Songklanakarin J. Sci. Technol.
46 (5), 476–483, Sep. – Oct. 2024

http://www.sjst.psu.ac.th

*Original Article*

# Analysis of physicochemical properties, trihalomethane levels, and trihalomethane formation potential in Cagayan de Oro city's primary drinking water source

Ronnie L. Besagas*, Romeo M. Del Rosario, and Angelo Mark P. Walag

*Department of Science Education, University of Science and Technology of Southern Philippines, Cagayan de Oro, Misamis Oriental, 9000 Philippines*

Received: 30 October 2023; Revised: 1 August 2024; Accepted: 7 August 2024


## Abstract

The raw and processed waters satisfied the Philippine, WHO, and USEPA standards for pH, conductivity, salinity, TDS, and TSS. While both waters exceeded the PNSDW total hardness threshold, the WHO does not consider this a health concern at the levels found in drinking water. Raw water turbidity exceeded the PNSDW, WHO, and USEPA regulations. Unlike total hardness, turbidity poses a health risk since it may stimulate microbial growth, leading to waterborne illness outbreaks. However, the processed or tap water's turbidity was well within the permissible limit, indicating that the treatment process is effective. The total trihalomethane (TTHM) of the processed water came out higher than the standard values for total trihalomethanes set by the PNSDW, USEPA, and WHO. On the other hand, the trihalomethane forming potential (THMFP) of the raw water was high as manifested by the high concentration of total trihalomethane (84 mg/L) produced after the simulated chlorination. The raw water high THMFP led to a processed water high THM concentration (41.7 mg/L). The total trihalomethanes are likely influenced by total organic carbon (TOC), turbidity, total hardness, total suspended solids (TSS), total dissolved solids (TDS), conductivity, salinity, and pH as indicated by statistically significant correlations.


**Keywords**: trihalomethane, trihalomethane forming potential, drinking water, disinfection byproducts, organic matter

## 1. Introduction

Numerous natural and anthropogenic events jeopardize the availability and safety of water resources. Climate change, rapid population growth, and economic development all place enormous strain on the world's finite freshwater supply. According to the World Health Organization (WHO, 2010), certain countries in South.East Asia (SEA) face chemical contaminants in groundwater such as arsenic and fluoride, as well as contamination from industries and agriculture. Contamination of water bodies due to industrial wastewater and agricultural run.off is a major public health concern. Inadequate data collection and surveillance, as well as lax regulation, are just some of the issues that must be addressed in order to prevent these man.made problems.

*Corresponding author
Email address: rlbesagas@ustp.edu.ph

In the City of Cagayan de Oro, the public water system is managed and operated by the Cagayan de Oro Water District (COWD) which is a Government.Owned and Controlled Corporation (GOCC). The water district has 28 production wells that supply potable drinking water to their consumers, but the bulk water supply is coming from a private supplier. The source of the bulk water supply is the Bubunawan River at Pualas, Baungon, Bukidnon. The company supplies 150,000 $m^3$/day of potable water to the COWD. The water is treated with coagulants/flocculants and chlorine.

While chlorine has the ability to kill pathogens, it also reacts with organic matter in water to produce disinfection byproducts, some of which are hazardous to one's health. Several organic compounds have been found to react with chlorine and chloroamines to produce disinfection byproducts such as trihalomethanes (THMs) and haloacetic acids (HAAs), which are carcinogenic, teratogenic, and/or genotoxic (Dodds, King, Woolcott, & Pole, 1999; Texas Commission on Environmental Quality, 2002).

Water that is safe and readily available is important for public health, regardless of whether it is used for drinking, domestic purposes, food production, or recreation. The provision of safe drinking water does not end with the elimination of waterborne pathogens; it also includes minimizing individuals' exposure to chemical and physical hazards that can be ingested through contaminated drinking water. Having ascertained that the drinking water is free from pathogenic microbes through the usual treatment with chlorine gas, the next imperative is to find out if there are no dangerous by.products like trihalomethanes (THMs) in the resulting processed water. The formation THMs in drinking water is associated with the trihalomethane forming potential (THMFP) of the raw water being used. THMs content is not usually part of the quality monitoring in drinking water production.

In the Philippines, the Department of Health (DOH) is mandated to set standards for drinking water that establish threshold limits for different impurities found in drinking water. Chapter II (Water Supply), Section 9 of the Code on Sanitation of the Philippines states that **"**Standards for drinking water and their microbiological and chemical examinations, together with the evaluation of results, shall conform to the criteria set by the National Drinking Water Standards**"**. The standard limits are intended for managing the risk from hazards that may compromise the safety of drinking water, thereby preventing deleterious health repercussions that result from lifelong exposure to impurities through consumption of water.

Two major objectives in this study have been to find out about the trihalomethane forming potential of the raw water or feed water, and the trihalomethane content of the processed water. How these could possibly relate to the important water quality characteristics, namely pH, alkalinity, salinity, conductivity, TDS, TSS, total hardness, turbidity, and total organic carbon, was then examined.

