DISINFECTION BY-PRODUCTS (DBPS) IN DRINKING WATER AND THEIR ASSOCIATED HEALTH RISK: A REVIEW

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ABSTRACT
A variety of known and unknown byproducts are formed through the reaction between disinfectants and natural organic matter during the disinfection process of water treatment for drinking purpose. Since their discovery in 1974, numerous studies have been carried out covering their formation, occurrence and associated adverse effects. These disinfection by products (DBPs) may pose both the non-carcinogenic and carcinogenic risks to human health. Most developed countries have their own guidelines, standards and regulations for DBPs in drinking water. However, the research and knowledge regarding this critical problem is still at rudimentary level in Bangladesh like other developing countries. Hence this paper reviews the various issues of DBPs and its adverse effects on human health available in the scientific literature to disseminate awareness about the presence of DBPs in the drinking water and the associated human health risk.

Keywords: Disinfection; drinking water quality; disinfection by-products; risk

INTRODUCTION
Since the dawn of the 20th century, the disinfection process has been routinely carried out to eradicate and inactivate the pathogens from water used for drinking purpose (Krasner et al., 2006; Richardson et al., 2008). Disinfection for drinking water reduces the microbial risk but may pose chemical threat to human health due to disinfection residues and their by-products (DBPs) when the organic and inorganic precursors are present in water (Sadiq and Rodriguez, 2004). Covering DBPs formation, occurrence and health effects, a significant research have been carried out in the last decade. DBPs in drinking water have received considerable attention because of their association with cancer and potential adverse reproductive effects. (Xiaomao et al., 2014). Disinfection byproducts are suspected to cause liver and kidney and human fetus damage (WHO, 2008). The most studied DBPs are the trihalomethanes (THMs) and haloacetic acids (HAAs), two classes of compounds that are regulated by the USEPA (2013), and have guidelines in Canada, Australia, the European Union, and the World Health Organization (WHO).

Both the Dhaka and Chittagong Water Supply and Sewerage Authority (DWASA and CWASA) use chlorine as disinfectant in water treatment for drinking purpose. Any process that uses chlorine gas directly or chlorine liberating chemicals or where chlorine is produced in the process, there is the possibility of the formation of chloro-organo compounds if alkanes, alkenes etc. are available. These include but are not limited to trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles, haloketones, haloaldehydes, chloropicrin, cyanogen chloride, and chlorophenols (Sadiq and Rodriguez, 2004). The by-products issue however has attracted relatively less attention in Bangladesh and no intensive study has been carried out yet. The goal of this paper is to present a brief overview of the occurrence of DBPs in drinking water and related human concern available in the scientific literature aiming at disseminating awareness about the presence of DBPs in the drinking water and the risk associated with the consumption of water containing DBPs to the inhabitant of the country.

DISINFECTANTS: BASIC INFORMATION
Water-soluble oxidants, which are produced either on-site (e.g., ozone) or off-site (e.g., chlorine) are used as chemical disinfectant. Chlorine, ozone, chlorine dioxide and chloramine are the most widely used chemical disinfectants (WHO, 2000). Beside these ultraviolet radiation are also applied to a number of water supply systems (AWWA, 2000; MOE, 2006). These disinfectants are administered as

a gas (e.g., ozone) or liquid (e.g. hypochlorite) at typical doses of several milligrams per litre, either alone or in combination (WHO Recommendations, 2008). Chowdhury et. al, (2009) summarizes the applications of various disinfectants, as well as their costs, disinfection efficiencies and stability in distribution systems which is given below (Table 1).

