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Cancer Risk Analysis in Untreated and Photocatalytic Treated Water Containing THM

Cemil ÖRGEV[1], N. Pınar TANATTI[*1], Hülya DEMİREL[1], İ. Ayhan ŞENGİL[2]

Abstract

In this study, cancer risk analysis was investigated in untreated trihalomethanes (THMs) containing water using synthetic THM solution and after photocatalytic treatment with TiO_2 and ZnO of this water. Trace amounts of disinfection by-products remain in the water. In this study, cancer risk assessment was investigated water containing trihalomethanes (THMs) constituted with synthetic THM solution and after the photocatalytic treatment of this water, the cancer risk was determined depending on the presence of THM in the water. With the photocatalytic treatment method using ZnO and nano TiO_2 particles, THM removal was studied with synthetic water with an initial concentration of 300 µg/L. In the ZnO-catalyzed process chloroform 25 µg/L, BDCM 2.4 µg/L and DBCM 35 µg/L were found. However, in the TiO_2-catalyzed process, chloroform 49 µg/L and DBCM 28 µg/L were obtained. The cancer risk analysis and the hazard index of THMs through oral, dermal and inhalation ingestion from these waters were evaluated. Comparing the three different pathways, humans have a higher risk of cancer through oral ingestion than dermal and inhalation pathways. It has been determined that the cancer risk for ZnO treated water was reduced by 62% and for TiO_2 treated water by 69% when THMs by oral ingestion have examined compared to untreated water in cancer risk analysis. The cancer risks of oral ingestion are determined as acceptable low risk, but the cancer risk of THMs through dermal ingestion from dibromochloromethane plays an essential role in this study.

Keywords: Cancer risk assessment, photocatalytic treatment, trihalomethanes (THMs)

1. INTRODUCTION

Disinfection is a method used to eliminate pathogenic microorganisms in drinking water and prevent waterborne diseases since the early 1900s [1]. Chlorine is the most common chemical used in water disinfection and protects against microbial contamination by keeping minimum chlorine residues along the water distribution line [2, 3]. However, it was determined in the 1970s that it created

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harmful disinfection by-products that caused health problems in disinfection [4].

During the disinfection of water, chlorine reacts with natural organic substances (NOM) in the water, and various disinfection by-products (DBP) are formed [5, 6]. The hypochlorous acid (HOCl) and hypochlorite (OCl^-) ions formed during disinfection with chlorine tend to react with the aromatic parts of the NOM [7]. Trihalomethanes (THM) and haloacetic acids (HAA) are predominantly disinfection by-products that occur as a result of disinfectant reactions with DOM [8]. The four main components of the THM group are Chloroform, Dibromochloromethane (DBCM), Bromodichloromehane (BDCM), and Bromoform and also the most dominant type in surface waters is chloroform [9, 10].

These compounds have negative health effects on humans and many have been classified as possible or possible human carcinogens [11]. USEPA [12] classified chloroform, BDCM, and bromoform as possible carcinogens [13]. Various international regulatory agencies have regulated THM limit values worldwide [14]. EPA has determined the maximum pollutant level (MCL) of THMs as 80 μg / L [2].

People are exposed to THMs in different ways throughout their lives. In addition to using clean water as drinking water, this exposure also occurs during breathing and regular human activities such as cooking, showering, and using swimming pools. Therefore, people have accepted being exposed to THM in three different ways, oral, dermal, and respiratory [14-16]. Many studies have been conducted on the effects of exposure on human health, and THMs have been proven to be associated with bladder, colon, leukemia, stomach, and rectum cancer risks [17-21]. Also, studies have demonstrated that DBPs have negatively affected reproductive and growth abilities, such as growth retardation, infertility, preterm/low birth in humans [22,23]. In disinfection drinking water/wastewater treatment plants, THM concentrations in water should be determined and compared with EPA (TR) limit values and possible effects (exposure risk) in humans should be determined. While evaluating the health risks of toxic substances, it was accepted that people were exposed to these substances mostly orally in the traditional approach, but in the light of the studies conducted, respiratory and skin contact should be considered in risk determination [14, 16, 24-25].

