WATER QUALITY ASSESSMENT OF AN INDOOR SWIMMING POOL

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Dedicated to my family……

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WATER QUALITY ASSESSMENT OF AN INDOOR SWIMMING POOL

This study investigated the quality of Boğaziçi University indoor swimming pool water by using physical, chemical and microbiological parameters.

Physical parameters were temperature, color, turbidity, conductivity, salinity and TDS. Chemical parameters were pH, alkalinity, hardness, free chlorine, ammonia, TKN, oxidizability, common anions, metals, and organic carbon. Moreover, UV-vis absorption and fluorescence spectra of samples were recorded. Microbiological parameters were heterotrophic plate count, total coliforms, fecal coliforms, fecal streptococci, *Pseudomonas aeruginosa* and *Escherichia coli*. Hygienic habits and behaviors of pool users were evaluated by questionnaires.

The results of physical and chemical parameters and heterotrophic plate count conformed to those recommended by authorities. *Escherichia coli*, total coliforms and fecal coliforms were not identified. 35 strains were identified: *Pseudomonas* spp. were the most frequently isolated bacteria (34%); 20% of the identified strains were *Pseudomonas aeruginosa;* the rest were various bacteria.

This study has revealed that waters of indoor swimming pools in Turkey have not been examined in this context. The results indicate that pool waters should be continually monitored and *Enterococci* should be used as a parameter. Surveys in heavily used pools will be beneficial in revealing the hygienic habits and behaviors of pool users and directing future research on pool water quality.

KAPALI BİR YÜZME HAVUZUNUN SU KALİTESİNİN DEĞERLENDİRİLMESİ

Bu çalışmada, Boğaziçi Üniversitesi kapalı yüzme havuzunun su kalitesi fiziksel, kimyasal ve mikrobiyolojik parametreler kullanılarak araştırılmıştır.

Bu çalışmada kullanılan fiziksel parametreler, sıcaklık, renk, bulanıklık, iletkenlik, tuzluluk ve toplam çözünmüş katı maddelerdir. Kimyasal parametreler ise pH, alkalinite, sertlik, serbest klor, amonyak, total Kjeldahl azotu, organik karbon, oksitlenebilirlik, anyonlar, ve metallerdir. Ayrıca, örneklerin UV/görünür bölge spektroskopisi ve floresans spectroskopisi ölçümleri kaydedildi. Kullanılan mikrobiyolojik parametreler heterotrof koloni sayımı, toplam koliform, fekal koliform, fekal streptokok, *Pseudomonas aeruginosa* ve *Escherichia coli* dir. Ayrıca havuz kullanıcılarının hijyenik alışkanlıkları ve davranışlarının su kalitesine olan katkıları hazırlanan anketlerle değerlendirilmiştir.

Havuz suyunun fiziksel, kimyasal parameter sonuçları ve heterotrof koloni sayısının otoriteler tarafından verilen limitlere uygun olduğu görülmüştür. Bu çalışmada *E.coli*, total koliform ve fekal koliform identifiye edilmemiştir. Havuz suyunda 35 suş identifiye edilmiştir: *Pseudomonas* spp. en sık izole edilen (%34) bakterilerdir; identifiye edilen bakterilerin %20'si *Pseudomonas aeruginosa*'dır. Bunun dışında çeşitli bakteriler de identifiye edilmiştir.

Bu çalışma ülkemizde bulunan kapalı yüzme havuzlarının sularının bu kapsamda incelenmemiş olduğunu göstermiştir. Çalışmanın sonuçları yüzme havuzlarının sularının sürekli olarak izlenmesinin ve Enterokokun da bir parametre olarak kullanılmasının gerekli olduğuna işaret etmektedir. Yoğun kullanımın olduğu havuzlarda yapılacak anketler havuz kullanıcılarının hijyenik alışkanlıkları ve davranışlarını ortaya çıkarmak açısından yararlı olacak ve gelecek çalışmalara ışık tutacaktır.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Symbol	Explanation	Units used
BCDMH	Bromochlorodimethylhydantion	
BU	Boğaziçi University	
BUISP	Boğaziçi University indoor swimming pool	
BUISPW	Boğaziçi University indoor swimming pool water	
CDC	Centers for Disease Control and Prevention	
DBPs	Disinfection by-products	
DOC	Dissolved organic carbon	(mg OrgCL^{-1})
EAEC	Enteroaggregative *E. coli*	
EIEC	Enteroinvasive *E. coli*	
EPEC	Enteropathogenic *E. coli*	
ETEC	Enterotoxigenic *E. coli*	
ExPEC	Extra intestinal pathogenic *E. coli*	
FC	Fecal coliforms	
FS	Fecal streptococci	
HAAs	Haloacetic acids	
HOCI	Hypochlorous acids acid	
HPC	Heterotrophic plate count	
HVAC	Heating, ventilation, and air conditioning systems	
IC	Inorganic carbon	(mg CL^{-1})
IES	Institute of Environmental Sciences	
ISKI	Istanbul Water and Sewerage Administration	
MF	Membrane Filter	
MNEC	Meningitis/sepsis associated *E. coli*	
NDMA	N-Nitrosodimethylamine	
NPOC	Non-purgeable organic carbon	(mg OrgCL^{-1})
PAM	Primary amoebic meningoencephalitis	
PWTAG	Pool Water Treatment Advisory Group	
STEC	Shiga toxin-producing *E. coli*	
Tot C	Total carbon	(mg CL^{-1})
TC	Total coliforms	
TDS	Total dissolved solid	(mg L^{-1})

THMs	Trihalomethanes	
TKN	Total Kjeldahl nitrogen	(mg L^{-1})
TMOH	Turkish Ministry of Health	
TOC	Total organic carbon	(mg $OrgCL^{-1}$)
TS	Turkish Standards	
TSI	Turkish Standards Institution	
UPEC	Uropathogenic *E. coli*	
USEPA	United States Environmental Protection Agency	
UV	Ultra-violet	
VOC	Volatile organic carbon	(mg $OrgCL^{-1}$)
WHO	World Health Organization	

1. INTRODUCTION

A swimming pool is an artificially created pool or tank filled with water, either indoors or outdoors. Swimming pools are used all over the world for swimming and other recreational or sports activities. A pool is generally built of long-lasting material such as concrete. The floor and sides must not allow loss of water (Perkins, 2000). The material used must resist humidity and corrosion without encouraging the growth of bacteria (TS EN 15288-1+A1, 2012). Indoor pools are equipped with heating, ventilation, and air conditioning (HVAC) systems.

Some swimming pools are private pools; they are located in private homes and are reserved for the use of a family and friends. Pools located in hotels, schools, or cruise ships are semi-public pools. There are also public pools, such as municipal pools, which are open for use by the public. Some swimming pools are built for a specific type of activity; among them are teaching pools, diving pools, paddling pools, or pools with water slides (WHO, 2006).

Pools naturally present some physical risks which the users need to be aware of. Non-swimmers, children, the elderly, and individuals with disabilities and those who are immune-compromised are more sensitive to hazards such as injuries or drowning. As for microbial hazards, swimming pools and similar recreational water bodies may be fecally contaminated because of feces from bathers, contaminated water source, and animal contamination. Another source of pathogenic microorganisms in pools and similar environments come from human shedding (*e.g.* vomit, mucus, saliva). Opportunistic pathogens (especially bacteria) are dropped by swimmers or transmitted through contaminated surfaces and water. Animal contamination (birds and rodents) is an important factor in outdoor swimming pools. In addition, infected people contaminate pool water and the environment with fungi and viruses. Such contamination results in skin and other infections (WHO, 2005; WHO, 2006; Nichols, 2006).

Various pathogens enter swimming pool area (WHO, 2006). *Escherichia coli* and *Pseudomonas aeruginosa* are two important pathogens in swimming pools. *P. aeruginosa* is a well-known aerobic Gram negative rod-shaped bacterium which is non-spore-forming and motile. The moist, warm swimming pool areas are suitable for the growth of *Pseudomonas*. *E. coli* O157 is another important pathogen in swimming pools. This bacterium is characterized by motile, non-spore-forming Gram negative rod and results in bloody diarrhea and hemolytic uremic syndrome especially in infants, young children and the elderly (Moore et al., 2002; Barben et al., 2005; WHO, 2006; Papadopoulou, 2008).

Disinfection of swimming pool water is an important process for the removal of pathogens and protection against infections and outbreaks. However, disinfectants may form disinfection by-products (DBPs) such as trihalomethanes (THMs) and chloramines, which also pose health risks. World Health Organization (WHO) is the main authority that provides information concerning potential health risks that pools might pose, the possible infections and outbreaks they may cause, and preventive measures. In Turkey, Turkish Ministry of Health and Turkish Standards Institution (TSI) focus on swimming pools and publish regulations and standards (WHO, 2006; TS 11899, 2007; TMOH Regulation 28143, 2011; TS EN 15288-1+A1, 2012; TS EN 15288-2, 2012).

This study investigated the quality of Boğaziçi University indoor swimming pool water by using physical, chemical and microbiological parameters. In addition, the operational conditions of the swimming pool and the hygienic habits and behaviors of pool users were evaluated by means of questionnaires designed to assess their contribution to water quality.

2. THEORETICAL BACKGROUND

This chapter covers general information about swimming pools, their disinfection systems, pool users, and physical, chemical and microbiological hazards associated with pool use. The quality of the pool water and relevant regulations set by various authorities are also summarized. Water quality parameters and their limit values as recommended by authorities are presented in the tables.

2.1. Swimming pool definition and classification

A swimming pool is defined as a body of water that is accumulated in a large structure for use in recreational activity (TS EN 15288-1+A1, 2012). Swimming pools are widespread in most parts of the world. According to the Center for Disease Control and Prevention (CDC) data, there are over 10 million residential pools and about 309,000 public swimming pools only in the USA. Swimming is one of the most popular activities in the United States and 15 % of adults and 36% of children and teens swim at least six times per year (CDC, 2016). Moreover, the European Union is ranked second with about 4.5 million pools behind the United States (Florentin et al., 2011).

WHO Guidelines for Safe Recreational Water Environments for Swimming Pools and Similar Environments classify swimming pools as domestic, semi-public and public pools. Domestic pools are designed for the private use of the family and guests of the owner. Semi-public pools include those in schools, hotels, health clubs, cruise ships and housing complexes whereas public pools are municipal pools. Pools may also be classified in terms of their location as indoor or outdoor. They may be filled with fresh, marine or thermal water and the water may be heated or unheated**.** In addition, there are also many specialist pools such as learner or teaching pools, diving pools and pools with water slides. Hot tubs, such as spa pools, whirlpools, whirlpool spas, heated spas, bubble baths and Jacuzzis are designed for sitting in and use heated, treated water. Plunge pools are designed to cool users coming out of saunas, steam rooms or hot tubs. Natural spas are supplied with thermal or mineral water and are used for various health treatments. Moreover, there are physical therapy or ‘hydrotherapy’ pools where professional treatments are offered to people with neurological, orthopedic, or other diseases. Therapy pools containing doctor fish (*Garra ruffa*) that feed on the scaly skin lesions are used in the treatment of psoriasis (WHO, 2006). Indoor pools have more advantages than outdoor pools as they can be utilized throughout the year and are exposed to fewer contamination problems caused by factors such as falling leaves or air-borne dirt, and fewer problems related with freezing in extreme temperatures (Perkins, 2000). Due to the popularity of swimming pools irrespective of the purpose of use, it is very important to understand swimming pool chemistry, human exposure and potential health risks (Lakind et al., 2010). Moreover, indoor swimming pools may also express significant health concerns due to the presence of various harmful volatile compounds released to the air in the swimming pool area. It should be noted that swimming pool water should endanger swimmers by infectious microorganisms or by noxious chemicals (Glauner et al., 2005).

According to standards of TSI, swimming pools are classified into three types as Type 1, Type 2 and Type 3. Type 1 includes pools where the major business is water related activities. Communal pools, leisure pools, aqua parks and water parks are categorized as Type 1. Hotel pools, camping pools, club and therapeutic pools are grouped under Swimming Pool Type 2. These types of pools do not constitute the main business of these venues; they are an additional service. All pools except for these two types and pools for private use are classified as Swimming Pool Type 3 (TS EN 15288-1+A1, 2012).

A different classification is made by American National Standard Institute; accordingly, pools are classified into 6 groups (ANSI/APSP-11, 2009):

- Class A: Pools that can be used by accredited competitive events such as USA Swimming or National Collegiate Athletic Association,
- Class B: Public recreational pools,
- Class C: Pools in hotels, apartments complexes, condominiums, etc.
- Class D: Class D covers a variety of pools as follows:
    - Wave Action Pools, used for general play or surfing,
    - Activity Pools for casual water play,
    - Catch Pools, the small pools at the foot of a waterslides, etc.
    - Leisure Rivers, where water is moved by pumps, giving a river-like flow,

  - Vortex pools, round pools equipped with a system to move people at high circular speeds,
  - Interactive Play pools, containing attractions such as water slides, climbing and crawling structures, etc.
- Class E: used for instruction, play or therapy with water temperature higher than 30ºC.
- Class F: Wading pools.

While there are numerous types of pools, the potential hazards they pose are not very different. These hazards may be grouped as physical, chemical, and microbiological. Detailed information on these hazards is provided in section 2.4.

2.2. Types of pool users

Pools can be used by the public, competitive swimmers, health club members, clients of hotels and outdoor camping parks, non-swimmers, members of exercise classes such as aqua-aerobics, water polo players, canoeists, and scuba divers. However, children, the elderly, persons with disabilities and those who are immunocompromised may be more predisposed to hazards associated with swimming pools (WHO, 2006).

2.3. Disinfection of pool water

Disinfection is the process used to inactivate microorganisms (whether or not pathogenic) to ensure the safety of water, and to prevent the transmission of water-borne illnesses (Tchobanoglous et al., 2004). Disinfection process differs from sterilization for the reason that not all of the microorganisms, especially bacterial spores are killed. This process involves the use of physical and chemical agents, mechanical means and radiation. Heat, light, and sound waves are the commonly used physical agents. However, physical disinfection is not applied in swimming pools. The mechanical means used to remove organisms are coarse screens, fine screens, grit chambers, plain sedimentation, chemical precipitation, trickling filters, activated sludge and chlorination of treated waste water. Electromagnetic, acoustic and particle radiation are the main types of radiation used. Mostly, chemical agents as well as UV radiation methods are used in swimming pools

(Tchobanoglous et al, 2004). A comparative assessment of disinfectants in swimming pool water with respect to antimicrobial activity of sodium hypochlorite was presented by Borgmann-Strahsen (Borgmann-Strahsen, 2003). The major disinfection methods used in swimming pools and similar environments are presented in Table 2.1.

Table 2.1. Disinfectants and disinfecting systems used in swimming pools and similar environments (WHO, 2006).

Disinfectants used most frequently in large, heavily used pools	**Disinfectants used in smaller pools and hot tubs**	**Disinfectants used for small scale and domestic pools**
Chlorine -Gas -Calcium/sodium hypochlorite -Electrolytic generation of sodium hypochlorite -Chlorinated isocyanurates Bromochlorodimethylhydantoin (BCDMH) Chlorine dioxide[a] Ozone[a] UV[a]	Bromine -Liquid bromine -Sodium bromide and/or hypochlorite Lithium hypochlorite	Bromine/hypochlorite UV[a] UV-ozone[a] Iodine Hydrogen peroxide/silver/ Copper Biguanide

[a] Usually used in combination with residual disinfectants (*i.e.* chlorine or bromine based)

2.3.1. Chemical agents

Chlorine and its compounds, bromine, iodine, ozone, phenol and phenolic compounds, alcohols, heavy metals and related compounds, dyes, soaps and synthetic detergents, quaternary ammonium compounds, hydrogen peroxide, peracetic acid and various acids and alkali compounds are chemical agents and they are used as disinfectants. The most commonly used disinfectant in this group is chlorine based disinfectants. Main application area is drinking water treatment (Tchobanoglous et al., 2004).

2.3.1.1. Chlorine-based disinfectants. Use of chlorine and chlorine containing agents for disinfection purposes dates back to the 1850's. Chlorination is the most widely used cost effective technique of disinfection to ensure water safety. Chlorine is effective against many pathogens especially bacteria and viruses. Its advantage lies in the fact that the remaining residual chlorine level in the distribution system prevents water recontamination. It is well-understood technology and has a good safety record. (Tchobanoglous et al., 2004; USEPA, 2011; Weiner, 2013). Chlorine is used in the form of chlorine gas, sodium, calcium and lithium hypochlorite as well as chlorinated isocyanurates. Reactions of chlorine with inorganic and organic compounds had been reviewed extensively by Deborde and von Gunten (Deborde and von Gunten, 2008).

On the other hand, chlorine usage also presents some problems. Although it is effective bacteria and viruses, *Crytosporidium* is not affected by chlorine usage. Moreover, its effect against *Giardia lamblia* protozoa is limited. Its reactions with natural organic matter can lead to the formation of DBPs. Because of the risks in handling chlorine gas, usage requires special safety equipment. Taste and odor problems may occur at high chlorine doses (Weiner, 2013).

Chlorine in water dissociates and hypochlorous acid (HOCl) is formed alongside the formation of H^+ and Cl^-; Hypochlorous acid dissociates to form hydrogen ion (H^+) and hypochlorite ion (OCl^-). The pertaining reactions are presented in the following equations;

$$Cl_2 + H_2O \leftrightarrow H^+ + Cl^- + HOCl \qquad K = 4.5 \times 10^{-4} \text{ at } 25^\circ C \qquad (2.1)$$

$$HOCl \leftrightarrow H^+ + OCl^- \qquad K_a = 2.7 \times 10^{-8} \text{ at } 25^\circ C \quad pK_a = 7.53 \qquad (2.2)$$

pH and temperature determine the proportions of hypochlorous acid and hypochlorite ions in these reactions. Hypochlorous acid exerts more disinfection capacity in comparison to OCl^-. Hypochlorous acid is dominant at low pH, and therefore, disinfection is more effective in these circumstances. In contrast, hypochlorite ion is dominant at high pH. When pH is between 6.5 and 8.5, hypochlorous acid almost completely dissociates. At pH 8.0, 21% of the free chlorine is present in the form of hypochlorous acid, a powerful oxidizing disinfectant, whereas at pH 8.5, 12% of that chlorine is present as hypochlorous acid. For this reason, pH value in swimming pool water should be maintained in a narrow range of 7.2-7.8. HOCl is a more powerful oxidizing agent than OCl^- (WHO, 2006). At a given pH, the amount of hypochlorous acid decreases by the increase in temperature due to the increase in dissociation. But at the same time, the increase in temperature also increases the activity of oxidation, which improves disinfection performance (USEPA, 2011).

In aqueous solutions, combination of HOCI and OCI^- are defined as free available chlorine. Besides, it is known that ammonia in water signifies recent pollution and presence of ammonia indicates nitrogenous organic wastes since it is the first product of the decay of these wastes. Ammonia reacts with chlorine and forms residual chlorine. When ammonia exists in water, the chloramines (monochlormine, dichloramine and trichloramine) are formed as in the reactions below (2.3- 2.5); they are known as combined available chlorine. Chloramines produce the typical swimming pool smell and may cause wheezing and eye irritation for some swimmers.

$$NH_4^+ + HOCI \rightarrow NH_2Cl \text{ (monochloramine)} + H_2O + H^+ \qquad (2.3)$$

$$NH_2Cl + HOCI \rightarrow NHCl_2 \text{ (dichloramine)} + H_2O \qquad (2.4)$$

$$NHCl_2 + HOCI \rightarrow NCl_3 \text{ (trichloramine)} + H_2O \qquad (2.5)$$

As already given by reactions 2.1 and 2.2, hypochlorous acid and hydrochloric acid are formed when chlorine dissolves in water. Then, hypochlorous acid reacts with ammonia in the water in the presence of excess chlorine, forming hydrochloric acid and nitrogen. The point where chloramines begin to break down is called the breakpoint. This technique is referred to as “breakpoint chlorination” (Perkins, 2000). A side effect of chlorine is that it produces trihalomethanes and other halogenated disinfection by-products by reacting with organic compounds such as humic acid**.** However, this can be controlled by optimization of the treatment system.

Although chloramines are not more efficient disinfectants than free available chlorine, they provide long term disinfection of water distribution system. Due to the above presented reactions, more ammonia in water increases chlorine demand (Manahan, 2000).

Super chlorination or shock treatment process devastates ammonia and organic compounds by adding more chlorine. Chloramines under neutral and alkaline conditions slowly dissociate to nitrate and N_2 since chloramines display weaker reactivity with organic material, lower concentrations of disinfection by-products should be expected. On the other hand, chloramine residuals are more stable than free chlorine; therefore, they provide better protection against bacterial regrowth (Jafvert and Valentine 1992).

Besides disinfection property of aqueous chlorine, the reaction between chlorine and inorganic species dissolved in water such as iron is important for conversion of ferrous iron (divalent) to ferric iron (trivalent), which are the two oxidation states that iron exists in the aquatic environments (equation 2.6 and 2.7).

$$Cl_{2(g)} + 2Fe^{2+} \leftrightarrow 2Fe^{3+} + 2Cl^- \qquad (2.6)$$

$$HOCl + H^+ + 2Fe^{2+} \leftrightarrow 2Fe^{3+} + Cl^- + H_2O \qquad (2.7)$$

The conversion takes place immediately at nearly neutral pH. Iron exists in the form of ferrous bicarbonate in ground water used for drinking. Oxidation of iron by means of chlorine is important for water treatment. Ferric chloride, which is formed during the reaction, hydrolyzes to ferric hydroxide and forms a reddish mass depending on the concentration of iron (Rizzo et al., 2007).

$$2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 \rightarrow 2Fe(OH)_3 + CaCl_2 + 6CO_2 \qquad (2.8)$$

Another chlorine based disinfectant is chlorinated isocyanurates. These are chlorine-containing derivatives of isocyanuric acid. They commonly used in private rather than public pools. They come in the form of tablets or solution. When added to the water, cyanuric acid is formed, which lowers the pH (Perkins, 2000).

Chlorine dioxide. Chlorine dioxide is a yellow gas; when it is in pure form, it is unstable and explodes when heated. It is a powerful oxidizing agent, and has a powerful effect on organisms. It may turn pool water to a yellowish-green color and it has a cloudy appearance when used on its own. This problem can be solved by the addition of chlorine as often as necessary (Perkins, 2000).

2.3.1.2. Bromine-based disinfectants. Bromide is a highly soluble red liquid characterized by a pungent smell. It freezes at –7.3ºC and boils at around 60ºC. Its reaction with ammonia in the water produces bromamines (Perkins, 2000). Two forms of bromine-based disinfectants are used. One is a compound of bromine and chlorine (Bromochlorodimethylhydantion-BCDMH); the second is a two-part bromine system which consists of a bromide salt (sodium bromide) and an oxidizer (hypochlorite, ozone). Bromine-based disinfectants are not commonly used for outdoor pools because bromine residual is depleted rapidly under the sun (WHO, 2006).

2.3.1.3. Ozone. Application of ozone in swimming pool treatment dates back to 1960's. Ozone is a very strong bactericide and a powerful oxidizing agent. It is very effective against bacteria and viruses, Giardia, and Cryptosporidium and also oxidizes organic matter in the water. It provides complete disinfection when combined with chlorine and bromine-based disinfectants, but since it is not a stable gas, it has to be generated as required on-site. Ozonized water is contaminated easily by bathers because it leaves no residual ozone disinfectant in the water. This problem can be solved by addition of low dose chlorine (Perkins, 2000; USEPA, 2011). Ozone decomposition reactions are described in equation 2.9 and 2.10 below (Tchobanoglous et al., 2004). Ozone leakage into the air from ozone generators and contact tanks poses an important risk for facility users because ozone is a strong respiratory irritant; therefore, ventilation of the area must be carefully monitored. The air quality guideline value for ozone is 0.12mg/m^3 for protection of pool user and workers (WHO, 2006).

$$O_3 + H_2O \rightarrow HO_3^+ + OH^- \quad (2.9)$$

$$HO_3^+ + OH^- \rightarrow 2HO_2 \quad (2.10)$$

$$O_3 + HO_2^{\cdot} \rightarrow HO^{\cdot} + 2O_2 \quad (2.11)$$

$$HO^{\bullet} + HO^{\cdot}_2 \rightarrow H_2O + O_2 \quad (2.11)$$

2.3.1.4. Other disinfectants and algaecides. Other disinfectants such as hydrogen peroxide and biguanide ($C_2H_7N_5$) can be used in small-scale outdoor pools. Hydrogen peroxide is used with some ions such as silver and copper, but to prevent buildup of these ions, water replacement is necessary. Biguanide in water slowly hydrolyse to ammonia and urea. Besides being more costly than chlorine, use of biguanide as disinfectant similarly requires water replacement. In the presence of sunlight, alongside with phosphate, nitrogen and potassium, algae growth would be expected in swimming pools. Moreover, algae spores may also enter indoor swimming pools by various means, including improper sanitation conditions. The use of algaecides keeps the growth of algae under control. Effective coagulation/filtration and good hydraulic design can solve the problem of algal growth and make it unnecessary to use algaecidal chemicals (WHO, 2006).

2.3.2. Ultra-violet (UV) radiation

Being a chemical free application, UV-disinfection is a physical process. Ultra-violet (UV) radiation is a popular method of disinfection for small private and semi-private pools. It is very effective against microorganisms and some pollutants such as chloramines. UV radiation is produced by low, medium and high pressure mercury vapor discharge lamps. In order for UV radiation to be effective, maximum penetration of the water is necessary; in order words, suspended and colloidal matter must be at the minimum level and TDS, especially iron salts and nitrates, must be low. Furthermore, due to the mode of action of light on microorganisms, UV irradiation wavelength must be between 200 and 300 to achieve disinfection efficiency (Perkins, 2000; WHO, 2006). The advantages of this method are that over dose is impossible and chemicals are not added to the water and it is 90% effective. However, since it leaves no residual in water, pools get contaminated again easily (Perkins, 2000). Therefore, co-application of chlorination is a necessity to maintain swimming pool water safety.

2.4. Hazards associated with swimming pools

The main hazards associated with swimming pools and similar recreational water venues are categorized as physical, microbial and chemical hazards.

2.4.1. Physical hazards

Pools and similar recreational water environments pose various physical hazards to users. These are:

- Drowning
- Major impact injuries (spinal, brain and head injuries)
- Fractures, dislocations and impact injuries, cuts and lesions
- Heat, cold and sunlight
- Disembowelment /evisceration
- Injuries related with "feature pools"

The primary factor contributing to drowning is not being able to swim, followed by accidental falls into the pool. Another factor related to drowning is alcohol consumption, especially in hot tubs or spas with water temperatures of more than 40ºC. Such high temperatures cause drowsiness and unconsciousness in adults, resulting in drowning. On the other hand, unsecured or unfenced pools pose a risk for children. Factors related with pool facilities such as pool size, pool configuration, water depth and water clarity also contribute to accidents ending in drowning.

The most serious injuries associated with swimming pools are brain, head and spinal injuries. The main cause of such injuries is jumping or diving into the shallow side of the pool. On the other hand, slippery decks, open drains, unchecked water entry, running on decks, tripping on objects left at the poolside and stepping on glass constitute the leading causes of fractures and dislocations, arm, hand, leg and foot or toe injuries as well as cuts and lesions.

Extreme heat or cold as well as sunlight in open pools are a further source of risks. For example, high temperatures in hot tubs may cause drowsiness, which may lead to loss of consciousness or to heat stroke and death. Exposure to low temperatures in plunge pools, on the other hand, may result in slowed heartbeat, hypothermia, and impaired coordination, loss of control of breathing, muscle cramps and loss of consciousness. Temperature extremes are particularly risky for pregnant women, people with medical problems and young children.

Strong suction in inlets and outlets can also result in accidents by trapping hair or a body part. Sitting on broken or uncovered drains can cause disembowelment due to the force of suction, which can be particularly dangerous for children in shallow pools. Feature pools, particularly those with water slides, present major physical hazards. Sliding in pairs or head first, stopping or slowing down on the slide all end up in serious injuries. All of these risks can be eliminated by improving the design and management of the pool, good maintenance and bather awareness (WHO, 2006).

2.4.2. Chemical hazards

Chemicals in swimming pools originate from various sources that could be expressed as water-derived chemicals, bather-derived chemicals and management-derived chemicals (WHO, 2006). Table 2.2 shows chemical hazards and their sources. There are three main routes of exposure to chemicals in swimming pools and similar environments: ingestion of water, inhalation and dermal contact. Amount of ingestion, inhalation and dermal contact depend on various variables including age, experience, skill and activity types as well as time spent in the pool, water temperature and concentration of the chemicals.

2.4.2.1. Source water-derived chemicals. Pool water should be the same quality as drinking water; however, source waters used to fill pools may contain some chemicals. For example, municipal water supplies may contain organic material mainly composed of humic substances. This is important because organic material is a precursor of disinfection by-products. This supply can also contain other disinfection by-products left over from previous treatments, lime and alkalis as well as monochloramines.

2.4.2.2. Bather-derived chemicals. Nitrogen-containing compounds such as urea, ammonia, amino acids, creatinine discharged from the bodies of bathers form many by-products by reacting with disinfectants. The total nitrogen content in urea, ammonia, amino acids, creatinine and other compounds in sweat and urine are roughly 1 gL^{-1} and 12 gL^{-1}, respectively. These values indicate that a considerable amount of nitrogen has entered into the swimming pool by urine. Table 2.3 shows the amounts of nitrogen-containing compounds in sweat and urine. The highest portion of nitrogen in the form of urea is in urine with 84% whereas the portion of ammonia is very low with 5% (Table 2.3).

Table 2.2. Sources of chemical hazards in pool, hot tub and spa water (WHO, 2006).

