] C. Tsaridou, A. J. Karabelas, "Drinking water standards and their implementation—A critical assessment," Water, Vol. 13(20), Article 2918, 2021. [CrossRef]

[189] J. C. Vickers, M. A. Thompson, and U. G. Kelkar, "The use of membrane filtration in conjunction with coagulation processes for improved NOM removal," Desalination, 102(1–3), pp. 57–61, 1995. [CrossRef]

[190] D. Ghernaout, B. Ghernaout, and A. Kellil, "Natural organic matter removal and enhanced coagulation as a link between coagulation and electrocoagulation," Desalination and Water Treatment, Vol. 2(1–3) pp. 203–222, 2009. [CrossRef]

[191] X. Wang, Y. Mao, S. Tang, H. Yang, Y. F. Xie, "Disinfection byproducts in drinking water and regulatory compliance: A critical review," Frontiers of Environmental Science & Engineering, Vol. 9(1), pp. 3–15, 2015. [CrossRef]

[192] Y. Qian, Y. Chen, Y. Hu, D. Hanigan, P. Westerhoff, and D. An, "Formation and control of C- and N-DBPs during disinfection of filter backwash and sedimentation sludge water in drinking water treatment," Water Research, Vol. 194, Article 116964, 2021. [CrossRef]

[193] J. M. Laîné, J. G. Jacangelo, E. W. Cummings, K. E. Carns, and J. Mallevialle, "Influence of bromide on low-pressure membrane filtration for controlling DBPs in surface waters," Journal AWWA, Vol. 85(6), pp. 87–99, 1993. [CrossRef]

[194] J. G. Jacangelo, R. Rhodes Trussell, and M. Watson, "Role of membrane technology in drinking water treatment in the United States," Desalination, Vol. 113(2¬–3), pp. 119–127, 1997. [CrossRef]

[195] V. Uyak, and I. Toroz, "Disinfection by-product precursors reduction by various coagulation techniques in Istanbul water supplies," Journal of Hazardous Materials, Vol. 141(1), pp. 320–328, 2007. [CrossRef]

[196] T. Bond, E. H. Goslan, B. Jefferson, F. Roddick, L. Fan, and S. A. Parsons, "Chemical and biological oxidation of NOM surrogates and effect on HAA formation," Water Research, Vol. 43(10), pp. 2615–2622, 2009. [CrossRef]

[197] G. S. Wang, S. T. Hsieh, and C. S. Hong, "Destruction of humic acid in water by UV light—catalyzed oxidation with hydrogen peroxide," Water Research, 34(15), pp. 3882–3887, 2000. [CrossRef]

[198] Y. Jiang, J. E. Goodwill, J. E. Tobiason, and D. A. Reckhow, "Comparison of ferrate and ozone pre-oxidation on disinfection byproduct formation from chlorination and chloramination," Water Research, Vol. 156, pp. 110–124, 2019. [CrossRef]

[199] Y. H. Chuang, A. Szczuka, F. Shabani, J. Munoz, R. Aflaki, S. D. Hammond, and W.A. Mitch, "Pilot-scale comparison of microfiltration/reverse osmosis and ozone/biological activated carbon with UV/hydrogen peroxide or UV/free chlorine AOP treatment for controlling disinfection byproducts during wastewater reuse," Water Research, Vol. 152, pp. 215–225, 2019. [CrossRef]

[200] Y. Lu, F. Tang, Y. Wang, J. Zhao, X. Zeng, Q. Luo, and L. Wang, "Biodegradation of dimethyl phthalate, diethyl phthalate and di-n-butyl phthalate by Rhodococcus sp. L4 isolated from activated sludge," Journal of Hazardous Materials, Vol. 168(2–3), pp. 938–943, 2009. [CrossRef]

[201] E. S. Peterson, R. S. Summers, and S. M. Cook, "Control of pre-formed halogenated disinfection byproducts with reuse biofiltration," Environmental Science & Technology, Vol. 57(6), pp. 2516–2526, 2023. [CrossRef]

[202] J. Hu, Q. Yang, and J. L. Wang, "Biodegradation of di-n-butyl phthalate in sequencing batch reactor bioaugmented with Micrococcus sp. and the bacterial community analysis," International Journal of Environmental Science and Technology, Vol. 12, pp. 2819-2828, 2015. [CrossRef]

[203] M. A. Zazouli, and L. R. Kalankesh, "Removal of precursors and disinfection by-products (DBPs) by membrane filtration from water; a review," Journal

of Environmental Health Science and Engineering, Vol. 15, pp. 25, 2017. [CrossRef]

[204] I. Petrinic, J. Korenak, D. Povodnik, and C. Hélix-Nielsen, "A feasibility study of ultrafiltration/reverse osmosis (UF/RO)-based wastewater treatment and reuse in the metal finishing industry," Journal of Cleaner Production, Vol. 101, pp. 292–300, 2015. [CrossRef]

[205] E. Molina Alcaide, and A. Nefzaoui, "Recycling of olive oil by-products: Possibilities of utilization in animal nutrition," International Biodeterioration & Biodegradation, Vol. 38(3–4), pp. 227–235, 1996. [CrossRef]

[206] N. T. Holland, M. T. Smith, B. Eskenazi, and M. Bastaki, "Biological sample collection and processing for molecular epidemiological studies," Mutation Research/Reviews in Mutation Research, Vol. 543(3), pp. 217–234, 2003. [CrossRef]

[207] C. M. López-Vázquez, C. M. Hooijmans, D. Brdjanovic, H. J. Gijzen, and M. C. M. van Loosdrecht, "Factors affecting the microbial populations at full-scale enhanced biological phosphorus removal (EBPR) wastewater treatment plants in The Netherlands," Water Research, Vol. 42(10–11), pp. 2349–2360, 2008. [CrossRef]