## 2. Materials and Methods

### 2.1 Determination of pH, conductivity, salinity, total dissolved solids, and turbidity

The pH of the sample was determined using a pH meter (Hachsens ION+ portable pH meter). On the other hand, a multi.meter, specifically a Hachsens ION5 meter, was used to determine the sample's conductivity, salinity, and total dissolved solids. For the turbidity of the sample, it was analyzed using a turbidimeter (Hach 2100Q portable turbidimeter).

### 2.2 Determination of alkalinity

Total alkalinity of the sample was determined using the titrimetric method. In this method a 100 mL sample was titrated with 0.02 N $H_2SO_4$ until the end point was reached, using bromocresol green indicator. The standard 0.02 N $H_2SO_4$ was standardized against a primary standard $Na_2CO_3$ solution. The alkalinity of the sample was calculated using the formula:

$$Alkalinity, mg\ CaCO_3/L = \frac{A \times N \times 50{,}000}{mL\ sample} \tag{1}$$

where:

A = mL standard acid used
N = Normality of standard acid

### 2.3 Determination of total suspended solids (TSS)

The glass.fiber filter was pre.weighed to a constant weight prior to using it with the sample. This preparation involved washing the glass.fiber filter with three successive portions of 20 mL of deionized water with an applied vacuum. The filter was carefully removed from the filtration apparatus using forceps and placed in a Petri dish. It was then dried for 1 hour at 103.105°C and cooled to ambient temperature in a desiccator before being weighed. This cycle of drying, cooling, desiccating, and weighing was repeated until the weight difference between two successive weightings was 0.5 mg or less.

To determine the sample's TSS, the filter was cleaned three times with 10 mL of deionized water. Then, with a vacuum applied, a 100 mL well.mixed sample was filtered through the glass.fiber filter. The filter was carefully taken from the filtering apparatus using forceps and placed in a Petri dish. It was then dried for 1 hour at 103–105°C, cooled to ambient temperature in a desiccator, and weighed. This cycle of drying, cooling, desiccating, and weighing was continued until the weight difference between two successive weightings was equal to or less than 0.5 mg. The sample's TSS was calculated using the following formula:

$$Total\ supended\ solids\ \left({}^{mg}/_{L}\right) = \frac{(A-B)\times 1000}{sample\ volume, mL} \tag{2}$$

where:

A = final weight of filter + dried residue, mg
B = weight of filter, mg

### 2.4 Determination of total hardness

The total hardness of the sample was determined using the EDTA Titrimetric method. A 50 mL sample was measured into a 250 mL Erlenmeyer flask and mixed with 1 mL of buffer solution and 100 mg of eriochrome black T indicator. It was titrated with an EDTA standard solution until the last trace of red disappears. Under normal conditions, the color of the solution at the endpoint is blue. Together with the sample, a blank was run. The total hardness of the sample was calculated using the following formula:

$$Hardness\ (EDTA)\ as\ mg\ CaCO_3/L = \frac{A \times B \times 1000}{mL\ sample} \tag{3}$$

where:

A = mL of titrant used for sample
B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant

### 2.5 Determination of total organic carbon (TOC)

The TOC was analyzed using the method developed by Hach Company. In this method the TOC is determined by first sparging the sample under slightly acidic conditions to remove inorganic carbon. In the outside vial, organic carbon in the sample is digested by persulfate and acid to form carbon dioxide. During digestion, the carbon dioxide diffuses into a pH indicator reagent in the inner ampule. The absorption of carbon dioxide into the indicator forms carbonic acid. Carbonic acid changes the pH of the indicator solution which, in turn, changes the color. The amount of color change is related to the original amount of carbon present in the sample. Test results were measured at 598 and 430 nm (Hach Company, 2014).

### 2.6 Trihalomethane forming potential (THMFP)

The trihalomethane forming potential (THMFP) is a simulation that determines the raw water's ability to generate trihalomethanes when subjected to direct chlorination. The HACH method for THMFP (Method 10224) was used in this research, which is based on the USEPA's Standard Methods of Examination for Water and Wastewater. In this method, the raw water is chlorinated under carefully controlled conditions of dosage rate, pH, temperature, and contact time. The THMs formed under these simulated conditions were determined using the THM Plus method of HACH.

### 2.7 Total trihalomethane (TTHM)

The total trihalomethane (TTHM) in the sample was determined using the THM Plus method of HACH (Method 10132). In this method, THM compounds in the sample react with N, N,-diethylnicotinamide under heated alkaline conditions to form a dialdehyde intermediate. The sample was cooled and acidified to pH 2.5. The dialdehyde intermediate reacts with 7.amino.1,3.napthalene disulfonic acid to form a Schiff base. The color that forms is directly proportional to the total amount of THM compounds in the sample. Test results were measured at 515 nm and reported as ppb chloroform.

