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Climate Change Factors and the Formation of Potential Brominated Disinfection Byproducts in Taiwan

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ABSTRACT

This review is on Climate Change Factors and the Formation of Potential Brominated Disinfection Byproducts in Taiwan. Disinfection byproducts (DBPs) formation is one of the drawbacks of disinfecting practices that occur due to the interaction between natural organic matter (NOM) and applied disinfectant. It has been observed that temperature has a clearly defined relationship with DBP formation possibly due to increase in the reaction rate between chlorine and organic matter content. Increasing global average temperature also resulted in thermal expansion in the oceans and melting of glaciers, leading to rising sea levels and accordingly increased saltwater intrusion into the coastal aquifers, resulted in the formation of brominated DBPs. In addition, increasing the frequency of storms is one of the driving forces for the increased NOM trend and consequently elevated DBP formation potential. Based on this, climate-induced factors have a critical role in the characteristics of released NOM and correspondingly DBPs formation.

Keywords: *Disinfection byproduct; Organic matter; Climate change; Extreme weather events*

INTRODUCTION

Disinfection byproducts (DBPs) formation is one of the drawbacks of disinfecting practices that occur due to the interaction between natural organic matter (NOM) and applied disinfectant. Disinfection is not without negative side effects. It is known that disinfection is affected by many parameters such as water temperature, pH, type of existing microorganisms, disinfection method, disinfectant dose, contact time, inorganic and organic material existing in water (Alver et al 2018). Water is not just involved in many important functions on the earth; it is one of the most essential component of any forms of life. Accordingly, safe and sanitized water supply are among the basic human needs and rights. “Water quality” is generally means the suitability of water to sustain various applications or processes. While a range of variables can define water quality, many practices

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have common requirements for certain variables (Meybeck et al. 1996). In most cases, the quality of water sources can decrease significantly when chemicals are transported into surface and ground waters (Delpla & Rodriguez 2016). Along with chemical compounds found in water, aquatic microbes as primary constituents of all known water sources might cause adverse effects to human health (Hess-Erga et al. 2019).

However, chemical and microbial load are not the only contributors to water quality. Recent studies have shown that climate change could have additional deleterious effects on chemical and microbiological water quality by rising levels of suspended sediments, organic matter (OM), pathogens and other contaminants in surface waters (Delpla & Rodriguez 2016). Variations in rainfall intensity, frequency and duration could possibly affect contaminant transport by run-off from the watershed to surface water sources including rivers and lakes, which in turn constitute additional burden on water treatment facilities (Delpla & Rodriguez 2017). Hurricane events can also alter the chemical composition of dissolved organic matter (DOM). An increase in aromaticity, lignin content, and abundance of humic-like compounds have been observed during hurricanes and storm events (Majidzadeh et al. 2020).Disinfecting is a common practice in water treatment plants and is largely responsible for the standard of health today. Drinking disinfected water has largely eradicated infectious waterborne diseases from our society (Tarhan 2019). Disinfection is thus a crucial water treatment method as it makes the water free of pathogenic micro organisms responsible for serious health issues (Mazhar et al. 2020).

Disinfection technologies

There are many available methods used for disinfection purposes. Boiling is the oldest and most common water treatment method in developing countries and among the vulnerable, poor population in rural areas (Rosa & Clasen 2010). Regarding more chemical-based disinfecting process, few techniques are currently being used in public health practices. A disinfectant should have some properties to be applied in disinfection process of water treatment strategies. It should be able to remove pathogenic organisms in the expected temperature range and the contact time provided in the composition and quantity of water to be disinfected, durable, economical and easy to use (APHA 1998). While many disinfectants are used alone or in combinations in the health-care setting, chlorine-based disinfectants are the most commonly used chemicals for disinfecting drinking or public water sources. Pros and cons of using different disinfectants have been described in Table 1.