Sources of Chemicals		
Source water-derived chemicals	**Bather--derived chemicals**	**Management-derived chemicals**
Disinfection by-products Precursors	Urine, sweat, dirt, lotions *e.g.* sunscreen, cosmetics, soap residues etc.	Disinfectants pH correction chemicals Coagulants
Disinfection by-products *e.g.* THMs, haloacetic acids, chlorate, nitrogen trichloride		

2.4.2.3. Management-derived chemicals. To maintain an adequate water quality standard**,** many chemicals are introduced to the pool. Disinfectants, pH correction chemicals and coagulants are part of this group. The major disinfectants used in swimming pools and similar environments are presented in Table 2.4. Plant malfunction and associated equipment can also cause chemical hazards. Such hazards can be minimized by proper installation and effective maintenance programs.

Table 2.3. Nitrogen-containing compounds in sweat and urine (WHO, 2006).

	Sweat		**Urine**	
Nitrogen containing compounds	Mean content mgL^{-1}	Total nitrogen %	Mean content mgL^{-1}	Total nitrogen %
Urea	680	68	10 240	84
Ammonia	180	18	560	5
Amino acids	45	5	280	2
Creatinine	7	1	640	5
Other compounds	80	8	500	4
Total nitrogen	992	100	12 220	100

Disinfectants. Some factors should be taken into account in selecting disinfectants. These are the safety of the pool operator, compatibility of the disinfectant with the source water, type and size of the pool, ability to remain in water as residual after application, bathing load and operation of the pool. The different types of disinfectants have been discussed in section 2.4.

pH correction chemicals and coagulants. Alkaline disinfectants need acid addition for pH adjustment whereas acidic disinfectants need an alkali addition such as soda ash to maintain ideal pH range. When used in the proper dose and the right pH range (7.2 to 8.0), these chemicals do not pose a health risk (WHO, 2006). Coagulants and flocculants are used to eliminate dissolved, colloidal or suspended material. Coagulants separate these materials from the solution as solids, which form a floc and are caught by the filter (WHO, 2006). Coagulants are important agents in removal of infective cysts and oocysts of *Cryptosporidium* and *Giardia*.

Disinfection by-products (DBP). Disinfection by-products are formed by the reaction between disinfectants and chemicals in the swimming pool water (Richardson et al., 2010). Table 2.4 shows major disinfectants used in pool water treatment and their associated disinfection by-products. THMs such as chloroform and haloacetic acids (HAAs) (*e.g.* di and trichloroacetic acid) occur in high concentrations. Beside chlorine-derived disinfection by-products, brominated by-products *e.g.* brominated THMs, are produced by inorganic bromide in water, which is oxidized to form bromine. Chloroform occurs in high concentrations in freshwater pools whereas bromoform is generally in high concentration in sea water pools (WHO, 2006). The chloramines and bromamines, especially the volatile nitrogen trichloride and nitrogen tribromide result in eye and respiratory irritations in pool users. Moreover, nitrogen trichloride gives an intense and unpleasant odor at such low concentrations as 0.02 mgL^{-1} (WHO, 2006).

Table 2.4. Major disinfectants used in pool water treatment and their associated disinfection by-products (WHO, 2006).

Disinfectant	**Disinfection by-products**
Chlorine/hypochlorite	THMs, haloacetic acids, haloacetonitriles, haloketones, chloral hydrate (trichloroacetaldehyde), chloropicrin (trichloronitromethane), cyanogen chloride chlorate, chloramines
Ozone	Bromate, aldehydes, ketones, ketoacids, carboxylic acids, bromoform, brominated acetic acids
Chlorine dioxide	Chlorite, chlorate
Bromine/hypochlorite BCDMH	THMs, mainly bromoform, bromal hydrate, bromate, bromamines

Formation of disinfection-by products in pools can be taken under control by minimizing the precursors through proper source water selection; hygienic practices by bathers; well-managed pool water treatment; and frequent addition of fresh supplies. However, since by-products such as chloroform and nitrogen trichloride will form in any case and will rise from the water surface to the air, good ventilation of the pool area is essential. The concentration of THMs in the pool water, temperature and amount of surface disturbance are instrumental in the rise of these volatile by-products to the air (WHO, 2006). Moreover, disinfection by-product dynamics in a chlorinated indoor swimming pool under heavy use conditions had been examined extensively (Weng and Blatchley III, 2011). The outcome of the study was reported as the stringent influence of swimmers on swimming pool water quality in terms of free chlorine concentration, volatile DBPs and urea.

2.4.3. Microbial hazards

Many microorganisms enter swimming pools. The origins of these organisms are fecal contamination and non-fecal shedding. Fecal contamination originates from accidental fecal release by bathers or fecal material on bathers' bodies, and animal contamination from rodents and birds. Exposure to water contaminated by fecal pollution pose a risk for bathers and public health, and may contribute to infections and outbreaks. General information about microbiological contamination in water as well as in swimming pool waters is very well documented (Nester et al., 1978). Another source of microorganisms in the swimming pools and similar environments is non-fecal human shedding. It results from mucus, saliva, vomit and skin. Table 2.5 shows potential microbial hazards in pools and similar environments (WHO, 2006).

<u>2.4.3.1. Fecally-derived microbial hazards.</u> Bacteria (such as *Shigella* spp., and *E. coli* O157), viruses (such as Adenovirus, Hepatitis A virus, Norovirus, and Enterovirus) and protozoa (such as *Giardia* and *Crytosporidium*) are fecally-derived microorganisms that cause outbreaks in swimming pools.

<u>*Fecally-derived bacteria*</u>. *Shigella* spp. and *E. coli* O157 are two important fecally-derived bacteria related with outbreaks in pools.

Shigella spp. They are facultative anaerobic Gram-negative non-motile rod-shaped bacteria and with the production of acid, they can ferment glucose but not lactose. They cause shigellosis, the symptoms of which are diarrhea, nausea and fever, especially in children (WHO, 2006).

Table 2.5. Major potential microbial hazards in pools and similar environments (WHO, 2006).

Microbial hazard	
Fecally-derived	**Non-fecally derived**
Bacteria	**Bacteria**
Shigella spp. *E. coli* O157	*Pseudomonas* spp. *Legionella* spp. *Staphylococcus* spp. *Mycobacterium* spp. *Leptospira* spp.
Viruses	**Viruses**
Adenoviruses Hepatitis A Noroviruses Enteroviruses	Molluscipoxvirus Papillomavirus Adenoviruses
Protozoa	**Protozoa**
Giardia *Crytoporidium*	*Naegleria fowleri* *Acanthamoeba* spp. *Plasmodium* spp.
	Fungi
	Triphophyton spp. *Epidermophyton floccosum*

S. dysenteriae, S. sonnei, S. boydii and *S. flexneri* are important species of *Shigella*. Food and water contaminated by infected people is the main transmission route of shigellosis (CDC, 2015). Humans and primates are natural hosts for *Shigella* bacteria. However, poor hygienic conditions in crowded communities, especially prisons and day-care centers have a risk of *Shigella* infections (WHO, 2006). The presence of *Shigella* spp. in water indicates recent fecal contamination. Many waterborne outbreaks related to *Shigella* spp. have been recorded (WHO, 2011).

Escherichia coli. *Escherichia* is one of the most important genera of *Enterobacteriaceae* and it is characterized by Gram-negative, oxidase negative rod-shaped bacteria that are motile with peritrichous flagella or nonmotile and aerobic or anaerobic. *E. coli* generally exists in the guts of humans and warm-blooded animals. Individuals who have undergone surgery or trauma and those whose immune systems are compromised are at great risk of infection with *E.coli* because it lives in intestinal flora, it is easily introduced to other tissues. It causes various bacterial infections, including urinary tract infection, bacteraemia, meningitis and enteric infections. Utilization of contaminated food and water, exposure to animals, person-to-person contact (which is important in schools and day care centers), and fecal contamination of environment are the main transmission routes. This bacterium is an indicator of fecal contamination (Nataro et al., 2011).

Strains of pathogenic *E. coli* may be classified into two groups in terms of the location of the disease (inside or outside of gut): extraintestinal pathogenic *E. coli* (ExPEC) and intestinal or diarrheagenic *E. coli.* ExPEC comprises uropathogenic *E. coli* (UPEC) and meningitis/sepsis associated *E. coli* (MNEC) whereas intestinal or diarrheagenic *E. coli* includes Shiga toxin-producing *E. coli* (STEC), enterotoxigenic *E. coli* (ETEC), enteropathogenic *E. coli* (EPEC), enteroinvasive *E. coli* (EIEC) and enteroaggregative *E. coli* (EAEC) (Nataro et al., 2011) (Table 2.6).

Table 2.6. Classificatio2.4.n of pathogenic *E. coli*.

Pathogenic *E.coli*	
Extraintestinal pathogenic *E. coli*	**Intestinal or diarrheagenic *E. coli***
UPEC	STEC
MNEC	ETEC
	EPEC
	EIEC
	EAEC

UPEC strains have been associated with community-acquired urinary tract infections whereas meningitis/sepsis associated *E. coli* (MNEC) causes neonatal meningitis (Nataro et al., 2011). STEC, which produces Shiga toxin, includes enterohemorrhagic *E. coli* (EHEC), that causes bloody diarrhea and hemorrhagic colitis. The most commonly identified diarrheagenic *E. coli* serotype is O157 STEC (*E. coli* O157:H7 and O157: nonmotile) (Nataro et al., 2011). In terms of swimming pools accidental fecal release is the main source of bacterial pathogen, *E. coli* O157 and *Shigella* spp. These contaminations can be prevented by education of bathers and adequate water treatment (WHO, 2006).

Another subset of diarrheagenic *E. coli* is Enterotoxigenic *E.coli* (ETEC) which secretes heat-stabile enterotoxin and /or heat-labile enterotoxin. Enterotoxigenic *E.coli* (ETEC) is the major cause of diarrhea in children in developing countries and traveler's diarrhea (Nataro et al., 2011). It is transmitted through food and water contaminated by fecal material originating from humans and animals (CDC, 2014). Children in developing countries are affected especially by enteropathogenic *E. coli* (EPEC) and enteroinvasive *E. coli* (EIEC). Non-bloody diarrhea, fever and vomiting are symptoms of EPEC. People are the main reservoirs for EPEC, ETEC and EIEC whereas cattle, sheep, goats, pigs and chickens are major reservoirs for STEC. Contaminated food and water, contact with animals and person-to-person contact are main transmission routes for *E coli* strains. The presence of *E. coli* or thermotolerant coliform bacteria are the suitable parameters for the detection of fecal contamination whereas STEC or EHEC strains are not detected in standard control tests (WHO, 2011). EAEC strains cause pediatric diarrhea in young children. Moreover, these strains may result in food-borne outbreaks and diarrhea in immunodeficiency virus-infected patients (Nataro et al., 2011).

Fecally-derived viruses: These include Adenoviruses, Hepatitis A, Noroviruses and Enteroviruses.

Adenoviruses. Adenoviruses have double-stranded DNA and non-developed icosahedral capsid with unique fibers. They take part in the *Adenoviridae* family. These viruses are more common in nature, mammals, amphibians and birds. More than 50 antigenic types of human adenoviruses have been classified and they cause many infections such as gastroenteritis, pneumonia, acute respiratory diseases, pharyngo-conjunctival fever, cervicitis, urethritis, and haemorrhagic cystitis. Adenoviruses also cause eye infections such as shipyard eye and swimming pool conjunctivitis (pharyngo-conjunctival fever). Adenoviruses types 40 and 41 are responsible for gastroenteritis in children (WHO, 2011).

Adenoviruses are present in the feces, sewage, and raw water sources and drinking water supplies. The information about enteric adenoviruses (types 40 and 41) is limited because they do not grow well in cell culture (WHO, 2011). Adenoviruses spread by person-to-person contact, including fecal-oral, oral-oral, and hand-eye contact and through contaminated surfaces and utensils. Many outbreaks caused by adenoviruses in hospitals, schools, and daycare centers and military facilities have been recorded. Limiting exposure of eyes to contaminated water, sharing of towels as well as sharing goggles at pools are crucial in the prevention of eye infection, especially shipyard eye. Human adenoviruses are resistant to disinfection processes, especially ultraviolet (UV) light irradiation. As a consequence of this, prevention of contamination of water source and distribution system by human waste is crucial (WHO, 2011; CDC, 2015).

Hepatitis A virus (HAV). One of the fecally-derived viruses related to swimming pool outbreaks is Hepatitis A virus. Hepatitis A virus is contained in Hepatovirus genus in the *Picornaviridae* family. PCR techniques are used for its identification. The disease Hepatitis A, commonly referred to as infectious hepatitis, is caused by HAV. The source of the virus is mainly contaminated water and food infected by fecal material. HAV spreads through the fecal-oral route. This water-related pathogen uses ingestion as a transmission pathway to reach the gastrointestinal tract and infects epithelial cells. Then, the virus arrives in the liver through the bloodstream and damages liver cells. This damage results in bilirubin accumulation, which causes jaundice and dark urine. Liver damage poses a big risk for those over 50 years of age whereas clinical symptoms are not observed in children, who gain life-long immunity. Preventing water contamination by human waste is crucial in decreasing the risk of HAV (WHO, 2011).

Noroviruses (Norwalk virus or Norwalk-like viruses). Noroviruses are another pathogen causing outbreaks in swimming pools. Noroviruses can also be transmitted in swimming pools although outbreaks of norovirus illness associated with swimming pools are rarely reported. This virus causes acute viral gastroenteritis, the symptoms of which are diarrhea, stomach pain, nausea and vomiting.

Contaminated food and drink, contact with contaminated areas and infected persons are transmission pathways of these viruses (CDC, 2013). Noroviruses cause viral diarrhea in adults whereas rotaviruses cause viral gastroenteritis in children. Rotaviruses which are in *Reoviridae* family and are also transmitted by fecal-oral contact cause serious outcomes such as hospitalization and infant deaths, especially in developing countries (WHO, 2011).

Enteroviruses. Polioviruses, echoviruses and coxsackieviruses types A and B are included in this group of viruses. Polluted water is the source of coxsackieviruses. Water contaminated by human waste and infected people is reservoirs for enteroviruses (WHO, 2011).

Fecally-derived protozoa. *Cryptosporidium* spp. and *Giardia* are fecally-derived parasites that cause outbreaks associated with pools. According to CDC, *Cryptosporidium* is the main cause of outbreaks related to all recreational waters, whereas *Giardia* is cited among the top ten causes of the outbreaks (CDC, 2016).

Giardia. *Giardia* causes giardiasis, which is an intestinal disease. Diarrhea and abdominal cramps are symptoms of this disease. *Giardia* has an outer shell, by means of which it survives in adequately chlorinated pools for up to 45 minutes. Swallowing water contaminated by fecal material including *Giardia* germ is the main transmission means in pools. In addition, food, water and an environment contaminated by human or animal feces infected by *Giardia* are other transmission pathways (WHO, 2006; CDC, 2015).

Cryptosporidium. *Cryptosporidium* causes cryptosporidiosis, an illness associated with swimming pools. Watery diarrhea, stomach cramps and dehydration are the main symptoms of cryptosporidiosis. It is believed that accidental fecal release by bathers and sewage cause *Cryptosporidium* contamination in the pools (WHO, 2006; CDC, 2015).

Giardia and *Cryptosporidium* are resistant to disinfectants, including chlorine as they have a cyst or oocyst form. In the case of *Cryptosporidium*, chlorine concentrations of 30 mgL^{-1} used for 240 minutes (at pH 7 and at 25ºC) can be effective. As for oocysts, disinfection becomes more effective when ozone, chlorine dioxide, or UV is used with chlorine. Use of filtration is a practical way of removing cyst and oocyst from pool water. Less than 4 µm filter porosity is necessary for *Cryptosporidium* oocysts whereas 7 µm or less is required for *Giardia* oocysts (WHO, 2006).

2.4.3.2. Non-fecally derived microbial hazards. The following are non-fecally derived pathogens related to outbreaks in pools and similar environments: Bacteria such as *Pseudomonas* spp., *S. aureus*, *Legionella* spp., *Mycobacterium* spp. and *Leptospira* spp.;

viruses such as molluscipoxvirus, papillomavirus and adenovirus; protozoa such as *Naegleria fowleri*, *Acanthamoeba* spp. and *Plasmodium* spp.; and fungi such as *Trichophyton* spp. and *Epidermophyton floccosum.* Sources of the non-fecally derived pathogens are present in swimming pools and similar venues; infection and diseases caused by these pathogens are shown in Table 2.7.

<u>Non-fecally derived bacteria</u>. *Pseudomonas* spp., *Legionella* spp., *Staphylococcus* spp., *Mycobacterium* spp. and *Leptospira* spp., comprise this group (Table 2.5 and Table 2.7). Bacterial shedding and biofilms that protect microorganisms from disinfectants are the main reservoirs of the non-enteric bacteria in swimming pools (WHO, 2006).

Pseudomonas spp. *Pseudomonas* is one of the most important genera in the Gram-negative rod-shaped bacteria. The members of the genus are characterized by aerobic, motile, non-spore forming straight or slightly curved Gram-negative rods. This genus includes several species such as *P. aeruginosa, P. fluorescens, P. putida, P. veronii, P. monteilii, P. mosselii, P. stutzeri, P. mendocina, P. alcaligenes, P. pseudoalcaligenes, P. luteola and P. oryzihabitans.*

P. aeruginosa. It is an important microorganism associated with swimming pools and similar venues. This group of bacteria is widespread in soil and water. Bacterial shedding from infected bathers is the main source of *P. aeruginosa* in pools and hot tubs as well as the surrounding environment. Warm and moist conditions of the decks, drains, benches and floors around pools and similar venues constitute the ideal habitat for *P. aeruginosa* (WHO, 2006).

Biofilms in filters are other reservoirs of this group of bacteria. Furthermore, due to inadequate chlorination, spray circuits and pumps are colonized with *P. aeruginosa.* Bathers may contaminate pool water by bacteria collected on their hands and feet. Perspiration and shedding of skin increases with high water temperatures and turbulence in aerated hot tubs and serve as protection against disinfectants for organisms. The result is an increase in the organic load, which decreases residual disinfectant level. These materials provide a source of nutrients for the growth of *P. aeruginosa* (WHO, 2006), which can grow at 42ºC. This ability distinguishes it from other fluorescent group of Pseudomonas.

Pigment production, positive oxidase test and grape-like odor are its characteristic properties (Henry and Speert, 2011).

P. aeruginosa is risky for hot tub users because it is a hydrophilic bacterium and inhabits at 42ºC. Folliculitis and otitis externa (swimmer's ear) are related to *P. aeruginosa* as well as conjunctivitis, especially for contact lenses users (CDC, 2015; Henry and Speert, 2011). In addition, *P. aeruginosa* in hot tubs also causes urinary and respiratory tract infections, wounds and cornea infections (WHO, 2006). The frequency of illnesses related to *P. aeruginosa* in swimming pools cannot be easily determined since the symptoms are mild and self-limiting, and consequently the patients do not feel the need to see a doctor (WHO, 2006). *P. aeruginosa* poses a threat for the high risk group, namely cystic fibrosis patients, as it may lead to pulmonary infections. Although *P. aeruginosa* species do not cause serious harm to healthy individuals, non *aeruginosa* species such as *P. fluorescens*, *P. putida*, *P. stutzeri*, *P. oryzihabitans*, *P. luteola*, *P. alcaligenes*, *P. mendocina*, and *P. veronii* pose a threat to immunocompromised persons. For example, in the respiratory secretions of cystic fibrosis patients, some of these species have been detected but their role in the disease has not been determined (Govan and Deretic, 1996). To prevent proliferation of *P. aeruginosa* in the pools, it is important to constantly check residual disinfectant level, clean the surrounding environments and encourage bathers to shower before swimming (WHO, 2006).

Legionella spp. It is an aerobic, motile, non-spore forming Gram-negative rod. It is widespread in aquatic venues. It may live freely, or with protozoa and amoebae, or in biofilms. The genus of *Legionella* grows well at temperatures over 25ºC. *Legionella* spp. exists in natural spas of thermal spring water and hot tubs as well as in filters. Legionella spp. causes respiratory diseases, namely legionellosis and pontiac fever, which are characterized by non-pneumatic, influenza-like illness. *L. pneumophila* is a more common cause of legionellosis (WHO, 2006). Growth of *Legionella* is also observed in hot water tanks, decorative fountains, large plumbing systems, and cooling towers that are part of the air-conditioning systems in large buildings (CDC, 2015). Showers also pose a risk for users (Leoni et al., 2001). Person-to-person contact is not a means of transmission for this microorganism whereas breathing of droplets that include legionella is an important route (CDC, 2015).

Staphylococcus spp. *Staphylococcus* is characterized by non-spore forming, non-motile and non-capsulated Gram-positive coccus. *Staphylococcus aureus* is an important microbial hazard for pools in this group. Since skin flora and nasal mucosa in humans are reservoirs of *S. aureus*, the organism arrives in the pool by shedding, and causes skin rashes, otitis externa, eye infections, urinary tract infections, wound infections and impetigo. Showering before swimming can prevent contamination of pool water with this organism. Cleanliness of changing rooms and surrounding areas decrease the presence of *S. aureus* in the pool.

Mycobacterium spp. They are known as acid-fast bacteria because they have high lipid content in their cell walls, which makes them resistant to decolonization by acids in the staining procedures. *M. marinum* causes swimming pool granuloma, that is, lesions caused by skin and soft tissue infections on abraded elbows and knees. Hypersensitivity pneumonitis is another disease caused by *M. avium* related to hot tubs. Inhalation of the contaminated aerosols in the hot tub is the transmission route in this disease. The cell wall with high lipid content ensures the resistance of these rod-shaped bacteria to disinfectants. Shock chlorination can be used for eradication of *Mycobacteria* species in biofilms in the pools and hot tubs (WHO, 2006).

Leptospira spp. *Leptospira spp.* is motile spirochaete bacteria. *L. interrogans sensu lato* is a pathogenic strain and it causes a disease named leptospirosis. It survives in the kidneys of domestic and wild animals such as rats, pigs and cows. Urine from infected animals contaminates pool water (WHO, 2006).

*Non-fecally derived viruses***.** These are present in swimming pools and similar venues. Infections and diseases caused by these pathogens are shown in Table 2.7.

Molluscipoxvirus. It is a double-stranded DNA virus and causes a benign skin disease called molluscum contagiosum. Person-to person contact and contaminated objects such as towels, pool equipment, toys or bathing sponges are its routes of transmission. Maintaining good hygiene habits and avoiding sharing personal items such as towels, swim suits, goggles, water toys or covering lesions by watertight bandages can prevent the virus from spreading (CDC, 2015).

Papillomavirus constitutes another type of the viruses linked to swimming pools which is a double-stranded DNA virus and causes benign cutaneous tumors. Papillomavirus causes verruca plantaris or plantar wart, an infection on the sole of the foot. This infection is transmitted by physical contact and through contaminated changing room floors. Papillomavirus does not spread with pool water or hot tub waters. Prevention requires firstly limiting contact with effected people. Furthermore, it is important to raise bather awareness and education on hygienic practices in the pool area, including showering before pool use, wearing of sandals in the showers and changing rooms, as well as diligent cleaning of the facilities (WHO, 2006).

Non-fecally derived protozoa. Non-fecally derived protozoa are present in swimming pools and similar venues. The infections and diseases caused by these protozoa *i.e.* *Naegleria fowleri* and *Acanthamoeba* spp. are shown in Table 2.7.

Naegleria fowleri. It is a free-living thermophilic amoeba and lives in warm fresh water and soil. Exposure to contaminated water in ponds, natural spas and artificial lakes through some activities such as diving and underwater swimming is a health risk. Waters contaminated by this free-living pathogen enters the body through the nose and travels to the brain. Infection with this pathogen referred to as "brain-eating amoeba" affects the brain and central nervous system, causing primary amoebic meningoencephalitis (PAM), a fatal disease. However, one cannot get infected by swallowing water contaminated this pathogen (CDC, 2015).

Acanthamoeba spp. *Acanthamoeba* spp. are microscopic, free-living amoeba live in swimming pools as well as all aquatic venues such as surface water, tap water and also contact lens solutions. *A. castellanii*, *A. culbertsoni*, *A. polyphaga* are pathogenic species for humans and they cause granulomatous amoebic encephalitis (GEA) and keratitis (inflammation of cornea), especially in contact lens wearers. Acanthamoeba are resistant to extreme temperatures (-20ºC to 56ºC) as well as disinfection and desiccation (WHO, 2006; WHO, 2011). Proper practices in cleaning and storing contact lenses are important; using tap water or non-sterile solutions poses a risk of infection. The presence of *Acanthamoeba* in swimming pools also rarely reported.

Table 2.7. Non-fecally derived major pathogens present in swimming pools and similar venues and the infections and diseases caused by them (WHO, 2006).

Organism	Infection/disease	Source
Non-fecally derived bacteria		
P. aeruginosa	Swimmer's ear (pools) Folliculitis (hot tubs)	Bather shedding in pools and hot tubs and on wet surfaces around them
Legionella spp.	Legionellosis (Pontiac fever) (Legionnaire's disease)	Aerosols from natural spas, hot tubs and HVAC systems Poorly maintained showers or heated water systems
S. aureus	Skin, wound and ear infections	Bather shedding in pool water
Mycobacterium spp.	Swimming pool granuloma Hypersensitivity Pneumonitis	Bather shedding on wet surfaces around pools and hot tubs Aerosols from hot tubs and HVAC systems
Leptospira spp.	Haemorhagic jaundice Aseptic meningitis	Pool water contaminated with urine from infected animals
Non-fecally derived viruses		
Adenoviruses	Swimming pool conjunctivitis (Pharyngo- conjunctivitis)	Other infected bathers
Molluscipoxvirus	Molluscum contagiosum	Bather shedding on benches, pool and hot tub decks, swimming aids
Papillomavirus	Plantar wart	Bather shedding on pool and hot tub decks and floors in showers and changing rooms
Non-fecally derived protozoa		
Naegleria fowleri	Primary amoebic meningoencephalitis (PAM)	Pools, hot tubs and natural spas, including water and components
Acanthamoeba spp.	Acanthamoeba keratitis Granulomatous amoebic encephalitis	Aerosols from HVAC systems
Plasmodium spp.	Malaria	Seasonally used pools which provide breeding habitat for mosquitoes carrying Plasmodium
Non-fecally derived fungi		
Trichophyton spp. *Epidermophyton floccosum*	Athlete's foot (Tinea pedis)	Bather shedding on floors in changing rooms, showers and pool or hot tub decks

Plasmodium spp. Rather than Plasmodium spp. itself, pools are contaminated by anopheline mosquito larvae, the insect vectors of Plasmodium. In certain climates, drained swimming pools fill with rain water, which provides a suitable environment for the breeding of the mosquito, leading to the risk of malaria. Prevention requires frequent draining of the pools and treatment with suitable larvicides (WHO, 2006).

Non-fecally derived fungi. They include *Trichophyton* spp. and *Epidermophyton floccosum*.

Trichuphyton spp. and *Epidermophyton floccosum*. *Epidermophyton floccosum* and some species of the *Trichuphyton* spp. cause fungal infections such as athlete's foot (tinea pedis), an infection of the foot skin. Person-to-person contact and physical contact with contaminated floors in changing rooms and around the pools are the main transmission routes. This infection is a common risk for lifeguards and competitive swimmers. Since the source of these fungi is infected bathers, educating bathers about the disease and the importance of medical treatment as well as limiting contact with infected bathers are the most common means of prevention.

2.5. Managing water and air quality of swimming pools

To minimize the risk of injury as well as microbial and potential chemical hazards, some points are crucial and should be strictly followed by pool users as well as by pool management. These are showering before swimming, water clarity, coagulation, treatment, dilution, circulation and pool hydraulics, bathing load, accidental release of feces or vomit into pools ventilation as well as education.

Showering before swimming is especially important because it can remove traces of sweat, urine, fecal material, cosmetics and suntan oil. Another important habit is the use of toilets before entering and after leaving the pool. This will prevent urination in the pool and accidental fecal releases. When these are eliminated, fewer chemicals are used in disinfecting the pools, thus reducing the risks as well as the money spent on chemicals. In addition, contamination of the pool water can also be minimized by the use of footbaths since they can prevent the outdoor dirt from entering the pool.

Water clarity is an important point to minimize the risk of injury and it can be achieved by adequate water treatment with filtration. Treatment includes filtration and disinfection, which will remove particulates and pollutants and kill microorganisms.

Pool hydraulics plays an important role in circulation of pool water and distributing the disinfectants throughout the pool and removal of contaminated water. Substances in the water can be diluted by adding fresh water. Swimming pool design should enable proper dilution of pool water with fresh water because dilution limits the build-up of pollutants from bathers, disinfection by-products, and other dissolved chemicals. To be effective, a minimum of 30 liters of fresh water per bather should be added to the pool water (WHO, 2006).

Filtration is necessary to removing turbidity to ensure water clarity; especially the visibility of pool underwater is essential for prevention of injuries. Removal of *Cryptosporidium* oocysts and *Giardia* cysts and some bacteria especially *Legionella* spp. and *Mycobacterium* spp. is possible by good filtration. There are three main types of filters: cartridge filters, sand filters and ultrafine filters. Cartridge filters last about two years; they have the capacity to filter down to 7 µm. They take up a small space, and are useful for small pools and hot tubs. Sand filters can filter down to about 7 µm when operated with coagulants such as polyaluminium chloride or aluminium hydroxychloride. With coagulant, these filters can remove almost all the *Cryptosporidium* oocysts in pool or drinking water. They can operate up to 5-7 years in indoor heated pools. Ultrafine filters can provide particle removal of 1–2 µm and provide good removal of *Cryptosporidium* oocysts. The filter medium is replaceable, and is added after each backwash.

General cleaning of the swimming pool area is also important to eliminate formation of biofilms, sediments and particulates from all surfaces and filters of the pool. On the other hand, use of chemicals for cleaning purposes may also cause health hazards. Ventilation of the swimming pool area is crucial in eliminating volatile disinfectant by-products produced by reactions of chlorine based chemicals for disinfection purposes. Bathing load can be defined as the number of individuals in the pool. Pool type, pool area, pool depth, bathing activity and comfort are determinants of maximum bathing load. (WHO, 2006).

