Turk J Public Health
Available online at: http://dergipark.org.tr/tjph/
Doi: 10.20518/tjph.1491894

TURKISH JOURNAL OF PUBLIC HEALTH

ORIGINAL ARTICLE

Land use and trihalomethanes generation in water reservoir, a case study from Istanbul, Türkiye

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Received: 01.06.2024, **Accepted:** 29.11.2024

Abstract

Objective: The Büyükçekmece and Terkos drinking water reservoirs occur in the European part of Istanbul, have been created by isolation of two coastal lagoon lakes from the sea, which supply approximately 25% of water consumption of the Metropolitan city.

Methods: Treated waters of these two reservoirs have quite different trihalomethanes (THMs) concentrations although being adjacent basins that range between 10 - 30 (mean 20.8) ppb for the Terkos and 20 – 65 (mean 41) ppb for the Büyükçekmece reservoir. THMs concentration in treated water for both Büyükçekmece and the Terkos reservoirs increase in the summer and decrease in the spring. Furthermore, THMs of the treated water of Büyükçekmece reservoir are so higher than those of the other reservoir waters of İstanbul.

Results: The main reason of the higher value of THMs for the Büyükçekmece reservoir water could be related to ongoing agricultural activity in the vicinity of drainage basin. Another important indicator parameter for the THM formation mechanism is Specific UV absorbance (SUVA) value, that showed both of reservoir's organics in water mostly composed with hydrophilic properties.

Conclusion: Seasonal variations of low nitrate–high THMs in summer and high nitrate–low THMs in winter in treated lake waters can be explained by nitrogen run off from the land and consumption by photosynthesis when the water reach favourable temperature in summer. High nitrogen input into the Büyükçekmece reservoir could be associated with agricultural activity in the drainage basin which controls the high amount of organic carbon formation and high THMs generation during the treatment by chlorine.

Keywords: Büyükçekmece Lake, Terkos Lake, Trihalomethanes, Agriculture, Land Use

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Cite This Article: Öztürk H, Güneysu S, Kocazeybek BS, Başa Ş, Ölmez Hancı T. Land use and trihalomethanes generation in water reservoir, a case study from Istanbul, Türkiye. Turk J Public Health 2024;22(3): 263-272.

INTRODUCTION

THMs are hazardous and carcinogenic matter which form as disinfection by-product during the water treatment by chlorine[1,2]. There are many research papers associated with public health effects of the THMs. The main concern dealing with the THMs are related to bladder cancer on male and fetal growth, stillbirth defects on female[3,4,5,6]. Many investigations have indicated a clear relation of bladder cancer and exposure to water disinfection by-products through ingestion, bathing, showering, and swimming in pools[7]. The allowable level of the THMs in drinking water changes from country to country or union states, for example the USA accepts 80 ppb as allowable limit, whereas EU 100 ppb. In last decades a big effort has been made by developed countries for reducing of the allowable THMs limit in drinking water[8]. However, owing to the high cost of the reducing of the THMs in drinking water, the allowable level has not been reduced to 40 ppb level.

THMs level of the drinking water of the Istanbul metropolitan is declared by its official web page of the Istanbul Water and Sewerage Administration Authority[9] for each treatment plant on average value basis. The THMs values of treated waters of İstanbul vary between 20–40 ppb, as a special case, treated water of the Büyükçekmece reservoir reveals the highest value of THMs as being between 20 – 65 ppb.

The first aim of this study is to understand why treated water from the Büyükçekmece reservoir includes the highest THMs value whereas the treated water of the nearby Terkos reservoir, reveals the lowest value. The second aim is to explain causes of the seasonal variations of THMs in treated water of the Büyükçekmece and Terkos reservoirs. For these purposes, variation in the nitrate content through the year of both treated waters have been comparatively investigated. During the study, land use map of the both drainage basins have been prepared for a comparative analysis of basin conditions. The ISKI water quality data[9], consisting of THMs, nitrate, chloride values of treated water of Büyükçekmece treatment plant and also the İkitelli treatment plant that purifiers the raw water of the Terkos reservoir have been used for both seasonality analyses. A land use map was prepared and calculated as percentage as settlement area, agricultural area, and forest- meadows area for both basins, using the Google earth 2023 data. Then a conceptual model explaining the variations and seasonality of THMs for two basin waters has been made on the basis of differences of land use characteristics and water chemistry.