Table 1: Basic disinfectants and their characteristics

Disinfection method	Characteristics	Advantages	Disadvantages	References
Chlorine gas	Toxic, yellow-green gas at normal pressure and liquid at high pressure	•Very effective against most types of pathogens •Relatively simple maintenance and operation •Inexpensive	•Corrosive •High toxicity • Taste and odor problem •Disinfection by-product formation	(Sorlini et al. 2015)
Chlorine dioxide	Reddish to yellowish-green gas at room temperature with a strong odor	•Very effective against most types of pathogens •Under proper conditions, halogenated DBPs are not formed •Not pH dependent	•Expensive •High toxicity •Unstable •Decomposes in sunlight • May form inorganic disinfection byproducts	(Anderson *et al.* 1982; Gilca et al. 2020)
Chloramination	Are formed when water-containing ammonia is chlorinated or ammonia added to chlorinated water.	•Effective bactericides •Less toxic and corrosive •Relatively long-lasting residuals •Less formation of DBPs	•Less effective against viruses or protozoa •Taste and odor problems •Need longer contact time	(Wang et al. 2019)
Ozone	Colorless gas with pungent odor which is formed by passing dry air through a high voltage electrodes system	•Very effective against most types of pathogens •No by-product formation •Requires shorter contact time and dosage	•Expensive •Highly unstable •No lasting residuals •Potential fire hazard and toxicity issue	(Pichel et al. 2019)
Ultraviolet	Short-wavelength ultraviolet light that penetrates the cell wall of an organism	•Very effective in against most types of pathogens •Requires shorter contact time •No DBP formation	•Less effective against viruses •No lasting residuals protection •Lack of sensitivity and selectivity	(Cimetiere and De Laat 2014; Afifi and Blatchley 2016)
Bromination	Bromine tablets slowly dissolve in water to provide active bromine sanitiser in the form of hypobromous acid	•Less pH dependent •No taste and odor problems •Needs less contact time	•Expensive •Acidic: destroys total alkalinity •High toxicity •Hard to obtain residuals •Brominated DBPs problem	(Richardson et al. 2010 Lourencetti et al. 2012)
Iodinization	Elemental iodine is less soluble in water. A saturated aqueous solution of iodine is produced by passing water through a column of crystalline iodine	• Low toxicity •Greater chemical stability •Provides protection across a wider pH range	•Less effective at low temperature •Expensive •Irritating •Long-term safety is not established	(WHO 2018; Liu et al. 2019)

Chlorine disinfection

The most common disinfectant for various water treatment scenarios, and the one that historically has made the greatest contribution to the eradication of waterborne disease worldwide, is chlorine. Chlorine for water treatment is generally used as either liquefied chlorine gas or as sodium hypochlorite solution. The near universal adoption of chlorination can be attributed to its convenience and highly satisfactory performance as a disinfectant, which has been proved by decades of use. Chlorination has been even considered as the standard and a reference of disinfection efficiency to be used for comparison purposes. Applied chlorine should be in sufficient quantity to cover demand for the oxidation of organic and inorganic substances and leave the excess of so-called free chlorine, assuring bacteriostatic proprieties of water. Hypochlorous acid occurs in the NaOCl solution with strong alkaline proprieties which itself forms by addition of gas chlorine to dilute soda lye. Typically, hypochlorite sodium is used in small-scale swimming pools (Dychdala 1991).

Chlorine dioxide disinfection

Chlorine dioxide (ClO_2) is a faster-acting disinfectant than elemental chlorine. Since it may end up with excessive amounts of chlorite in the treated water, it is relatively rarely used. Although most of the ClO_2 is used up during the treatment, it by-product – chlorite (ClO_2^-) and chlorate (ClO_3^-) ions appear in the distribution system. Some studies on chlorine dioxide have also identified taste and odor problems as numbers of complaints about taste and odors were increased with the presence of ClO_2 (Dietrich et al. 1992).

Chloramination disinfection

Chloramines are formed during a reaction between chlorine (Cl_2) and ammonia (NH_3). To have chloramines as a disinfectant, ammonia is added to chlorinated water. The chlorine and ammonia then react to form chloramine. The use of chloramine is becoming more common as a disinfectant. Although chloramine is not considered as a strong oxidant, it provides a longer-lasting residual than free chlorine due to its lower redox potential compared to free chlorine. While the reaction mechanism is slower, chloramines are as effective as chlorine for the deactivation of bacteria and other microorganisms. However, water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates as a by-product. It is thus suggested to use chloramine decay index to monitor the occurrence of nitrification in drinking water distribution system (Moradi et al. 2017).