It was determined that THM concentrations exceed the reference limit values of EPA in disinfection with chlorine in many studies [7]. Therefore, THM treatment has become important. Many literature studies have investigated the removal method of THM precursors, and the research of THMs removal methods has gained speed today. Adsorption [26], coagulation-flocculation [27] and ion exchangers [28] methods have been studied as removal methods of THM precursors. Microfiltration [29] and advanced oxidation processes have been studied as THM removal methods.

In this study, synthetic water containing THMs was first formed, and THMs purification was carried out in this water by photocatalytic oxidation. The health risk of THMs in synthetic waters before and after treatment has been determined. The presence of THMs in the treated waters was investigated due to the use of photocatalytic methods to minimize the disinfection by-products in the waters. Finally, it has been revealed by using the possible health risk (multi-pathway risk assessment) that may occur in people with the discharge of treated water to the receiving environment.

2. MATERIAL AND METHODS

2.1. Measurement method of THMs

THM measurements have been made according to SM 6232 C with the

SHIMADZU brand QP 2010 model GC/MS device. Extraction has done by shaking with a Tert Butyl Methyl Ether (Merck, Extra Pure) in a 1:1 (v:v) ratio for a 5 ml sample containing THM for 1 minute and phase separation has waited. Sodium Sulfate Anhydrous (Merck, Extra Pure Food Grade), which is conditioned at 450 °C for 4 hours to hold water that can remain in the samples, is taken into 4 ml vials and added to the sample after extraction.

Temperature program developed in GC / MS: column temperature is started at 40 °C for 2 minutes, waiting time increases by 8 °C per minute, reaching 220 °C and waiting for 5 minutes. The injection and detector temperature are 225 °C. Nitrogen was used as the carrier gas and the column pressure was 82.5 kPa.

2.2. Photocatalytic reactor design

The batch type of slurry photoreactor used for THM removal is shown in Figure 1. The outer part of the reactor is made of bright chrome steel and is in the shape of a cylinder with a height of 300 mm and a diameter of 100 mm. Six 6 Watt UV lamps are placed on the inner surface of the reactor at equal distances, which can be controlled separately. THM samples were placed in quartz tubes with a volume of 150 ml and placed in the center of the reactor.

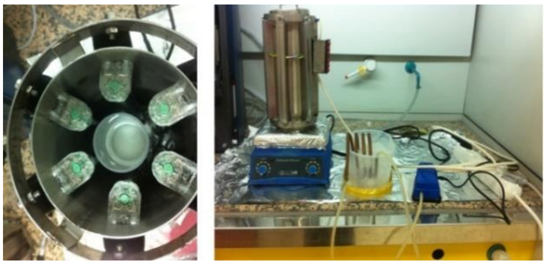

Figure 1 Batch-type slurry photoreactor

In the experiments, synthetic wastewater with an initial concentration of 300 μg/L THMs was obtained using RESTEK brand THMs stock solution. This synthetic was photocatalytically treated for cancer risk analysis. Particle doses, UV light intensity and reaction time parameters were investigated in the wastewater's pH value.

2.3. Health risk assessment

Cancer risk assessment refers to the probability of cancer risk that may occur in an individual because of an individual's (male and female) exposure to THM for life. During cancer risk assessment, data collection and interpretation, possible exposure, the toxicity of the substance (pollutant), risk determination and management stages are considered. During the cancer risk assessment, USEPA [30] guideline and Lee [15] were based on and potential THM exposure was determined based on the THM concentrations of the water samples before and after the two different photocatalytic oxidation methods [23, 31]. Depending on THM concentrations, possible cancer risk was determined by taking a chronic daily dose (CDI), exposure route (dermal, oral, inhalation) and corresponding slope factor (SF) [15,30-32]. Chronic daily doses determined for each exposure route specified in Equations 1-3 were calculated and then possible cancer risk was found using equation a 4 based on three different exposures.