## 3. Results and Discussion

### 3.1 Physico.chemical characteristics

The results of the physicochemical analyses of the raw water and tap (processed) water are summarized in Table 1. The findings indicate that the quality parameters of both raw and processed water are generally within the limits set by the Philippine National Standards for Drinking Water (PNSDW), the United States Environmental Protection Agency (USEPA), and the World Health Organization (WHO). The two exceptions are the total hardness of raw and processed water, as well as the turbidity of raw water. Both raw and treated water had an extraordinarily high total hardness of 1,411 mg/L and 2,789 mg/L $CaCO_3$, respectively. According to the PNSDW, total hardness in drinking water should not exceed 300 mg/L as calcium carbonate. The difference in total hardness between the two types of water and the standard limit, as determined by the one sample t.test, is statistically significant at the 5% significance level. Also, the raw water's turbidity is much higher than the standard of 5 NTU set by the PNSDW, USEPA, and WHO. At 44.31 NTU, the raw water's turbidity is significantly higher than the standard.

Natural waters contain a wide variety of minerals, which alter the quality of the water. The total hardness of water is a measure of the mineral content, mainly calcium and magnesium. Calcium and magnesium are both important minerals that are beneficial to human health in numerous ways. Thus, water hardness does not pose a direct threat to human health. Indeed, neither the United Sates Environmental Protection Agency (USEPA) nor the WHO have established guideline values for water hardness. Nonetheless, the Philippines has set a limit for the aforementioned parameter of 300 mg/L $CaCO_3$. However, water hardness is critical for customer acceptance, household operations, and economic concerns. To varying degrees, dissolved minerals contribute to the taste of drinking water. Water's acceptability is typically determined by the user's taste and familiarity. Hard water, when mixed with other factors like pH and alkalinity, can cause increased soap consumption and scale buildup in the water distribution system, the formation of metal carbonates that coat surfaces and make heat exchangers less efficient when heated with hard water, and a tendency to corrode, especially with very hard water (United Sates Geological Survey [USGS], 2018).

Turbidity is another indicator of water quality and the extent to which suspended particles are removed during treatment. Suspended and colloidal particles, such as clay, silt, organic and inorganic matter, plankton, and other microbes, cause it. Turbidity, like hardness, has an effect on the aesthetic qualities of drinking water, including its appearance, color, and even flavor. Additionally, it may pose a health risk. Suspended and colloidal particles can act as food sources and shields for pathogens. Turbidity particles can reduce the effectiveness of UV disinfection by blocking or absorbing UV radiation (Allen, Brecher, Copes, Hrudey, & Payment, 2008). In other words, turbidity shelters bacteria by minimizing their exposure to disinfectants and, if not removed, can promote pathogen regrowth in the water system, resulting in outbreaks of waterborne disease (United States Environmental Agency [USEPA], 1999b).

While the majority of the physical and chemical characteristics of the two types of water are acceptable, they are not of comparable quality. As displayed in Table 2, the pH, conductivity, TDS, TSS, alkalinity, total hardness, and turbidity of the two waters are significantly different. The treatment technique significantly reduced pH, TSS, and turbidity levels. On the other hand, treated water has higher conductivity, total dissolved solids (TDS), alkalinity, and total hardness than raw water. Nonetheless, all of these qualities of treated water are acceptable, with the exception of total hardness, as discussed above.

### 3.2 Trihalomethane forming potential and total trihalomethanes

Trihalomethanes (THMs) are disinfection byproducts produced during water treatment, most notably chlorination, a prevalent procedure used in public water supply systems. The public and scientific community have raised concern about THMs' potential carcinogenic effect on human health. Table 3 shows the trihalomethane forming potential (THMFP) of the raw water and the total trihalomethane (TTHM) of the processed drinking water. The simulated chlorination of raw water, which resulted in a high THM concentration of 84 mg/L $CHCl_3$, suggests the presence of substances, notably organic matter, that act as precursors to the formation of THM in bodies of water. Organic compounds such as humic and fulvic acid may be converted to potentially hazardous byproducts such as trihalomethanes (THMs), haloacetic acids (HAAs), chlorophenols, chloral hydrate, and haloacetonitriles (HANs) during chlorination (Achour & Chabbi, 2014; Hrudey, 2009). The general reaction of chlorine with organic matter can be expressed by this equation (Fooladvand, Ramavandi, Zandi, & Ardestani, 2011):