Accidental fecal release or vomit into the swimming pool can cause outbreaks of infections due to fecal-derived pathogens. When this occurs in hot tubs or small pools, the best thing to do is to empty and clean the pool before refilling and operating. Large-scale pools, on the other hand, cannot be emptied and refilled due to high cost. In that case, bathers must be evacuated immediately and the material must be removed. Disinfectant levels should be increased or chlorination to 20 mgL^{-1} at pH 7.2–7.5 should be performed (shock dosing) for 8 hours. If appropriate, the water should be filtered using a coagulant. The pool can be opened after checking the final residual level and pH value.

In terms of health and comfort of bathers and staff and building fabric, air quality in indoor swimming pools is important because of volatile disinfection by-products. These undesirable by-products may be reduced by encouraging showering and ventilation with fresh air.

Health risks resulting from water and air quality of swimming pools and bather behaviors can be reduced by education. Public education is necessary for pool safety and prevention of water related infections (WHO, 2006). Moreover, there is also swimming pool etiquette that every pool user should follow. Etiquette and rules for pools are posted near the pool area.

2.6. Regulations on swimming pools

Regulations and guidelines on the physical and chemical properties of swimming pool water provided by Turkish Ministry of Health, TSI, and WHO are given in Table 2.8 (TMOH Regulation 28143, 2011; TS 11899, 2007; WHO, 2006). Microbiological properties of swimming pool water regulated by these authorities as well as by UK Pool Water Treatment Advisory Group (PWTAG) are given in Table 2.9. According to TSI standards (TS 11899, 2007) characteristics of swimming pool water should comply with TS 266 (water intended for human consumption). Therefore, both tables include recommended values set by TSI 266 for drinking water as well (TS 266, 2005).

TSI have been publishing standards for swimming pool water since 1995, covering water preparation, technical construction, control, maintenance and management as well as safety requirements for operation and design. These standards provide information characteristics of pool water, in particular the maximum recommended values of physical, chemical and microbiological parameters (TS 11899, 2000; TS 11899, 2007). TSI 2007

Regulations (TS 11899, 2007) were later withdrawn and new standards went into effect in 2012 (TS EN 15288-1, 2012; TS EN 15288-2, 2012).

In 2006, World Health Organization published a guideline for recreational water safety in swimming pools and similar environments. The guideline recommends monitoring water by using some chemical and microbiological parameters. These parameters and their operational values are shown in Table 2.10. Operational levels of turbidity, residual disinfectant level, pH, and oxidation and reduction potential (ORP) were determined whereas TDS, alkalinity and calcium hardness are classified as ‘other operational parameters’ and their operational values are not mentioned. However, these parameters are important for swimming pools. Alkalinity is an important parameter with respect to pH adjustment. High alkalinity makes pH arrangement difficult. Monitoring of calcium hardness is recommended in order to prevent any damage to the pool fabric such as etching of surfaces, metal corrosion and scaling water. TDS is another important operational parameter which needs to be monitored for the evaluation of pool water and source water. TDS levels may increase due to pool chemicals, disinfectants and bather pollution, and in such a case, dilution is necessary to lower TDS levels (WHO, 2006). In addition, various water quality parameters and their limit values for drinking water as well as pool water provided by various authorities are also presented for comparison purposes (Table 2.11).

Furthermore, various water quality parameters and their limit values for drinking and pool water provided by various authorities during sampling period and in the 2016 version are also presented in Table 2.11 and Table 2.12, respectively. Noticeable changes are observed in microbiological parameters in these tables. The only primary standard monitored for microbiological quality in drinking water was coliform bacteria, as seen in Table 2.11. In addition to this parameter, *E. coli* and enterococci were added in Istanbul Water and Sewage Administration (ISKI) Water Quality Reports after April 2014 (Table 2.12). In terms of chemical parameters, boron and nickel have been added to the reports since March 2014 (Table 2.12).

Table 2.8. Recommended values for physical and chemical parameters according to pool and drinking water standards.

Parameter	Pool Water			Drinking water
	TS 11899 2007	**TMOH 28143 2011**	**WHO 2006**	**TS 266 2005**
Physical parameters				
Temperature, °C	26-28	26-28	--	--
Color	$Color_{436}$ 0.5 m^{-1}	10 PtCo		1-20 mgL^{-1} PtCo
Turbidity	0.5 FNU	$5SiO_2$ or 5JTU or 0.5NTU or 0.5 FNU	0.5 NTU	5 NTU
Conductivity	--	--	--	2500 μScm^{-1}
Salinity	--	--	--	--
TDS	--	--	--	--
Chemical parameters				
pH	6.5-7.6	6.5-7.8	7.2-7.8	6.5-9.5
Alkalinity	--	--	--	--
Hardness	--	--	--	--
Free chlorine,	0.3-0.6 mgL^{-1}	1.0-1.5 mgL^{-1}	1.0 mgL^{-1}	--
Ammonium	0.5 mgL^{-1}	0.5 mgL^{-1}	--	0.50 mgL^{-1}
TKN	--	--	--	--
Organic carbon	--	--	--	x
Oxidizability	0.75 or 3 mgL^{-1}	--	--	--
Phosphate	--	--	--	--
Chloride	--	--	--	250 mgL^{-1}
Fluoride	--	--	--	1.5 mgL^{-1}
Bromide	--	--	--	--
Nitrite	--	0.5 mgL^{-1}	--	0.50 mgL^{-1}
Nitrate	20 mgL^{-1}	50 mgL^{-1}	--	50 mgL^{-1}
Sulphate	--	--	--	250 mgL^{-1}
Copper	--	1 mgL^{-1}	--	2000 μgL^{-1}
Iron	--	--	--	200 μgL^{-1}
Aluminum	--	0.2 mgL^{-1}	--	200 μgL^{-1}
Manganese	--	--	--	50 μgL^{-1}
Spectroscopic measurements	--	--	--	--

-- No value mentioned
x Noticeable change should not be observed

Table 2.9. Microbiological parameters concerning swimming pool water and drinking water quality.

Parameter	Unit	Pool Water				Drinking water
		TS 11899 2007	**TMOH 28143 2011**	**WHO 2006**	**PWTAG 2015**	**TS 266[f] 2005**
Microbiological parameters						
Colony count at 20±2 °C as CFU	1/mL	100	200			--
Colony count at 36±1 °C as CFU	1/mL	100	200	<200	<10 [d]	--
Escherichia coli 36±1 °C	1/100 mL	cp	0		0	0
Pseudomonas aeruginosa 36±1 °C	1/100 mL	cp	0	<1[e]	0	--
Legionella pneumophilia 36±1 °C	1/mL	cp[a]				
	1/100 mL	--		<1 [b]		
Total coliform	0/100 mL		0		0	
Thermo tolerant coliforms and *Escherichia coli*	1/100 mL			<1		
Staphylococcus aureus	1/100 mL			100[c]		
Enterococci	1/100 mL					0

-- No value mentioned
cp Cannot be proved
[a] In hot whirlpools and pools where water is ≥23 °C
[b] Periodic testing for Legionella should be carried out, particularly in hot tubs to detect if filters are being colonized
[c] Recommended for wider investigation, not for routine monitoring
[d] More than 100 CFU/mL is unsatisfactory
[e] For pools that are continuously disinfected
[f] For Class 2 type 2

Table 2.10. Parameters and operational levels recommended by WHO (WHO, 2006).

Parameters	Operational level	
Turbidity	0.5 NTU	
pH	7.2-7.8	
Residual disinfectant level		
Chlorine-based disinfectants	Free chlorine	1.0 mgL^{-1}
	Combine chlorine	< 0.2 mgL^{-1}
Bromine-based disinfectants	2.0-2.5 mgL^{-1} [a,b]	
Oxidation-Reduction Potential	>720 mV (for silver/ silver chloride electrode) or 680 mV (for calemol electrode)	
Microbial quality		
Heterotrophic Plate Count (37°C 24 hours)	<200 CFU / mL	
Thermo tolerant coliforms and *Escherichia coli* [c]	< 1 /100 mL	
Pseudomonas aeruginosa	< 1 / 100 mL in disinfected pools < 10 / 100 mL in natural spas with no residual disinfectant > 100 / 100 mL[d]	
Legionella spp.[e]	< 1 / 100 mL	
Staphylococcus aureus[f]	< 100 / 100 mL	
Other operational parameters		
Total Dissolved Solid Alkalinity Calcium Hardness	Not mentioned	

[a] total bromine level
[b] 15-20 mgL^{-1} (in case of utilization of ozone combination)
200 mgL^{-1} (dimethylhydantoin value for bromine source of BCDMH)
[c] Indicators of fecal contamination
[d] Turbidity, disinfectant residuals and pH, resample, backwash should be checked, and reassembled after one turnover and resample.
[e] Notable for hot tubs
[f] Continuous monitoring is not recommended

Table 2.11. Parameters and their recommended values for drinking water and pool water according to various authorities complied from ISKI (between 6th December, 2012 and 16th June, 2013) (ISKI, 2013).

	Drinking water				Pool Water		
Parameter	**TS 266 2005**	**WHO 1993**	**EPA 2003**	**EC 1998**	**TS 11899 2007**	**TMOH 28143 2011**	**WHO 2006**
Turbidity	1.0 NTU	5.0 NTU	1.0 NTU	1.0 NTU	0.5 FNU	5 SiO_2 or 5 JTU or 0.5 NTU 0.5 FNU	0.5 NTU
Primary standards (microbiological), EMS 100 mL $^{-1}$							
Coliform Bacteria	<1	0	<1	0	--	0	--
Primary standards (disinfection by-products), µgL $^{-1}$							
Total THMs	100	460	80	100	--	--	--
Bromate	10	10	10	10	--	--	--
Primary standards (inorganic chemicals), mgL^{-1}							
Aluminium	0.200	0.200	0.200	0.200	--	0.2	--
Arsenic	0.01	0.01	0.01	0.01	--	--	--
Barium	--	0.7	2.0	--	--	--	--
Cadmium	0.005	0.003	0.005	0.005	--	--	--
Chromium	0.05	0.05	0.10	0.05	--	--	--
Bromide	--	--	--	--	--	--	--
Fluoride	1.5	1.5	2.0	1.5	--	--	--
Cyanide	0.05	0.07	0.20	0.05	--	--	--
Lead	0.01	0.01	0.015	0.010	--	--	--
Mercury	0.001	0.001	0.002	0.001	--	--	--
Nitrate	50	50	45	50	[a]	50	--
Selenium	0.01	0.01	0.05	0.01	--	--	--
Silver	--	0.1	0.10	--	--	--	--
Antimony	0.005	0.020	0.006	0.005	--	--	--
Berillium	--	--	0.004	--	--	--	--

Table 2.11 continued

Parameter		Drinking water: TS 266 2005	WHO 1993	EPA 2003	EC 1998	Pool Water: TS 11899 2007	TMOH 28143 2011	WHO 2006
Secondary standards (aesthetic), mgL^{-1}								
Chloride		250	250	250	250	--	--	--
Color (units)		20	15	15	--	0.5 m^{-1}	10 PtCo	--
Copper		2.0	2.0	1.0	2.0	--	1	--
Iron		0.2	0.3	0.3	0.2	--	--	--
Manganese		0.05	0.1	0.05	0.05	--	--	--
Odor Causing Compounds	Geosmin	--	--	--	--	--	--	--
	MID	--	--	--	--	--	--	--
pH		6.5-9.5	6.5-8.0	6.5-8.5	6.5-9.5	6.5-7.6	6.5-7.8	7.2-7.8
Sulphate		250	500	250	250	--	--	--
TDS		--	1000	500	--	--	--	[b]
Zinc		--	3.0	5.0	--	--	--	--
Additional parameters, mgL^{-1}								
Calcium		--	300	--	--	--	--	--
Hardness (as $CaCO_3$)		--	500	--	--	--	--	[c]
Magnesium		--	--	--	--	--	--	--
Potassium		--	--	--	--	--	--	--
Sodium		200	200	--	200	--	--	--
Residual Chlorine		--	5.0	4.0	--	[e]	[e]	[e]
Ammonia		0.5	1.5	--	0.5	[c]	[c]	[d]

-- No value mentioned

[a] The amount of nitrate concentration to be added to the nitrate concentration present in the water used to fill the pool should not exceed 20 mgL^{-1} (TS 11899, 2007).

[b] Operational parameter but no information about its limit values (WHO, 2006).

[c] Crucial for operational purposes but there is no information about its limit values (WHO, 2006).

[d] Ammonium rather than ammonia value is given

[e] free chlorine level is recommended

Table 2.12. Parameters and their recommended values for drinking water and pool water according to various authorities complied from ISKI 2016 version (ISKI, 2016).

	Drinking water				Pool Water		
Parameter	**TS 266 2005**	**WHO 2011**	**EPA 2008**	**EC 1998**	**TS 11899 2007**	**TMOH 28143 2011**	**WHO 2006**
Turbidity	1.0 NTU	5.0 NTU	1.0 NTU	1.0 NTU	0.5 FNU	$5SiO_2$ or 5JTU or 0.5NTU 0.5 FNU	0.5 NTU
Primary standards (microbiological), EMS 100 mL $^{-1}$							
E.coli	0	0	0	0	--	0	<1
Enterococci	0	0	--	0	--	--	--
Coliform Bacteria	0	0	0	0	--	0	--
Primary standards (disinfection by-products), µgL $^{-1}$							
Total THMs	100	460	80	100	--	--	--
Bromate	10	10	10	10	--	--	--
Primary standards (inorganic chemicals), mg L^{-1}							
Aluminium	0.200	0.200	0.200	0.200	--	0.2	--
Arsenic	0.01	0.01	0.01	0.01	--	--	--
Boron	1.0	2.4	--	1.0	--	--	--
Nickel	0.02	0.02	--	0.02	--	--	--
Barium	--	0.7	2.0	--	--	--	--
Cadmium	0.005	0.003	0.005	0.005	--	--	--
Chromium	0.05	0.05	0.10	0.05	--	--	--
Bromide	--	--	--	--	--	--	--
Fluoride	1.5	1.5	2.0	1.5	--	--	--
Cyanide	0.05	0.07	0.20	0.05	--	--	--
Lead	0.01	0.01	0.015	0.010	--	--	--
Mercury	0.001	0.001	0.002	0.001	--	--	--
Nitrate	50	50	45	50	[a]	50	--
Selenium	0.01	0.01	0.05	0.01	--	--	--
Silver	--	0.1	0.10	--	--	--	--
Antimony	0.005	0.020	0.006	0.005	--	--	--
Berillium	--	--	0.004	--	--	--	--

Table 2.12 continued

Parameter		Drinking water TS 266 2005	Drinking water WHO 1999	Drinking water EPA 2008	Drinking water EC 1998	Pool Water TS 11899 2007	Pool Water TMOH 28143 2011	Pool Water WHO 2006
Secondary standards (aesthetic), mgL^{-1}								
Chloride		250	250	250	250	--	--	--
Color (PC)		20	15	15	-	$0.5m^{-1}$	10 PtCo	--
Copper		2.0	2.0	1.0	2.0	--	1	--
Iron		0.2	0.3	0.3	0.2	--	--	--
Manganese		0.05	0.1	0.05	0.05	--	--	--
Odor Causing Compounds	Geosmin	--	--	--	--	--	--	--
	MID	--	--	--	--	--	--	--
pH		6.5-9.5	6.5-8.0	6.5-8.5	6.5-9.5	6.5-7.6	6.5-7.8	7.2-7.8
Sulphate		250	500	250	250	--	--	--
TDS		--	1000	500	--	--	--	[b]
Zinc		--	3.0	5.0	--	--	--	--
Additional parameters, mgL^{-1}								
Calcium		--	300	--	--	--	--	--
Hardness (as $CaCO_3$)		--	500	--	--	--	--	[c]
Magnesium		--	--	--	--	--	--	--
Potassium		--	--	--	--	--	--	--
Sodium		200	200	--	200	--	--	--
Residual Chlorine		--	5.0	4.0	--	[e]	[e]	[e]
Ammonia		0.5	1.5	--	0.5	[c]	[c]	[d]

-- No value mentioned

[a] The amount of nitrate concentration to be added to the nitrate concentration present in the water used to fill the pool should not exceed 20 mgL^{-1} (TS 11899, 2007).

[b] Operational parameter but no information about its limit values (WHO, 2006).

[c] crucial for operational purposes but there is no information about its limit values (WHO, 2006).

[d] Ammonium rather than ammonia value is given

[e] free chlorine level is recommended

3. MATERIALS AND METHODS

3.1. General information about the pool and its operation

The subject area of this study is the indoor swimming pool of Boğaziçi University (BUISP) located on Hisar Campus in Rumelihisarı, Sarıyer. The swimming pool is located within Hisar Sport Complex and operated by the Department of Health, Culture and Sports. The facility has been providing service since January 2007.

Hisar Sport Complex with a total closed area of 2925 m^2 is equipped with floor heating, air conditioning and dehumidification systems. It consists of three blocks: A, B and C. Block A houses locker rooms, toilets, showers and three offices. The indoor swimming pool, which covers 1050 m^2, and an engine room of 550 m^2 closed space are located in Block B. The engine room contains a dehumidification unit, pool filter, pool pump, electrical panel, natural gas pipes, hot water tank, two reserve tanks (one for toilets and showers and the other for pool water) and air conditioning and ventilation systems. Block C houses an 85 m^2 apartment for a staff member, technical service offices (325 m^2), and a fitness center with its locker rooms, showers and toilets (325 m^2). The facility is used by current and retired staff (academic and non-academic), students and graduates of BU. In addition, spouses and children of current and retired staff as well as their guests may also can use the Hisar Sports Complex as well (Boğaziçi University Webpage, 2015). The indoor swimming pool is 15 m wide and 33 m long, with a depth of 1.75 m. It has six swimming lanes.

3.2. Questionnaires on BU Indoor Swimming Pool

In order to be able to obtain detailed information about BUISP, several questionnaires were prepared and administered to four groups: pool management, pool staff, Department of Construction and Technical Affairs of the University and pool users. Department of Construction and Technical Affairs of the University answered the survey questions before the sampling period started, whereas other groups responded to the questionnaires after the sampling period. The questionnaires were designed by taking into account literature findings on similar questionnaires used in some pool-related studies such as those by Fantuzzi and colleagues as well as Schet and co-workers (Fantuzzi et al., 2001; Schet et al., 2011). Questionnaires used in this study are presented in Appendix A-F. Information obtained from the questionnaires is summarized below.

3.2.1. Information received from BU Indoor Swimming Pool Management

Appendix A contains the questionnaire administered to the pool management. This questionnaire covered six subtitles. These were: general information about the pool; pool water source characteristics and disinfection practices; maintenance and management issues; questions on amenities available for bathers; questions on water quality monitoring; and other variables about the swimming pool. All questions were answered by the respective members of the pool management.

3.2.1.1. General information about the pool. Besides the information compiled from the web-site of the BU, the pool management did not provide any further data on pool capacity, pool volume or person volumetric load. Business hours of the facility on weekdays and weekends are between 07:30-21:30. The facility is closed on official holidays. The staff comprises a total of 13 employees: 5 cleaning staff, 3 receptionists, 2 pool operators, 1 fitness instructor and 1 swimming instructor and 1 manager. There is no lifeguard at the pool since the pool is used by only BU members who are accepted as good swimmers.

3.2.1.2. Pool water source characteristics and disinfection practices. The swimming pool receives water from the Istanbul Metropolitan Water Supply Distribution System. The source of water represents the drinking water quality as reported by ISKI (ISKI, 2013). Pool water chlorination is carried out manually, using a powder chlorination agent (NALCO). Following the completion of this study, the management started to use liquid chlorine by automatic dosing system in 2014. No information about shock chlorination was provided. However, pool management stated that pool water would be completely discharged as a safety measure in case of any accidental release of feces or vomit into the swimming pool. pH was checked by using on-site measurement kit.

Pool chemicals used in the pool are supplied by private suppliers. Quaternary ammonium compounds (NALCO PT 24) are used for algaecide whereas hydroxyethtlene diphosphonic acid (NALCO PT 41) is used to stabilize water hardness and maintain water clarity. Polyaluminum chloride (NALCO PT 31) is used as flocculent for the removal of suspended solids in the pool water. In addition, sulfuric acid (NALCO PT 10) is used as pH regulator. For disinfection of the pool users' feet before stepping in the pool, a special chemical *i.e.* dimethyl benzyl ammonium chloride is used (Wat Fg, Petro-kim).

3.2.1.3. Maintenance and management issues. According to information received from the survey, the following products are used as cleaning agents and disinfectants in BUISP: Tana SR 15 Ecological alcohol based multipurpose cleaner (floor polish), Persona M107 Foam soap (liquid soaps and hand disinfectants), Persona M104 Shower gel (hair and body shampoos), Culina M328 Qac Alkaline cleaning product with additives (hygienic products and disinfectants), Purina M214 Chlorine based sanitary cleaner gel (floor polish), Purina M209 Acidic sanitary cleaner (floor polish), Purina M215 Hygienic multipurpose cleaner (hygienic product and disinfectant) and Powermax CIF cream cleaner (multipurpose cleaner). These products are supplied by Eczacıbaşı. The authority responsible for control of pool chemicals is pool operators as well as Erim Kimya (supplier) and Artek Mühendislik. Cleaning agents, disinfectants and pool chemicals are supplied by private suppliers as indicated above. Microbiological analyses are performed by an accredited laboratory; chemical analyses comprise measurements of chlorine level and pH and are performed by pool operators and a private supplier. The maintenance and management of the pool involves a building cleaning program. All ground surfaces of the building, toilets, showers, lockers, information desk, and fitness equipment are cleaned every day. Toilets and showers are checked regularly every 20 minutes when the pool is open. Glass surfaces are cleaned every week. The pool environment and foot disinfection bath are cleaned every day. Pool floor is deep cleaned three times a week. Pool apparatus like kickboards is cleaned after every use. Garbage is collected on daily basis. Insect control is carried out once a month.

3.2.1.4. Amenities available for bathers. According to information received from the pool management, the facility has a total of 110 lockers for pool users: 50 lockers for women pool users and 60 for men. A total of 8 showers are available for pool users in the facility.

4 urinals and 3 toilets are provided in the men's section and 3 toilets in the women's section; one in each section is reserved for users with disabilities. Rules for pool use (Appendix E) are posted on two notice boards, one in the pool area and another in the reception area. An emergency contact number is posted at the reception area. First aid kits are available in the building.

3.2.1.5. Information about water quality monitoring. Questions on pool water quality were also answered by the pool management. According to information received from the pool management, the monitoring program involves continuous monitoring of pool water temperature as well as pH and chlorine levels. Data about pool water quality has been recorded since January 2013. Serious problems like accidental fecal releases or vomit have not been encountered in the pool; therefore, there has been no need to close the pool.

It is worth noting that before this study began, the pool management was not able to provide adequate data on the physical, chemical and particularly the microbiological quality of the pool water. As a consequence, this study included microbiological parameters and increased the number of microbiological samplings. Shortly after the study started, the pool management changed, and a private laboratory started to carry out monthly microbiological control of the pool water, using the microbiological parameters recommended by the Ministry of Health and also used in this study-namely, total colony count, total coliform bacteria, *E.coli* and *P. aeruginosa.* Monitoring records of pool water became available as of January 2013. A powerful smell of chlorine which could be felt upon entering the sports complex also decreased after this study started. After 2014, liquid chlorine was used as disinfectant in lieu of powder chlorine, which was manually dosed. It should also be stated that, confirmation was obtained from BU Department of Health, Culture and Sports prior to conduction of this study.

Free and combined chlorine levels and pH are also checked by the technicians of the private supplier as well as by the pool operators. According to data provided by pool management, before each water analysis, two scheduled samples per day are taken for the measurement of free chlorine and pH levels (one in the morning and one in the evening). The pool management stated that they also do two random samplings but did not specify the frequency or basis of such samplings.

3.2.1.6. Information on other variables about the pool. The busiest days of BUISP are Mondays, Wednesdays and Fridays. The maximum number of swimmers per hour does not exceed 30. The busiest hours of use are from 17:00 to 21:00. According to information provided by pool management, the average number of pool users per year is 57,600. The average number pool users provided by pool management is 160. On the other hand, according to the Department of Construction and Technical Affairs, the average number of pool users per day is 150. The average number of pool users per day provided by pool management is not consistent with the information received from the Department of Construction and Technical Affairs of the University. In addition, the maximum number of pool users per day according to the pool management was reported as 110, which clearly indicates an inconsistency in the information provided by them. Furthermore, the data given by the two departments also lack consistency.

3.2.2. Information received from BU Indoor Swimming Pool Staff

A questionnaire was given to the employees of the BU indoor swimming pool (Appendix B). A total of 13 persons (five females and eight males) work in the facility, with the average age of 38.5. These are 5 cleaning workers, 3 receptionists, 2 pool operators, 1 manager, 1 fitness trainer and 1 swimming trainer. Four of the employees of the Sport Complex are university graduates, two are graduates of two-year colleges, two are high-school graduates and three are primary school graduates. All information was provided on a voluntary basis. Two of the employees chose not to provide information about their educational background. The questionnaire also surveyed swimming habits of the employees. The answers indicate that only one person uses the pool for swimming every day, whereas five employees swim occasionally. Four staff members cannot swim at all and two never use the pool for swimming. As for their smoking habit, nine employees are non-smokers and two are ex-smokers. Two staff members are smokers: one had been smoking for 5 years and the other for 10 years at the time the questionnaire was administered. The length of time spent in different sections of the swimming pool area was another topic investigated in this questionnaire. This question was answered by only of the two pool operators, and they indicated that they spend 1 hour in the pool area, 2 hours in the engine room and 5 hours at the poolside on a daily basis. These two staff members had been working as pool operators for 12 and 14 years.

The employees were also asked about any certificates they hold on pool operations as well as on first aid. The survey revealed that only 3 workers attended the first aid seminar offered by the university management. 2 male pool workers earned certificates upon completion of the Ministry of Education Pool Operator Training Courses (TMOE, 2012). While Turkish Standards Institution does not offer any information about pool operator training, Article 15 of the Ministry of Health Regulations covers information related to such training (TS 11899, 2007; TMOH Regulation 28143, 2011). Since the regulations do not stipulate a certification requirement for cleaning staff, cleaning personnel do not have any certificates.

3.2.3. Information received from the Department of Construction and Technical Affairs

There was no information about the technical specifications of the BU indoor swimming pool in the university web pages (Boğaziçi University Webpage, 2015). For this reason, a questionnaire was prepared and given to the management of the Department of Construction and Technical Affairs of the University. The questionnaire consisted of 30 questions specially selected in accordance with the specifications indicated in TSI and presented in Appendix C (TS 11899, 2007). The information derived from the answers provided by the Department of Construction and Technical Affairs of Boğaziçi University is presented below.

Technical specifications of the BUISP

Flow rate of water pumped into the pool: 1.8 – 2.6 ms^{-1}
Flow rate of water sucked out of the pool: 1.0 – 1.25 ms^{-1}
Flow rate of water in low-gradient drains pipes: 0.6 ms^{-1}
Water turnover rate: 4 hours
Retention time: no retention time (24 hours water turnover)
Circulation: 210 $m^3 h^{-1}$
Make-up water: 60 – 80 tons m^3d^{-1}
Make-up water flow rate: 6 – 8 hours (Ld^{-1}) (app. 10 tons h^{-1})

Filter types:

Cartridge filters Number: number not given

Sand filters Number: 4

Ultrafine filters Number: Not answered

Precoat filters Number: None

Filter area: 12.6 m^2 (4 filter areas)

Filter run time: 4 d

Backwash frequency: Not answered

Backwash time: 5-7 min

Water Heating System: 406,977 Watt natural gas burner boiler

Availability of a coagulation system: Present

Ventilation: 24,000 m^3h^{-1}

Air conditioning: serpentine capacity 132,614 W

Air flow rate: 117 m^3h^{-1}

Air turnover time: 3 times h^{-1}

Water detention time: 140 h

Saturation Index: 0.1

Overflow water circulation: 147 m^3h^{-1} from overflow channel, and 63 m^3h^{-1} from drain

Hair catchers: 4 pieces

In-pool lighting: Present

Sewage disposal: Present

Inlets and outlets: Not answered

Frequency of chlorine measurements: 3 times a day

Average chlorine level: 1.0-1.5 mgL^{-1}

Average of pH levels: 7.6

Average number of pool users per day: 150

3.2.4. Information received from BU Indoor Swimming Pool Users

The questions aim at gathering information on user profile, time and frequency of pool use, knowledge and observance of pool rules and health problems encountered following pool use. The questionnaire is presented in Appendix D. Detailed information is presented in Section 4.6.

3.3. BUISP water quality parameters

Boğaziçi University Indoor Swimming Pool water (BUISPW) was examined in terms of physical, chemical and microbiological parameters, which are shown in Table 3.1.

Physical parameters were water and air temperatures, color, turbidity, conductivity, salinity and total dissolved solid (TDS).

Chemical parameters were pH, alkalinity, hardness, free chlorine, ammonia, total Kjeldahl nitrogen (TKN), oxidizability, common anions (chloride, fluoride, bromide nitrite, nitrate sulfate and phosphate) and metals (copper, iron, manganese, aluminum). Total carbon (Tot C), Total organic carbon (TOC), Dissolved organic carbon (DOC), Non-purgeable organic carbon (NPOC), Volatile organic carbon (VOC) were used to display the organic content of the BU swimming pool water. UV-vis spectroscopic measurements and fluorescence spectroscopic measurements as emission and synchronous scan modes were used for spectroscopic parameters. Specified UV-vis parameters ($Color_{436}$, $Color_{400}$, UV_{365}, UV_{280}, and UV_{254}), fluorescence parameters ($FI_{emis350}$, $FI_{emis370}$ and FI_{syn}) and derived UV-vis and fluorescence parameters (as $SCoA_{436}$, $SCoA_{400}$, $SUVA_{365}$, $SUVA_{280}$, $SUVA_{254}$ and $SFIs_{yn}$) were also calculated and presented.