$$CDI_{oral} = \frac{(CW\times IR\times EF\times ED)}{(BW\times AT)} \quad (1)$$

$$CDI_{dermal} = \frac{(CW\times SA\times PC\times ET\times EF\times ED)}{(BW\times AT)} \quad (2)$$

$$CDI_{inhalation} = \frac{(CA\times IR\times ET\times EF\times ED)}{(BW\times AT)} \quad (3)$$

$$Cancer\ Risk\ for\ THMs = \sum CDI_i \times SF_i \quad (4)$$

CW is the chemical concentration in water, mg/L, IR is the ingestion rate, L/day, EF is the exposure frequency (days/year), ED is exposure duration (years), BW is the body weight (kg), AT is the average lifetime (days), SA is a skin-surface area exposed to water (m^2), ET is the exposure time (h/day), CA is the concentration of THMs in the air

(mg/m^3). PC is the chemical-specific dermal permeability constant (cm/h), IR is the inhalation rate (m^3/h) and SF is the corresponding slope factor/potential factor of specific THMs. The statistical distributions and values of parameters are shown in Table S1[33-41].

2.4. Non-cancer risk assessment (Hazard index)

At the same time, the hazard index (HI) of THMs in different exposure routes is calculated to assess for non-carcinogenic risk assessment. The assessment of hazard indexes for ingestion route and dermal absorption is as follows:

$$\text{Hazard index for THMs of oral route} = CDI_{oral} / RfD_{THMs} \quad (5)$$

$$\text{Hazard index for THMs of dermal route} = CDI_{dermal} / RfD_{THMs} \quad (6)$$

RfD is the reference dose for a specific substance, which is given in many experiments [39, 42]. CDI value for inhalation ingestion is lower than the others so inhalation adsorption is neglected and the hazard index is calculated for only oral and dermal ingestion.

3. RESULTS AND DISCUSSION

3.1. Photocatalytic treatment method

Photocatalytic treatment of THMs was investigated by using TiO_2 nanoparticles and ZnO in synthetic water containing THMs. Samples have been prepared using the RESTEK brand THM standard. The photocatalytic treatment method determined optimum conditions by studying the particle dose, light intensity, and reaction time of the wastewater containing THM at its pH value. The amount of TTHM in the samples where the experiments are carried out is 300 µg/L.

In order to determine the optimum TiO_2 and ZnO dose, experiments have been carried out at pH 6.89, 24 Watt light intensity and 30 min reaction time. Table S2 shows the effect of particle dose on THM removal. Table S1 shows the effect of particle dose on THM removal. With the oxidation of ZnO, THM is reduced below 50 mg/L in THM removal and below 100 µg/L in all other doses. For this reason, 50 mg/L was chosen as the appropriate ZnO dose in ZnO oxidation. In TiO_2 oxidation, THM removals below 100 µg/L are obtained at 200 mg/L and above doses.

For this reason, the optimum dose for TiO_2 oxidation was chosen as 200 mg/L. The effect of light intensity on THM removal is presented in Table S3. As can be seen from Table S2, high THM removals are obtained at all light intensities between 12 Watt and 36 Watt. 12 Watt light intensity was determined as the optimum value for THM removal by photocatalytic treatment for both processes. The effect of reaction time on THM removal has been investigated from 5 min to 60 min and the results are given in Table S3. THM removal is obtained at values less than 100 µg/L after 30 minutes for both processes.

The optimum conditions for THM removal by photocatalytic treatment for both processes were determined as pH 6.89, 200 mg/L TiO_2 dose, 50 mg/L ZnO dose, 12 Watt light intensity and 30 minutes reaction time. THM removals obtained under optimum conditions for THM treatment in photocatalytic treatment using ZnO and TiO_2 are given in Table S4. The THM concentrations of the untreated water containing THM and the water treated using two different photocatalytic treatment methods, given in Table S5, were used in the cancer risk analysis.

3.2. Evaluations of lifetime cancer risks for THMs

The cancer risk assessments of THMs through oral, dermal and inhalation ingestion were done using parameters given in Table S5. Total water ingestion of 2.0 L/day per person was accepted considering the water consumption habits of people in Turkey for evaluation of lifetime cancer risks [33]. The cancer risk was interpreted as follows:

Negligible risk ($CR<10^{-6}$), acceptable low risk ($1\times10^{-6} \leq CR<5.1\times10^{-5}$), acceptable high risk ($5.1\times10^{-5}\leq CR<10^{-4}$), and unacceptable risk ($CR\geq10^{-4}$) [38, 43, 44].