Table 1. Physico.chemical characteristics of the raw water and the processed drinking water

| Parameter | Water source [mean (std deviation)] | | Standard limits | | |
|---|---|---|---|---|---|
| | Raw | Processed | PNSDW[1] | USEPA[2] | WHO[3] |
| pH | 8.140 (0.224) | 7.467 (0.175) | 6.5 – 8.5 | 6.5 – 8.5 | Not of health concerns at levels found in drinking water |
| Conductivity (µS/cm) | 111.8 (8.1) | 199.1 (21.4) | | | |
| Salinity (ppt) | 0.1 (0.1) | 0.1 (0) | | | |
| TDS (mg/L) | 59.1 (4.3) | 106.0 (11.6) | 600 mg/L | 500 mg/L | |
| TSS (mg/L) | 8.3 (1.7) | 0.6 (0.7) | | | |
| Alkalinity (mg/L $CaCO_3$) | 65.33 (20.54) | 136.85 (10.51) | | | |
| Total hardness (mg/L $CaCO_3$) | 1,411 (127) | 2,789 (169) | 300 mg/L | | Not of health concerns at levels found in drinking water |
| Turbidity (NTU) | 44.31 (57.30) | 1.36 (1.23) | 5 NTU | <5 NTU | <5 NTU |
| TOC (mg/L C) | 1.2 (0.6) | 1.0 (0.4) | | | |

[1]Philippine National Standards for Drinking Water (2017)
[2]United States Environmental Protection Agency – Water Standards and Health Advisories (2012)
[3]World Health Organization – Guidelines for Drinking Water Quality (2011)

Table 2. Independent sample t.test results: Raw water versus processed water in terms of the physico.chemical characteristics

| Physico.chemical parameter | t | p |
|---|---|---|
| pH | 7.113 | < 0.001* |
| Conductivity | .11.438 | < 0.001* |
| TDS | .11.366 | < 0.001* |
| TSS | 12.423 | < 0.001* |
| Alkalinity | .9.300 | < 0.001* |
| Total Hardness | .19.545 | < 0.001* |
| Turbidity | 2.248 | 0.039* |
| TOC | 1.084 | 0.294 |

*Statistically significant result at α = 0.05

Table 3. Trihalomethane forming potential (THMFP) of the raw water and the total trihalomethane (TTHM) of the processed drinking water

| Parameter | Water source | Result [mean (std deviation)] |
|---|---|---|
| THMFP (mg/L) | Raw water | 84 (55.3) |
| TTHM (mg/L) | Processed water | 41.7 (5.6) |

$$\text{organic matter} + \text{free chlorine} \longrightarrow \text{THMs} + \text{HAAs} + \text{HANs} + \text{cyanogen halides} + other\ DBPs \quad (4)$$

The high trihalomethane forming potential of the raw water has been translated to a high TTHM concentration of 41.7 mg/L in the processed water or tap water. This possibly means that the pretreatment of the raw water by coagulation and flocculation is not efficient enough to remove the precursor compounds prior the chlorination; thus the formation of THM. Another possibility is the formation of THM along the distribution lines by the reaction between the residual chlorine and the organic matter that enters the system from leaky pipes. Both the THMFP and TTHM of the raw water exceed the acceptable levels for total trihalomethanes indicated in Table 4. According to the results of the t.test shown in Table 5, the differences between the TTHMFP and TTHM and the standard values from the PNSDW, the USEPA, and the WHO are statistically significant. Numerous studies have demonstrated that trihalomethanes are carcinogenic, regardless of whether they are ingested, inhaled, or absorbed via the skin.

Table 4. Standard maximum limits for total trihalomethane

| | Standard value |
|---|---|
| PNSDW[1] | 1 mg/L |
| USEPA[2] | 0.08 mg/L |
| WHO[3] | The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1 |

[1]Philippine National Standards for Drinking Water (2017)
[2]United States Environmental Protection Agency – Water Standards and Health Advisories (2012)
[3]World Health Organization – Guidelines for Drinking Water Quality (2011)

Table 5. One sample t.test results: Total trihalomethane of the processed water against the standard values

| Parameter | Standard | t | p |
|---|---|---|---|
| TTHM | PNSDW[1] | 21.737 | < 0.001* |
| | USEPA[2] | 22.229 | < 0.001* |
| | WHO[3] | 21.737 | < 0.001* |

[1]Philippine National Standards for Drinking Water (2017)
[2]United States Environmental Protection Agency – Water Standards and Health Advisories (2012)
[3]World Health Organization – Guidelines for Drinking Water Quality (2011)
*Statistically significant at α = 0.05

The presence of TTHM in such high concentrations implies that the tap water is unsafe for human consumption. Individuals are exposed to these carcinogenic volatile organic chemicals in three ways: ingestion, inhalation, and dermal absorption. In southern Taiwan, exposure to THMs via ingestion was found to be 47.9 µg/day, whereas exposure via inhalation as a result of showering was reported to be 30.7

µg/day (Lin & Hoang, 2000). This literature findings imply that inhalation and dermal adsorption due to showering and other activities increase the body burden of THMs.