Microbiological parameters were Heterotrophic Plate Count (HPC), total coliforms (TC), fecal coliforms (FC), fecal streptococci (FS), *Pseudomonas aeruginosa* (PA) and *Escherichia coli* (EC).

3.4. Sampling Program

Sampling program was designed in accordance with the working hours of the facility taking into consideration the hours and days that the pool was open. Sampling could not be performed during the semester break when usage was at its lowest and during holidays when the pool was closed. Detailed information about sampling and sample storage conditions prior to analysis are also presented in this section under appropriate sub-headings (sections 3.4.1-3.4.3). Some measurements such as turbidity, TDS, alkalinity, conductivity, and especially microbiological analyses of pool water were carried out immediately after sample collection.

Table 3.1. Physical, chemical and microbiological parameters of BUISPW.

<table>
<tr><th>Physical parameters</th><th>Chemical parameters</th><th>Microbiological parameters</th></tr>
<tr><td rowspan="4">Temperature
Color
Turbidity
Conductivity
Salinity
TDS</td><td>pH
Alkalinity
Hardness
Free chlorine
Ammonia, TKN</td><td rowspan="4">Heterotrophic Plate Count
Total coliforms
Fecal coliforms
Fecal streptococci
Pseudomonas aeruginosa
Escherichia coli</td></tr>
<tr><td>Common Anions: Phosphate
Sulfate, Nitrite, Nitrate
Chloride, Fluoride, Bromide</td></tr>
<tr><td>Metals: Copper, Iron,
Manganese, Aluminum</td></tr>
<tr><td>Organic content: Tot C, TOC
DOC, NPOC, VOC
Oxidizability</td></tr>
<tr><td colspan="3">Spectroscopic measurements</td></tr>
<tr><td colspan="3">UV-vis : Color $_{436}$, Color $_{400}$, UV_{365}, UV_{280}, UV_{254}
Fluorescence: $FI_{emis350}$, $FI_{emis370}$, FI_{syn}
Derived UV-vis and fluorescence parameters
$SCoA_{436}$, $SCoA_{400}$, $SUVA_{365}$, $SUVA_{280}$, $SUVA_{254}$, SFI_{syn}</td></tr>
</table>

Before these analyses, preliminary preparation for the experiments like sterilization of the bottles was completed for each sampling. For analyses to be performed later, samples were stored in proper storage conditions (Table 3.2, 3.3 and 3.4). Before the sampling program was designed, the pool was monitored for two weeks for the purpose of collecting data on bather density, peak hours and frequently used lanes and points. According to Standard Methods, sampling for microbiological examinations should be done during periods of maximum bather load (Standard Methods, 2005).

According to data collected by monitoring the pool, the indoor swimming pool is used by academicians from 7:30 am to 9:00 am every day; this time period is allocated to the use of academicians only. Samples were not collected during this period because it was off-peak time for the pool. The pool was used intensively on weekdays partly because of swimming courses offered to students as part of their course load, especially on Mondays, Wednesdays and Fridays from 9:00 am to 11:00 am and 1:00 pm to 4:00 pm. All samples were collected in this intensive period of pool usage with the exception of three samples that were taken when minimum usage was recorded. The pool is reserved for the training and matches of the BU water polo team after 8:00 pm on Tuesdays, Thursday and Sundays. On Mondays and Wednesdays two lanes are allocated to the swimming team from 8:00 pm to 9:30 pm. Thus, during training hours of the swimming team, pool usage is limited for other bathers. Weekends are not preferred by pool users therefore, number of pool users was at a minimum on weekends. During sampling, water temperature, ambient air temperature, pH and free chlorine levels were recorded on-site.

3.4.1. Sampling

The sampling program was conducted in a period of over six months in 2013 (between 6th December, 2012 and 16th June, 2013). A total of 20 samples were collected for physical, chemical and microbiological analyses according to the sampling program. Separate samples were collected for physical, chemical and microbiological parameters. Clean dark glass-colored 2500 mL bottles were used for physical and chemical parameters whereas sterile, dark glass-colored 1 L bottles were used for microbiological samples. Before sample collection, bottles were cleansed and rinsed with deionized water; those used for microbiological sampling were further sterilized in an autoclave (Nüve steamArt-OT 40L). Sodium thiosulfate, $Na_2S_2O_3$, (Merck) was added as dechlorinating agent (0.1 mL 10 % $Na_2S_2O_3$ solution in a 120 mL bottle) (Standard Methods, 2005).

Samples were collected according to the recommended regulations and standards (TS 11899, 2000; TMOH Regulation 27866, 2011; Standard Methods, 2005). In general, sampling was carried out during times of heavy use, as explained previously. In accordance with the recommendations of both the Turkish Standards Institution and Turkish Ministry of Health Regulations, samples were collected from water body 20 cm below the surface of the water and 50 cm away from the edge of the pool (TS 11899, 2007; TMOH Regulation 27866, 2011). Samples were taken from points where there is minimum water flow rate. During the sampling process, number of bathers, conditions in the pool area as well as free chlorine level, pH, water temperature and ambient air temperature were recorded. Samples were transferred immediately to the laboratory of the Institute of

Environmental Sciences (IES), which is housed in the building right across from the Sport Complex. Therefore, the transfer of the samples took no longer than fifteen minutes. Samples were treated immediately in accordance with the specified conditions, with respect to the type of the analysis to be performed as well as to the experimental details. All analyses were conducted in the laboratory of IES. Identification of the colonies was performed at Department of Medical Microbiology, İstanbul Faculty of Medicine, Istanbul University.

3.4.2. Sample volume

BUISPW samples were taken according to the parameters to be investigated. Special attention was paid to the microbiological parameters with respect to the standards set by the various authorities as well as to the Standard Methods.

As explained in the Standard Methods of Analysis, expected bacterial density is an important criterion in determining the sample size. The ideal sample volume is one that provides 20 to 80 coliform colonies and not more than 200 colonies of all types on a membrane filter surface. Therefore, sample volume for membrane filter total coliform test should be sufficient for expressing the CFU/100 mL of swimming pool water (Standard Methods, 2005). However, 500 mL is the minimum official microbiological sample volume recommended by Turkish Ministry of Health regulations for microbiological parameters (TMOH Regulation 28143, 2011). To maintain experimental precision and reproducibility in microbiological analysis, sample size was increased to 500 mL and 750 mL per type of the bacteria, *i.e.* TC, FC, FS, PA and EC. Subsequently, to increase the probability of identification of these bacteria, 1 L swimming pool water was also used for each parameter except HPC. TSI standards (TS 11899, 2007) on swimming pools do not recommend a sample volume for monitoring of the microbiological quality of swimming pool water. Like Turkish Standards Institution, WHO Guidelines also does not recommend any sample volume (WHO, 2006). However, pool size and complexity of the swimming pool conditions are important criteria in determining sample numbers and locations (WHO, 2006). In addition, PWTAG mentions the norm for sample volume as 500 mL (PTWAG, 2014b).

3.4.3. Sample storage conditions

Since sample storage conditions constitute the major step prior to the analysis, special attention was devoted to all samples to be stored in appropriate conditions required by Standard Methods (Standard Methods, 2005). Sample storage conditions of the selected physical, microbiological and chemical parameters are compiled and presented in Table 3.2, 3.3 and 3.4, respectively. Laboratory instruments used in this study are presented in Appendix F.

Table 3.2. Sample storage conditions related to physical parameters.

Physical parameters		
Parameters	**Sample Storage Condition**	**Reference**
Temperature	Analyze immediately Taken at pool location	TMOH Regulation 28143, 2011 Standard Methods, 2005
Color	Refrigerate for 48 hours	Standard Methods, Ref. 1060B Standard Methods, 2005
Turbidity	Analyze within 24 hours, keep refrigerated dark up to 24 hours	
Conductivity	Refrigerate for 28 days	
Salinity	Analyze immediately or keep wax sealed for 6 months	
TDS	Refrigerate	

Table 3.3. Sample storage conditions related to microbiological parameters (Standard Methods Ref. 9060) (Standard Methods, 2005).

Microbiological parameters	
Parameters	**Sample Storage Condition**
Heterotrophic plate count	Analyze immediately, or within 8 hours If not possible keep at 4 ºC for up to the 24 hours
Total coliforms Fecal coliforms Fecal streptococci *Pseudomonas aeruginosa* *Escherichia coli*	Analyze immediately

It should also be stated that for each microorganism a separate sample was taken and subjected to respective procedure as outlined above.

Table 3.4. Sample storage conditions related to chemical parameters (Standard Methods Ref. 1060B) (Standard Methods, 2005).

Chemical parameters	
Parameters	**Sample Storage Condition**
pH	Analyze immediately
Alkalinity	Refrigerate and analyze within 24 hours
Hardness	Add nitric or sulfuric acid to pH< 2 up to 6 months
Free chlorine	Analyze immediately
Chemical parameters related to nitrogen containing parameters	
Ammonia[a]	Analyze as soon as possible or add sulfuric acid to pH< 2 , refrigerate for 7 days
TKN[a]	Add sulfuric acid to pH< 2 , refrigerate for 7 days
Chemical parameters related to common anions	
Anions Phosphate Sulfate Nitrite Nitrate Chloride Fluoride Bromide	For phosphate, nitrite and nitrate, keep samples at 4 ºC for 48 hours. Disinfected samples are used for nitrate analysis up to 14 days. For sulfate, cool sample at 4 ºC for 28 days cold storage is not necessary for others and finalize in 28 days.
Chemical parameters related to metals	
Metals Copper Iron Aluminum Manganese	Filter immediately, add nitric acid to pH< 2 for dissolved metals Maximum storage up to 6 months
Chemical parameters related to organic matter	
TOC	Analyze immediately or keep samples in a dark location at 0-10 ºC
Oxidizability[b]	Analyze immediately, store glass materials in dust free conditions
UV-vis and fluorescence spectroscopic parameters	
UV-vis	Rinse filter and filter assembly with organic-free water
Fluorescence	Not mentioned, kept as UV-vis

[a] No temperature value has been specified for ammonia and TKN.
[b]Rump and Krist, 1992.

3.5. Methodology

All physical, chemical and microbiological parameters are presented in Table 3.1. Physical parameters and methods used in this study are given in Table 3.5 whereas chemical and microbiological parameters and methods are shown in Table 3.6 and 3.7, respectively. At the time of sample collection, free chlorine level, pH, temperature pool water, ambient air temperature of pool area were recorded on-site. Immediately after sample collection, turbidity, alkalinity, conductivity, TDS, oxidizability, microbiological analyses were performed. Oxidizability was determined according to a volumetric method based on potassium permanganate consumption (Table 3.6). Color measurements require a specific instrument either expressed as $Color_{436}$ or Pt-Co units. Turbidity measurement was performed using 2100P Turbidimeter-HACH 46500-00 (Appendix F). Conductivity, salinity and TDS measurements were performed simultaneously using an instrument with an in-built automatic temperature corrector. All of these physical parameters were determined according to the methodologies explained in Standard Methods (Standard Methods, 2005).

Table 3.5. Physical parameters and determination methods.

Parameter	**Method**	**Reference**
Water temperature, °C	Thermometer	Standard methods Ref.2550 Standard Methods, 2005
Color, Pt-Co	Spectrophotometric (Single-Wavelength Method)	Standard methods Ref.2120 C Standard Methods, 2005
Turbidity, NTU	Nephelometric Method	Standard Methods Ref.2130 B Standard Methods, 2005
Conductivity, μScm^{-1}	Electrical resistance	Standard methods Ref.2510 Standard Methods, 2005
Salinity, mgL^{-1}		
TDS, mgL^{-1}		

Table 3.6. Chemical parameters and determination methods.

Parameter	Method	Reference
pH	Electrometric Method	Standard Methods Ref. 4500-H^+ B Standard Methods, 2005
Alkalinity, $mgCaCO_3L^{-1}$	Titration Method	Standard Methods Ref. 2320B Standard Methods, 2005
Hardness, $mgCaCO_3L^{-1}$	EDTA Titrimetric Method	Standard Methods Ref. 2340 C Standard Methods, 2005
Free chlorine, mgL^{-1}	DPD Colorimetric Method	Standard Methods Ref. 4500-Cl G Standard Methods, 2005
Parameters related to nitrogen containing parameters		
Ammonia	Nessler method (Method 8038)	Standard Methods, 1989 Hach DR/2010 Spectrophotometer Handbook, 1997
TKN	Nessler method (Method 8075)	Hach DR/2010 Spectrophotometer Handbook, 1997
Parameters related to organic matter		
Tot C , DOC, NPOC	Wet oxidation/NDIR method	Standard Methods Ref.5310D Standard Methods, 2005 TOC-VWP Total Organic Carbon Analyzer, User's Manuel, 2004
Oxidizability	Potassium permanganate consumption	Rump and Krist, 1992
Anions, mgL^{-1} Phosphate Sulfate Nitrite Nitrate Chloride Fluoride Bromide	Ion Chromatography with Chemical suppression of eluent conductivity	Standard Methods Ref.4110 B Standard Methods, 2005
Metals, mgL^{-1} Copper Iron Aluminum Manganese	Inductively Coupled Plasma (ICP) Method	Standard Methods Ref.3120 C Standard Methods, 2005
Spectroscopic parameters		
UV-vis	Ultraviolet- visible absorption spectra	Standard Methods Ref.5910B Standard Methods, 2005
Fluorescence	Fluorescence spectra	[a]

[a] Not mentioned

Table 3.7. Microbiological parameters and determination method (Standard Methods, 2005).

Parameters	Reference
Heterotrophic plate count	Standard Methods Ref. 9215
Total coliforms	Standard Methods Ref. 9222B
Fecal coliforms	Standard Methods Ref. 9222D
Fecal streptococi	Standard Methods Ref. 9230
Pseudomonas aeruginosa	Standard Methods Ref. 9213E
Escherichia coli	Standard Methods Ref. 9222

3.6. Analytical methods related to organic content specific parameters

3.6.1. Analyses of organic content

Parameters used to determine the organic content of the BU indoor swimming pool water include Tot C, TOC, DOC, NPOC and VOC. All of these parameters are expressed with a unit of mg $OrgCL^{-1}$. Non-purgeable organic carbon contents were determined separately using NPOC mode of the instrument. In addition, since total carbon is composed of total organic carbon and inorganic carbon, the formula Tot C = TOC+IC was used for the calculation of IC contents (Bisutti et al., 2004; Visco et al., 2005). As all swimming pool water samples were filtered through 0.45μm membrane filters, filtered fraction of TOC are referred to as DOC (Maestre et al., 2003). Moreover, since VOC is defined as volatile organic carbon, the difference between DOC and NPOC accounts for VOC (Bisutti et al., 2004; Visco et al., 2005). Therefore, DOC= NPOC+VOC equation was used for the calculation of VOC.

A Shimadzu TOC Vwp Total Organic Carbon Analyzer was used for Tot C measurements of all swimming pool water samples. Calibration of the instrument was done by using potassium hydrogen phthalate, sodium carbonate and sodium bicarbonate. Tot C standard solution was prepared by using potassium hydrogen phthalate whereas sodium bicarbonate and sodium carbonate were used to prepare IC standard solution (TOC-Vwp Total Organic Carbon Analyzer User’s Manuel, 2004).

3.6.2. Spectroscopic measurements

3.6.2.1. UV-vis spectroscopic measurements. UV-vis spectroscopic absorbance measurements of BU swimming pool water samples were recorded on Perkin Elmer Lambda 35 UV-vis Double beam spectrophotometer employing Hellma quartz cuvettes of 1.0 cm optical path length. Organic matter content and color forming components in indoor swimming pool water were specified by using UV-vis parameters (Color $_{436}$, Color $_{400}$, UV_{365}, UV_{280} and UV_{254}) (Uyguner and Bekbolet, 2005; Uyguner-Demirel and Bekbolet, 2011).

Specified UV-vis parameters are explained below:

$Color_{436}$: Color forming moieties, absorbance at 436 nm, m^{-1}
$Color_{400}$: Color forming moieties, absorbance at 400 nm, m^{-1}
UV_{365}: Organic matter content, absorbance at 365 nm, m^{-1}
UV_{280}: Organic matter content, absorbance at 280 nm, m^{-1}
UV_{254}: Organic matter content, absorbance at 254 nm, m^{-1}

3.6.2.2. Fluorescence spectroscopic measurements. Fluorescence spectroscopic measurements of BU swimming pool water samples were performed on Perkin Elmer LS 55 Luminescence Spectrometer equipped with a 150 W Xenon arc lamp and a red sensitive photomultiplier tube. Fluorescence spectra in emission and synchronous scan modes were recorded with 1-cm path length quartz cells used. A scan speed of 400 nm min $^{-1}$ with a slit width opening of 10 nm was used in the measurements. The emission fluorescence spectra of swimming pool water samples were obtained in the range of 360-600 nm and 380-600 nm at 350 nm and 370 nm excitation wavelengths, respectively. Synchronous fluorescence spectra of the samples were recorded in the excitation wavelength range of 200-600 nm with the bandwith of $\Delta\lambda$=18 nm between the excitation and emission monochromators. Fluorescence parameters are explained below:

$FI_{emis350}$: maximum fluorescence emission at 450 nm
$FI_{emis370:}$ maximum fluorescence emission at 460 nm
FI_{syn}: maximum fluorescence emission at 383 nm

3.6.3. Derived UV-vis and fluorescence parameters

Specific UV-vis parameters are determined by normalization of absorbance values of specified UV-vis parameters (Color $_{436}$, Color $_{400,}$ UV_{365}, UV_{280} and UV_{254},) to DOC value. $SCoA_{436}$, $SCoA_{400,}$ $SUVA_{365}$, $SUVA_{280}$ and $SUVA_{254}$ were used as specific UV-vis parameters. These parameters were defined as given below:

$SCoA_{436}$: Color $_{436}$ absorbance / DOC, m^{-1} mg^{-1} L
$SCoA_{400:}$ Color $_{400}$ absorbance / DOC, m^{-1} mg^{-1} L
$SUVA_{365:}$ UV_{365} absorbance / DOC, m^{-1} mg^{-1} L
$SUVA_{280}$: UV_{280} absorbance / DOC, m^{-1} mg^{-1} L
$SUVA_{254:}$ UV_{254} absorbance / DOC, m^{-1} mg^{-1} L

Specific fluorescence parameters are determined by normalization of fluorescence intensities as emission scan mode and synchronous scan mode to DOC value.

SFI_{emis}: FI_{emis} / DOC
SFI_{syn}: FI_{syn} / DOC

3.7. Microbiological analyses

Heterotrophic Plate Count, Total Coliforms, Fecal Coliforms, Fecal Streptococci, *Pseudomonas aeruginosa* and *Escherichia coli* were determined in the laboratory at IES of BU. Identification of the colonies was performed at Department of Medical Microbiology, İstanbul Faculty of Medicine, Istanbul University, Istanbul. Indicator microorganisms, sample volume and the culture media used are given in Table 3.8.

All media (except CN Agar and ECC Agar) were prepared according to instructions of manufacturers. (CN Agar and ECC Agar were used as commercially prepared). All microbiological parameters were examined according to Membrane Filter (MF) Technique outlined in Standard Methods (Standard Methods, 2005). Duplicate dishes were used for each sample.

Table 3.8. Microbiological parameters, sample volume and culture media used.

Microbiological parameters	Sample volume used		Culture media
	mL	L	
Heterotrophic Plate Count	10	-	Standard Methods agar
Total Coliforms	500; 750	1; 15	M-Endo medium
Fecal Coliforms	500; 750	1; 15	M-FC medium
Fecal Streptococci	500; 750	1; 15	KF Streptococcus agar
Pseudomonas aeruginosa	--	1; 15	CHROMagar™ Pseudomonas CN Agar
Escherichia coli	--	1; 15	CHROMagar™ ECC ECC agar

3.7.1. Heterotrophic Plate Count

10 mL sample volume, which was determined so as to contain 20 to 200 CFU (colony forming units) per filter, was filtered through a 47-mm, 0.45-µm-pore-diam, cellulose acetate gridded membrane filters (Millipore). The filter was placed on Standard Methods Agar (Acumedia, USA). Duplicate plates were used and incubated at 32ºC ± 1°C for 48 hours. All colonies were counted and recorded as CFU/mL (Standard Methods, 2005; Acumedia, 2011).

3.7.2. Total Coliforms

This group of bacteria is Gram-negative rod shaped bacteria that are facultative anaerobic and non-spore forming. To distinguish this group of bacteria, a lactose containing medium, namely, m-Endo medium (Acumedia, USA) was used. Samples of 500 mL, 750 mL, 1 L and 15 L volume were filtered and the filter was put on the medium. A red colony with a golden luster on the medium was described as coliform bacteria after incubation at 35ºC for 24 hours (Standard Methods, 2005; Acumedia; 2011).

3.7.3. Fecal Coliforms

For detection of this group of bacteria in pool water, m-FC agar (Acumedia, USA) with rosolic acid was used. Replicate plates were incubated at 44.5ºC ± 0.2ºC for 24 ± 2 hours. Colonies with different shades of blue on m-FC agar were assessed as fecal coliform bacteria whereas non-fecal coliform colonies were gray to cream colored, as suggested by

Standard Methods and instructions of the manufacturer (Standard Methods, 2005; Acumedia, 2012).

3.7.4. Fecal Streptococcus

KF Streptococcus Agar (Acumedia, USA) was used and incubated at 35ºC ± 2°C for 46-48 hours. Presence of red centered colonies was assessed as fecal streptococci according to manufacturer's instructions (Acumedia, 2011).

3.7.5. *Pseudomonas aeruginosa*

For *P. aeruginosa*, CHROMagar™ Pseudomonas (CHROMagar, France) and CN Agar (Biokar Diagnostics, France) were used with MF technique. Duplicate dishes were incubated at 30ºC for 24 hours and the blue-green colonies on dishes were evaluated as *P. aeruginosa* (CHROMagar™ Pseudomonas, 2016; Biokar Diagnostics, 2016).

3.7.6. *Escherichia coli*

Escherichia coli is an indicator of fecal contamination of water bodies. It is a well-known bacterium of fecal coliform group. After incubation (37ºC for 24 hours) blue colonies on the CHROMagar™ ECC (CHROMagar, France) are typical appearance of *E.coli* whereas other coliforms give mauve colonies on CHROMagar™ ECC. Other bacteria colonies appear as colorless or inhibited (CHROMagar, 2012).

3.7.7. Identification of bacteria

Identification of strains at species level was performed at Department of Medical Microbiology, İstanbul Faculty of Medicine, Istanbul University, Istanbul. Pure colonies were used for identification of strains. All strains identified by classical microbiological methods according to the conventional methods; the API ID 32 GN test system (BioMérieux, France) was used when required (Nataro et al., 2011; Vaneechoutte et al., 2011; Wauters et al., 2011; Henry and Speert, 2011; Lipuma et al., 2011; Teixeira et al.,2011; Abbott, 2011; Becker and von Eiff, 2011).

Information about groups of bacteria and their morphology was collected by means of Gram staining. Lactose and glucose fermentation was checked by using triple sugar iron (TSI) agar. Oxidase, catalase, motility tests, colony morphology and colony pigmentation were the basic characteristics used for identification of strains. Biochemical tests were also performed for identification of bacteria including hydrogen sulfide production, acid production from sugars, urease test, lysine deamination and lysine decarboxylation, ornithine decarboxylation, citrate utilization, indole production, Voges-Proskauer test. Moreover, green pigmentation (pyoverdin) on Mueller-Hinton Agar was checked. *P.aeruginosa* was distinguished from others by its motility, pigment production and ability to grow at 42ºC (Versalovic et al, 2011; Standard Methods, 2005). Microscopic examination, oxidase test, motility, acidification of carbohydrates, PYR (pyrrolidonyl aminopeptidase), esculin and urea hydrolysis, indole test, lysine and ornithine decarboxylation, were performed for identification of gram-negative nonfermenters before the API ID 32 GN (BioMérieux, France) was used (Versalovic et al, 2011). To distinguish acid producers from carbohydrates or sugars, oxidation/fermentation (OF) medium was used. Catalase test, the ability to grow in 6.5% sodium chloride and at 45ºC temperature, bile-esculin test, PYR and LAP tests were used in the identification of Enterococus (Teixeira et al., 2011).

3.7.8. API ID 32 GN test system

The API ID 32 GN (BioMérieux, France) is a standardized automatic identification system for Gram negative bacteria. Test strip encloses 32 cupules that include dehydrated carbohydrate substrates. Automatic reading and interpretation of the strips (BioMérieux SA ID 32 GN, 2012) was performed with the mini API® instrument. According to the applied methodology, a 0.5 McFarland bacterial suspension was prepared in the API® NaCl 0.85 % medium (2mL) from microbial cultures (18-24 hours old). 200 µl saline suspension was transferred into the API AUX Medium (7mL). Inoculated API AUX Medium was homogenized. Then, 135 µl of the medium was transferred into every cupule of the strip with ATB Electronic Pipette. The strip was closed and incubated at 29ºC ± 2°C for 24 ± 2 hours. The mini API® instrument with database V3.1 was used for reading and interpretation of microorganisms. Growth in every cupule was searched by the reader and the information is transferred into the computer. The computer changed the information into an 11-digit numerical profile. This profile referred to names of bacteria. Incubation was continued in some cases, for instance when there was low discrimination, or an unacceptable or doubtful profile (BioMérieux SA ID 32 GN, 2012).

4. RESULTS AND DISCUSSION

This chapter covers a general outlook on regulations on swimming pool water, general information about BU indoor swimming pool water source, and the results of all physical, chemical and microbiological parameters in BUISPW (sections 4.3, 4.4 and 4.5). Survey results are presented in Section 4.6. Tables 2.8 - 2.11 and Table 4.1 presented previously display the values recommended by various authorities, which were used in evaluating the results obtained in this study.

4.1. General outlook

The results of all analyses in this investigation were evaluated according to the limit values provided for parameters specified by the regulations and standards on swimming pool water. For unspecified parameters, drinking water quality standards were considered since pool water should have the same quality as drinking water (TS 11899, 2007; TS 266 2005; White, 1972). It should be indicated that no direct regulation is set for swimming pool water quality although a directive is published concerning the management of bathing water quality excluding swimming pools (EC Directive 76/160 EEC, 2006). On the other hand, The UK's authoritative guide on swimming pools and spas is also considered for the evaluation of swimming pool water quality (PWTAG, 2015).

Table 2.8 shows limit values for all physical and chemical parameters investigated in this study as recommended by the Ministry of Health regulations, standards provided by Turkish Standards Institution and WHO directives (TMOH Regulation 28143, 2011; TS 11899, 2007; WHO, 2006). Recommended values of conductivity, salinity, TDS, alkalinity hardness, ammonia, TKN, organic carbon and some anions and metals for swimming pool water are not mentioned or specified by these authorities. In the case of these unspecified parameters, Turkish Standards Institution regulations concerning water intended for human consumption are taken into consideration (TS 266, 2005). Moreover, European Union Directives on "The Quality of Water Intended for Human Consumption" is considered for the evaluation of the swimming pool water quality as drinking water (EC Directive

98/83/EC, 1998). Parameters such as turbidity and pH are specified by all of the authorities for pool water as well as for drinking water. Free chlorine limits showed variations ranging between 0.3-1.5 mgL^{-1} with respect to the regulations set for pool water. These limits indicate that chlorination should only be the applied disinfection method unless otherwise no limits would be available for attaining safe swimming pool water. Moreover, WHO regulations did not indicate any limits to the selected parameters except for turbidity, pH and free chlorine (WHO, 2006). Referring to the information presented above on the regulations and water quality, a table is prepared to provide a broader perspective based on the ISKI water quality report scheme (Table 2.11) (ISKI, 2013). ISKI water quality report covers information regarding the regulations set by TSI, WHO, USEPA and EC (TS, 2005; WHO, 2011; USEPA, 2008; EC Directive 98/83/EC, 1998). Appendix F includes ISKI Water Quality Report for 2016.

4.2. Pool water source quality parameters

According to the management of BUISP, the pool is filled with water distributed from Kağıthane Drinking Water Treatment Plant. Information given by ISKI indicated that the source of the water treated at Kağıthane Drinking Water Treatment Plant is Terkos Lake and Alibeyköy Reservoirs located on the European part of Istanbul. For comparison purposes and to present baseline information on drinking water quality, the respective values of physical, chemical and microbiological parameters of the drinking water during the sampling period of this study are compiled and presented in Table 4.1.

Due to unavoidable sample processing conditions, temperature is not included as a parameter as expected. During the sampling period color of drinking water showed no variation, and remained constant at 2.5 units expressed in mgL^{-1}. Turbidity values of drinking water were between 0.1-0.2 NTU. Minimum, maximum and average TDS values of drinking water were 224 (May and June, 2013), 270 (April, 2013) and 237 mgL^{-1}, respectively. Water quality reports prepared by ISKI did not include the physical parameters of conductivity and salinity. Neutral pH conditions could also be assessed in relation to the presence of hardness in the range of 134 $mgCaCO_3L^{-1}$ (May, 2013) to 145 $mgCaCO_3L^{-1}$ (January, 2013) with an average value of 139 $mgCaCO_3L^{-1}$.

Table 4.1. ISKI-Istanbul Water Quality Report for all parameters of drinking water from Kağıthane Treatement Plant during the sampling period (December 2012- June 2013).