Ozone disinfection

Ozone is an unstable molecule, consists of three oxygen atoms which readily gives up one atom of oxygen providing a strong oxidant which is toxic to most waterborne and harmful microorganisms. Ozone is becoming a popular drinking water disinfectant worldwide, mainly due to its satisfactory efficiency for eradicating microorganisms (Richardson et al. 1999) as well as the call to decrease the use of free chlorine in water treatment practices. In addition, when ozone decomposes it generates intermediates radical that are even more powerful oxidizing agents than ozone itself (Machulek et al. 2013). However, since ozone is relatively unstable in water, it decomposes to oxygen at a rate proportional to the pH of the water. For instance, at pH 8, typical pH of many drinking-water supplies, the ozone half-life is less than one hour, which is too short to ensure that a residual disinfectant capacity will remain in effective levels at the far reaches of a distribution network. Moreover, ozone reacts with natural organic substances producing low-molecular-weight oxygenated byproducts that generally are more biodegradable than their precursors. These substances will stimulate “regrowth” issue by promoting biological growth in a distribution system, which further limits the disinfection efficacy of ozone (Glaze 1987).

Ultraviolet (UV) disinfection

UV has been successfully used in various types of industries including, pharmaceutical and cosmetic, food and beverage, construction and electronic engineering, and wastewater treatment. UV was first used for drinking water treatment in the early 1900s but was abandoned shortly thereafter due to high operating costs, less reliable equipment, maintenance issues, and the advent of chlorination with high reliability and efficiency. However the comparison result is not same for all cases, particularly virus-based contamination. Evaluating the field performance of UV systems, Slade et al. (1986), compared well-head disinfection of virus-contaminated groundwater using free chlorine and UV, and found that UV is a stronger virucide than free chlorine. Nevertheless, UV light is only able to remove microorganisms and does not remove other contaminants like heavy metals, salts, chlorine or man-made contaminants. Moreover, UV light is easily affected by water clarity and is only effective in low turbidity water. Besides, UV systems are energy dependent and are not suitable for emergency cases where electricity is not available (Adeyemo et al. 2019).

Bromination and iodinization disinfection

Bromine and iodine can also be used as disinfectants. Historically, travelers and backpackers have used iodine to disinfect their portable drinking water because it is both economical and easy to use. However many people do not like the unpleasant taste of iodine in their treated water and some may have concerns with the thyroid disorders risk associated with iodine ingestion in water treatment. Accordingly, iodine is better suited to temporary situations such as disaster response and emergency operations as there is still considerable controversy about the maximum safe iodine dose and duration of consumption after iodine is ingested more than recommended daily intake (Backer & Hollowell 2000).

Bromine is another oxidizing halogen used successfully in the disinfecting of swimming pool waters. It is considered as a good germicidal agent while it is easy to use with low handle risk. Moreover, bromine does not cause eye irritations and odors problems among swimmers. It has been also used in water fountains and cooling towers. However, bromine application in potable water disinfection is very limited due to the operating costs, associated risk with brominated by products, and lack of knowledge on its efficacy in certain areas (WHO 2018).

Disinfection efficiency and climate change

Disinfection is not without negative side effects. It is known that disinfection is affected by many parameters such as water temperature, pH, type of existing microorganisms, disinfection method, disinfectant dose, contact time, inorganic and organic material existing in water (Alver et al 2018). Although disinfection is the method for the removal or inactivation of pathogens, it may end up with the formation of certain byproducts called disinfection byproducts (DBPs). While many different DBPs exist in treated drinking water trihalomethanes (THMs) and haloacetic acids (HAAs) are of the most concern, as they are good indicators of the overall DBPs in chlorinated water (Egorov et al. 2003; Tsitsifli & Kanakoudis 2018). DBPs are formed because of the disinfectants reaction with organic or inorganic molecules present in the treated water. Several factors affecting DBP formation including contact time, type and concentration of chemical disinfectant, temperature, type of available microorganisms, and water characteristics (Tarhan 2019).