Water supply in Istanbul

The city of İstanbul has not an important river for water supply and hence depends on collecting rain waters in seven small–sized drainage basins. Three of them occur in the Asian side and the four in the European side. Population of the İstanbul metropolitan city still increases and has reached from 3 to 18 million in the last 40 years. Today, managing of the mega city nearly equals to managing of the water resources. The city consumes 3.0 million cubic meter (Mm^3) water daily, which is roughly 1.1 billion m^3 water/year. However, the maximum water collection capacity of the seven water reservoirs of İstanbul is 847 million m^3. The Anatolian side water reservoirs collect 337 Mm^3 water (Elmalı 10 Mm^3, Ömerli 220 Mm^3 and Darlık 107 Mm^3), whereas the European side reservoirs collect 410 Mm^3 water (Büyükçekmece 148 Mm3, Terkos 162 Mm^3, Sazlıdere 68 Mm^3 and the Alibey 34 Mm^3). Additionally, some water is taken from the Yeşilçay River to the Darlık reservoir (Figure 1).

During an extra dry season whole dam capacity of İstanbul drops to 500–600 Mm^3/year. For solving the water shortage of İstanbul two water carrying pipe lines have been constructed to transfer water from the neighbouring eastern (Melen River) and the western (Kazandere and Pabuçdere water dams) water basins (Figure 1).

The Melen basin water transfer project has been planned for a one billion cubic meter water transfer from the Melen basin to İstanbul along approximately 190 km length pipe line. After the first phase of the project roughly 400 Mm^3 water/year have been transferred to İstanbul by this pipe line during the driest year of 2014. When the Melen Project completed in a few years, 1 billion cubic metre w ater will be transferred to the İstanbul.

The western water transfer structures consist of two main dams as the Pabuçdere and the Kazandere which collects totally 160 Mm^3 water in forestry regions, far from the agricultural and other urban activity. This water transferred to the closest and the oldest water reservoir of İstanbul, the Terkos Dam via 60 km length pipe line (Figure 1).

Daily water treatment capacity of ISKI is 4,310,000 m^3 with six treatment plants in the Asian side (2,360,000 m^3) and six plants in the European side (1,950,000 m^3). Water sources of the İstanbul as both internal and external are nearly equal and disinfected using chlorine in the treatment plants (Table 1). Capacity of the all-water treatment plants, treatment methods have been summarised in Table 1. Water treatment process begin as either pre–ozonisation or pre–chlorination for reducing the organics and followed by aeration–coagulation–flocculation–filtration and chlorination. Owing to high water demand of the European side of Istanbul, the Melen water was treated in the Cumhuriyetköy treatment plant in Asian side and pumped to the European side, to the Kağıthane distribution centre by a tunnel that opened under the İstanbul Strait.

Today, ISKI makes big effort for supplying water for residents of İstanbul metropolitan city that created an interconnect water network for treated water. But there are no extra chlorination stations beyond the treatment plants, once a treated water given into the system no chlorine adding into the water anymore. Pre–ozonisation aims oxidation of the organics with two exceptions, the Büyükçekmece reservoir water and Melen water. Pre–ozonisation do not apply in to the raw waters of the Büyükçekmece because of its high bromine ions. High bromine in the Büyükçekmece lake water is possibly related to salty sea water intrusion from the Marmara Sea, which may have been infiltrated from the sand bar into the coastal dam by strong squeezing force of the sea waves. As it is known, bromide oxidise to the carcinogenic bromate forms during the ozonisation therefore, this process does not use for this lake water. The explanation of the without pre–ozonisation treatment for the Melen water in Cumhuriyetköy treatment plant is its low amount of organic matter content.