Table 1: Basic information of some widely used disinfectants (adapted from Chowdhury et. al, 2009)

Disinfectants	**Application**	**Cost**	**Disinfection efficiency**	**Oxidation**	**Stability**
Chlorine	Most common	Lowest	Excellent	Strong	Stable
Chloramine	Common	Moderate	Good	Weak	Stable
Chlorine dioxide	Occasional	High	Excellent	Selective	Unstable
Ozone	Common	High	Excellent	Strongest	Unstable
Ultraviolet Radiation	Emergency Use	Extremely high	Good	None	Unstable

Table 1 shows that in most cases, chlorine is relatively inexpensive and very effective disinfectant and has been widely used throughout the world as a chemical disinfectant, serving as the principal barrier to microbial contaminants in drinking-water (Clark et al, 1994; Sadiq and Rodriguez 2004; USEPA, 2013). Disinfectants have varying capacities to inactivate or kill pathogens. The environmental conditions such as temperature and pH as well as the types and nature of organisms, also affect the disinfection process. The efficiency of disinfection process can be characterized by dose and intensity and it is affected by different physico-chemical and biological factors (Gates, 1998). Table 2 shows a comparison of the disinfection efficiency of three disinfectants under varying environmental conditions. Disinfection efficiencies can be determined from the product of residual disinfectant concentration (C) and the contact time of the disinfectant in the water (t). Generally, inactivation of organisms' increases with increasing contact time (MWH, 2005). The pH has different effects on different disinfectants but in general chlorine is more effective against organisms in acidic conditions rather than in alkaline conditions (Sadiq and Rodriguez, 2004).

FORMATION OF DBPs IN DRINKING WATER

Upon the chemical reaction of organic and inorganic precursors present in water with chemical disinfectants, DBPs are formed. Natural organic matter (NOM) which is generally measured as total organic carbon (TOC) serves as the organic precursor, whereas bromide ion (Br^-) serves as the inorganic precursor (Rook, 1974). DBPs constitute a large family of compounds presenting various levels of toxicological effects: more than 600 DBPs have been detected, but few have been identified. Several hundred DBP species have been identified and new ones continued to emerge (Richardson, 2003).

Different water quality parameters such as pH, temperature, ammonia, carbonate alkalinity, TOC, bromide, and treatment conditions (e.g., disinfectant dose, contact time, removal of NOM before the point of disinfectant application, prior addition of disinfectant) influenced the formation of DBPs (WHO, 2000). Table 3 summarizes the DBPs identified as being formed from the use of chlorine, chlorine dioxide, chloramine and ozone. Trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles HANs, haloketones, chloropicrin and chloral hydrate are the identified major chlorination DBPs (AWWA, 2000)

Table 2. Disinfectant's efficiency at varying conditions (adapted from Sadiq and Rodriguez 2004)

Disinfectant	Dose (mg/l)	Organism (Group)	Contact Time (min)	pH	T(^{0}C)	Efficiency (%)
Chlorine	0.5	*Rota Virus* (V)	0.25	6.0	5	>99.99
	0.6-2.5	*Polio Virus* (V)	0.7-2.4		5	>99
	0.1	*C.jejuni* (B)	1	6.0	4	>99.99
	0.5	*Coliform* (B)	30	7.0	20	>99.99
	1.5	*G.lamblia* (P)	10	6-7	25	~ 99
	2.0	*MS2coliphage* (V)	10	6-7	25	~99.99
	2.0	*V. chloerae* (B)	30	7.0	20	>99.99
	1.1	*E. coli* (B)	2	7.0	5	>99.999
	0.61	*A. butzleri* (B)	1	7.1	5	>99.999
Monochloramin	10.0	*Rota virus* (V)	>360	8.5	5	~99
	1.0	*C.jejuni (B)*	15	8.0	5	>99
	80.0	*C.parvum* (P)	90		5	~99
	2.0	*MS2coliphage (V)*	1	7.0	5	~99
	2.0	*E.Intestinals*(P)	8-16			~99
Chlorinedioxide	0.5	*V.chloerae* (B)	< 1	6.0	5	>99

B: Bacteria, V: Viruses, P: Protozoa

Table 3: Disinfectants and their possible disinfectant by-products (WHO, 2000)