	Dec. 2012	Jan. 2013	Feb. 2013	Mar. 2013	April 2013	May 2013	June 2013	Average
Physical parameters								
Temperature[a]	--	--	--	--	--	--	--	--
Color, units	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Turbidity, NTU	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.14
Conductivity[a]	--	--	--	--	--	--	--	--
Salinity[a]	--	--	--	--	--	--	--	--
TDS, mgL^{-1}	232	239	241	226	270	224	224	237
Chemical parameters								
pH	7.1	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Alkalinity[a]	--	--	--	--	--	--	--	--
Hardness[b]	137	145	140	139	140	134	142	139
Residual chlorine, mgL^{-1}	1.1	1.0	1.1	1.0	1.0	1.0	1.0	1.0
Ammonia, mgL^{-1}	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
TKN[a]	--	--	--	--	--	--	--	--
TOC[a]	--	--	--	--	--	--	--	--
NPOC[a]	--	--	--	--	--	--	--	--
Oxidizability[a]	--	--	--	--	--	--	--	--
Common anions, mgL^{-1}								
Chloride	41.2	37.3	32.2	31.1	31.8	31.7	34.9	34.3
Fluoride	0.05	0.06	0.05	0.05	0.05	0.05	0.06	0.05
Bromide	0.06	0.05	<0.05	0.05	0.05	0.06	0.05	0.05
Nitrate	2.50	3.05	3.33	2.68	2.62	1.36	1.25	2.39
Sulfate	50.9	58.5	63.6	60.5	82.5	63.5	56.5	62.2
Phosphate[a]	--	--	--	--	--	--	--	--
Metals, mgL^{-1}								
Copper	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Iron	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Aluminum	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	0.05	<0.05
Manganese	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Microbiological parameters, MPN/100 mL								
Coliform bacteria	0	0	0	0	0	0	0	0

[a] not mentioned in Istanbul Water Quality Report
[b] as $mgCaCO_3$ L^{-1}
BDL: Below detectable level of 0.012 mgL^{-1} for bromide

Ammonia was reported as below 0.03 mgL^{-1} throughout the sampling period. Moreover, residual chlorine values displayed an almost constant variation with an average of 1.0 mgL^{-1} in accordance with the expected limit value in the distribution system.

Water quality reports prepared by ISKI did not include chemical parameters of alkalinity, TKN, TOC, NPOC and oxidizability. Organic matter contents of the water samples were not monitored although organic matter contents are directly related to the formation of disinfection by-products, more specifically trihalomethanes. Although UV_{254} is accepted as a surrogate parameter for organic matter content present in drinking water, no interest was directed to the spectroscopic parameters including $Color_{436}$.

Variations in common anion contents, *i.e.* chloride, fluoride, bromide, nitrate and sulfate, displayed comparatively similar results during the sampling period. Ammonia and nitrate contents were monitored as nitrogen containing species with the exclusion of TKN as indicated. Moreover, phosphate contents were also monitored. Metals as copper, iron, and manganese were detected as < 0.02 mgL^{-1} whereas aluminum was < 0.02 mgL^{-1}. The only microbiological parameter mentioned in ISKI reports was coliform bacteria, and the count of coliform bacteria in drinking water was reported as 0 MPN/100 mL during the sampling period. It should be indicated once more that analyses were performed on finished water before being distributed. Therefore, the absence of coliform bacteria could be directly related to the presence of free chlorine as a residual disinfectant in the distribution system. However, this condition might not satisfy the requirement of safe drinking water at the point of use, *i.e.* quality of incoming water to the swimming pool.

4.3. Physical Parameters of BUISPW samples

Physical parameters examined in this study are water and air temperatures, color, turbidity, conductivity, salinity and total dissolved solids. Of those parameters, water temperature, color and turbidity of swimming pool water are specified in the regulations and standards (TS 11899, 2007; TMOH Regulation 28143, 2011). Related limit values are compiled and presented previously in Table 2.8. On the other hand, conductivity, salinity and total dissolved solids are also tested in this study although these properties are not specified in the standards and regulations. Physical parameter values measured in this study are displayed in Table 4.2 under appropriate headings, presenting a general look at the minimum, maximum and average values of these parameters measured in BUISPW samples.

Table 4.2. Minimum, maximum and average values of the physical parameters.

	Unit	Minimum	Maximum	Average
Physical parameters				
Temperature (on-site)	°C	26	28	27
Temperature (Lab)	°C	20.0	27.1	24.8
Color	Pt-Co	2	7	4
$Color_{436}$	m^{-1}	0.00	1.81	0.38
Turbidity	NTU	0.27	0.50	0.37
Conductivity	μScm^{-1}	736	828	776
Salinity	mgL^{-1}	0.0	0.2	0.08
Total dissolved solids	mgL^{-1}	301	331	311

4.3.1. Water temperature

Water temperature should be measured on-site according to the Turkish Ministry of Health Regulations (TMOH Regulation 28143, 2011). Sample dependent variations in on-site measurements of swimming pool water temperatures are presented in Figure 4.1. Minimum value observed was 26°C while maximum value was 28°C, with an average of 27°C. Figure 4.1. also covers information on temperature measurements performed in the laboratory as well as ambient air temperature in the pool area.

In addition to on-site measurements of swimming pool water temperature, laboratory measurements were also performed within 20 or 30 minutes of sampling time. Minimum and maximum temperatures recorded in the lab were 20.0°C and 27.1°C, respectively (Figure 4.1). The average temperature was 24.8°C, with 60% of the samples resting above the average and 40% below the average. With the exception of sample number 3, variation among samples was minimal. Turkish Ministry of Health regulations allow for a minimum water temperature of 26°C and a maximum of 28°C for indoor pools (a much broader range is allowed for outdoor pools, namely, 26°C and 38°C, respectively) (TMOH Regulation 28143, 2011).

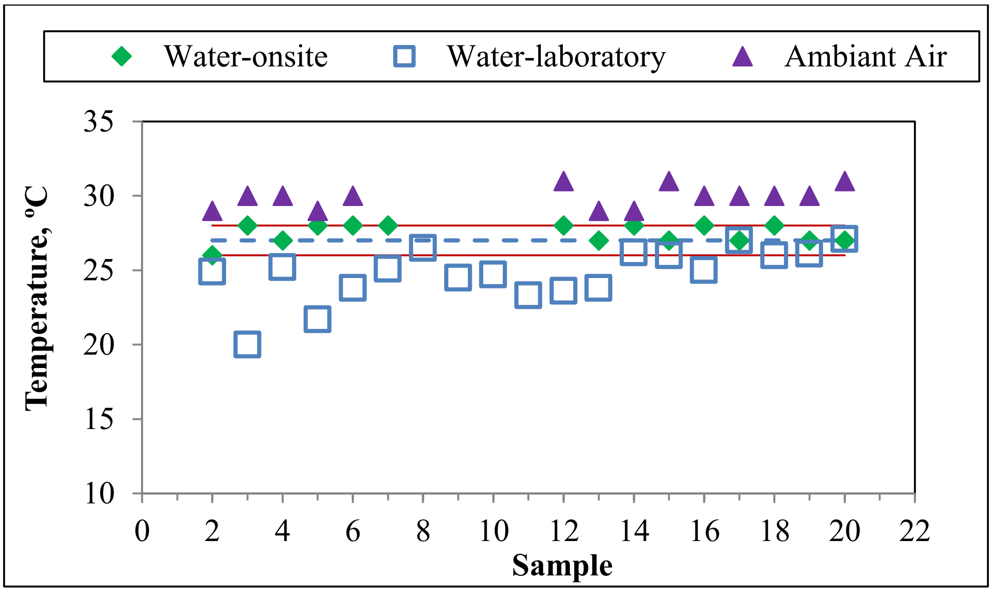

Figure 4.1. Water temperature and ambient air variations in BUISPW. (Dashed line indicates the average of on-site measurements and straight line indicates recommended range).

Temperature measurements recorded at the pool location were within the indicated limits of 26-28°C. However, temperatures measured at the laboratory showed only 35% of the samples complying with the indicated limits of 26-28°C. It should be noted that the laboratory measurements were performed in the Institution of Environmental Sciences Laboratory, which is located next to the swimming pool. Since the samples were taken between 6th December, 2012 and 16th June, 2013, a slight decrease in temperature during transportation could be expected. However, the variations observed in on-site measurements could not be explained in a similar manner**.** As seen in Figure 4.1, the maximum temperature differences between laboratory and on-site measurements were observed in three samples: sample 3 (one of the three samples taken in January), sample 5 (the second sample taken in February) and sample 12 (the third sample taken in May). These temperatures were 8°C, 6.3°C and 4.4°C, respectively. On the other hand, sample number 17 did not display any difference between the two measurements. This sample was collected in June. The last sample collected for this experiment, namely sample number 20 of June 16, showed a slight increase of 0.1°C between on-site and laboratory measurements. June samples, with the exception of sample number 20, show slight decreases despite the fact that June is a warmer month as compared to the others. However, it should be noted that these decreases get gradually smaller.

Pool Water Treatment Advisory Group has recommended temperature ranges based on the type of activity regardless of the type of the swimming pool, *i.e*. indoor and outdoor pools. For example, 26-28°C is their recommended temperature range for competitive swimming and diving, fitness swimming and training, whereas 27-29°C is their recommended temperature range for recreational swimming and adult teaching (PWTAG, 2010).

High water temperature increases possible release of sweat and oil into the pool water. Rising ammonia and urea levels caused by sweating would increase combined chlorine and irritant nitrogen trichloride levels. Moreover, weakly soluble dissolved gases result in foul smell in the pool. In addition, water temperature affects ambient temperature, energy consumption and building material (PWTAG, 2010).

Temperature is an important parameter in the assessment of microbiological quality of water. Kush and Hoadley surveyed presence of *P. aeruginosa* in relation to water quality characteristics of eight commercial whirlpool baths in Atlanta and they reported temperatures ranging between 24°C and 42°C (Kush and Hoadley, 1980). Whirlpools are shallow pools with a 1.2 m maximum water depth designed for therapeutic and recreational purposes (Standard Methods, 2005).

Besides the assessment of microbiological quality of pool water, temperature is also a crucial parameter of swimming pools in relation to disinfection by-product formation. As well as temperature, presence of organic precursors, time of reaction, free chlorine concentration and pH are critical factors for THM formation (Symons et al., 1981). Chu and Nieuwenhuijsen focusing on THM concentration in eight different indoor swimming pools in London reported minimum and maximum water temperatures as 27.5-34.5°C (Chu and Nieuwenhuijsen, 2002). A former study conducted by Fantuzzi and colleagues assessed occupational exposure to THMs in five indoor swimming pools in Modena, Italy (Fantuzzi et al., 2001). They reported a narrower water temperature range (27°C to 29°C). In a later study, Fantuzzi and co-workers studying twenty indoor swimming pools for irritative symptoms in pool workers and occupational exposure to DBPs, reported water temperatures in the range from 27°C to 29°C (Fantuzzi et al., 2010).

Bessonneau and colleagues examined water and air quality of indoor swimming pools in terms of chlorination by-products. They reported the range of water temperature in fifteen swimming pools in France as 26.8°C to 32.6°C (Bessonneau et al., 2011). Parinet and co-workers examined eight swimming pools and reported the average values of temperatures in seven of them as 29.4°C-33.2°C, while one had a lower mean temperature value of 20.1°C (Parinet et al., 2012). Although Parinet and colleagues indicated values similar to those reported by Bessonneau and co-workers, their eight indoor pools are different from others because they are seawater pools and they are filled with water from the Mediterranean.

Silva and colleagues investigated the occurrence and determining factors of THMs in 30 indoor swimming pools in Lisbon. The study reported the range of water temperatures as 27°C to 31°C (Silva et al., 2012). Minimum and maximum pool water temperatures of BUISP were 26°C and 28°C. These results conformed to the results of the two studies conducted by Fantuzzi and colleagues (Fantuzzi et al., 2001; Fantuzzi et al., 2010) as both studies examined indoor swimming pools. Apart from these studies, a study conducted in indoor swimming pools reported a wide temperature range of 26.8°C to 32.6°C (Bessonneau et al., 2011).

Ambient air temperature of the pool area. Minimum, maximum and average ambient air temperatures in the pool area as displayed in the digital panel on the wall of the swimming pool area were 29°C, 31°C and 30°C, respectively (Figure 4.1). Nearly half of the measurements (47%) of ambient air temperature were recorded as 30°C, whereas 31°C was read in three of the measurements (20%). On some sampling days, ambient air temperature in the pool area could not be recorded (samples number 7-11) due to some technical problems in the pool equipment. Ambient air temperature for pool area is not specified in the regulations and standards (TMOH Regulation 28143, 2011; TS 11899, 2007). Previously discussed studies focusing on THM concentration in the pool waters reported air temperatures between 22°C and 26°C, 22.3°C and 34°C and, 21°C and 33°C, respectively (Fantuzzi et al., 2001; Chu and Nieuwenhuijsen, 2002; Silva et al., 2012).

4.3.2. Color

For the evaluation of color of the BUISP water samples, Turkish Ministry of Health Regulations (TMOH Regulation 28143, 2011) and the standards of Turkish Standards Institution (TS 11899, 2007) were considered. The measurement unit for color in pool water is defined as Platinum-Cobalt (Pt-Co) in the Turkish Ministry of Health Regulations (TMOH Regulation 28143, 2011). However, Turkish Standards Institution presented pool water color as determinant of the spectral absorption co-efficient at wavelength λ=436 nm, reporting the results in m^{-1} (TS 11899, 2007).

Color of BUISP water samples was measured according to the methodology outlined in both directives. There is no information about test methods in the Standards (TS 11899, 2007) whereas according to regulations of Turkish Ministry of Health (TMOH Regulation 28143, 2011), laboratories are required to have received ISO/IEC 17025 Testing and Calibration Accreditation certificate as well as procedure accreditation for specific parameters. Color variations in the swimming pool water are given in Figure 4.2.

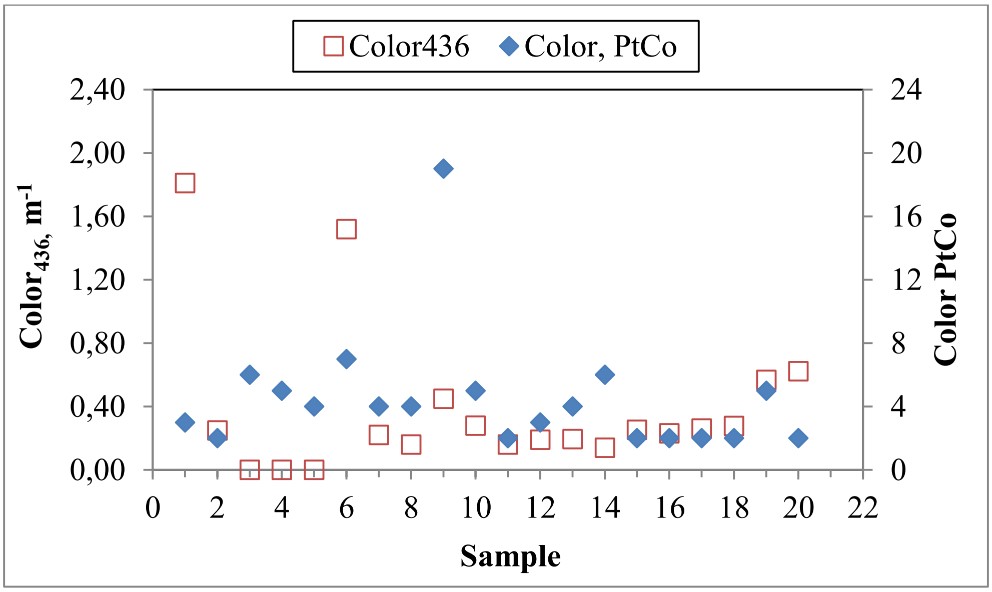

Figure 4.2. Color variations in BUISPW.

Minimum and maximum color values of swimming pool water were 2 and 7 Pt-Co, excluding the extreme value, which was 19 Pt-Co (sample 9) (Table 4.2 and Figure 4.2). Excluding this value, the average color value was calculated as 4 Pt-Co. Of the remaining samples, 47% measured below and 32% above the average, with 21% at the average value. Minimum, maximum and average values of color Pt-Co are presented in Table 4.2. According to Turkish Ministry of Health regulations, 10 Pt-Co is the recommended water color value for swimming pool water (TMOH Regulation 28143, 2011). With the exception of 19 Pt-Co, all color results were below the recommended value specified in the regulations (Table 2.8). In terms of spectroscopic measurements, Turkish Standards Institution recommended measuring pool water color by determining the spectral absorption coefficient at λ=436 nm and reporting the results in units of m^{-1} as indicated previously (TS 11899, 2007). This recommendation was expressed as parameter of $Color_{436}$, (m^{-1}) and was used for comparative measurement of color in swimming pool water. Minimum, maximum and average values of $Color_{436}$ were 0.00 m^{-1}, 1.81 m^{-1} and 0.38 m^{-1}, respectively (Table 4.2, Figure 4.2). Samples number 3, 4 and 5 did not express any $Color_{436}$. The average value of $Color_{436}$, m^{-1} was calculated as 0.38 m^{-1} when these three samples were included. The average values of $Color_{436}$, m^{-1} was below the standard value of 0.5 m^{-1} (TS 11899, 2007).

Based on these different standards, Figure 4.3 was constructed to express the $Color_{436}$ versus Color Pt-Co variations in BUISPW. Color Pt-Co variations with respect to $Color_{436}$ expressed a cluster type distribution leading to non-existence of any correlation. It should be indicated that $Color_{436}$ was measured following filtration through 0.45 μm membrane filter to remove any suspended material whereas the measurement of color as Pt-Co of the pool water was analyzed without filtration. It should also be indicated that all samples should fulfill the clarity requirement prior to any colorimetric measurements. However, these two recommendations on color should be considered simultaneously for the assessment of the color of swimming pool water (TMOH Regulation 28143, 2011; TS 11899, 2007).

Color is an important indicator of water quality of a swimming pool since water color is defined as a valuable parameter as a surrogate for the presence of dissolved organic matter (Thurman, 1985). In an aqueous medium, organic matter (*e.g.* humic and fulvic acids) and metals (*e.g.* iron, copper and manganese) affect the color of water. Green, brown or black pool water indicates the presence of these metals in excessive amounts (ANSI/APSP-11, 2009; USEPA, 2015).

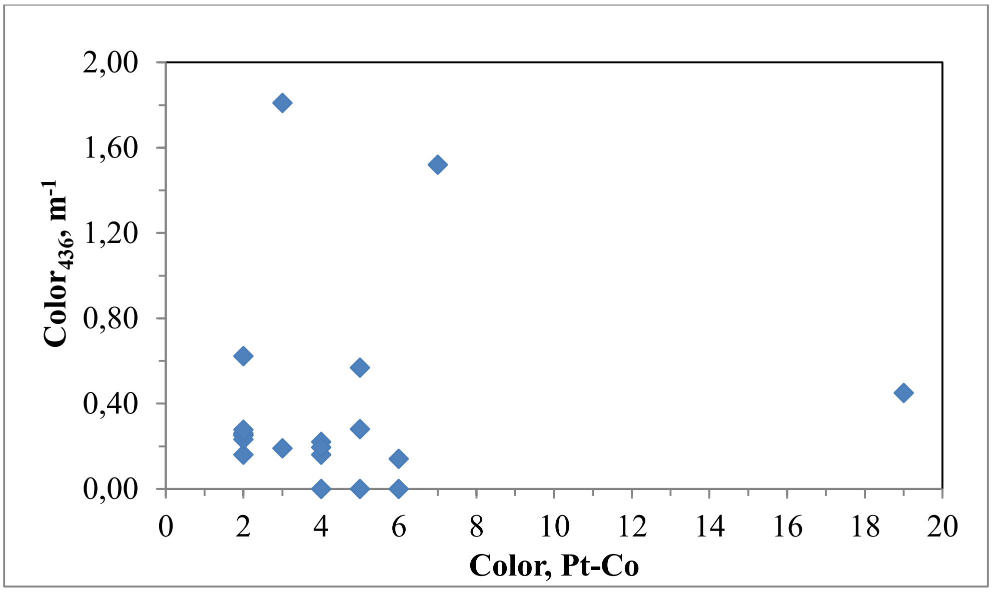

Figure 4.3. $Color_{436}$ versus Color Pt-Co variations in BUISPW.

As mentioned before, pool water should have the same quality as drinking water (TS 11899, 2007; PWTAG, 2014a, TS 266, 2005). Color is also an important parameter for drinking water. Colored organic matter and metals influence the aesthetic acceptance of drinking water. Metals may indicate contamination of water by industrial effluents (WHO, 2011). Appearance of color in water caused by dissolved and suspended particles is important because they are precursors of the formation of DBPs. WHO 2006 guidelines on recreational water safety in swimming pools and similar environments recommend monitoring of pool water but do not specify any values for color (WHO, 2006). Color analysis method for drinking water was not specified in the EU directives (98/83/EC of 3 November 1998). Recommended color value in the standards of TSI (TS 266, 2005) is 1 Pt-Co (for class 1 and class 2 type 1 water) and 20 Pt-Co (for class 2 type 2 water). According to Turkish Ministry of Health Regulations (TMOH Regulation 28580, 2013) concerning water intended for human consumption, color should reflect no abnormal change and should be acceptable to consumers. Although there is no health-based guideline value for color in drinking water in WHO guidelines, less than 15 true color units (TCU) is an acceptable color value for consumers for aesthetic reasons. Drinking water should not have any visible color (WHO 2011). On the other hand, 15 color units is the recommended level of color set by U.S. EPA for secondary drinking water quality standard (USEPA; 2014).

4.3.3. Turbidity

Minimum turbidity value measured in BUISP water was 0.27 Nephelometric Turbidity Unit (NTU) while 0.50 NTU was the maximum value (Table 4.2). Average turbidity was calculated as 0.37 NTU. 55% of the samples were below and 45% were above the average. The values for the turbidity of BUISP water are shown in Figure 4.4. Turkish Ministry of Health regulations specify the recommended value for turbidity in swimming pool water as 0.5 NTU (TMOH Regulation 28143, 2011). In this study, the average turbidity value observed was 0.37 NTU. Thus, turbidity values in the study were lower than the values established by the Ministry of Health regulations. Only in two samples did the values reach 0.5 NTU. Moreover, TSI standards revised in 2007 recommend four different values for this parameter (Table 2.8): 0.5 NTU; 0.5 FNU (Formazin Nephelometric Unit); 5 SiO_2 (Silica Unit); or 5 JTU (Jackson Turbidity Units) (TS 11899, 2007). FNU is similar to NTU in that they both measure scattered light at 90 degrees to incident beam. However, NTU determines turbidity by using a white light (EPA method 180.1) whereas FNU, as recommended by ISO, uses an infrared light source, which is the light source used by many submersible turbidimeters (USGS, 2013).

Determination of turbidity according to Standard Methods depended on Jackson Candle Turbidimeter in the past. Jackson Candle Turbidimeter could not notice turbidity levels of less than 25 JTU (Jackson Turbidity Units). Furthermore, standard suspensions of pure silica that were used in calibration of Jackson Candle Turbidimeter in the past are not used anymore. 40 NTU are equivalent to 40 JTU in the case of formazin standard usage (Sawyer et al., 2003). Compared with the recommended value of 0.5 NTU, the average turbidity value of 0.37 NTU observed in BUISPW was lower.

Suspended and colloidal particles such as organic and inorganic matter, clay, silt, plankton and bacteria in water result in turbidity and they restrict light transmission in the water (Standard Methods, 2005). Moreover, turbidity is regarded as a significant parameter in water quality in terms of disinfection, aesthetics and filtration (Sawyer et al., 2003). For this reason WHO (2006) recommends routine monitoring of this parameter in swimming pools and stipulates average operational level of turbidity as 0.5 NTU, as determined by nephelometric method (International Organization for Standardization 1999).

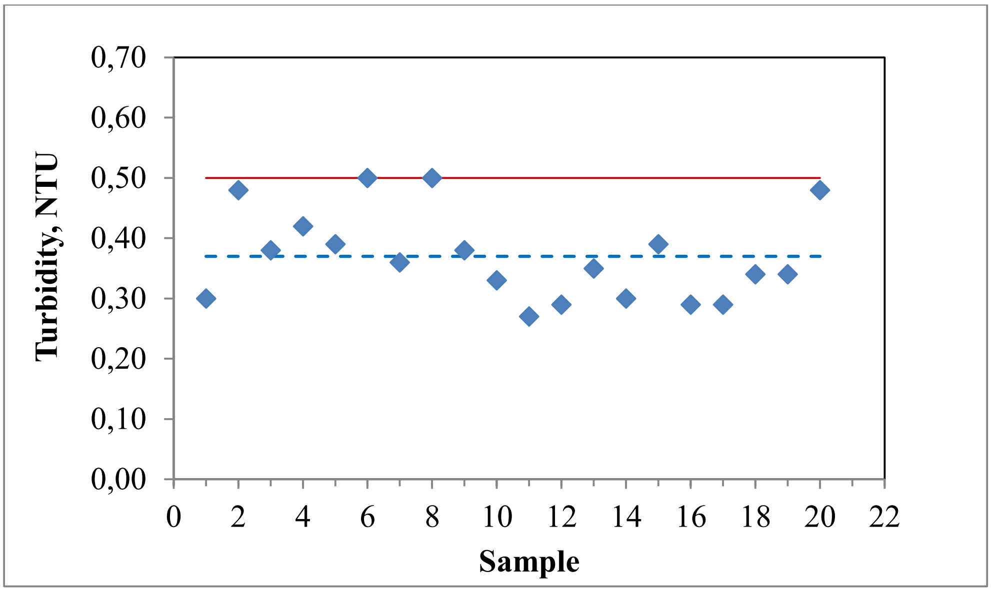

Figure 4.4. Turbidity variations in BUISPW.

(Dashed line indicates average level and straight line indicates recommended value)

As for water intended for human use, TSI standards recommend the level of turbidity as 5 NTU (TS 266, 2005). In the EU directive 98/83/EC of 3 November 1998 and Ministry of Health regulations, customer acceptance and lack of any abnormal change are considered as adequate criteria for turbidity. Recommended level of turbidity in drinking water is less than 1 NTU in terms of disinfection effectiveness as outlined by WHO drinking water guidelines (WHO, 2011).

4.3.4. Conductivity, Total dissolved solids and Salinity

Conductivity, total dissolved solids and salinity are not specified parameters in the Ministry of Health regulations and the standards of TSI (TMOH Regulation 28143, 2011; TS 11899, 2007). However, these parameters were examined in this study and the minimum, maximum and average values obtained are given in Table 4.2.

4.3.4.1. Conductivity. Conductivity values in BUISPW samples are presented in Figure 4.5 below. Results are expressed in units of μScm^{-1}. Figure 4.5 shows conductivity and TDS variations in BUISPW. Minimum, maximum and average values of conductivity in BUISPW samples were 679.7 μScm^{-1}, 828 μScm^{-1} and 768.8 μScm^{-1}, respectively (Table

4.2 and Figure 4.5). 35% of the samples had lower conductivity than average whereas 65% had higher.

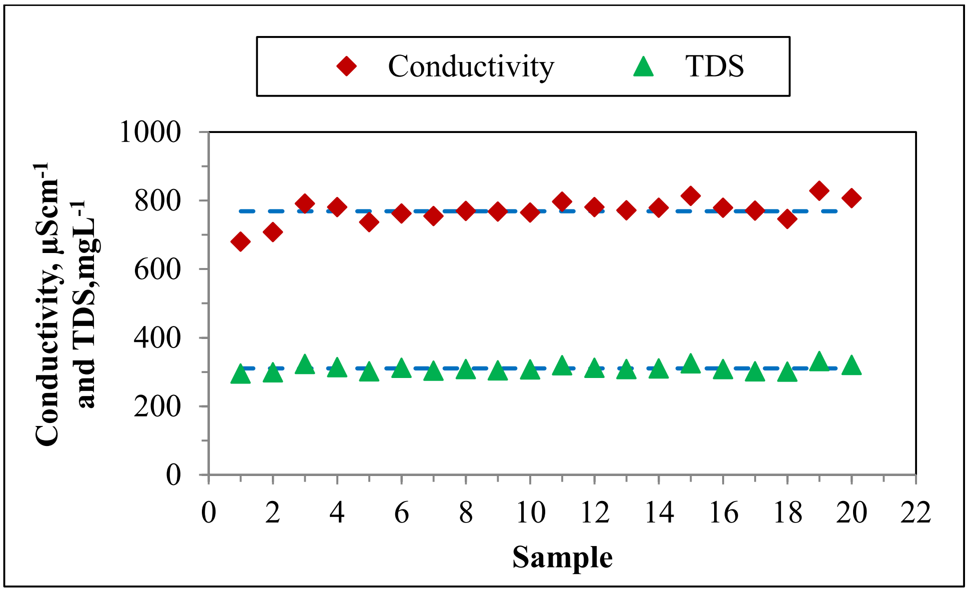

Figure 4.5. Conductivity and TDS variations in BUISPW.
(Dashed line indicates average level)

Turkish Ministry of Health regulations (TMOH Regulation 28143) and TSI Standards (TS 11899) have not set any standards for conductivity in swimming pool water. Similarly, there are no recommendations about conductivity values for pool water and drinking water in the WHO guidelines (WHO, 2006; WHO, 2011). According to the Code of Practice outlined by PWTAG, swimming pool water should be compatible with quality standards of potable water (PWTAG, 2014a). Parametric value of conductivity recommended by EU Council directives 98/83/EC regarding water intended for human consumption is 2500 μScm^{-1} at 20°C. Turkish Standards Institution (TS 266, 2005) and Turkish Ministry of Health (TMOH Regulation 28580, 2013) recommend the same parametric value for drinking water.

Conductivity values were lower than the recommended value by TS 266 (Table 2.8) (TS 266, 2005). Water conductivity refers to water's ability to conduct electricity. Temperature and ionic content of water bodies generally affect this parameter. Inorganic compounds like anions and cations conduct electrical current better than organic compounds such as alcohol, sugar and oil. Conductivity values are reported at 25°C due to influence of temperature on this parameter (Standard Methods, 2005). The results obtained for common anions in this study are given in the Anions and Metals section.