The USEPA listed trihalomethanes as primary pollutants owing to their tumorigenic effects and adverse effects on the nervous system, as revealed by animal studies (Walter & Tassos, 1997). Correspondingly, epidemiological studies have found that populations exposed to chlorination by.products have higher rates of brain, bladder, and colon.rectum cancers (Hsu, Jeng, Chang, Chien, & Han, 2001). Furthermore, it has been reported that trihalomethanes are suspected to cause miscarriage, birth defects, retarded fetal growth, kidney and liver damage (Ristoiu *et al.*, 2009; Wright, Schwartz, & Dockery, 2004). In view of the epidemiological evidence, the four trihalomethanes, namely, chloroform, chlorodibromo methane, bromodichloromethane, and bromoform, are classified by the USEPA as possible human carcinogens (USEPA, 1999a).

To ensure that drinking water is safe and free of trihalomethanes' hazardous effects, techniques for controlling THMs in the water must be implemented. Three basic ways for reducing trihalomethane concentrations in water have been described in the literature (Durmishi, *et al.*, 2015; Latifoglu, 2003):

- removal of humic substances and other precursor compounds;
- removal of the generated THM; and/or
- reduce or prevent THM formation by using alternative disinfectants.

The THM precursor can be removed by adsorption, filtration, and coagulation and chemical oxidation. Reduction of up to 50% to 60% in the THM concentration was reached by the removal of the precursor using coagulation, followed by sedimentation, and then filtration (Latifoglu, 2003). Results in the literature show that ozone is effective in degrading THM precursors, particularly humic substances, into low molecular weight compounds that are less reactive towards chlorine (Amy, Tan, & Davis, 1991; Graham, Preis, Lambert, Ma, & Li, 1994). Advanced oxidation methods that have catalytic effects in the reaction, such as ozone in the presence of UV light or hydrogen peroxide, are usually more effective than using only one oxidant (Duguet, Brodard, Dussert, & Mallevialle, 1985; Glaze, Peyton, Huang, & Burleson, 1982). Humic materials can also be decomposed by hydrogen peroxide in the presence of UV light that thereby reduces the THM formation potential (Akata & Gurol, 1992; Gen.Shuh, Su.Ting, & Chia.Swee, 2000). Generated THMs in drinking water can be removed using activated carbon or air bubbles. Chloramines, chlorine dioxide, moving the chlorination points and application of powdered activated carbon are some of the technologies for controlling trihalomethanes based on the US National Intern Primary Drinking Water (Durmishi *et al.*, 2015). Since THMs are highly volatile chemicals, boiling is another way consumers use to reduce the levels of THMs in their tap water. A study shows that boiling water reduces the THM concentration by 61–82% (Kuo *et al.*, 1997).

### 3.3 Interrelation between trihalomethanes and other water quality characteristics

Table 6 and Table 7 shows the Pearson product.moment correlation coefficient of the relationship between the trihalomethanes and the other quality characteristics of the raw and processed waters. Correspondingly, the scatter plots shown in Figures 1 and 2 provide a graphical picture of the relationships between variables.

Table 6. Correlation between THMFP and other quality characteristics of raw water

| Variable | | | Pearson's r | p |
|---|---|---|---|---|
| THMFP | and | TOC | 0.790 | 0.011 |
| THMFP | and | Turbidity | 0.920 | < .001 |
| THMFP | and | Hardness | 0.725 | 0.027 |
| THMFP | and | Alkalinity | .0.706 | 0.034 |
| THMFP | and | TSS | 0.797 | 0.010 |
| THMFP | and | TDS | 0.890 | 0.001 |
| THMFP | and | Conductivity | 0.890 | 0.001 |
| THMFP | and | Salinity | 0.783 | 0.013 |
| THMFP | and | pH | 0.830 | 0.006 |

Table 7. Correlation between tthm and other quality characteristics of processed drinking water

| Variable | | | Pearson's r | p |
|---|---|---|---|---|
| TTHM | — | TOC | 0.916 | < .001 |
| TTHM | — | Turbidity | .0.078 | 0.842 |
| TTHM | — | Hardness | .0.531 | 0.141 |
| TTHM | — | Alkalinity | 0.900 | < .001 |
| TTHM | — | TSS | .0.317 | 0.406 |
| TTHM | — | TDS | 0.820 | 0.007 |
| TTHM | — | Conductivity | 0.819 | 0.007 |
| TTHM | — | pH | 0.738 | 0.023 |