Moreover, DBPs are formed along the water distribution network depending on the retention time in storage tanks and pipelines, as well as the disinfectant ability to maintain a residual along the distribution network (Tsitsifli & Kanakoudis 2018). The potential effect of climate change on water resources is a matter of concern as both the quantity and quality of water sources are being deteriorating as a result of increased temperature and extreme weather events (Kantamaneni & Du 2017). The increases in temperature and sea level rise over the past 20 years have been reported to be much greater than those over the last 100 years, and extreme precipitation events are likely to become more intense and frequent in the future (IPCC 2014a,b). In recent years, strong typhoons and hurricanes have frequently hit Southeast Asia and the eastern United States. Coastal and low-lying areas covered with muddy waters experiencing severe soil erosion after heavy rain consist of large quantity of clay and silt. Storm runoff in the flooding season affect the water quality where turbidity of large rivers significantly increases. In early March of 1995, a heavy spring precipitation caused the turbidity in the Missouri River to increase from 100 to over 1,000 NTUs. In Taiwan, the number of typhoons per year increased after 2004, and the turbidity in many rivers and reservoirs often exceeded 10,000 NTUs during storm seasons (Chin et al. 2010). In the similar way, a considerable rise in hurricane counts between 1980 and 2013, along with much of the interannual variability have been observed in the North Atlantic Ocean (Figure 1).

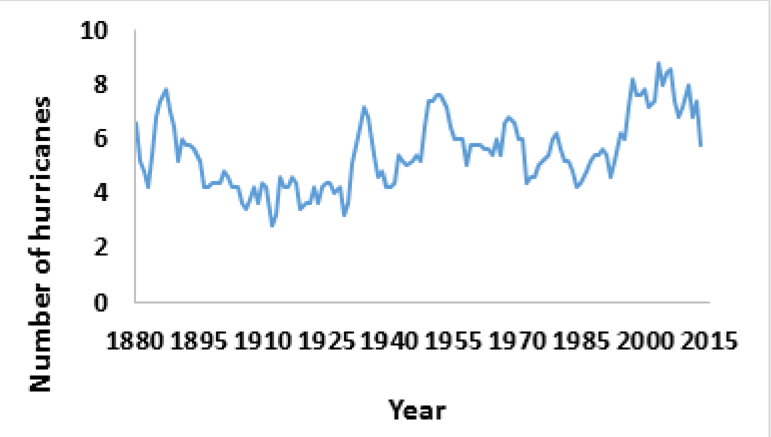

Fig 1: Total number of hurricanes that formed in the North Atlantic Ocean each year from 1880 to 2013 (Data source: NOAA 2016).

Effect of Temperature

Temperature is one of the most crucial climate-related factors that can cause considerable changes in water quality. Relying on the most conservative model, it is expected to have an increase in ambient temperature about 4.8 °C from 2081 to 2100 (IPCC 2014a,b). Following the increase in ambient temperature, water temperature, especially at the surface, will also increase. According to the prediction results by Komatsu et al. (2007), the 10-year average surface water temperature in the 2090s could be 3.4 °C higher than that in the 1990s. Compare with other climate change effects, temperature has a more clearly defined relationship with DBP formation. Water temperature may vary seasonally between 5 and 25ºC at the treatment plant and in the distribution system.

Besides, many homes residents store water in rooftop tanks to maintain access to safe water when there is a lapse in the supply. Accordingly, water with a chlorine residual content may be heated to as high as 40ºC for a significant time period in customers' water heaters (Zhang et al. 2013). With the Arrhenius equation being widely accepted, it is generally known that chemical reactions increase with temperature. Therefore, increasing temperature increases the rate of reaction leading to increase in DBPs formation (Saidan et al. 2015). Zhang et al. (2013) noted that the regulated DBPs increase steadily even at the highest temperatures (50ºC) and Hua and Reckhow (2008) observed an increase in THM and HAA concentrations as temperature was increased from 5 to 30 °C.