4.3.4.2. Total Dissolved Solids. The lowest and highest TDS values recorded were 295 mgL^{-1} and 331 mgL^{-1}, respectively. The average TDS value was calculated as 311 mgL^{-1} (Table 4.2). TDS values of 55% of the samples were lower than the average TDS value. Figure 4.5 displays TDS variations measured for the BUISPW samples. As indicated above, the Ministry of Health and TSI do not set standard values for TDS in pool water (TMOH Regulation 28143, 2011; TS 11899, 2007). With regard to TDS values, the results showed uniformity with not much variation among the samples. TDS are composed of inorganic salts (calcium, magnesium, sodium, bicarbonate, chlorides and sulfates, potassium) as well as dissolved organic matter. According to WHO, TDS should be an important operational parameter for assessment of pool water and source water quality since any increase in TDS levels could be related to the presence of pool chemicals, disinfectants and bather pollution and therefore should be monitored (WHO, 2006). According to UK CoP data, TDS concentration should not exceed 1000 mgL^{-1} (PWTAG, 2014a). WHO guidelines for drinking water quality report TDS levels of less than 600 mgL^{-1} as acceptable for palatability of drinking water (WHO, 2011). At TDS values higher than 1000 mgL^{-1}, drinking water generally becomes unpalatable. WHO provides no health-related value for TDS. However, it is known that high TDS may cause corrosion of pool equipment. It should also be mentioned that there is no recommended value for TDS for drinking water in the regulations and standards (TS 266, 2005; EC Directive 98/83/EC, 1998). According to a technical paper of the European Union of Swimming Pool and Spa Associations on water quality for domestic swimming pools, TDS should be maintained below 500 mgL^{-1} (EUSA, 2010).

4.3.4.3. Salinity. The results obtained from BUISPW samples did not show any variation. With the exception of one sample (sample 19) expressing salinity of 0.2, all others displayed salinity of 0.1. No recommended values of salinity were provided by the Ministry of Health or Turkish Standards Institution for swimming pool water (TMOH Regulation 28143, 2011; TS 11899, 2007). In addition, neither TSI nor Istanbul Water Quality Reports recommend any salinity values for water intended for human consumption (TS 266, 2005; ISKI, 2013).

As a basic definition, salinity is the total concentration of all dissolved salts in water composed of electrolytes; therefore, salinity is a strong contributor to conductivity. Moreover, conductivity is also used as a surrogate parameter for TDS in clean waters (Weiner, 2013). Total dissolved solids express the sum of all ion particles that are smaller than 2 microns, including all of the disassociated electrolytes. Figure 4.6 displays a possible correlation between TDS, conductivity and salinity.

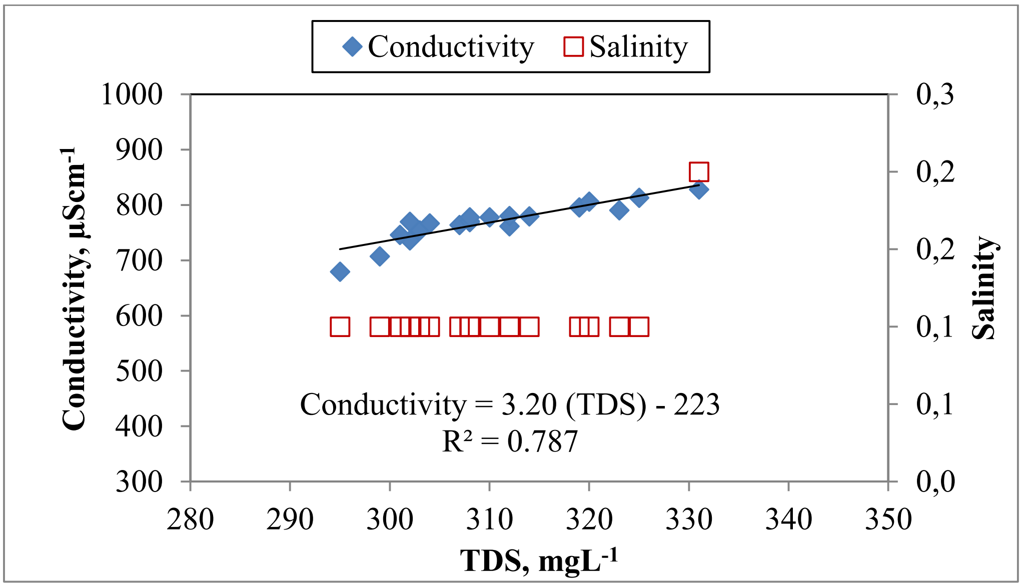

Figure 4.6. Conductivity and Salinity versus TDS variations in BUISPW.

It should be mentioned that the residuals of the pool chemicals used for various purposes could also contribute to the physical quality parameters as TDS, conductivity and salinity conditions of the swimming pool waters. Moreover, bathers load at the specific days of samples should also be taken into account for possible contamination. That could also be related to these parameters, NALCO PT 31, one of the pool chemicals used in BUISP, includes polyaluminum chloride ($Al_nCl_{(3n-m)}(OH)_m$) and is used as coagulant for removal of suspended solids in the pool water. After coagulation process, particles agglomerate and chloride released to the pool water.

4.4. Chemical parameters of BUISPW samples

Chemical parameters examined in this study were pH, alkalinity, hardness, free chlorine as residual disinfectant, nitrogen containing species, common anions (phosphate, sulfate, nitrite, nitrate, chloride, fluoride and bromide), metals (copper, iron, manganese and aluminium), oxidizability, parameters related to organic content, and spectroscopic parameters (UV-vis and fluorescence). Of those parameters, pH, free chlorine, alkalinity, ammonium, nitrite, nitrate, copper and aluminum are specified in the regulations issued by Turkish Ministry of Health (Table 2.8) (TMOH Regulation 28143, 2011). On the other hand, hardness, common anions (phosphate, sulfate, chloride, fluoride and bromide), metals (iron and manganese), oxidizability, parameters related to organic content, and spectroscopic parameters (UV-vis and fluorescence) are not specified in the Ministry of Health regulations. Variations in chemical parameters are displayed in Table 4.3 under appropriate headings representing a general look at the minimum, maximum and average values in BUISPW samples.

Table 4.3. Minimum, maximum and average values of chemical parameters.

	Unit	**Mininum**	**Maximum**	**Average**
Chemical parameters				
pH		6.67	7.51	7.21
Alkalinity	$mgCaCO_3L^{-1}$	19.5	49.8	31.2
Hardness	$mgCaCO_3L^{-1}$	259	370	327
Residual disinfectant				
Free chlorine	mgL^{-1}	0.07	1.67	0.86

4.4.1. pH

pH readings of BUISPW are presented in Figure 4.7. The observed maximum and minimum pH values were 7.51 and 6.67, respectively (Table 4.3). The average pH was calculated at 7.21, displaying 60% of the results above and 40% below the average pH level. The range recommended by the Turkish Ministry of Health regulations for this parameter is between 6.5 and 7.8 (TMOH Regulation 28143, 2011). The average pH value of 7.21 obtained in this study falls within this range while none of the measurements reach the maximum value of 7.8 cited by the Turkish Ministry of Health regulations (TMOH Regulation 28143, 2011).

Similarly, Turkish Standards Institution has set the range for recommended levels of pH as 6.5-7.6, as indicated by a red line in Figure 4.7 (TS 11899, 2007). Maximum pH level established by the TSI is slightly lower than the maximum value set by the Ministry of Health regulations. All pH readings observed in this study were within the recommended range WHO's recommended range for pH of 7.2-7.8 for chlorine disinfectants. 65% of the samples complied with this range. However, a more limited range of 7.2-7.4 is given by PWTAG and 45% of the samples in this study met this standard.

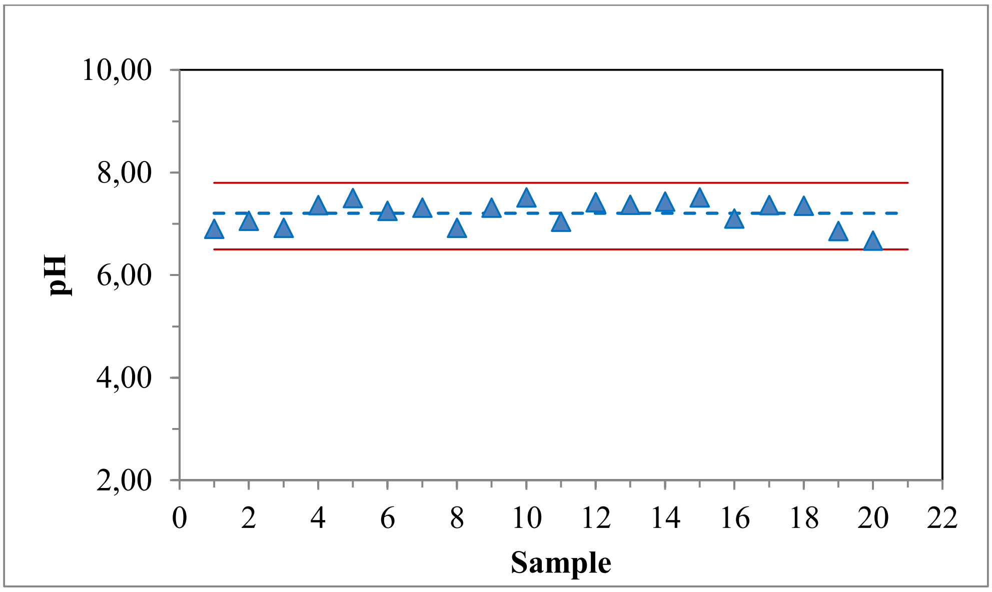

Figure 4.7. pH variation in BUISPW.

(Dashed line indicates average level and straight line indicates recommended range)

Most of the studies displaying pH conditions were performed for the assessment of disinfection by-products, namely THM formation potentials of swimming pool water upon chlorination. Kush and Hoadley reported the range of pH as 5.8-7.8 (Kush and Hoadley, 1980). A study performed by Fantuzzi and colleagues observed a narrow pH range of 7.5 to 7.7 in five indoor swimming pools located in Modena, Italy (Fantuzzi et al., 2001).

Another study conducted by the same research group reported a mean pH value of 7.3 in twenty indoor swimming pools in the Emilia-Romagna region of Northern Italy (Fantuzzi et al., 2010). Lee and colleagues examined 183 indoor swimming pools in Korea in terms of THM production and associated health risk assessment. 72 of those pools were treated with chlorine, 86 with ozone/chlorine and 25 with electrochemically generated mixed oxidants. pH was also reported as 6.2-8.5, 6.3-8.3 and 7.3-8.2 for these three disinfection methods, respectively (Lee et al., 2009). Mean pH values of eight seawater swimming pools in France were found in the range of 6.7-8.2 (Parinet et al., 2012). Air and water quality of 15 swimming pools treated with chlorine for disinfection purposes expressed minimum, maximum and average values of pH as 6.72, 8.02 and 7.46, respectively (Bessonneau et al., 2011).

4.4.2. Alkalinity

As observed in Figure 4.8 presenting variations in alkalinity data, the maximum and minimum alkalinity values were 49.8 and 19.5 $mgCaCO_3L^{-1}$, respectively, with an average value of 31.2 $mgCaCO_3L^{-1}$, which falls close to the minimum limit value indicated by a dashed line in the figure (Table 4.3). Almost 60% of the samples displayed higher alkalinity values than the average. 60% of the results were within the recommended alkalinity range for swimming pool water as 30-180 $mgCaCO_3L^{-1}$.

The average value observed in this study (31.2 $mgCaCO_3L^{-1}$) was close to the minimum value specified by the Ministry of Health regulations since 40% of the alkalinity results were below the minimum limit of 30 $mgCaCO_3L^{-1}$ stipulated in these regulations (TMOH Regulation 28143, 2011). The range for alkalinity recommended by PWTAG is 75-150 $mgCaCO_3L^{-1}$ (PWTAG, 2015). The alkalinity results of the present study do not comply with this range. According to WHO Guidelines, alkalinity is an operational parameter because high alkalinity causes difficulty in pH adjustment; however, the guidelines do not stipulate any recommended value for alkalinity (WHO, 2006). The importance of alkalinity could be explained by the capacity to maintain resistance to rapid pH changes, thereby stabilization of pH levels. Swimming pool water alkalinity is mainly due to the presence of bicarbonates, which that is also measured as inorganic carbon. Moreover, since alkalinity is not considered as a parameter in water quality reports, no comparison could be assessed with reference to the incoming feed water quality (Table 4.1).

4.4.3. Hardness

The minimum hardness level found in BUISPW was 259 mg $CaCO_3L^{-1}$, while the maximum value was 370 mg $CaCO_3L^{-1}$. The average value of hardness found in this study was 327 mg $CaCO_3L^{-1}$, with 50% of the results above the average (Table 4.3, Figure 4.9).

WHO guidelines on swimming pools and similar environments highlight calcium hardness and point out that it damages the pool fabric (surface etching and metal corrosion) but does not give limit values (WHO, 2006). However, WHO does offer specific values for drinking water. It is reported that calcium hardness lower than 100 mgL^{-1} may cause corrosion in water pipes whereas a level above 200 mgL^{-1} may cause scale deposits in treatment and distribution systems, pipes and tanks in buildings (as shown by red lines in Figure 4.9). On the other hand, PWTAG recommends hardness range as 75-150 $mgCaCO_3L^{-1}$ for swimming pool water (PWTAG, 2015). However, for swimming pool waters, hardness range of 250-300 mg $CaCO_3L^{-1}$ could be regarded as expected according to the recommended range as 150-1000 mg $CaCO_3L^{-1}$ (ANSI/APSP-11, 2009).

4.4.4. Residual disinfectant level

Free chlorine. Free chlorine level of the pool water was first measured at the location by on-site test-kits and then in the laboratory within 10 minutes by using the same DPD colorimetric method according to Standard Methods (Standard Methods, 2005). Minimum free chlorine level was recorded as 0.070 mgL^{-1} and 1.64 mgL^{-1} as the maximum level. The average free chlorine level was calculated as 0.86 mgL^{-1} (Table 4.3; Figure 4.10). 53% of the measurements were higher while 47% were below than the average. Recommended ranges of free chlorine (between 0.3-1.5) are shown in Table 2.8.

In the Ministry of Health regulations, free chlorine level stipulated for indoor swimming pool water ranges from 1.0 to 1.5 mgL^{-1} (TMOH regulation 28143, 2011). In this study, more than thirty percent (31.5%) of the results conformed to this range; 58% of the results were lower than the minimum free chlorine level of 1 mgL^{-1} and 10.5 % were higher than the maximum free chlorine level. Free chlorine levels are presented in Figure 4.10. Turkish Standards Institution (TSI) requires the maximum free chlorine concentration not to exceed 1.2 mgL^{-1}. (TS 11899, 2007). It should also be mentioned that on-site measurements were slightly lower than the measurement performed in the laboratory.

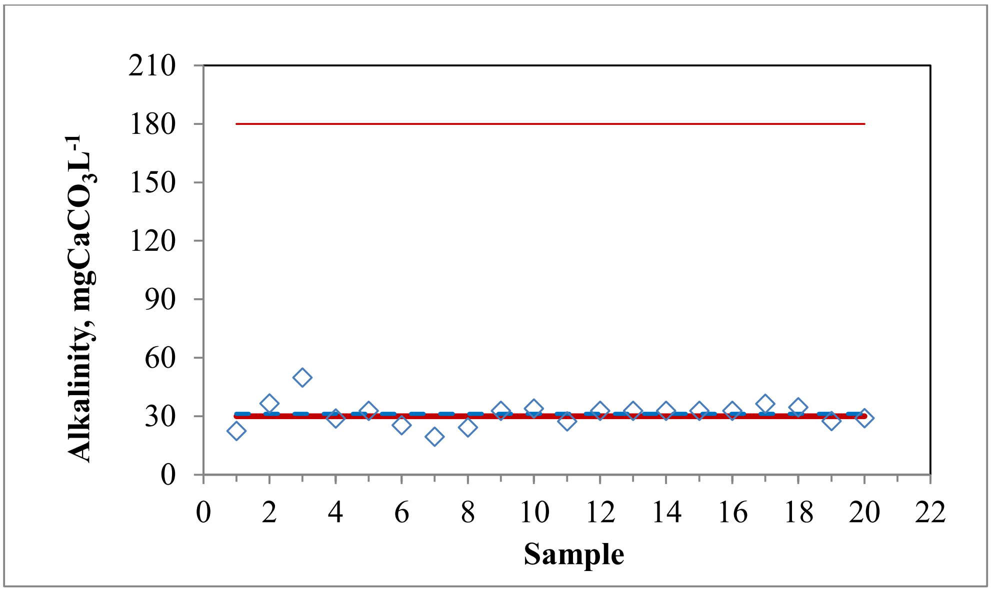

Figure 4.8. Alkalinity variation in BUISPW.

(Dashed line indicates average level and straight line indicates recommended range)

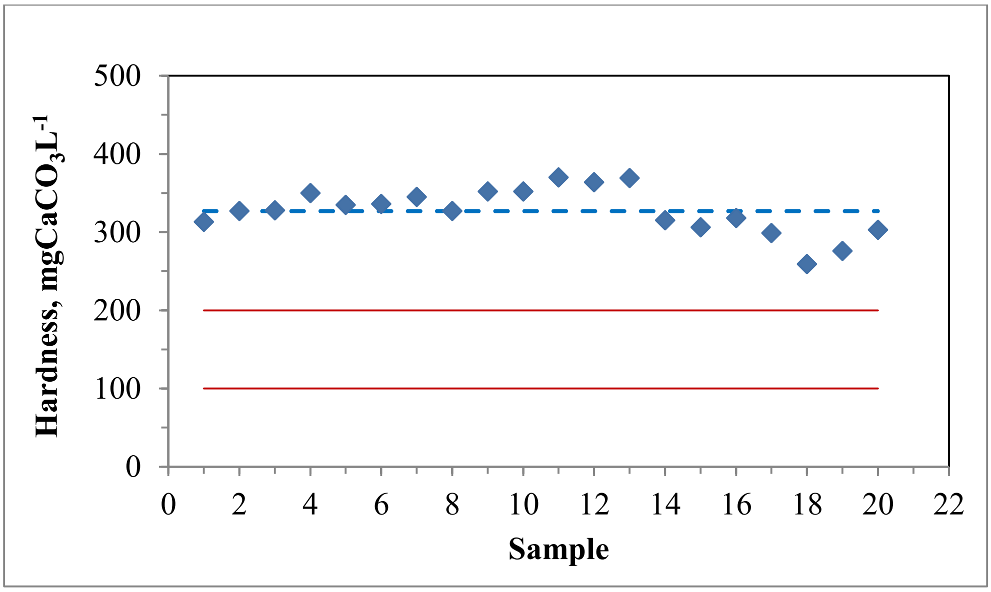

Figure 4.9. Hardness variation in BUISPW.

(Dashed line indicates average level and straight line indicates recommended range)

Moreover, no data were displayed for 35% of the samples due to various uncontrolled reasons. Acceptable microbiological quality of swimming pool water depends on the residual disinfectant level. According to WHO guidelines, efficient disinfection may be maintained at 1.0 mgL^{-1} free chlorine level for well-designed and operated pools (Table 2.8) (WHO, 2006). Only 16% of the samples had a free chlorine level of 1 mgL^{-1}. More than fifty percent of the samples (58%) were below 1 mgL^{-1} while 26% of the specimens measured above the level recommended by WHO. In addition, the Code of Practice of PWTAG indicates a range of 0.5-1.0 mgL^{-1}, and 57.8% of our samples complied with this standard (PWTAG, 2015).

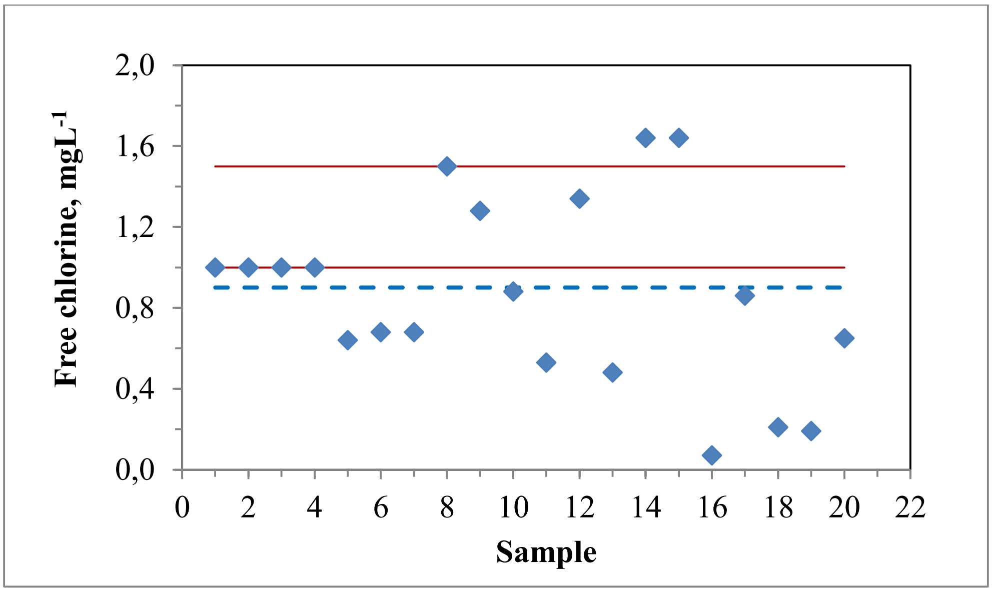

Figure 4.10. Free chlorine variation in BUISPW.

(Dashed line indicates average level and straight line indicates recommended range)

The data on residual chlorine levels observed in various studies are summarized as follows. Mean total residual chlorine levels of eight seawater swimming pools feeding from Mediterranean Sea treated with chlorine were reported as 1.7, 1.6, 1.5, 1.8, 1.7, 0.6, 1.4 and 0.6 mgL^{-1} Cl_2 (Parinet et al., 2012). Free chlorine values in five indoor swimming pools studied by Fantuzzi and co-workers ranged from 0.43 to 1.47 mgL^{-1} (Fantuzzi et al., 2001). In a later study, the range of free chlorine was reported to be between 0.7 and 2.0 mgL^{-1} in 20 indoor swimming pools (Fantuzzi et al., 2010). In an earlier study conducted by Kush and Hoadley, the range of total residual chlorine was reported as 0.0-3.0 mgL^{-1}, being significantly higher (Kush and Hoadley; 1980). Bessonneau and colleagues reported high results. They observed minimum and maximum free chlorine levels as 0.40 and 4.00 mg^{-1}, respectively, in fifteen swimming pools located in Rennes, France (Bessonneau et al., 2011). Lee and colleagues' study which investigated 183 indoor swimming pools in Korea in terms of THM production and associated health risk assessment reported that, 72 of the pools were treated with chlorine, 86 with ozone/chlorine combined system and 25 with electrochemically generated mixed oxidants. The ranges of free chlorine residual in these pools were 0.06-2.0 mg^{-1}, 0.1-1.5 mg^{-1} and 0.08-0.9 mg^{-1} whereas the average values of free chlorine residual were reported as 0.7 mg^{-1}, 0.5 mg^{-1} and 0.5 mg^{-1}, respectively (Lee et al., 2009). Although presence of residual disinfectant level is a strict condition to maintain microbiological safety of swimming pool water, all of above discussed studies focused mainly on the formation of disinfection by-products.

4.4.5. Common Anions

Chloride, fluoride, bromide, sulfate, and phosphate levels were determined according to the procedure outlined in section 3, Materials and Methods. Nitrate and nitrite contents were evaluated as nitrogen containing species (Section 4.4.6). Minimum, maximum and average levels of the common anions determined in BUISPW samples are presented in Table 4.4. Since bromide values are found to be below detection limit, halogen ions are displayed in Figure 4.11, and sulfate and phosphate variations are given in Figure 4.12. Sample dependent variations are also displayed in Figure 4.12. Table 4.5 have been taken into consideration in assessing common anions and metals. Unlike Tables 2.11 and Table 2.12, Table 4.5 includes values presented by WHO, 2011 and USEPA, 2009. Moreover, Table 4.5 also presents a value for nitrite, which is not included in the other two tables (Table 2.11 and Table 2.12). It has been observed that nitrate value set by USEPA has dropped from 45 mg^{-1} to 10 mg^{-1}; sulfate value was revised by WHO as 250 mg^{-1}, the value indicated by other authories (Table 2.11 and Table 2.12).

4.4.5.1. Chloride. Minimum and maximum values of chloride ions are 135.02 mgL^{-1} and 215.29 mgL^{-1}, respectively. The average chloride level was 175.62 mgL^{-1} (Table 4.4). 45% of our samples were below the average while 55% of the samples were above the average (Figure 4.11).

Table 4.4. Minimum, maximum and average values of common anions.

Common Anions	**Minimum**	**Maximum**	**Average**
	mgL^{-1}		
Chloride	135.02	215.29	175.62
Fluoride	0.06	0.27	0.09
Bromide	BDL	BDL	BDL
Sulfate	166.07	270.41	210.29
Phosphate	4.86	10.87	7.80

BDL: Below detectable level of 0.014 mgL^{-1} for bromide (Standard Methods, 2005).

Table 4.5. Contaminant level of anions and metals in drinking water according to European Union Council (98/83/EC), Turkish Standards Institution (TS 266), Environmental Protection Agency and World Health Organization and Istanbul Water and Sewerage Administration.

	EU 98/83/EC	**TS 266[a] 2005**	**US EPA[b] 2009**	**WHO 2011**	**ISKI[c] 2013**	**BUISPW[d]**
Anions	mgL^{-1}					
Chloride	250	250	250	250	34.3	175.62
Fluoride	1.5	1.5	4.0-2.0[e]	1.5	0.05	0.09
Bromide[f]	--	--	--	--	0.05	BDL
Nitrite	0.50	0.50	1.0	3.0[g]	--	<LOD[h]
Nitrate	50	50	10	50[j]	2.39	6.00
Sulfate	250	250	250	250	62.2	210.29
Phosphate[f]	--	--	--	--	--	7.80
Metals						
Copper	2.0	2.0	1.3-1.0[e]	2.0	<0.02	0.0046
Iron	0.2	0.2	0.3	0.3	<0.02	0.117
Aluminum	0.2	0.2	0.05 to 0.2	0.1	<0.05	0.0947
Manganese	0.05	0.05	0.05	0.1	<0.02	0.0030

[a] Water for class 2 type 2
[b] Maximum contaminant level
[c] Average value of incoming water supply (from Kağıthane Drinking Water Treatment Plant)
[d] Average value
[e] Primary drinking water level and secondary maximum contaminant level, respectively
[f] No value mentioned
[g] As nitrite ion or 0.9 mgL^{-1} as nitrite- nitrogen
[h] LOD , $NO_2^- < 5 \mu gL^{-1}$
[j] as nitrate ion or 11 mgL^{-1} as nitrate-nitrogen

In this study, chloride level of 175.62 mgL^{-1} is low as compared to the recommended level. Chloride is an important parameter as it influences acceptability of potable water. Health-based guideline value for chloride is not offered by WHO but it is known that high levels of chloride ions result in an undesired salty taste (WHO, 2011).

4.4.5.2. Fluoride. Minimum, maximum and average values of fluoride ions in BUISPW samples are 0.06 mgL^{-1}, 0.27 mgL^{-1} and 0.09 mgL^{-1}, respectively (Table 4.4). In 55% of the samples, fluoride results are below the average whereas 45% displayed values above the average. Figure 4.11 shows fluoride variation in BUISPW samples. Contaminant level of fluoride in drinking water is 1.5 mgL^{-1} according to European Union Council (98/83/EC), Turkish Standards Institution (TS 266) and WHO regulations (EC Directive 98/83/EC, 1998; TS 266, 2005; WHO, 2006). Unlike these regulations, USEPA recommended a higher level for fluoride (4.0-2.0 mgL^{-1}, primary drinking water level and secondary maximum contaminant level, respectively) (Table 4.5). The fluoride values in BUISPW could be considered as low in comparison to the limits set by the above mentioned authorities.

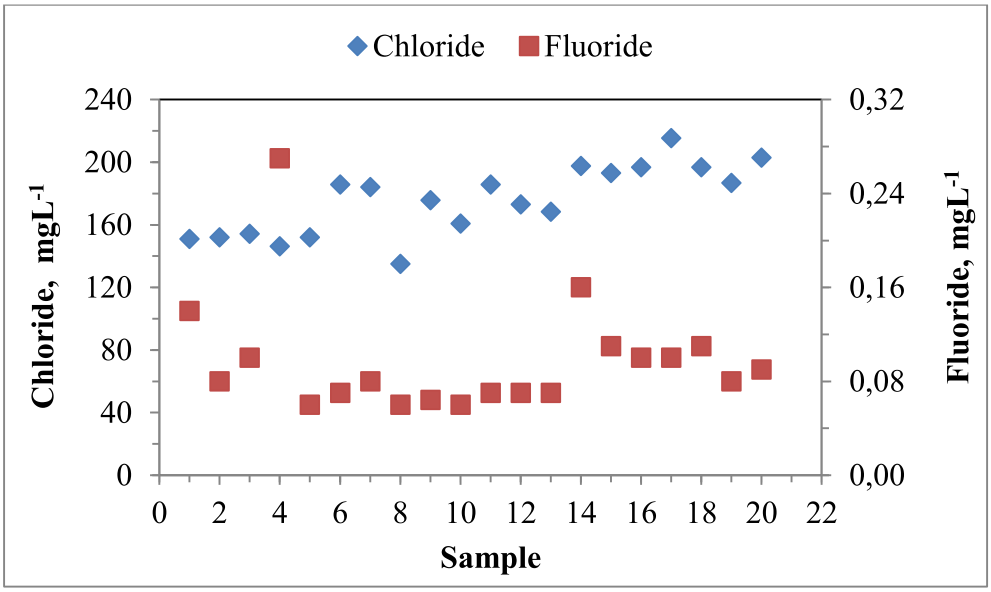

Figure 4.11. Chloride and fluoride variations in BUISPW.

4.4.5.3. Bromide. All measurements of bromide ions in BUISPW samples are below 0.014 mgL^{-1}, the lowest detectable level for bromide in the instrument used (Table 3.6). Bromide concentration in fresh water can go up to 0.5 mgL^{-1} while in desalinated water it is close to 1.0 mgL^{-1}. These levels of bromide do not cause any health concerns. Bromide takes part in the reaction between chlorine and organic matter in drinking water and forms by-products THMs and HAAs (halogenated acetic acids).