Two basin and two different waters

The Büyükçekmece and the Terkos drainage basin are two adjacent basins which are located in the western part of İstanbul city. Surface water of both basins were flowing into the shallow lagoon lakes, which were connected with the sea via narrow channels. Both shallow lagoon lakes were a few meters' depth isolated from the sea with earth fill–type dam structure and transformed to water reservoirs. Both reservoirs have a max depth of 7–8 m and collects 148 and 162 Mm^3/year water, respectively.

Raw water of the Büyükçekmece reservoir is treated at the lake shore, whereas the Terkos reservoir water is transferred to the Taşoluk, İkitelli and Alibey treatment plants. On the other hand, 160 million cubic meters' water/year of the Pabuçdere and the Kazandere dams located outside the city is diverted into the Terkos reservoir by pipeline. These two waters collecting dams have been constructed in the area covered by forest which provides environmentally suitable conditions for a reservoir far from any settlements, industry and the agricultural activities. Seawater intrusion are characterised by chloride ion increase in reservoir of Büyükçekmece and Terkos during the dry seasons of 2014. Agricultural activity and urbanization in the Büyükçekmece basin is higher than the Terkos basin. Contrary to the Büyükçekmece, the Terkos basin is surrounded by forest–meadows land (Figure 2).

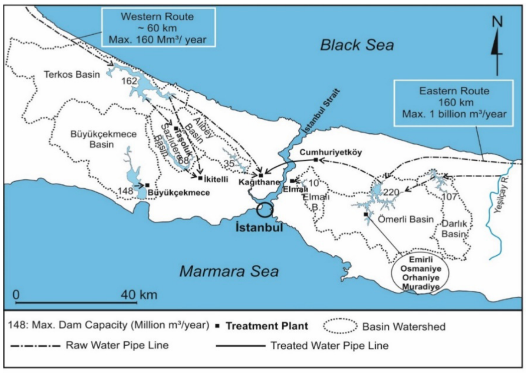

Figure 1 Main drainage basins, water reservoirs, water treatment plants and water transfer pipe lines of İstanbul.

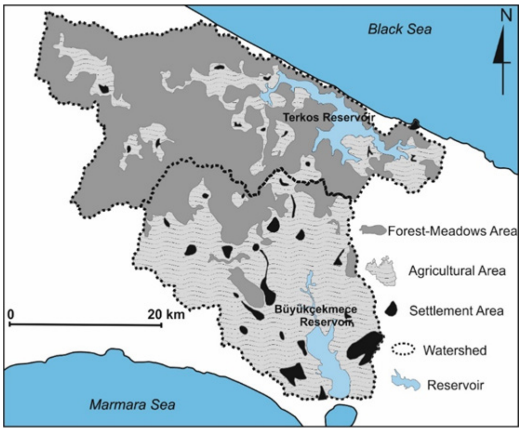

Figure 2. Land use map of the Büyükçekmece and Terkos drainage basins.

Table 1. Physical characteristics and treatment phases of the water treatment plants of İstanbul city

Treatment plant	Water source	Capacity (m^3/day)	Treatment method
Büyükçekmece	Büyükçekmece	400,000	Ch, A, C/F, F, Ch
Cumhuriyetköy	Melen	720,000	A, Ch, C/F, F, Ch
Ömerli	Ömerli + Melen	1100,000	A, P, C/F, F, Ch
Osmaniye		200,000	
Muradiye		300,000	
Orhaniye		550,000	
Kağıthane	Terkos + Melen +Alibey	700,000	A, P, C/F, F, Ch
Çelebi Mehmet Han			
Yıldırım Beyazıd Han			
Emirli	Yeşilçay + Darlık	500,000	A, C/F, F, Ch
İkitelli	Terkos + Istranca	800,000	A, P, C/F, F, Ch
Fatih Sultan Meh. Han		400,000	
II.Beyazıd Han		400,000	
Taşoluk	Terkos	50,000	A, P, C/F, F, Ch
Elmalı	Elmalı	40,000	A, P, C/F, F, Ch

A: Aeration P: Pre-ozonisation, C/F: Coagulation/Flocculation, F: Filtration Ch: Chlorination[9]

METHOD

Analytical Data

ISKI has analysed the raw and treated water as daily base and we used their last 5 years data. Organic carbon is defined by 5310SM, nitrates 4110SM, THMs 6232SM method[10]. Monthly mean values of the organic carbon, nitrates, THMs and chloride of the Büyükçekmece and Terkos water were calculated for five years period.