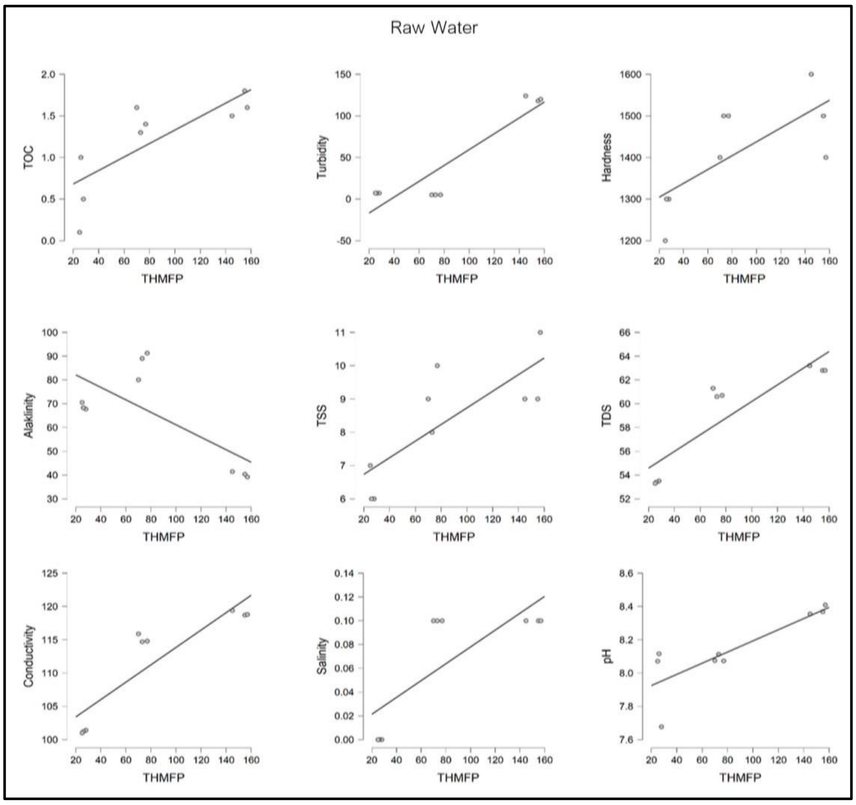


Figure 1. Scatter plots of the correlation between THMFP and other quality characteristics of raw water

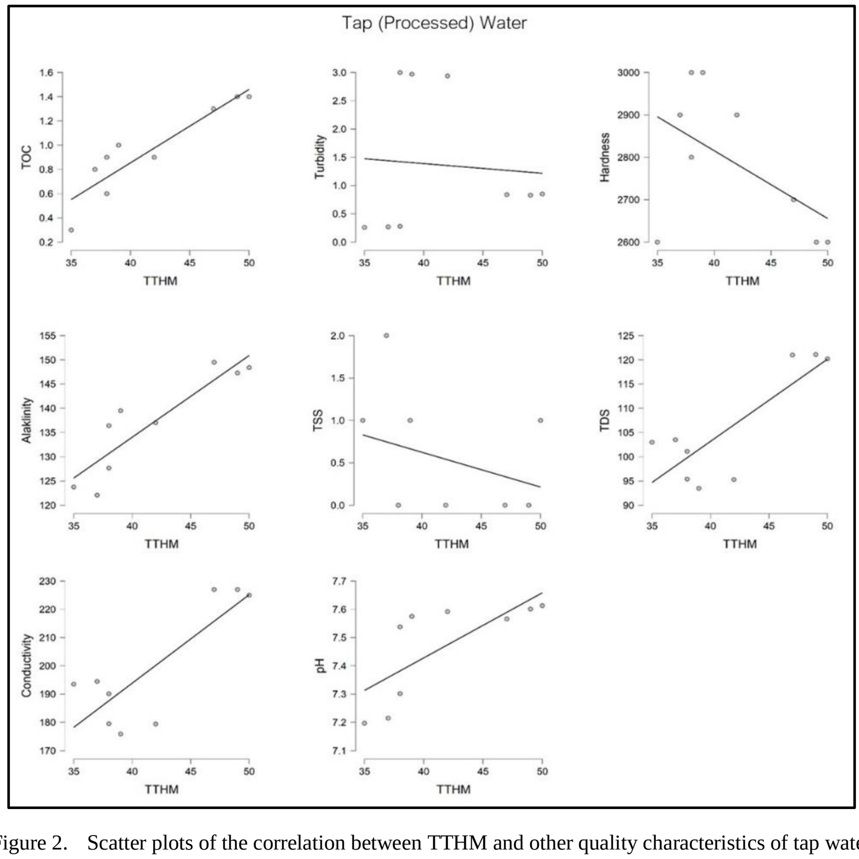


Figure 2. Scatter plots of the correlation between TTHM and other quality characteristics of tap water

The trihalomethanes forming potential (THMFP) observed in raw water as a result of simulated chlorination were found to be positively correlated with total organic carbon (TOC), turbidity, total hardness, total suspended solids (TSS), total dissolved solids (TDS), conductivity, salinity, and pH. The negative correlation with alkalinity is subject to further verification since the alkalinity level is rather low and is not strongly significant. In like manner the total trihalomethanes in tap water were positively correlated with total organic carbon, alkalinity, total dissolved solids (TDS), conductivity, and pH. These findings corroborate previous research indicating that the formation of trihalomethane in water is dependent on the total amount of organic carbon, pH, and temperature, as well as other factors, including the type and dosage of chlorine, the type of humic substances, contact time, water flow paths, operating conditions, and practices for maintaining a residual disinfectant (Durmishi *et al*., 2015; Latifoglu, 2003). In the case of TOC, it is expected that when free chlorine is present in the water, the THM content will increase proportionately, as the precursors of THM are organic matter. Simpson and Hayes (1998) determined the THM formation's dependency on TOC by chlorinating various sources of raw water with high TOC concentrations in Australia. One of their findings was that at 11.3 mg/L TOC (the highest concentration), the measured THM concentration was 189 μg/L.