Chemical Class of DBPs	Types of Disinfectants			
	Chlorine/ hypochlorous acid	**Chlorine dioxide**	**Chloramine**	**Ozone**
Organo halogen compounds	THMs, HAAs, HANs, chloral hydrate, chloropicrin, chlorophenols, *N*-chloramines, halofuranones, bromohydrins	-------	HANs, cyanogen chloride, organic chloramines, chloramino acids, chloral hydrate	Bromoform, cyanogen bromide
Inorganic compounds	Chlorate (mostly from hypochlorite use)	Chlorite, chlorate	Nitrate, nitrite, chlorate, hydrazine	Chlorate, iodate, bromate, hydrogen peroxide, hypobromous acid, epoxides, ozonates
Non halogenated compounds	Aldehydes, cyanoalkanoic acids, alkanoic acids, benzene.	Unknown	Aldehydes, ketones	Aldehydes, ketoacids, ketones, carboxylic acids

ADVERSE EFFECTS OF DBPs

Carcinogenic and non-carcinogenic risks to human health may be posed due to chronic exposure to disinfection byproducts through the ingestion of drinking water, inhalation and dermal contact during regular indoor activities like showering, bathing, cooking (Xie YF, 2000). WHO recommendations (2008) report the adverse health effects through toxicological laboratory studies and adverse effects of some of the important DBPs. Linking chloroform to cancer in laboratory animals, the National Cancer Institute of USA published results in 1976. As a result, an important public health issue was born. Table 4 depicts significant adverse effects caused by various DBPs.

Table 4: Adverse effects of some important DBPs (adapted from Sadiq and Rodriguez, 2004)

By-product group	Compounds	Rating	Adverse effects
Trihalomethanes (THM)	Chloroform	Probable human carcinogen	Liver, kidney and reproductive effects and cancer
	Dibromochloromethane	Possible human carcinogen	Nervous system, liver, kidney and reproductive effects
	Bromodichloromethane	Probable human carcinogen sufficient laboratory evidence	Cancer, liver, kidney, and reproductive effects
	Bromoform	Probable human carcinogen sufficient laboratory evidence	Nervous system, Cancer, liver and kidney effects
Haloacetonitrile (HAN)	Trichloroacetonitrile	Possible human carcinogen	Cancer, mutagenic and clastogenic effects
Haloacetic acids (HAA)	Dichloroacetic acid	Probable human carcinogen sufficient laboratory evidence	Cancer, reproductive and developmental effects
Halogenated aldehydes and ketones	Formaldehyde	Probable human carcinogen	Mutagenic

OCCURANCE LEVEL AND GUIDELINES

Due to the potential health risks and widespread occurrence of DBPs in drinking water, many countries regulate DBPs in their drinking water. The common DBPs in drinking water are generally present at low-to-mid- $\mu g{\cdot}L^{-1}$ or sub-$\mu g{\cdot}L^{-1}$ levels in drinking water (Xie YF, 2000). Based on evidence of their adverse human health effects the DBPs regulation has been set, in particular cancer and reproductive disorders (Xiaomao *et al*., 2014). The US EPA (2013) has established the maximum allowable contaminant level of 0.08 mg/l for total THMs and of 0.06 mg/l for HAAs. However, in Bangladesh no drinking water quality guideline exists for DBPs, and awareness and monitoring of DBPs in drinking water is critically important for the country.

CONCLUDING REMARKS

Water disinfection has been used to improve the hygienic quality of drinking water by removing waterborne bacterial pathogens, and it is essential to understand better the chemistry, toxicology and epidemiology of chemical disinfectants and their associated DBPs. This will help create a balance between microbial and chemical risks and minimize the health risks associated with drinking-water. The research on DBPs in Bangladesh is still at rudimentary level, and hence standard set guidelines for DPBs is missing in the country to comply with. It is now a pressing demand to focus on the issues associated with DBP formation, health effects, regulatory compliance, including methods for DBPs analysis, occurrence levels, the mathematical models to estimate the formation and the fate of DBPs.

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