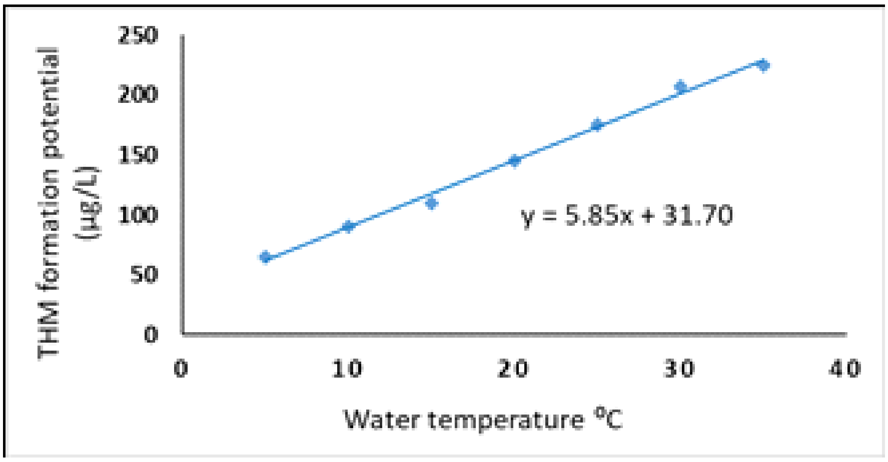

Fig. 2: The influence of water temperature on the THMFP (water pH: 7.15, reaction time: 80 h, TOC content: 4.38 mg/L) (Ramavandi et al. 2015).

While increased temperature is known to increase the rate of most reactions, it has a greater effect on halogenation reactions than dehalogenation, resulting in higher concentrations of DBPs (Zhang et al. 2013; Hua & Reckhow 2008).

Moreover, the characteristics and composition of organic precursors have been found to be significantly influenced by microbial factor and seasonal variations (Uyak et al. 2005). The highest formation rate of THMs mainly occurs in the summer due to the high microbial activity resulted in higher TOC to promote THMs formation while the lowest formation rate of THMs occurs in winter due to the low microbial activity. For instance, Uyak et al. found that while the reactivity of organic matter varied annually, the maximum concentrations can be observed in autumn when the proportion of hydrophobic material is at its peak, before falling to a minimum in winter (Uyak et al. 2008).

Effect of algal blooms

In surface waters increased temperature will affect gas partitioning, lowering down the concentration of dissolved oxygen (DO), and more favorable to algal blooms, which mainly occur in higher water temperatures and reduced mixing (George et al. 2007). Warmer water also makes movement of small organisms easier resulted in floating algae on the surface faster. Algal blooms absorb sunlight, making water even warmer and thus promoting more blooms (EPA 2019). Besides, algal-based DOM consists of more proteinaceous material that is associated with DBPs formation and is more difficult to remove and therefore eutrophic waterbodies could pose a potential long-term consequences and health risk (Ritson et al. 2014; Krasner 2009).

In a study by Gonsior et al. (2019) Algal-derived DOM from lysed *Microcystis aeruginosa* cells was drastically transformed upon chlorination with free chlorine. A diverse group of N-compounds with presumed chloramine functional groups was observed in their study which highlights the important role of ADOM and its ability to form different DBPs when compared to allochthonous or terrestrially-derived DOM (Gonsior et al. 2019).

Effect of sea level change

Increasing global average mean temperature is expected to cause thermal expansion in the oceans and melting of glaciers, leading to rising sea levels (USGCRP 2014; IPCC 2013). With continued global warming, sea level is likely to rise at least twice as fast as it did during the 20th century, resulting in a significant rise by 2050 and between 0.5 to 1 m of rise by 2100 (Figure 3).

Seawater contains elevated concentrations of bromide. As a result, coastal aquifers are expected to be subject to increased saltwater intrusion. Sea-level rise, combined with increased groundwater pumping can surge saltwater intrusion in coastal aquifers and estuaries in which may impair drinking water resources through warming groundwater and increasing salt content.