3.3. Oral ingestion

The result of lifetime cancer risk through oral ingestion is shown in Figure 2 for the initial dose and treatment methods. The lifetime cancer risks of chloroform ($CHCl_3$) were higher than 10-6, which is the negligible risk level defined by USEPA. All cancer risks are defined as acceptable low risk for $CHCl_3$. The highest risks are determined for females and males in the initial dose. Also, when photocatalytic oxidation methods are compared, the highest risk is observed at $3.40x10^{-6}$ for females in the TiO_2 oxidation method. The lifetime cancer risks of bromodichloromethane (BDCM) are higher than 10^{-6} which is the negligible risk level defined by USEPA. All cancer risks are defined as acceptable low risk for BDCM. The cancer risks are observed at $1.7x10^{-6}$ and $1.65x10^{-6}$ for females and males the in ZnO oxidation method. The lifetime cancer risks of dibromochloromethane (DBCM) are higher than $5x10^{-5}$ for initial doses and the risks are stated as acceptable low risk. Cancer risks are negligible for the treatment methods, and the risks range from $2.61x10^{-5}$ to $3.35x10^{-5}$. Bromoform wasn't detected in the waters treated by both photocatalytic treatment methods.

Therefore, no risks can be mentioned for bromoform. When TTHMs are compared in the waters treated by both photocatalytic treatment methods, the highest risk values are observed ZnO oxidation method both in females and males. The average lifetime cancer risk for THMs from high to low was in the order of $CHBr_2Cl$, $CHCl_3$ and $CHCl_2Br$. Exposure to multiple toxicants results in additive or synergistic effects. Therefore, these compounds, if not alone, have considerable cancer risk [45]. The percentage contribution of average cancer risks through oral ingestion for THMs in the ZnO treatment method indicated that dibromochloromethane made the highest contribution (91%) to total risks, followed by chloroform (5%), and bromodichloromethane (4%). The percentage contribution of average cancer risks through oral ingestion for THMs in the TiO_2 treatment method indicated that dibromochloromethane made the highest contribution (89%) to total risks and chloroform (11%).

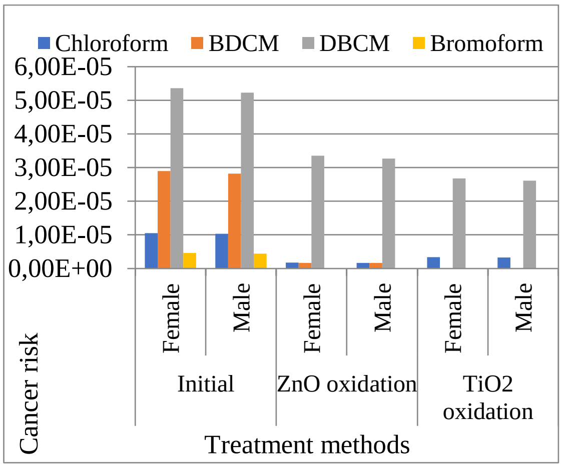

Figure 2 Lifetime cancer risk of THMs through oral ingestion

3.4. Dermal ingestion

Skin contact with water during showering, bathing, and swimming can result in the penetration of contaminants into the body. The different available skin-surface areas for males and females are reported 1.94 m^2 and 1.69 m^2, respectively by USEPA [36]. The cancer risk of THMs lifetime cancer risk of THMs through dermal ingestion exposure for initial dose and treatment methods are shown separately in Figure 3. The lifetime cancer risks of chloroform ($CHCl_3$) except the ZnO treatment method are higher than 10^{-6} which is the negligible risk level defined by USEPA. All cancer risks are defined as acceptable low risk for $CHCl_3$. On the other hand, the highest risk is observed at 1.34 $x10^{-6}$ for males in the TiO_2 oxidation method. The lifetime cancer risks of BDCM are higher than 10^{-6}. Bromoform wasn't detected in the waters treated by TiO_2 photocatalytic treatment method. The cancer risks are observed at $6.45x10^{-7}$ and $7.52x10^{-7}$ for females and males in the ZnO oxidation method. The lifetime cancer risks of DBCM range from $1.13x10^{-5}$ to $1.65x10^{-5}$ for the treatment methods and the cancer risks are defined as acceptable low risk. When the risks of DBCMs are compared, the highest risk values are observed in the ZnO oxidation method both in females and males.