THMs, nitrates, organic carbon and salinity of two basin water

For a comparative analysis of the possible causes of seasonal variation in processed water of the two reservoirs a variation graph for THMs, nitrate, organic carbon and salinity has been prepared for a five-year period (Figure 3(a)–(b)).

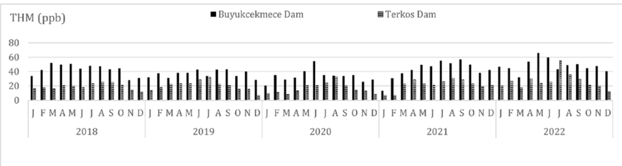

Figure 3(a). Seasonal variations of the THMs in treated waters of the Büyükçekmece and Terkos reservoirs[9].

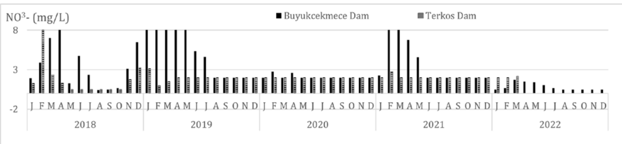

Figure 3(b). Nitrate variations in treated waters of the Büyükçekmece and Terkos reservoirs[9].

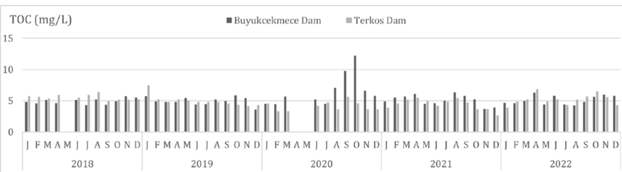

Figure 3(c). TOC variations in treated waters of the Büyükçekmece and Terkos reservoirs[9].

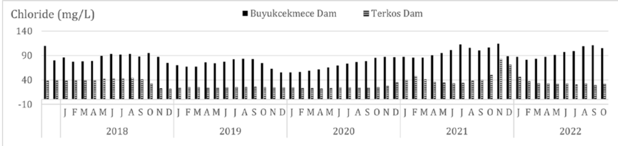

Figure 3(d). Seasonal change of chloride concentrations in treated water of the Büyükçekmece and Terkos water reservoirs[9].

RESULTS

THMs

THMs values for both reservoirs show very regular pattern as high in the summer and low in the spring season. THMs of the both reservoirs reveal a minimum value in 2018 considering the last 5 years. The lowest THMs values is in January and the highest are in June and July. This cyclic pattern should be related to the water temperature, which control the organic carbon synthesis in the lake water, that begins in April and reach the peak in August. Nitrate plays also a key role as another constituent that creates a biological–organic chain in the lake water in summer time (Figure 4).

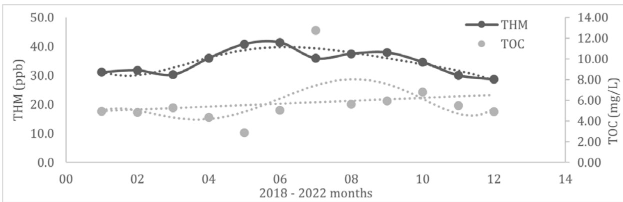

Figure 4. The figure shows the change in the mean of THM versus TOC in the waters of Büyükçekmece Lake for the last 5 years.

Figure clearly indicates a marked periodicity of THMs as peaks in June and July whereas the depletion in December and January.

Nitrates

Nitrate values of the lake water do not coincide with the THMs as shown in Figure 3(b). Nitrates of the Buyukçekmece and Terkos lake reveal a lowest value in 2020. In time period of 2018 to 2022, nitrate displays a marked cyclic change (the lowest is November and the highest is April–May). A possible explanation of the lowest nitrate concentration in the treated water is completely consumption of nitrate during the creation of the organic matter in a whole suitable summer season. Another cause of nitrate depletion is limited rain and limited nitrate run off from the surrounding agricultural areas (Figure 5).