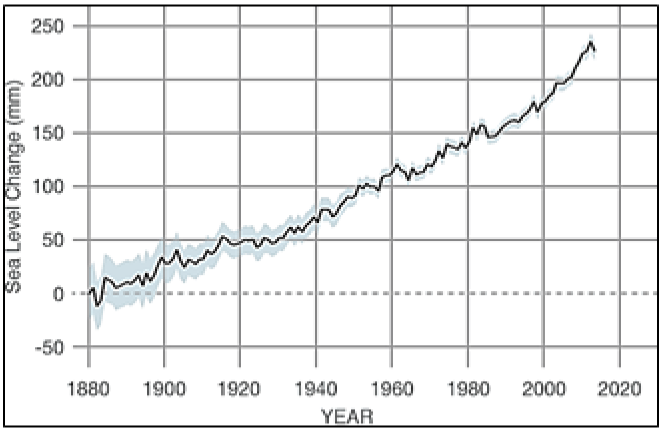

Fig. 3. Coastal tide gauge records of Global Mean Sea Level (GMSL): 1870-2013 (NASA 2020)

Moreover, climate-induced sea level rise may change natural groundwater flow patterns, causing an inland migration of the saltwater-freshwater interface (Badaruddin et al. 2015; Carretero et al. 2013; Giambastiani et al. 2007). In addition, seawater contains significantly higher concentrations of bromide than freshwater, resulting in higher bromide concentrations in source water affected by saltwater intrusion (WHO 2010). Elevated bromide concentrations in source water would in turn increase the formation and change the speciation of DBPs during drinking water treatment (Motz et al. 2014; Chen et al. 2010). When source water containing bromide is subjected to disinfection, the bromide is oxidized to form bromine, which then reacts with organic matter present in source water to form brominated and/or mixed bromo-chloro DBPs. Therefore, having bromide in source waters increases the rate and extent of DBP formation, especially when is known that the rate of bromination of organic matter is higher than the rate of chlorination (Heeb et al. 2014). Moreover, brominated DBPs showed negative outcomes at lower concentrations than their chlorinated analogs (Cantor et al. 2010; Richardson et al. 2007), and thus, the presence of bromide in source waters increases the health risk associated with the use of chlorinated drinking water (Regli et al. 2015; Yang et al. 2014).

To illustrate the effect of bromine concentration on DBPs formation, researchers used bromine incorporation factor (BIF) which is the ratio of moles of organic bromine to moles of total organic halogen (neglecting iodinated species) for a class of DBPs. The equations used to calculate the BIF for TTHMs is shown as an example (Boyer & Singer 2005):

$$BIF_{TTHM} = \frac{BDCM + 2.DBCM + 3.BF}{3.(CF + BDCM + DBCM + BF)} \qquad (1)$$

where: BDCM is bromodichloromethane,
DBCM is dibromochloromethane,
BF is bromoform, and
CF stands for chloroform.

The BIF for TTHM as a function of the molar ratio of initial bromide concentration to chlorine dose has been reported by Ged and Boyer (2014) (Figure 4). As shown, the BIF is greater than 0.5 for Br^{-}/Cl_2 equal to 0.065 meaning that the DBPs (here TTHM as an example) are greater than 50% brominated despite chlorine being present at 15 times higher concentration than bromide. Thus, the bromine addition to THMs is on the order of 10 times more effective than chlorine addition (Ged & Boyer 2014).

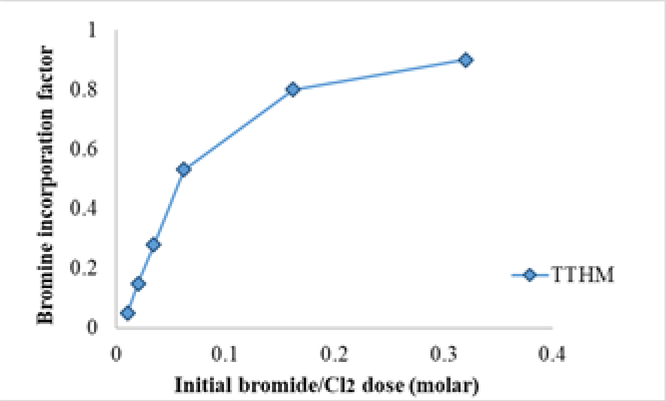

Fig. 4. Bromine incorporation factor for TTHM, as a function of the molar ratio of initial bromide concentration to chlorine dose.
Conditions:
pH = 8, temperature = 25 °C, reaction time = 24 h,
DOC ≈ 1.4 mg/L, Cl2/DOC mass ratio ≈ 2,
bromide = variable (Ged & Boyer 2014).