Previous research has shown that the formation of THMs increases when the pH level is higher (Rook, 1976; Stevens, Slocum, Seeger, & Robeck, 1976). This is because the formation of THM is a base.catalyzed halogenation reaction (Latifoglu, 2003). The effective catalytic activity of temperature is also expected to increase the rate of reaction. For example, a higher concentration of THM was measured in samples collected after chlorination at higher temperatures. Another factor that affects the formation is the applied chlorine dosage. At high chlorine dosages, oxidative degradation rather than substitution reaction occurs, thereby increasing the THM formation (Johnson & Jensen, 1986).

## 4. Conclusions

Carefully evaluating the above findings has led to the formulation of the following conclusions:

The treatment process implemented on major drinking water supply of Cagayan de Oro is effective in producing quality drinking water in terms of pH, conductivity, salinity, TDS, TSS, and turbidity. The raw and processed water of the Cagayan de Oro Water District meet the PNSDW, WHO, and USEPA standards for these parameters. Because the raw water comes from an open source and it can be contaminated in many ways, it has a high level of turbidity. The treatment process, however, is able to reduce turbidity to an acceptable level.

The disinfection produces a tap water with high concentration of total trihalomethanes. This is a serious human health concern because trihalomethanes are carcinogenic and enter the body through ingestion, inhalation, and dermal absorption. On the other hand, the source water from Bubunawan River has high trihalomethane forming potential. It is therefore imperative to implement strategies to control the formation of trihalomethanes at the treatment facility and at the distribution system. The total trihalomethanes are influenced by total organic carbon (TOC), turbidity, total hardness, total suspended solids (TSS), total dissolved solids (TDS), conductivity, salinity, and pH. The correlations are significant positive correlations.

## 5. Recommendations

The findings and conclusions of this research point to a number of issues and concerns that need to be acted upon in order to provide the people with quality and safe drinking water. Appropriate actions are important to avert serious occurrences later.

The alarmingly high levels of total trihalomethanes in the tap water indicate the need to evaluate the disinfection scheme and implement strategies to control THM formation. THM formation can be prevented by removing the precursor organic matter in the raw water through the methods of coagulation, adsorption, and filtration, or by using alternative disinfectants such as chloramines and chlorine dioxide. Chemical oxidants that degrade THM precursor such as ozone and hydrogen peroxide can also be used. Generated THM can be removed by using activated carbon or air bubbles. The formation of trihalomethane can also be prevented by using alternative disinfectants such as chlorine dioxide, which does not produce chlorinated byproducts, particularly trihalomethanes.

Authority should always impose policies and programs that maintain the drinking water supply free from physico.chemical problems, such as metallic and microbial contaminations. Because freshwater resources are vulnerable and always affected by anthropogenic and natural events, regular monitoring of water quality must be conducted. Trihalomethanes must be included in the list of parameters to be monitored regularly.

## References

Achour, S. & Chabbi, F. (2014). Disinfection of drinking water.constraints and optimization perspectives in Algeria. *Larhyss Journal, 19*, 193.212.

Akata, A. & Gurol, M. D. (1992). Photocatalytic oxidation processes in the presence of polymers. *Ozone: Science and Engineering, 14*, 367.

Allen, M. J., Brecher, R. W., Copes, R., Hrudey, S. E., & Payment, P. (2008). Turbidity and microbial risk in drinking water. *The Minister of Health Province of British Columbia pursuant to Section 5 of the Drinking Water Act (S.B.C. 2001).* Canada. Retrieved from http//www.health.gov.bc.ca/protect/pdf/TAC submitted.pdf.

Amy, G. L., Tan, L., & Davis, M. K. (1991). The effects of ozonation and activated carbon adsorption on trihalomethane speciation. *Water Research, 25*, 191–202.

Dodds, L., King, W., Woolcott, C., & Pole, J. (1999). Trihalomethanes in public water supplies and adverse birth outcomes. *Epidemiology (Cambridge, Mass.), 10*(3), 233–7.

Duguet, J. P., Brodard, E., Dussert, B., & Mallevialle, J. (1985). Improvement in the effectiveness of ozonation of drinking water through the use of hydrogen peroxide. *Ozone: Science and Engineering, 7*, 241–258.