4.4.5.4. Sulfate. Variations in sulfate values of BUISPW samples are given in Figure 4.12. The minimum sulfate level observed was 166.07 mgL^{-1}, and the maximum was 270.41 mgL^{-1} (Table 4.4). The average sulfate level was 210.29 mgL^{-1} with 50% of the specimens below the average and 50% above the average (Figure 4.12).

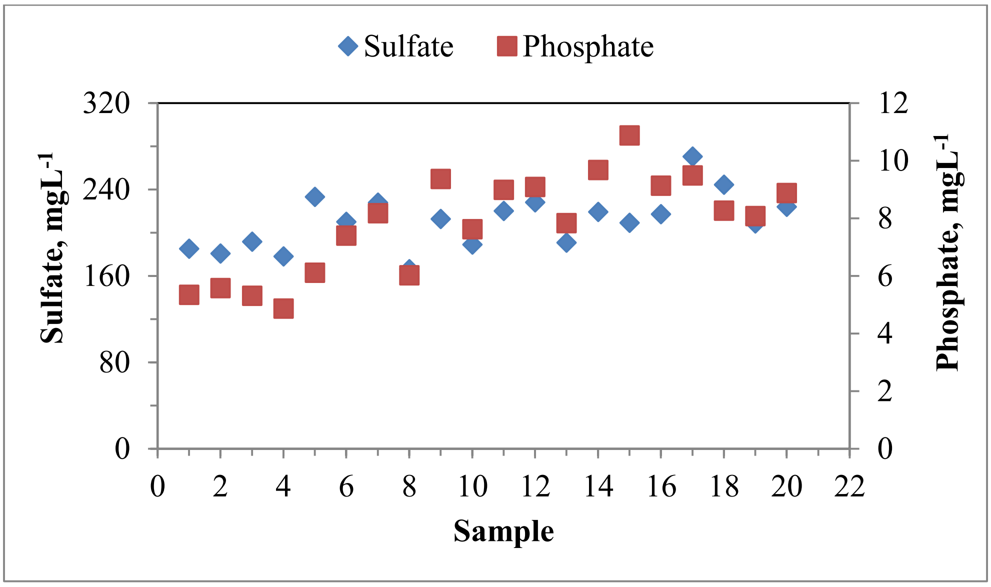

Figure 4.12. Sulfate and phosphate variations in BUISPW.

There is no available data for recommended sulfate level in swimming pool water in the Regulations of the Ministry of Health, Turkish Standards Institution, or WHO (TMOH Regulation 28143, 2011; TS 11899, 2007; WHO, 2006) (Table 2.8). According to PWTAG Code of Practice, sulfate level should not exceed 360 mgL^{-1} in pool water (PWTAG, 2015). Sulfate value in other standards about drinking water quality is 250 mgL^{-1} (EC Directive 98/83/EC, 1998; TS, 2005; USEPA, 2009; WHO, 2011). In light of these data, average sulfate value in BUISPW could be considered as low. Sulfate level for one sample (sample 17) only was recorded high as 270.41 mgL^{-1}. Sulfate is a commonly used chemical in industry and reaches water bodies through industrial wastes and atmospheric deposition. Sulfate in water causes taste problems. Beside undesirable taste problems, high level of sulfate in potable water has gastrointestinal effects. Since swimming pool water should have drinking water quality, sulfate concentrations should also be carefully controlled.

4.4.5.5. Phosphate. As seen in Table 4.4, minimum and maximum phosphate values observed in this study were 4.86 and 10.87 mgL^{-1}, respectively. The average value for phosphate was 7.80 mgL^{-1}, and 60% of the samples were above the average level. Sample dependent variations of phosphate are given in Figure 4.12. Swimming pool authorities did not present any information about recommended levels of this anion (Table 2.8). However due to the fact that swimming pool water should be of drinking water quality, the presence of phosphates should be addressed. Moreover, BUISP Management indicated that hydroxyethylene diphosphoric acid could be used as hardness stabilizer. However, no further relationship could be established between the use of this chemical and possible release of phosphates into the pool water. Considering the pH conditions of the samples (section 4.4.1), phosphate species should be in the composed form of $H_2PO_4^-$ and HPO_4^{2-} as pK_{a2}=7.2 for H_3PO_4. Since phosphates are nutrients for algae growth, the presence of phosphates causes serious problems in outdoor swimming pools rather than indoor swimming pools.

4.4.6. Nitrogen containing species

Nitrogen containing species are mainly nitrite, nitrate, ammonia, and TKN. Ammonium, nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen, ammonium-nitrogen, total inorganic nitrogen (Total Inorg-N), total organic nitrogen (Total Org-N) and total nitrogen (Total- N) are also presented for comparison purposes.

The major source of these compounds in swimming pool water is bathers. By means of sweat and urine, high amount of nitrogen containing compounds enter into the swimming pool (White, 1972, WHO, 2006). In addition, nitrite, nitrate, ammonia and TKN amounts, ammonium, nitrite-nitrogen, nitrate-nitrogen, ammonia nitrogen, ammonium nitrogen, Total Inorg-N, Total Org-N and Total-N were calculated and their results are also given in Table 4.6.

Since pool water is expected to have the same quality as drinking water, both swimming pool water and drinking water quality standards of various agencies were considered in evaluating the results of nitrogen containing species present in BUISPW (White 1972; TS 11899, 2007; PWTAG, 2015). As mentioned before, BUISP is filled with municipal water from the Kağıthane Drinking Water Treatment Plant. The properties of incoming water presented in Table 4.1 are also considered. Nitrate displayed a variation of 1.36 mgL^{-1}-3.33 mgL^{-1} with an average of 2.39 mgL^{-1}. Moreover, no data is available for nitrite and TKN.

Table 4.6. Minimum, maximum and average values of nitrogen containing species.

	Minimum	**Maximum**	**Average**
	mgL^{-1}		
Nitrogen containing species			
Nitrite[a]	<LOD	0.349[b]	--
Nitrate	4.33	10.92	6.00
Ammonia	0.19	0.79	0.41
Ammonium	0.20	0.84	0.44
Total Kjeldahl Nitrogen	3.60	9.00	5.34
Nitrogen containing species expressed as -N			
Nitrite –nitrogen	--	0.106	--
Nitrate-nitrogen	0.980	2.47	1.36
Ammonia nitrogen	0.15	0.65	0.34
Ammonium nitrogen	0.16	0.65	0.34
Total inorganic nitrogen	1.13	2.47	1.66
Total organic nitrogen	3.22	8.61	5.04
Total nitrogen	4.73	10.27	6.70

[a] Nitrite LOD < 5 μgL^{-}
[b] Sample 15

As presented previously in Table 2.8, maximum amounts of ammonium and nitrate concentration of the pool water were specified in TSI standards whereas the amount of nitrite was not set in the TSI standards (TS 11899, 2007). Turkish Ministry of Health set maximum limit values for ammonium, nitrite and nitrate as 0.5 mgL^{-1}, 0.5 mgL^{-1} and 50 mgL^{-1}, respectively, in swimming pool water (TMOH Regulation 28143, 2011). With respect to WHO directives, nitrogen containing species are not mentioned as parameters for swimming pools but nitrite and nitrate are important parameters in drinking water quality to decrease the risk of methaemoglobinemia, a blood disorder mostly referred to as "blue baby syndrome" (WHO, 2006; WHO, 2011). Nitrite, nitrate and ammonium are parameters given in the standards of TSI (TS 266) whereas no data is provided by any of the authorities about organic nitrogen, TKN, and other nitrogen containing species (Table 2.8).

4.4.6.1. Nitrite. BUISPW samples expressed contents below the detectable level of 5µgL^{-1} (LOD) excluding the nitrite content of Sample 15 measured as 0.349 mgL^{-1}. The maximum value of nitrite in swimming pool water has been set to 0.5 mgL^{-1} by the regulations of the Turkish Ministry of Health (TMOH Regulation 28143, 2011). As indicated previously, TSI (TS 11899, 2007) does not set a standard value for nitrite in swimming pool water. However, the water of swimming pools should be of the same quality as drinking water (White 1972; TS 11899, 2007; PWTAG, 2015). According to the limits set by EU, TS 266, EPA and WHO, nitrite contents vary between 0.50 and 3.0 mgL^{-1} (Table 4.5). Contaminant level of nitrite in drinking water is 0.50 mgL^{-1} as set by EU 98/83/EC and TS 266 (2005), but 1.0 mgL^{-1} according to USEPA (USEPA, 2009). The highest nitrite contaminant level for drinking water is stated by WHO at 3.0 mgL^{-1}. The nitrite content of Sample 15 was lower than the limits set by authorities for both swimming pool water and drinking water. Drinking water is one of the most important sources of nitrite and nitrate intake for humans. WHO Drinking Water Guidelines recommend an optimum level of 3 mgL^{-1} for nitrite in drinking water to alleviate the risk of methaemoglobinemia (Blue Baby Syndrome) in bottle-fed infants (WHO, 2011). Nitrite can react with amines to form N-nitroso compounds or nitrosamines. Choi and Valentine's research focused on the formation of nitrogen containing disinfection by-products, namely N-Nitrosodimethylamine (NDMA) (Choi and Valentine, 2002). It was also reported that the reaction of dimethylamine (C_2H_7N) with chlorine and chlorine dioxide in the presence of ammonia ions could result in NDMA formation (Andrzejewski et al., 2005). Nitrosamines are among of the most environmentally significant nitrogen-containing compounds as they are known to express carcinogenic properties. In this group, NDMA is important because it is classified as a probable human carcinogen (WHO, 2011). Consequently, the presence of NDMA as a contaminant in potable and surface waters is of major concern from public health point of view.

4.4.6.2. Nitrate. The amounts of nitrate in BUISPW samples are presented in Figure 4.13. Minimum and maximum nitrate levels in the pool water were measured as 4.33 mgL^{-1} and 10.92 mgL^{-1} respectively (Table 4.6). The average nitrate value was calculated as 6.00 mgL^{-1} and 65 % of the samples were found to contain nitrate below the average. As indicated, Sample 1 displayed the highest nitrate as 10.92 mgL^{-1}, being significantly higher than the rest of the data.

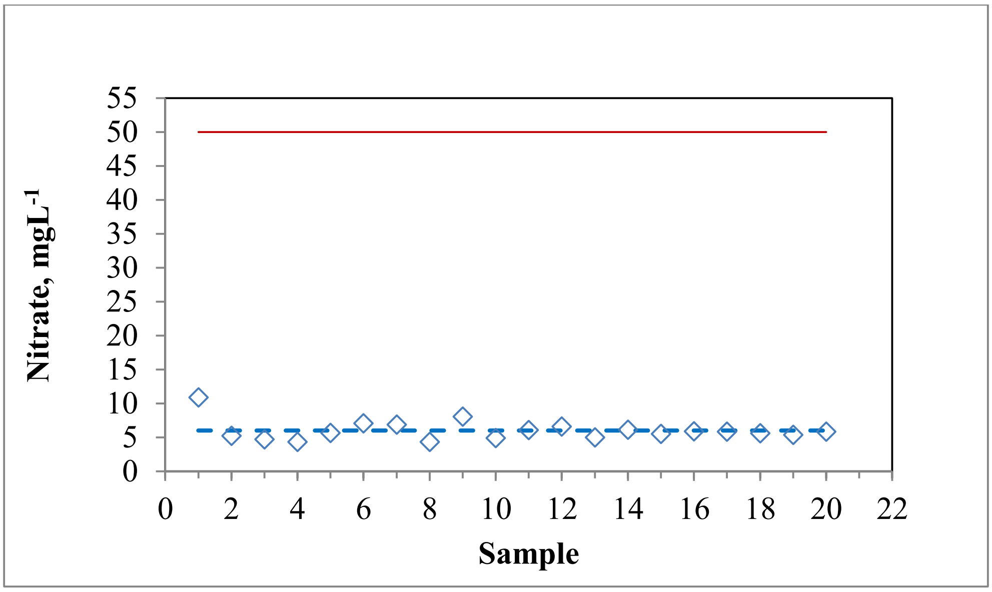

Figure 4.13. Nitrate variations in BUISPW.

(Dashed line indicates average level and straight line indicates recommended value)

The maximum value for nitrate in swimming pools according to the regulations of the Turkish Ministry of Health (TMOH Regulation 28143, 2011) is 50 mgL^{-1}. However, TSI states that the amount of nitrate concentration to be added to the nitrate concentration present in the water used to fill the pool should not exceed 20 mgL^{-1} (TS 11899, 2007). Assuming that the level of nitrate concentration in the make-up water is 20 mgL^{-1} maximum, then the total nitrate concentration in BUISPW may be roughly 30 mgL^{-1}. This approximate value is low when compared with the limit of nitrates in drinking water; however, it is high in comparison to the value (10 mgL^{-1}) specified by EPA (Table 4.5). On the other hand, nitrate value in drinking water according to EU, TS 266, and WHO standards is 50 mgL^{-1} whereas the value of nitrate expressed by EPA is 10 mgL^{-1} (Table 4.5). The average value observed in this study as 6.00 $mgL^{-1} \pm 1.48$ could be regarded as well below both of the set values for swimming pool water and drinking water.

BUISP was supplied with water from Kağıthane Drinking Water Treatment Plant. The minimum, maximum and average values of nitrate in incoming water provided by the municipal distribution system were 1.25 mgL^{-1}, 3.33 mgL^{-1} and 2.39 mgL^{-1} (Table 4.5). In comparison, the average nitrate value in this study was 6.00 mgL^{-1}, which is higher than incoming water value. However, this average value of 6.00 mgL^{-1} was lower than the values recommended for swimming pool water and drinking water by EU, TSI, USEPA, and WHO (EC Directive 98/83/EC, 1998; TS 266, 2005;USEPA, 2009; WHO, 2011) (Table 4.5).

As yet no studies on water quality of pool water or nitrogen containing species in swimming pools in Turkey have been published. However, such research has been conducted in many countries around the world (Beech et al., 1980; Judd and Bullock, 2003; Michalski and Mathew, 2007; Lee et al., 2010; Dallolio et al., 2013).

Beech and colleagues reported concentrations of nitrate, chlorates and THM in four groups of chlorinated open air pools (saline pools, hotel and motel pools, condominium and apartment building pools, and municipal pools) (Beech et al., 1980). All pools except saline pools were filled with city municipal water, which had an average nitrate concentration of less than 0.1 mgL^{-1}. Average nitrate concentration in freshwater pools was 8.6 mgL^{-1}, the highest concentration being 54.9 mgL^{-1}. The average nitrate concentrations of saline pools, hotel and motel pools, condominium and apartment building pools, and municipal pools were 2.7 mgL^{-1}, 7.4 mgL^{-1}, 16.5 mgL^{-1} and 4.5 mgL^{-1}, respectively. Condominium and apartment building pools which were used by families with children had a higher nitrate level (average 16.5 mgL^{-1}) than municipal pools (average 4.5 mgL^{-1}), which were used by adults only. The high nitrate level was explained by the existence of urea, which contains two nitrogen atoms that turn into nitrate when oxidized by chlorine (Beech et al., 1980). Since the source of urea in swimming pools is urine, high nitrate levels in condominium and apartment building pools which are frequented by children is to be expected. The reactions are given in the equations 4.1- 4.4 below.

$$Cl_2NCONCl_2 + HOCl \rightarrow NCl_3 + CO_2 + NCl \quad (4.1)$$

$$NCl_3 + HOCl + 2H_2O \rightarrow HNO_3 + 4HCl \quad (4.2)$$

$$NCl + OH^- \rightarrow NOH + Cl_2 \quad (4.3)$$

$$2NOH \rightarrow H_2N_2O_2 \rightarrow N_2O + H_2O \quad (4.4)$$

On the other hand, the reaction between tetrachlorourea and hypochlorous acid gives dichloramine. When dichloramine decomposes by breakpoint chlorination, nitrate and nitrogen are produced as in equations 4.5 and 4.6 below (Wojtowicz, 2001).

$$Cl_2NCONCl_2 + HOCl \rightarrow NCl_3 + NHCl_2 + CO_2 \quad (4.5)$$

$$NHCl_2 + 2HOCl + H_2O \rightarrow 3H^+ + NO_3^- + 2Cl^- \quad (4.6)$$

Urea is a significant precursor for NCl_3 formation. Moreover, chlorination of urea results in the formation of nitrate in the pool. These reactions lead to loss of urea-N, 12-18% of which may be explained by nitrate N, depending on pH. Nitrate may accumulate in pools in which the presence of free chlorine will prevent reduction to nitrite (Blatchley III and Cheng, 2010).

Judd and Bullock studied chlorine and organic materials in swimming pools using analogues of body fluids which contain the primary endogenous organic amino compounds and humic acid. After 200-500 hours of operation, organic carbon, chloramines and THM arrived at a steady state and only nitrate was found to accumulate, accounting for 4-28% of the dosed amino nitrogen. The study revealed that minor amounts of the volatile by-products were found to be lost to the atmosphere. In terms of THM formation tendency, humic acid was eight times that of the body fluid analogue. In addition, nitrate, organic nitrogen and ammonia nitrogen were determined and organic nitrogen concentration surpassed 3 mgL^{-1}. This revealed that a significant amount of ammoniacal nitrogen was present in the pool water, explaining the rest of the TKN measurement. (Judd and Bullock, 2003).

Nitrate concentration was detected in five chlorinated and two ozonated pools in the range of 4.17-9.25 mgL^{-1} and 16.25-26.34 mgL^{-1}, respectively (Michalski and Mathew, 2007). In BUISPW, nitrate level was between 4.33-10.92 mgL^{-1}. This result corresponded to the results of Michalski and Mathew's study (Michalski and Mathew, 2007).

Lee and colleagues measured concentrations of nitrate in 86 public swimming pools in Seoul and reported nitrate levels in pool waters ranging from 6.6 mgL^{-1} to 24 mgL^{-1} in chlorinated pools, 1.2 mgL^{-1} to 22 mgL^{-1} in ozone-chlorine treated pools, and 11 mgL^{-1} to 49 mgL^{-1} in swimming pools treated with electrochemically generated mixed oxidants (Lee et al., 2009). Like Beech and colleagues, Lee and co-workers indicate higher nitrate concentration in pool water than in tap water (Beech et al., 1980; Lee et al., 2010). Similarly, the average nitrate level of incoming water from Kağıthane Treatment Plant during the sampling period of this study (2.39 mgL^{-1}) was lower than the average nitrate level of BUISPW observed in this study (6.00 mgL^{-1}) (Table 4.5).

In a recent study carried out in Italy by Dallolio and colleagues, a total of 144 pools in Bologna, Italy (69 indoor and 75 outdoor) were examined in terms of their chemical and microbiological quality in the three year period from 2010 to 2012, after ten years of implementing Italian guidelines. Compliance of swimming pools to Italian Standards (smaller than or equal to 20 mgL^{-1} above supply water) for nitrate level in indoor pool waters was almost 100% (Dallolio et al., 2013).

4.4.6.3. Ammonia. Ammonia variation in BUISPW is presented in Figure 4.14. Minimum, maximum and average ammonia values found in the samples were 0.19 mgL^{-1}, 0.79 mgL^{-1} and 0.41 mgL^{-1}, respectively (Table 4.6). 50% of the results were below the average. Samples 1 and 12 were below the lowest detection limit of 0.06 mgL^{-1}.

Regulations and standards about pool water include a value for ammonium but not for ammonia in swimming pools (TMOH Regulation 28143, 2011; TS 11899, 2007, WHO, 2006). In this study, results of ammonia were evaluated in terms of ammonium ion as calculated.

Ammonia nitrogen may be found in water either as ammonia gas or ammonium ion forms (equation 4.7). This depends on the level of pH and temperature in the water.

$$NH_3 + H^+ \leftrightarrow NH_4^+ \qquad pK_a = 9.25 \tag{4.7}$$

At pH 9.25, half of the ammonia (50%) will be in unionized form, the other half in ionized form. At pH levels above 7, unionized form of ammonia is predominant whereas at pH level below 7, ammonium is predominant (Tchobanoglous et al., 2004; Weiner, 2013).

Ammonia is much more toxic for aquatic life than ammonium; for that reason the pH and temperature of water at the sampling site is very important (Weiner, 2013). Average pH of BUISPW samples in this study was 7.2. Therefore, all ammonia in this study is in the form of ammonium.

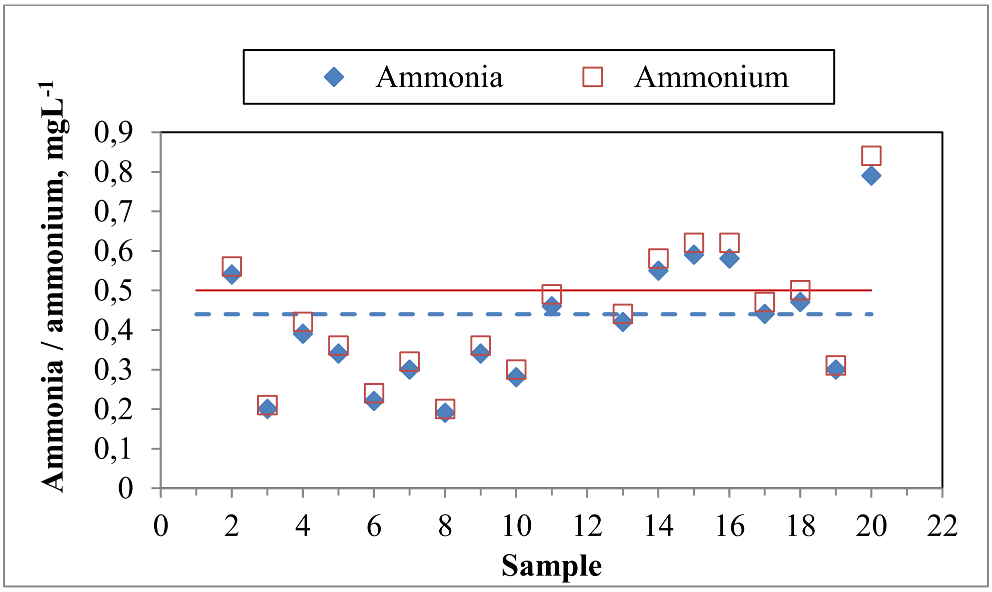

Figure 4.14. Ammonia and ammonium variations in BUISPW.
(Dashed line indicates average level and straight line indicates recommended ammonium value)

Kush and Hoadley conducted a study on eight commercial whirlpool bath waters in Atlanta, and reported the range of ammonia as 0.1-21 mgL^{-1} (Kush and Hoadley, 1980). The average ammonia level found in BUISPW samples was 0.41 mgL^{-1}.

Ammonia is an important nitrogen containing compound in chloramine formation. In the presence of ammonia, monochlormine, dichloramine and trichloramine are formed as in the equations 2.3-2.5. These are referred to as combined available chlorine and they cause the typical pool smell as well as eye irritation. Ammonia naturally exists in most waters and it is oxidized to nitrite and nitrate (Weiner, 2013). In terms of disinfection efficiency, nitrite formation, and filter problems, this chemical is important. Ammonia can lead to formation of nitrite in distribution systems because it can compromise the efficiency of disinfection. This can harm the filters used to remove manganese and create odor and taste problems (WHO, 2011).

4.4.6.4. Ammonium ion. Minimum ammonium value was measured as 0.20 mgL^{-1} whereas maximum was 0.84 mgL^{-1}. The average ammonium value was 0.44 mgL^{-1} and 50 % of the samples were below the average (Table 4.6). Ammonium levels observed in the samples used in this study are given in Figure 4.14.

According to the regulations of the Turkish Ministry of Health (TMOH Regulation 28143, 2011), the maximum recommended ammonium level for swimming pool water is 0.5 mgL^{-1} (Table 2.8). In this study, 25% of the results exceeded the maximum recommended limit whereas 75% were below or equal to 0.5 mgL^{-1}. The maximum ammonium concentration standard specified by TSI (TS 11899) was 0.1 mgL^{-1} in 2000. However, in 2007, the standard was revised and the maximum ammonium concentration was expressed as 0.5 mgL^{-1}. In accordance with the revised standard, the average ammonium value in this study was low.

Keeping in mind that the swimming pool water should be of drinking water quality, the acceptable level of ammonium for fresh water recommended by both the Turkish Standards Institution (TS 266) and the EU Council Directive (98/83/EC) was the same as the level recommended by TSI for pool water (TS 11899, 2007), namely 0.50 mgL^{-1}.

4.4.6.5. Total Kjeldahl Nitrogen (TKN). Results of Total Kjeldahl Nitrogen (TKN) determined in BUISPW samples are presented in Figure 4.15. The maximum TKN level was 9.00 mgL^{-1} and the minimum was 3.6 mgL^{-1}, giving an average TKN level of 5.34 mgL^{-1} (Table 4.8). Results indicated that 65% of samples were below and 35% were above the average.

The values of TKN for the seven samples (samples 1, 2, 3, 4, 8, 18 and 19) which were collected in December, January, April and June were recorded above the average whereas TKN content of the other samples collected in February, March, April, May and June was recorded below the average. As mentioned before, the source of nitrogen containing compounds in swimming pool water is bathers. Information collected on pool users will be given in Section 4.6. However, bather numbers are presented there. The number of bathers at the time these seven samples (samples 1, 2, 3, 4, 8, 18 and 19) were taken was 18, 21, 10, 17, 3, 17 and 12. Minimum number of users recorded in this study was 3 and that belonged to sample 8. Free chlorine levels of these 7 samples were within the range of 1.00-1.50 mgL^{-1}, with the exception of samples 18 and 19. Free chlorine levels of these two samples (18 and 19) were 0.21 and 0.19 mgL^{-1}, respectively.

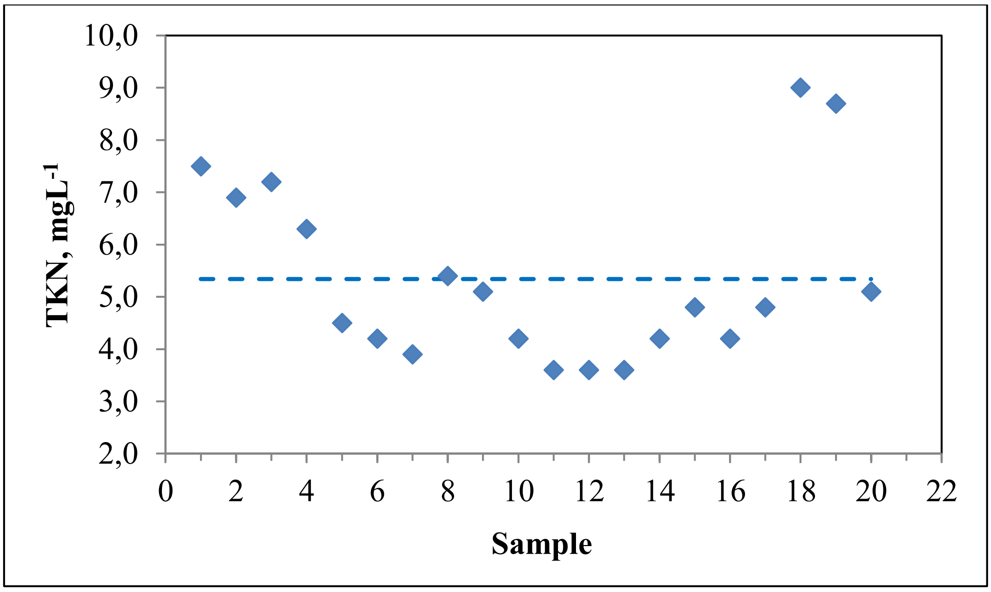

Figure 4.15. TKN variation in BUISPW.
(Dashed line indicates average level)

Kush and Hoadley investigated conditions in commercial whirlpool bath waters in Atlanta and surveyed populations of *P. aeruginosa.* Characteristics of waters were determined by temperature, pH, total residual chlorine, TOC, nitrogen (as TKN and ammonia) and most probable number of bacteria. The range of TKN was reported as 1.5-91.0 mgL^{-1}. The maximum value of TKN was higher than the value found in this study (9 mgL^{-1}) (Kush and Hoadley, 1980).

Fifteen chlorinated swimming pools in France were examined in terms of water and air quality conditions during eight sampling campaigns from June to November (Bessonneau et al., 2011). The researchers found minimum and maximum Kjeldahl Nitrogen values as 0.35 and 2.50 mgL^{-1}, respectively. 44% of their samples were below Limit of Quantification (LOQ of 0.48 mgL^{-1} and were therefore excluded. The geometric mean was then calculated as 0.60 mgL^{-1}. These results indicated low contamination of nitrogen containing compounds.

TKN consists of organic nitrogen and ammonia nitrogen (Tchobanoglous et al., 2004). Thus, Org-N in BUISPW was calculated and the variation of Org-N in the swimming pool water is given in Figure 4.16. As seen in Figure 4.16, the minimum and maximum Org-N levels were 3.22 and 8.61 mgL^{-1}, respectively. The average value was 5.04 mgL^{-1}. 65% of the results of this study were below and 35% above the average. The two highest Org-N levels of 8.61 mgL^{-1} and 8.46 mgL^{-1} were observed in samples 18 and 19, respectively. Presence of high organic nitrogen in pool water may be considered microbiological contamination under inadequate disinfection circumstances. Microbiological results of BUISPW are presented in Section 4.5 where this point is detailed.