Effect of storms and heavy rainfall

Two types of extreme weather events are associated with precipitation: drought and heavy rainfall. Unlike drought, the effects of extremely heavy rainfall remain uncertain. Hrdinka et al. (2012) showed that even for a short period of time, extreme rainfalls has a stronger effect on water quality than drought. During heavy rainfall, high concentrations of dissolved organic matter (DOM) enters the water through different alluvial washouts, causing the deterioration of water quality. Moreover, the risk of waterborne diseases increases if extreme weather events become more frequent and intense (Hunter 2003). Severe rainfall events have a negative effect on source water quality and further influence DBP formation during water treatment process (Delpla & Rodriguez 2016). It is showed that organic matter increased between pre- and post-typhoon periods with a greater proportion of aromatic compounds. They also demonstrated the increasing percentage distribution of THM species throughout the distribution network, probably due to a longer contact time between chlorine and the organic matter in the pipelines. Rising DOM levels over a short period with a temporary change in dissolved organic carbon (DOC) structure can cause serious problems for water treatment. Presence of higher organic matter input suggest that allochthonous DOM will dominate over autochthonous types during storm events (Ritson et al. 2014). Therefore, monitoring and process optimization action to DOM quality change is highly needed.

In addition, in many countries, hurricanes, and typhoon rainfall significantly contribute the total annual rainfall. High loading of sediments and debris carried in stream flows during typhoon events may also cause heavy damage and serious water supply problems. In the study by Fakour et al. (2016), the average concentration of THMs in tap and drinking water samples collected after typhoon Soudelor (2015) increased compared with their pre-typhoon analogs. Based on their study, similar to Specific UV Absorbance (SUVA), turbidity and DOC distribution patterns (Figure 5), the THM levels in tap water samples after the typhoon increased from the maximum level of 32.8 ìg/L in pre-typhoon samples to 64.9 ìg/L for the samples collected after the typhoon event (Fakour et al. 2016). Furthermore, with increasing trend of DOC concentration in fresh waters reported in different studies (Skjelkvale et. Al. 2005; Freeman et al. 2001; Hongve et al. 2004), an increased frequency of typhoon events can be considered one of the driving forces responsible for the global DOC trend. Accordingly, formation potential of DBPs increases with increasing DOC concentration (Ramavandi et al. 2015; Fakour et al. 2016; Neale & Leusch. 2019).