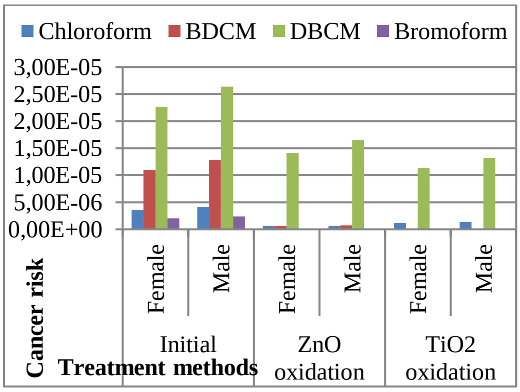

Figure 3 Lifetime cancer risk of THMs through dermal ingestion

Bromoform, one of the disinfectant by-products, couldn't be detected in the waters treated by both photocatalytic methods. The cancer risks of THM for female and male is determined as $1.54x10^{-5}$ and $1.79x10^{-5}$, respectively in the ZnO oxidation method. The percentage contribution of average cancer risks through oral ingestion for THMs in the ZnO treatment method indicated that dibromochloromethane made the highest contribution (92%) to total risk chloroform by chloroform (4%), and bromodichloromethane (4%). The percentage contribution of average cancer risks through oral ingestion for THMs in the TiO_2 treatment method indicated that dibromochloromethane made the highest contribution (91%) to total risks and chloroform (9%). As a result, the cancer risk of THMs through dermal ingestion from dibromochloromethane plays an important role in this study. According to risk values, females have been determined to have higher cancer risks compared to males due to skin surface area, body weight and lifetime.

3.5. Inhalation ingestion

Inhalation ingestion occurs when the air contains compounds volatilized during water usage, such as bathing, showering, laundering, and cooking [14, 15, 46]. Showering is the predominant contributor to volatile compounds through inhalation exposure [47]. The cancer risk of THMs through the inhalation route of exposure depends on different treatment methods are shown in Figure 4. The cancer risk assessment of total THMs due to inhalation exposure is lower than 10^{-6} both TiO_2 and ZnO photocatalytic treatment methods. Also, the risks can be identified as negligible risks. The highest cancer risk is observed in chloroform compounds in both initial and TiO_2, ZnO treatment methods.

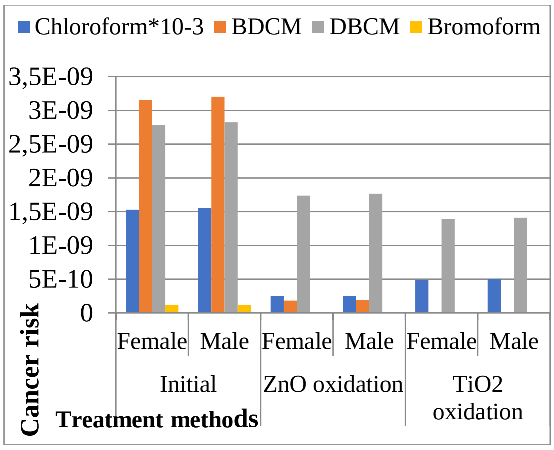

Figure 4 The cancer risk of THMs through the inhalation route of exposure

Because of the boiling point of chloroform at low temperatures, people are exposed to chloroform during bath and shower. So, chloroform is the main contributor to the total cancer risk in inhalation exposure. The major contributor through inhalation is $CHCl_3$ $2.51x10^{-7}$, $2.55x10^{-7}$ in the ZnO method and 4.92 $x10^{-7}$, 5 $x10^{-7}$ for females and males, respectively. $CHCl_3$ has a major contribution (99%), (99.2%) to total risks and dibromochloromethane (1%), (0.8%) both in ZnO and TiO_2 methods. It's stated that males have a higher cancer risk than females, depending on Turkey's living conditions, similar to different studies [14, 15, 31].