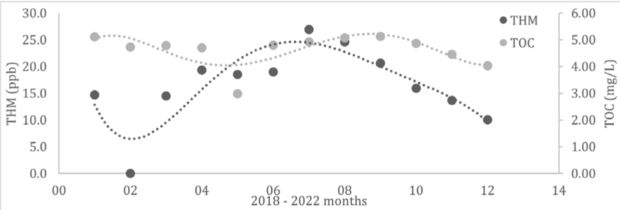

Figure 5. The figure shows the change in the mean of THM versus TOC in the waters of Terkos Lake for the last 5 years.

Organic carbon

Organic carbon content of the Terkos Basin water ranges between 3.66 and 5.85 mg/L whereas the Buyukçekmece lake ranges 4.29 to 12.21 mg/L (Figure 3c). Organic carbon values show a general enrichment at the summer season for the Terkos basin and reach top level at April and decrease to minimum point at January. On the other hand, organic carbon value of the Buyukçekmece lake reveals ondulatory pattern. The TOC values begin with 4.90 mg/L in January and drastically fall to 4.60 mg/L in April and again reach to 5.20 mg/L level int October and fall again to 4.75 mg/L level in December (Figure 6-7).

Salinity

Chloride values of the Buyukçekmece and Terkos lake water for 5 years period is shown in Figure 3(d)(Figure 3(d)). Chloride values of the Buyukçekmece Lake range between 60 to 120 mg/L which is higher than the Terkos lake (30- 80 mg/L) water because of the limited sea water dam water exchange in the Buyukçekmece Lake. Chloride values show a very well seasonality and a has a general increasing salinity trend. Salinity figure show a relative chloride peak in 2020 which is coincide with dry season for last 5 years.

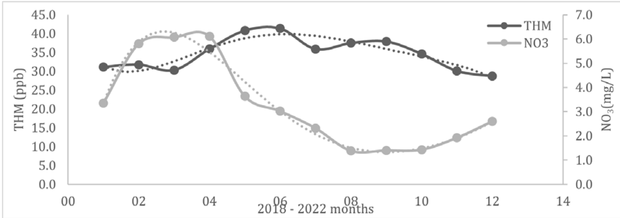

Figure 6. The figure shows the change in the mean of THM versus nitrate in the waters of Büyükçekmece Lake for the last 5 years.

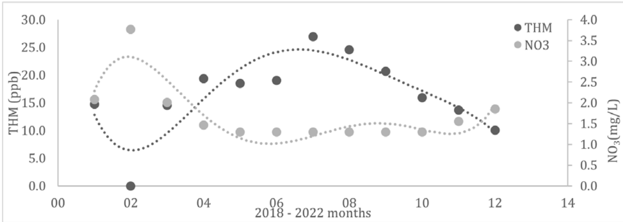

Figure 7. The figure shows the change in the mean of THM versus nitrate in the waters of Terkos Basin for the last 5 years.

Land Use

A zonal protection strategy for the drinking water basins has been declared by the Ministry of Water and Forestry in 2003 to be applicable to whole Turkey with minor additions by the municipalities[11]. According to the ministry regulation, from the lake shore towards 300 meters is defined as absolute protection zone, 300 meters to 1000 meters' proximate protection zone, 1000 meters to 2000 meters mediate protection zone, and 2000 meters to the basin as remote protection zone. Some limitations have been defined in that zones regarding settlement or agricultural manner[12,13]. For example, agricultural activity using fertilizer and organic chemicals is not allowed in these zones. However, fertilizers and pesticides more or less are widely used in all water basins and enhances if they close to market. It is also stated that nitrate inputs associated with agricultural activity or natural ways into the Ömerli water reservoirs of İstanbul and its impacts on the environmental degradations[14].

ISKI also made some site planning approach for water catchment areas in 2003 where the first two zones have been banned to all constructions (0–1000 m), and third and fourth zones have been limited by 10 persons/hectare, and 20 persons/hectare, respectively. However, controlling of agriculture or other activities of people in the water basin is so difficult, especially for expanding cities and vote–based political circumstances. Today, the agricultural activities and the population are increasing and associated pollution and eutrophication is staying a growing environmental problem for the drinking water reservoirs.