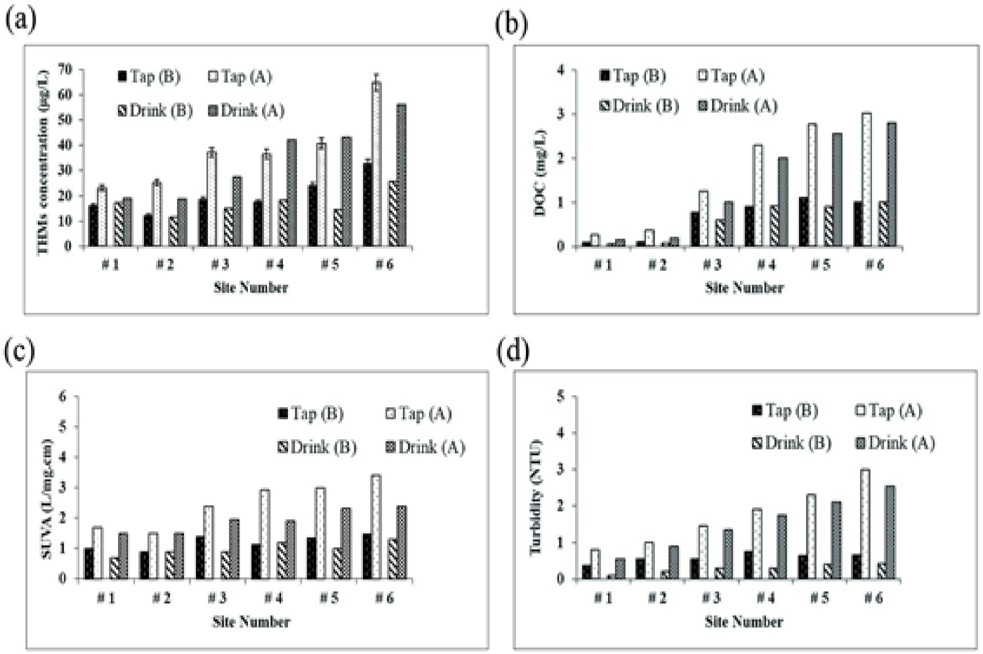

Fig 5: THMs (a), DOC (b), SUVA (c), and turbidity (d) variation before (B) and after (A) typhoon Soudelor (2015) at the six studied sampling sites (Fakour et al. 2016)

Effect of drought

Drought, the most obvious consequence of increasing temperature, may cause more severe environmental problems due to the effects of drying-wetting cycles (Evans et al. 2005). Although droughts are a natural feature of the hydrological regimes in most regions, it is yet hard to predict. Climate change, in turns has the potential to increase the frequency and magnitude of future droughts. Not only water scarcity and lack of accessibility are obvious results of droughts, but also there are severe water quality effects that occur during and after droughts (Wright et al. 2014). While there is an initial decrease in DOM concentration during the droughts, it is often followed by a large DOM ‘flush’ once rainfall occurs and high levels of DOM then remain in the region for a longer time (Evans et al. 2005; Worrall & Burt 2004).

During the drought, water consumption is restricted resulted in increased water age and lower chlorine residuals in the distribution network. When the rainfall re-occur and water source is re-filled, the TOC concentrations increase and DBP formation is thus enhanced as well (Wright et al. 2014). Moreover, due to prolonged drought and the drying climate, many large water reservoirs have detention times of up to several years, which affect the water quality and accordingly DBP formation potential in water treatment feeding by such waters (Liew et al. 2015). It is worth to note that droughts can fundamentally change many water quality parameters including nutrient cycling and biodiversity within both watersheds and reservoirs that may remain even for years after the event (Wright et al. 2014).

Summary and conclusions

Climate change effects are making extreme weather events, storms, droughts and heating events more frequent and intense. Many catchments and water reservoirs are likely to experience significant changes in their water quality reaching treatment plants. To control and limit public exposure to DBPs, which are unintended consequence of the water disinfection practices, the availability of precursors and contributing factors should be carefully monitored. The effects of climate-induced factors on DBP formation have been discussed in this review to capture the extent of contributing factors in source water quality parameters, which are then incorporated into DBP formation. Global warming has do far more than just increasing ambient temperature, as many DBP contributing factors including sea level rise, droughts, and algal blooms are important consequences of climate change crisis. The results of increasing heavy storms and extreme rainfall suggested that water quality deteriorates during and after the extreme events and the consequences remain in the region for considerable length of time. Along with heavy storms and land erosions, abundant DOM is washed out of soil, increasing DBP formation potential in leading water treatment plant. Climate-induced sea level rise increases salt intake in drinking water wells and feeding water reaching to treatment plant due to saltwater intrusion in coastal aquifers. As seawater contains elevated levels of bromine, when the sea level rise becomes severe, bromide may interact with functional groups in soils and promote the formation of additional DBP precursors, and a potential increase in brominated DBPs in the treated water. Regarding the coincident effects of contributing factors such as the linkage between drought and algal blooms, climate-induced water quality deteriorations depends on the combinatory effect of different environmental factors, which should be considered for future management plans and DBP formation modeling practices.

The information presented in this review, can be used for monitoring and management systems while presenting the basic principles for the development of an early warning system for water quality authorities. Further studies are also required to understand the specific relationship between different characteristics of each released DOM fractions by climate related factors and correspondingly formed DBPs, which are expected to increase with continues climate change effects.

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