3.6. Non-cancer risk assessment

The hazard indexes of THMs through different exposure are calculated to determine the non-carcinogenic risks of disinfection by-products. The potency factor and the reference dose (RfD) values for the four THM compounds were taken from literature based on USEPA [39]. The hazard index values through oral and dermal ingestion for males and females are given in Figure 5 and Figure 6, respectively. The results indicated that the oral route has higher HI values than the dermal route, similar to various studies [39,46-48]. Chloroform has the highest contribution to average total HI values for females and males in TiO_2 and ZnO photocatalytic treatment methods. The hazard index values for THMs from high to low are in the order of $CHCl_3$, $CHBr_2Cl$ and $CHCl_2Br$ for females and males in the treated water.

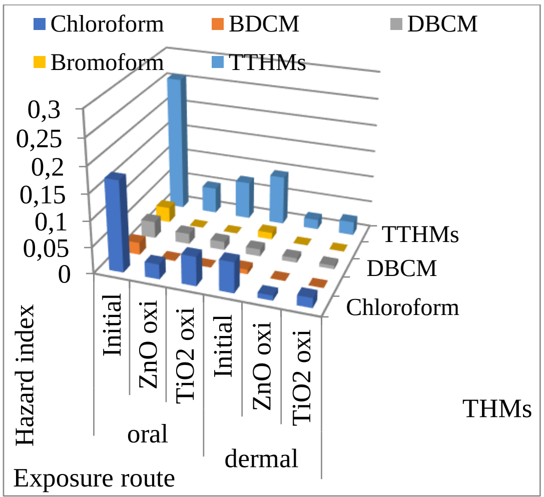

Figure 5 The hazard index values through oral and dermal ingestion for females

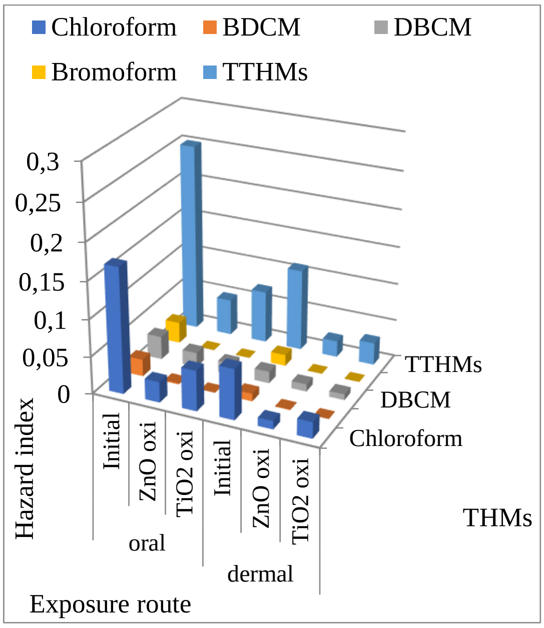

Figure 6 The hazard index values through oral and dermal ingestion for males

4. RESULTS

Three different exposure routes evaluated the association between trihalomethanes (THMs) exposure and lifetime cancer risks. This study evaluates the potential carcinogenic and non-carcinogenic risks of disinfection by-products and provides a primary human health risk categorization for THMs in synthetic water and treated water with TiO_2 and ZnO photocatalytic treatment methods. The results showed that people have a higher risk of cancer through oral ingestion. The lifetime cancer risks through oral ingestion of $CHCl_3$, $CHBrCl_2$, and $CHBr_2Cl$ from treated water are higher than 10^{-6} and the cancer risks are identified as acceptable low risk. Bromodichloromethane has a higher cancer risk to people through dermal exposure than the other THMs. In addition to this, it's found that males have a higher cancer risk than females in exposure to THMs in inhalation digestion. The result of the present study is also good in line with the findings of many studies [46-53]. In a study on THMs removal by advanced oxidation method, the females were found to have a higher cancer risk than males for oral and dermal digestion, similar to this study. The non-carcinogenic risk analysis denoted that the risk is substantially through oral ingestion in contrast with dermal ingestion, have almost negligible risk.