Land use map of the Büyükçekmece and Terkos basins and surface area calculations has been made from the google earth data of October 2022. The land has been divided into three areas from the picture: as forest - meadows, agriculture and settlement. Calculations from the google earth indicated that settlement area covers 9%, forestry-meadows areas 19%, and agricultural area 72% for the Büyükçekmece basin whereas, 1% settlement, 17% agricultural and 82% forest area - meadows for the Terkos Basin. These proportional comparisons clearly indicate that agriculture-based environmental degradation is a major concern for the Büyükçekmece lake basin.

Figure shows the nitrate peaks in April and is low in October. A relative nitrate depletion of the two-basin water 2020 is seen so obvious. Please note that while THMs values is low (Figure 3a) nitrate is high or vice versa. This relationship clearly indicates that nitrogen originated from the land and stored in the reservoir water during the rainy and cool season then consumed by organic matter formation in summer time that causes THMs generation (Figure 8).

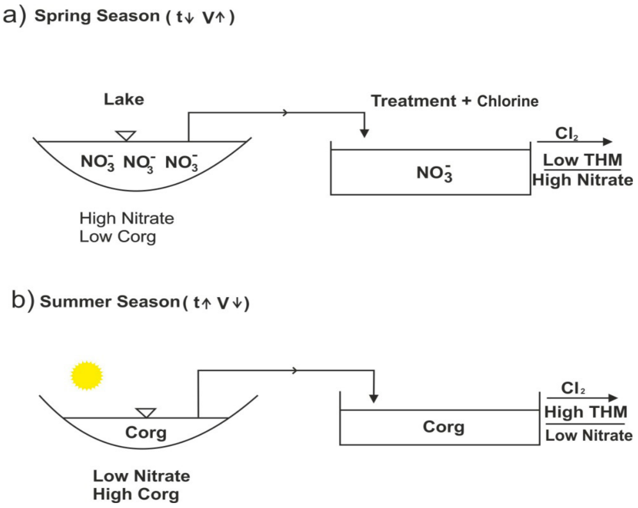

Figure 8. Conceptual model explaining causes of low THMs - high nitrate in summer and high nitrate-low THMs in spring season in treated waters of the Büyükçekmece and Terkos reservoirs. Corg: organic carbon, t: temperature, v: volume.

DISCUSSION

Water treatment plants of İstanbul produce up to 3.0 Mm^3 per day of drinking water. Although the treatment steps of these plants reveal some differences process is usually carried out in the following order: pre–chlorination, aeration, coagulation, flocculation, sedimentation, filtration and post chlorination. Pre–chlorination aims the reducing the organic matters and killing the microorganisms and pathogens that may cause the illness in humans. However, some THMs occurs during this pre–chlorination stage, then removed by following aeration processes. Removal of the whole organics in a limited time span is not possible; therefore, a final chlorination is needed to prevent re–growth of any kind of microorganism in the pipeline. For this purpose, legal limit of free chlorine at the end point of the distribution network of Istanbul city is regularly controlled by ISKI.

In addition to TOC and NO_3^- parameters in the formation of THM in chlorinated water, an important indicator is also presenting analysis of UV absorbed (UV254) and specific UV absorbance (SUVA) parameters at 254 nm. SUVA parameter is the most important organic parameter used in estimating the structure of natural organic substances in surface waters and the formation of substances such as THM that occur during chlorination[15,16]. SUVA parameter > 3 L/mg.m indicates the presence of hydrophobic organic substances, while SUVA <3 L/mg.m indicates the presence of hydrophilic organic substances[17]. In the raw waters of Terkos Lake, which has the highest SUVA value, the organic compounds were found to be mostly composed of organics with hydrophilic properties.