Durmishi, B. H., Reka, A. A., Gjuladin.Hellon, T., Ismaili, M., Srbinovski, M., & Shabani, A. (2015). Disinfection of drinking water and trihalomethanes: A review. *International Journal of Advanced Research in Chemical Science (IJARCS), 2*(11), 45–56.

Fooladvand, M., Ramavandi, B., Zandi, K., & Ardestani, M. (2011). Investigation of trihalomethanes formation potential in Karoon River water, Iran. *Environmental Monitoring and Assessment, 178*(1), 63–71.

Gen.Shuh, F. W., Su.Ting, H., & Chia.Swee, H. (2000). Destruction of humic acid in water by UV light.catalyzed oxidation with hydrogen peroxide. *Water Research, 34*(15), 3882–3887.

Glaze, W. H., Peyton, G. R., Huang, R. Y., & Burleson, J. L. (1982). Destruction of pollutants in water with ozone in combination with ultraviolet radiation. 2. Natural trihalomethane precursors. *Environmental Science and Technology, 16,* 454–458.

Graham, N., Preis, S., Lambert, S., Ma, J., & Li, G. (1994). The impact of pre.treatment with ozone, chlorine dioxide and potassium permanganate on THM formation: Laboratory case studies. *Proceedings of the first international research symposium on water treatment by products poitiers, France, 1*, 9.1–9.15.

Hach Company. (2014). Organic carbon, total. *Hach Company/Hach Lange GmbH*, 1989–2014. Retrieved from http//www.OrganicCarbonTotalDirectTNT_ DOC 316.53.01093.pdf.

Hsu, C. H., Jeng, W. L., Chang, R. M., Chien, L. C. & Han, B. C. (2001). Estimation of potential lifetime cancer risks for trihalomethanes from consuming chlorinated drinking water in Taiwan. *Environmental Research, 85*(2), 77–82.

Hrudey, S. E. (2009). Chlorination disinfection byproducts, public health risk tradeoffs and me. *Water Research, 43*, 2057–2092.

Johnson, J. D. & Jensen, J. N. (1986). THM and TOX formation: Routes, rates and precursors. *Journal of American Water Works Association, 70*, 156–161.

Kuo, H. W., Chiang, T. F., Lo, I. I., Lai J. S., Chan C. C., & Wang J. D. (1997). VOC concentrations in Taiwan's household drinking water. *Science of the Total Environment, 208*, 41–47.

Latifoglu, A. (2003). Formation of trihalomethanes by the disinfection of drinking water. *Indoor and Built Environment, 12*(6), 413–417.

Lin, T. F. & Hoang, S. W. (2000). Inhalation exposure to THMs from drinking water in south Taiwan. *Science of the Total Environment, 246*, 41.49.

Ristoiu, D., von Gunten, U., Mocan, A., Chira, R., Siegfried, B., Kovacs, M. H., & Vancea, S. (2009). Trihalomethane formation during water disinfection in four water supplies in some river basin in Romania. *Environmental Science and Pollution Research, 16*, 55–65.

Rook, J. J. (1976). Haloforms in drinking water. *Journal of American Water Works Association, 68*, 168–172.

Simpson K. L. & Hayes K. P. (1998). Drinking water disinfection by products: An Australian perspective. *Water Research, 32*(5), 1522–1528.

Stevens, A. A., Slocum, C. J., Seeger, D. R., & Robeck, G. G. (1976). Chlorination of organics in drinking water. *Journal of American Water Works Association, 68*, 615–620.

Texas Commission on Environmental Quality. (2002). Total organic carbon (TOC) guidance manual. Retrieved from http//www.tceq.gov/publications/rg/rg.379. html/at.download/file.

United States Environmental Protection Agency. (1999a). Alternative disinfectants and oxidants guidance manual (EPA 815.R.99.014). Retrieved from https://nepis.epa.gov.

United States Environmental Protection Agency. (1999b). EPA guidance manual turbidity provision, chapter 7, importance of turbidity. Retrieved from http// www.epa.gov/ogwdw000/mdbp/pdf/turbidity/cahp_ 07.pdf.

United States Geological Survey. (2014). *Copper: Statistics and information*. Retrieved from http://minerals. usgs.gov/minerals/pubs/commodity/copper.

Walter, Z. T. & Tassos, S. (1997). Oxidation kinetics and mechanisms of trihalomethanes by Fenton's reagent. *Water Research, 31*(5), 1117.1125.

World Health Organization. (2010). Drinking water quality in the South.East Asia region. Retrieved from https:// iris.who.int/handle/10665/204999?show=full.

Wright, J. M., Schwartz, J., & Dockery, D. W. (2004). The effect of disinfection by.products and mutagenic activity on birth weight and gestational duration. *Environmental Health Perspective, 112*, 920–925.