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Authors' contributions
NPT has done all the experiments of the study. HD has done all cancer risk assessments. All parts of the writing belong to CÖ, NPT, HD, and İAŞ.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

Table S1. Effect of particle dose on THM removal

	ZnO					TiO_2				
Particle doses (mg/L)	50	100	200	300	500	50	100	200	300	500
Chloroform (µg/L)	21.8	20.37	18.77	16.94	15.48	88.69	69.05	41.78	36.21	34.48
BDCM (µg/L)	1.96	1.71	1.54	1.25	0.99	1.01	0.06	-	-	-
DBCM (µg/L)	29.34	25.44	23.86	20.97	19.38	31.8	27.29	24.11	22.17	19.86
Bromoform (µg/L)	-	-	-	-	-	0.86	-	-	-	-
TTHMs (µg/L)	53.1	47.52	44.17	39.16	35.85	12.36	96.4	65.89	58.38	54.34

Table S2. Effect of light density on THM removal

	ZnO				TiO_2			
Light density (Watt)	12	18	24	36	12	18	24	36
Chloroform (µg/L)	25	24.64	21.8	19.23	49	46.69	41.78	37.65
BDCM (µg/L)	2.4	2.27	1.96	1.51	-	-	-	-
DBCM (µg/L)	35	33.8	29.34	25.44	28	26.98	24.11	21.04
Bromoform (µg/L)	-	-	-	-	-	-	-	-
TTHMs (µg/L)	62.4	60.71	53.1	46.18	77	73.67	65.89	58.69

Table S3. Effect of reaction time on THM removal

	ZnO				TiO_2			
Reaction time (min)	5	15	30	60	5	15	30	60
Chloroform (µg/L)	73.29	48.87	25	23.89	91.09	65.79	49	41.83
BDCM (µg/L)	15.54	4.56	2.4	1.81	10.73	3.03	-	-
DBCM (µg/L)	38.41	37.12	35	33.26	43.71	35.2	28	19.52
Bromoform (µg/L)	18.34	3.11	-	-	14.69	2.32	-	-
TTHMs (µg/L)	145.58	93.66	62.4	55.91	160.22	106.34	77	61.35

Table S4. THM concentrations

	Chloroform (µg/L)	BDCM (µg/L)	DBCM (µg/L)	Bromoform (µg/L)	TTHMs (µg/L)
Initial	152	41	56	51	300
ZnO oxidation	25	2.4	35	-	62.4
TiO_2 oxidation	49	-	28	-	77

Table S5. The statistical distributions and values of parameters

Input parameters	Units	Values		References
Oral ingestion				
The concentration of the chemical in water (CW)	mg/L			This study
Ingestion rate (IR)	L/day	2		[33]
Exposure frequency (EF)	days/year	365		[15]
Exposure duration (ED)	years	30		[34]
Body weight (BW)	kg	Female: 65 Male: 72		[22]
Average time (AT)	days	Female: 29565 Male: 26280*		[35]
Dermal ingestion				
Area of surface skin expose to water (SA)	m^2	Female: 1.69 Male: 1.94		[36]
Chemical-specific dermal permeability constant (PC)	cm/h	Chloroform:0.16 BDCM: 0.18 DBCM:0.2		[37]
Exposure time (ET)	h/day	0.25		[38]
Inhalation ingestion				
The concentration of studied THM species in the air (CA)	mg/m^3	Calculation**		This study
Inhalation rates (IR)	m^3/h	0.83		[15]
Reference doses (RfD)	mg/kg/day	Chloroform:0.01 BDCM: 0.02 DBCM:0.02 Bromoform: 0.02		[39]
Slope factor/ potential factor (SF)	mg/kg/day	Oral Chloroform:0.0061 BDCM: 0.062 DBCM:0.084 Bromoform: 0.0079	Dermal Chloroform:0.081 BDCM: 0.13 DBCM:0.094 Bromoform: 0.0039	[40]

* Exposure duration (ED) was considered 81 years for women on average life and 75 years for men on average life in Turkey according to TUİK [35] data.

** THMs concentration in air CA has been calculated by many studies based on statistical models and experimental datas [23,38,40,41]. The CA for chloroform was calculated by a statistical model based on Legay [38]. For the other three THMs, a volatilization factor of $5\times10^{-4}\times1000$ L/m^3 was used for the estimation of CA.

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