Seasonal Variation Mechanisms

Beyond the seasonality of the THMs values, basin differences are also needed to explanation. Processed waters of the Büyükçekmece reservoir reveals the highest THMs values among the Istanbul reservoirs because of the dense agricultural activity and settlements in this drainage basin. Contrary to the Büyükçekmece, its adjacent Terkos reservoir water has the lowest THMs value because of the relatively forest- meadows nature of the drainage basin.

Land Use Impacts

The nitrate introduction via surface runoff from the agricultural–rural areas into the water reservoir possible enhance the formation of the organic matter. Beginning of the organic matter formation in the water nitrate simultaneously starts to decrease in summer. Particulate or dissolved organic carbon possibly reacts with chlorine during the water treatment processes and causes high TMHs–bearing water (Figure 8) in summer. In fact, during the low water level in summer time, large areas of the reservoirs are exposed where vegetation quickly develops. During the high-water level period in spring, this vegetation is flooded and begins to degradation and releases dissolved organic carbon in to the water. Instead of harvesting vegetation, dredging of organic matter - rich muds may be another THMs reducing processes during the low water period in summer. Today we have no data on the organic carbon content of the raw water of the Büyükçekmece and the Terkos water reservoirs.

Health Impact Discussion

The most recent studies on the epidemiological relationship between bladder cancer and THM levels were set out many researchers[18]. The study shows that daily THM dose in swimming pool increased it more than three times; 1,3 µg/day to 3,9 µg/day according to non swimmers[19]. Daily water use poses a danger, especially for water with high THM levels. Taking long showers, brushing teeth and washing hands significantly increase the daily THM dose we took.

Proposed Mitigation Strategies

In this context, reducing the THMs in water can be achieved by reducing organic carbon by three ways as stated[20], a: using membrane filter for trapping particulate organic carbon prior to chlorination, b: harvesting vegetation along the reservoir shore line and, c: Diverting the first 24 hours of water transfer. They argued that harvesting the vegetation and removing it from the reservoir margins prior to flooding could improve water quality by reducing THM formation.

Policy and Regulation Challenges

In addition, there is no big effort for reducing the organic matter content of the water reservoirs. Farming areas or private settlement with in the absolute protection zone have not been completely expropriated by ISKI yet. Therefore, THMs values of the raw waters possibly will not decrease owing to on-going environmental detritions in the water basins in Istanbul in near future.

CONCLUSION

Despite the public health importance of THMs, there are limited publications related to THMs levels in the drinking water of Istanbul city both international journals and local meeting abstracts[21,22,23,24]. It is argued that THM enrichments on summer session in treated water of the Büyükçekmece reservoir is related to bromide increase in the lake water owing to evaporation[22]. On the other hand, increase in the THMs in treated waters of both coastal and inland reservoirs, in the summer, requires a valid explanation for the mechanism for high THMs generation.

In this context, the land use seems to main concern of the high THM generation. Pre–ozonation should be the first process for the Büyükçekmece reservoir water in order to decrease of the organic matter and/or THM values. For this purpose, sea water intrusion has to be control or stopped by making an impermeable barrier in coastal sandy material by concrete injection.

Indications of the high THMs concentrations in public water supplies to fatal growth, stillbirth and birth weight have been studied in different regions in the world for example in England and USA[3,25]. Similarly, health effects of THMs on residents of the western part of İstanbul should be comparatively study on the basis of bladder cancer case and other health problems.

ACKNOWLEDGEMENTS

The authors thank to ISKI (Istanbul Water and Sewerage Administration Authority) for sharing water quality test data. We also thank to research assistant Zeynep Örü for her contribution for drawing the figures.

Financial Support: No financial support has been received.

Conflict of Interest: No conflict of interest

Ethical Declaration: The type of this study is different, ethics committee approval is not required

Author contributions: Concept and design: HÖ, SG, BSK, ŞB, TÖH, Data collection: HÖ, SG, BSK, ŞB, TÖH, Analysis and interpretation of data: HÖ, SG, BSK, ŞB, TÖH, Drafting the manuscript: HÖ, SG, BSK, ŞB, TÖH, Critical revision of the article: HÖ, SG, BSK, ŞB, TÖH, Final approval of the article: HÖ, SG, BSK, ŞB, TÖH,

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