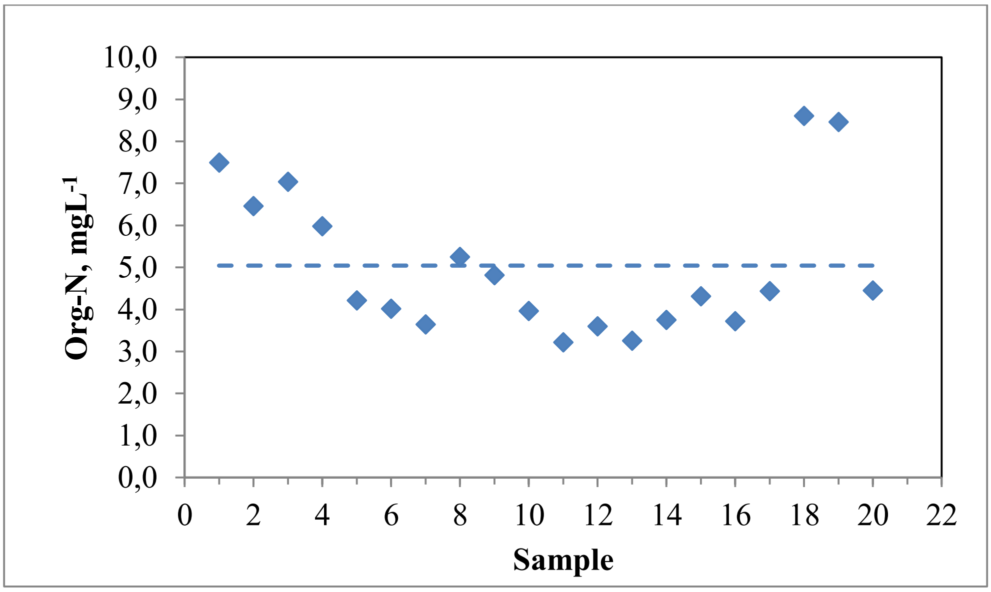

Figure 4.16. Organic nitrogen variation in BUISPW.
(Dashed line indicates average level)

Nitrogen contains compounds such as ammonia, uric acid, creatinine and amino acids, which are discharged into the swimming pool water by bathers (WHO, 2006). Urea, ammonia, amino acids and creatinine are nitrogen containing compounds in sweat and urine which are discharged into the pool by bathers and they react with disinfectants to form many unwanted by-products. Urine, an important anthropogenic excretion originating from bathers, is the main nitrate source. High nitrogen content come into the pool by means of urine at the amount of 25-30 mL per bather and can go up to 77.5 mL per bather according to WHO (WHO, 2006). Ammonia in water, which results from urine, reacts with chlorine and bromine to form chloramines and bromamines. According to WHO (2006), the mean urea and ammonia content in sweat is 680 mgL^{-1} and 180 mgL^{-1} whereas the mean urea and ammonia content in urine is 10 240 mgL^{-1} and 560 mgL^{-1}. Chloramines and bromamines, especially nitrogen trichloride and nitrogen tribromide, cause eye and respiratory irritation in pool users because they are volatile. The main means of exposure to these volatile compounds is inhalation and dermal absorption (WHO, 2006). Tissues, excretions and dirt are the main substances introduced to the pool by bathers. Sweat, urine, mucus from nose and chest, hair, fecal matter and skin flakes are main pollutants of pool water. 1L sweat, 1 billion skin flakes and 38g grease are produced by an adult every day.

According to PWTAG, a bather releases an average of 30 mL urine into the pool, which is about 200 mg of urea. Most bathers release an average of 950 mL sweat per hour, namely about 250 mg of urea in the pool. The reaction between disinfectant and the breakdown products of urea in urine and sweat result in chloramines and they cause eye and skin irritation. Some of these compounds produce irritant gas above the pool and have a negative impact on pool users and staff. Trihalomethanes are important chlorination by-products because they are volatile and found in the air above the pool area. Therefore, toilet use and pre-swim showering are crucial in preventing the release of pollutants into the pool (PWTAG, 2011).

In the presence of organic nitrogen in water, some strains of *Yersinia* spp. replicate, even in temperatures as low as 4ºC. *Yersinia* spp. is a member of *Enterobacteriaceae* which is Gram negative rods. Some strains of *Yersinia*, namely *Y. enterocolitica, Y. pestis* and *Y. pseudotuberculosis* are pathogens for humans. The cause of bubonic plague is *Y. pestis* whereas *Y. enterocolitica* causes ulceration of the terminal ilium. The major reservoir of Yersinia is animals. Meat and its products and milk and dairy products are main sources of Yersiniosis. However, ingestion of contaminated water also poses a risk of infection. However, these organisms are minimized with adequate disinfection practices and protection of water from waste originating from animals and humans (WHO, 2011). Not only in terms of chloramines but also bacteria and algae, urea is an important compound because it is a nutrient.

<u>4.4.6.6. Inorganic nitrogen.</u> The values of nitrite-nitrogen, nitrate-nitrogen and ammonia-nitrogen were combined to express total inorganic nitrogen value. Figure 4.17 shows inorganic nitrogen variations in the BUISPW samples. Minimum, maximum and average values of inorganic nitrogen in these samples are presented in Table 4.6.

As seen in Figure 4.17, nitrite–nitrogen was calculated for only one sample (sample 15) because the content of nitrite in BUISPW samples was below the detectable level of $5 \mu gL^{-1}$. Minimum, maximum and the average levels of nitrate-nitrogen were 0.980 mgL^{-1}, 2.47 mgL^{-1} and 1.36 mgL^{-1}, respectively. 65% of the samples were below the average. Minimum, maximum and the average levels of ammonia-nitrogen were 0.15 mgL^{-1}, 0.65 mgL^{-1} and 0.34 mgL^{-1} (Table 4.6). 50 % of the samples were below the average.

The minimum and maximum values of Total Inorg-N in BUISPW were 1.13 mgL^{-1} and 2.47 mgL^{-1} (Table 4.6). The average inorganic nitrogen level was 1.66 mgL^{-1}, with 45% of the samples falling below the average. Inorganic nitrogen variation is shown in Figure 4.17 and Figure 4.18.

<u>4.4.6.7. Total nitrogen.</u> Calculated minimum, maximum and average values of Total-N in BUISPW were 4.73 mgL^{-1}, 10.27 mgL^{-1} and 6.70 mgL^{-1}, respectively (Table 4.6). 65% of the results fell below the average while 35% were above the average. Figure 4.18 shows the total nitrogen variation.

Parinet and colleagues investigated levels of exposure levels to brominated compounds in eight seawater swimming pools treated with chlorine for disinfection purposes. Beside daily frequentation, they examined some physical and chemical parameters such as pH, conductivity, salinity, total residual chlorine, redox potential, dissolved oxygen, bromide, chloride, TOC, UV absorbance at 254 nm and total nitrogen (TN). The average values of TN in the eight pools ranged from 0.7 $mgNL^{-1}$ to 7.7 $mgNL^{-1}$ (Parinet et al., 2012). Although the pool water was seawater, the parameters displayed variation in correlation with the pool users rather than the source water characteristics. As can be observed in Figure 4.16, TN values in BUISPW were higher than those in the study mentioned. This difference between the values observed in these two studies may be a result of the pool chemicals used; quaternary ammonium compounds are used for algaecide in BUISPW.

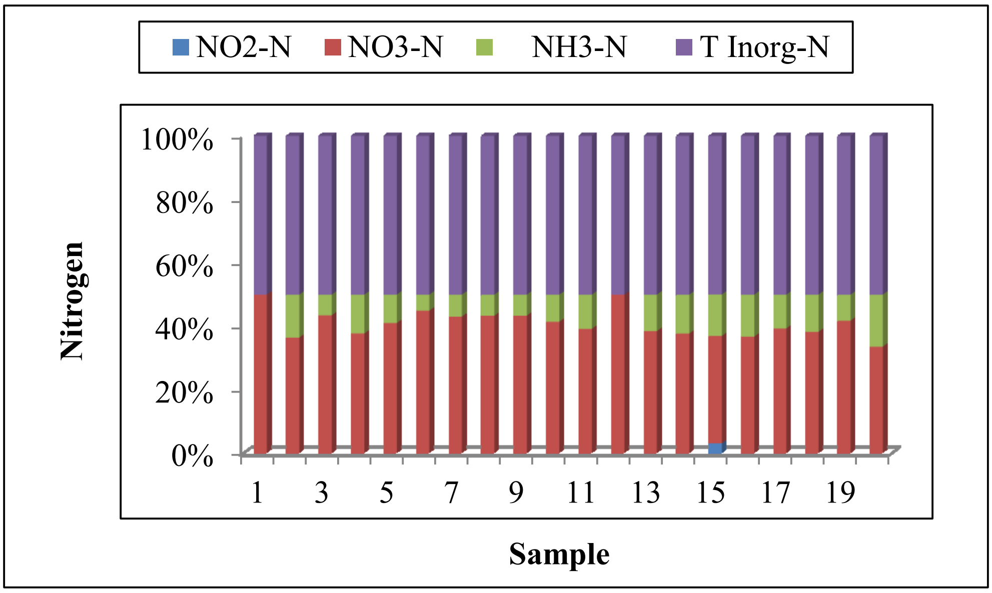

Figure 4.17. Inorganic nitrogen variation in BUISPW.

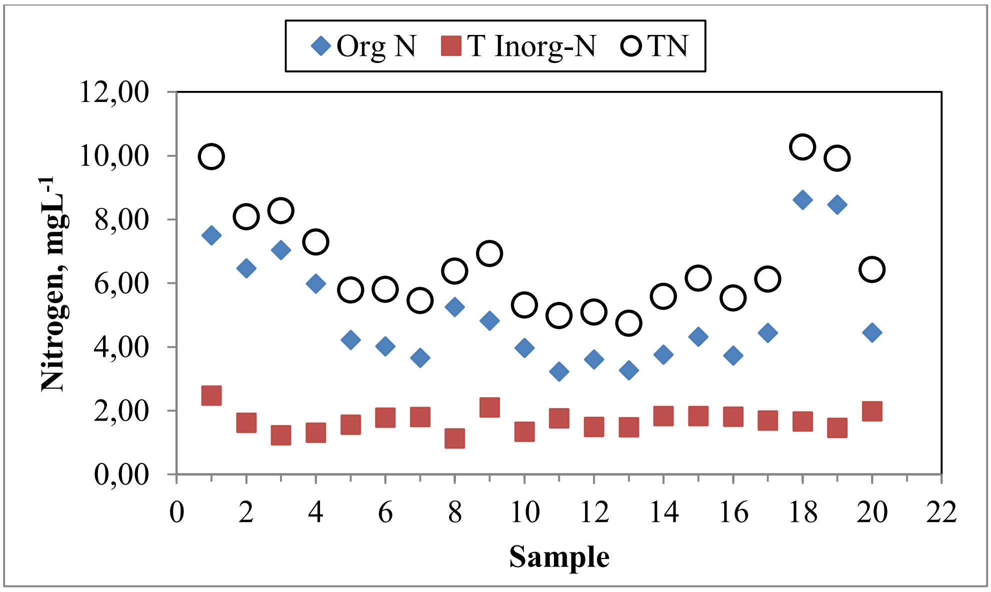

Figure 4.18. Total nitrogen, total inorganic nitrogen and organic nitrogen variations in BUISPW.

4.4.7. Metals

Copper, iron, aluminum, and manganese levels in BUISPW samples are determined by optical emission spectrometric method as presented in the Materials and Methods Section (section 3). The observed minimum, maximum and average levels of these metals are presented in Table 4.7.

Contaminant levels of metals in drinking water according to the regulations of European Union Council (98/83/EC), Turkish Standards Institution, Environmental Protection Agency and World Health Organization have been presented in Table 4.5 (EC Directive 98/83/EC, 1998; TS 266, 2005; USEPA, 2009; WHO, 2011). For simplicity purposes, copper, iron, aluminum and manganese are compiled in one figure and sample dependent distribution of their levels measured in this study are given in Figure 4.19.

Table 4.7. Minimum, maximum and average levels of metals.

Metals	Minimum	Maximum	Average
	mgL^{-1}		
Copper	0.001	0.018	0.004
Iron	0.025	0.223	0.117
Aluminum	0.067	0.129	0.094
Manganese	0.001	0.007	0.003

4.4.7.1. Copper. No trace of copper was found in the analyses of four samples (Figure 4.19). In the remaining 16 samples, the lowest copper level measured was 0.001 mgL^{-1} and the highest was 0.018 mgL^{-1}. The average level of copper was 0.0046 mgL^{-1} (including the 4 samples). 65% of the results were below the average.

The recommended upper limit for copper in pool water set by the Turkish Ministry of Health regulations is 1.0 mgL^{-1} (TMOH Regulation 28143, 2011). On the other hand, TS 11899, does not provide a standard level for copper in pool waters (TS 11899, 2007). No limit is set for copper by WHO for pool water (Table 2.8).

In general, pool water quality is expected to meet acceptable drinking water criteria. Level of copper in drinking water stipulated by the Turkish Standards Institution as well as by EPA, EU and WHO have been presented in Table 4.5. The average copper level of 0.0046 mgL^{-1} observed falls below the levels recommended for both drinking water and swimming pool water by Turkish Ministry of Health swimming pool regulations (TS 266, 2005; EC Directive 98/83/EC, 1998; USEPA, 2009; TMOH Regulation 28143, 2011).

Copper is an important drinking water contaminant. Copper corrosion in pipes results in green and blue staining of equipment, blue water and taste problems. A copper containing substance like copper sulfate pentahydrate may be used for algaecide in swimming pools. High level of this metal in the blood causes gastric irritation (WHO, 2011). Due to the redox chemistry, the presence of copper poses significant concern in swimming pool water quality.

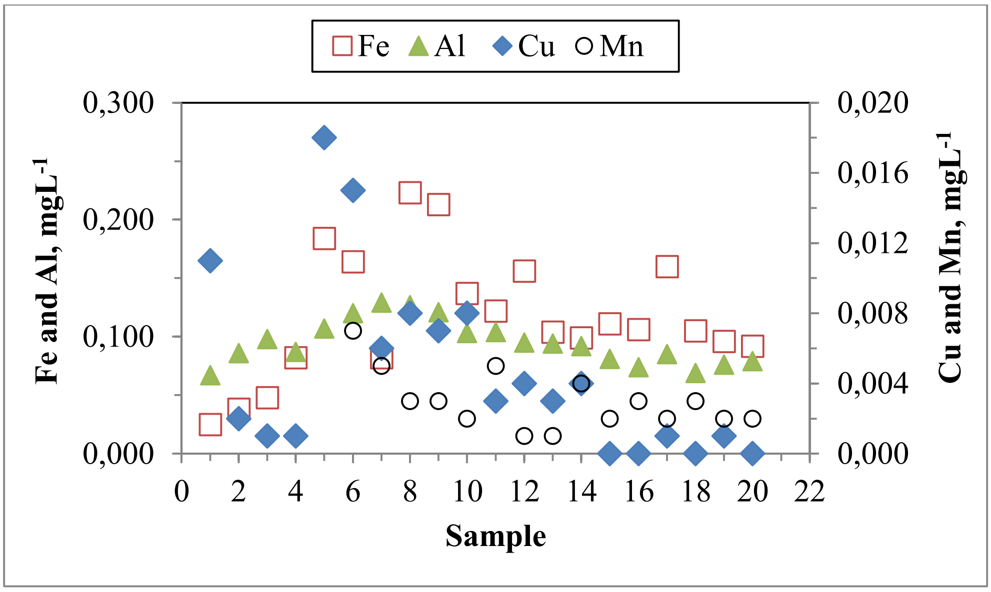

Figure 4.19. Variations of copper, iron, aluminum and manganese in BUISPW.

<u>4.4.7.2. Iron.</u> In comparison to the other metals, iron levels in BUISPW samples are found to be higher. Displaying a wider variation, maximum level of iron measured was 0.223 mgL^{-1}, the lowest level of iron was 0.025 mgL^{-1} giving an average of 0.117 mgL^{-1} (Table 4.7). 60% of the results fell below the average and 40% of the results were above the average.

Contaminant levels of iron in drinking water are shown in Table 4.5. Neither Turkish Ministry of Health nor Turkish Standards Institution has set standards for iron in pool water (TMOH Regulation 28143, 2011; TS 266, 2005). The average iron level in BUISPW was lower than the recommended minimum level of iron in drinking water. Iron variation in the BUISPW samples is presented in Figure 4.19.

Iron occurs naturally in the Earth's crust and in natural fresh waters. Ferrous iron in ground water under anaerobic conditions does not cause any turbidity or color problems. Oxidation of ferrous iron to ferric iron by exposure to air gives a reddish-brown color to water as indicated previously in Section 2.4. Furthermore, oxidation also leads to the growth of iron bacteria, which receive energy from this oxidation process and create a slimy coating on the distribution system (WHO, 2011). Excessive presence of iron is mainly related to the color of the swimming pool water. Furthermore, iron may also cause reddish-brown or black strains on swimsuits, ladders and pool surfaces. However, no such case has been reported by the pool management during the sampling period. Since no iron based coagulant/flocculant was used, the variations in iron content could only be attributed to the source water characteristics (Table 4.1).

4.4.7.3. Aluminum. As presented in Table 4.7, aluminum content of BUISPW samples ranged from a minimum value of 0.067 mgL^{-1} to a maximum value of 0.129 mgL^{-1}. The average for aluminum was 0.094 mgL^{-1}. 55% of the results were lower than or equal to the average and 45% were above the average. These results are also presented in Figure 4.19.

The Turkish Ministry of Health regulations stipulate the maximum aluminum level in swimming pool water as 0.2 mgL^{-1} (TMOH Regulation 28143, 2011) whereas EU, TS 266, EPA and WHO have specified standards for drinking water, but not for pool water (EC Directive 98/83/EC, 1998; TS 266, 2005; WHO, 2011). The average value of 0.094 mgL^{-1} falls below the mentioned pool and drinking water standards (Table 2.8 and Table 4.5). Main source of aluminum in water is aluminum salts that are used in water treatment processes as coagulants to decrease turbidity, color, organic matter and microbiological contamination. Color and turbidity problems originate from high residual level of aluminum (WHO, 2011). Moreover, source water characteristics displayed aluminum variation as < 0.05-0.07 mgL^{-1} (Table 4.1).

4.4.7.4. Manganese. Like other metals, manganese level in the swimming pool water was analyzed and minimum, maximum and average levels were recorded as, 0.001 mgL^{-1}, 0.007 mgL^{-1} and 0.003 mgL^{-1}, respectively. 73% of the samples were found to be lower than or equal to the average. Only 23% of the samples displayed values above the average. Variations in manganese levels in BUISPW samples are presented in Figure 4.19.

TSI, Turkish Ministry of Health, or WHO do not offer any recommendations regarding manganese levels in pool water (TS 11899, 2007; TMOH Regulation 28143, 2011). The results of this study are lower than the standards set for drinking water, as seen in Table 4.5. Manganese is a common metal in the Earth's crust. Manganese exists naturally in potable water. It is also important for some processes like bleaching, disinfection and cleaning; manganese greensand is used in drinking water treatment. Manganese causes black deposits in water bodies, taste problems and staining in the laundry and sanitary ware (WHO, 2011). Moreover, source water characteristics displayed manganese content as <0.02 mgL^{-1} throughout the sampling period (Table 4.1).

4.4.8. Organic content

Parameters used to determine the organic content of the BUISPW were Tot C, TOC, DOC, NPOC, VOC and IC. The minimum, maximum and average values of Tot C, DOC, NPOC, oxidizability, VOC and IC observed in BUISPW are shown in Table 4.8.

Table 4.8. Minimum, maximum and average values of Tot C, DOC, NPOC, VOC, oxidizability, and IC.

	Minimum	**Maximum**	**Average**
Tot C, mg CL^{-1}	9.571	20.63	16.54
Organic Carbon			
DOC, mg $OrgCL^{-1}$	8.258	20.31	15.78
NPOC, mg $OrgCL^{-1}$	8.299	11.98	10.45
VOC, mg $OrgCL^{-1}$	0.00	8.33	5.33
Oxidizability, mgL^{-1}	7.16	14.20	10.55
Inorganic carbon			
IC, mg CL^{-1}	0.1903	4.895	0.7737

Figure 4.20 shows Tot C, DOC and IC variations in BUISPW. Minimum and maximum Tot C in BUISPW samples were 9.571 mgL^{-1} and 20.63 mgL^{-1} , respectively, with an average of 16.54 ± 2.72 mgL^{-1} (Table 4.11). 40% of Tot C results were below the average of 16.54± 2.72 mgL^{-1} (Figure 4.20). DOC values ranged from a minimum of 8.258 mgL^{-1} to a maximum of 20.31 mgL^{-1}. The average for DOC was 15.78 ± 2.74 mgL^{-1} (Table 4.8). DOC values of 50% of the samples were lower than the average (Figure 4.20). Minimum, maximum and average levels of NPOC in the samples were 8.299 mgL^{-1}, 11.980 mgL^{-1} and 10.45± 1.12 mgL^{-1}, respectively (Table 4.8). 40% of NPOC results were below the average. Minimum, maximum and average VOC in the pool water were 0.00 mgL^{-1}, 8.33 mgL^{-1} and 5.33 ± 2.02 mgL^{-1} (Table 4.8). IC recorded in this study ranged from a minimum value of 0.1903 mgL^{-1} to a maximum value of 4.895 mgL^{-1}. The average for IC was 0.7737 ±1.41 mgL^{-1} (Table 4.8). 85 % of the samples were below the average. Only three of the results (samples 3, 14 and 16) were above the average, and they had the highest IC values with 1.313, 4.785 and 4.895 mgL^{-1}, respectively. However, DOC values of these three samples were lower than the rest (Figure 4.20).

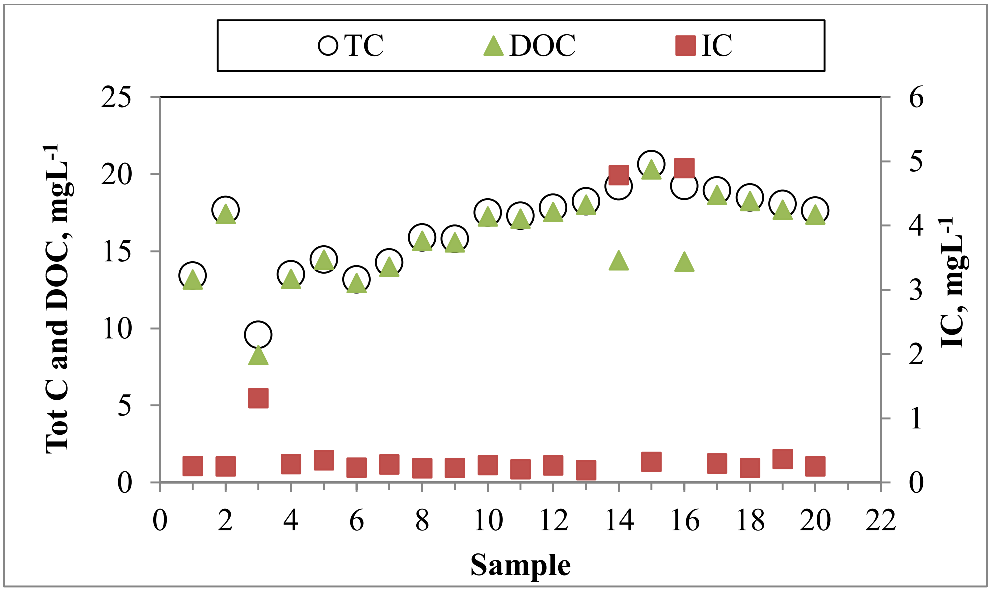

Figure 4.20. Tot C, DOC and IC variations in BUISPW.

A recommended value for organic carbon in swimming pool water is not mentioned in the standards of TSI, regulations of Turkish Ministry of Health or WHO Guidelines (Table 2.8). Furthermore, this parameter was not mentioned in ISKI Water Quality Reports for properties of finished water processed in Kağıthane Water Treatment Plant that will constitute the incoming water to the BUISP during the sampling period (Table 4.1). However, in terms of organic content of drinking water, TS 266 has one criterion for total organic carbon value, which is "noticeable change should not be observed" (Table 2.8).

Figure 4.21 shows DOC, NPOC and VOC contents of the samples taken from BUISP. The relationship between DOC and VOC is based on the formula DOC=VOC+NPOC. NPOC is used to analyze drinking and surface water. Because of the low particulate organic matter (POM) content that can be disregarded in drinking water, NPOC is often regarded as the equivalent of TOC (Ghabbour and Davies, 2001). VOC was not detected in one sample (sample 3). As a consequence, DOC value of this sample was close to its NPOC value. VOC range of the remaining samples was 2.85-8.33 mgL^{-1}. The highest DOC and VOC values were obtained in sample 15. Sample number 15 was also the only sample where nitrite could be measured, and it was 0.349 mgL^{-1}. To understand the significance of the case, the experimental data for the day sample 15 was collected was reviewed and some remarkable points were observed. Tot C, IC, DOC, NPOC and VOC amounts of sample 15 were determined as 20.63 mgL^{-1}, 0.3198 mgL^{-1}, 20.31 mgL^{-1}, 11.980 mgL^{-1} and 8.33 mgL^{-1}. The Tot C, DOC and VOC results were the highest in this study (Figure 4.20 and Figure 4.21).

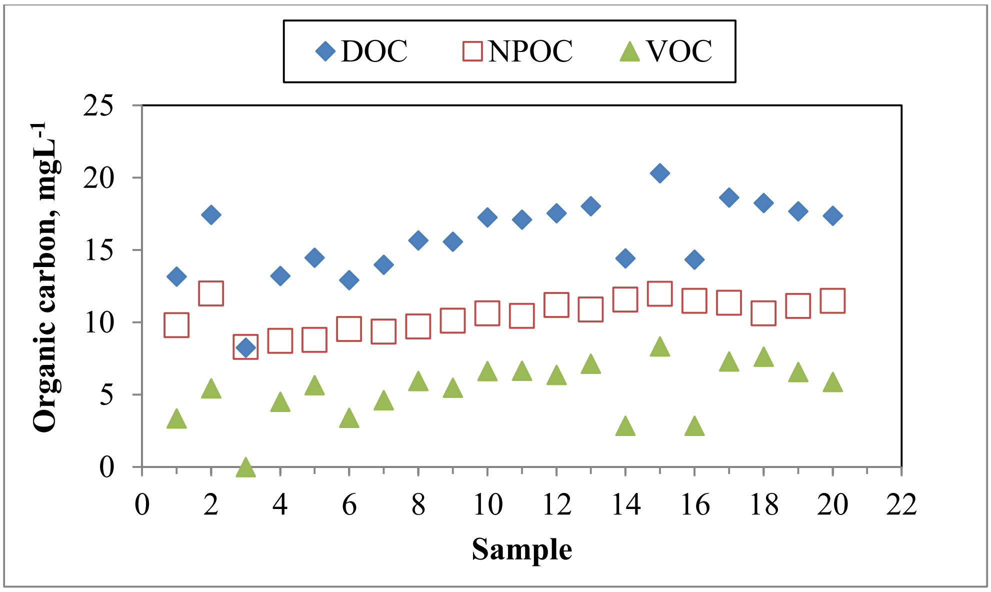

Figure 4.21. DOC, NPOC and VOC variations in BUISPW.

Organic nitrogen and ammonia nitrogen exist in recently polluted waters. In time, organic nitrogen is converted to ammonia nitrogen and then, in the presence of aerobic conditions, ammonia is oxidized to nitrite and nitrate (Sawyer et al., 2003). The existence of nitrite in sample 15 indicates the presence of organic contamination on that particular day. In addition, NPOC values in this study displayed consistency, except for samples 1 and 2 (Figure 4.21). Organic matter may be a food source for bacteria. This point will be considered in Section 4.5.

4.4.9. Oxidizability

Oxidizability is determined by potassium permanganate consumption in mgL^{-1}. Potassium permanganate acts as an oxidizing agent used to determine organic compounds in water with a major drawback of being reactive towards inorganic water constituents. However, the method is applicable to water samples with a chloride content < 300 mgL^{-1} (Rump and Krist, 1992). Minimum, maximum, and average potassium permanganate consumption in BUISPW samples were 7.16 mgL^{-1}, 14.20 mgL^{-1} and 10.55 ± 2.44 mgL^{-1}, respectively (Table 4.8). Figure 4.22 shows oxidizability variations in BUISPW samples.

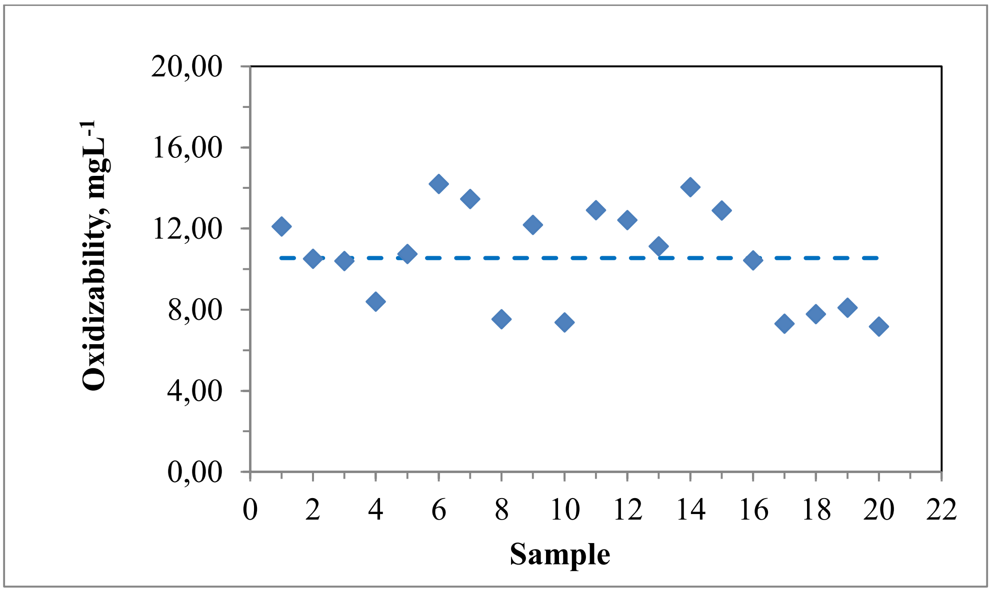

Figure 4.22. Oxidizability variations in BUISPW.

(Dashed line indicates average level)

There is no recommended limit for oxidizability of pool water in the Ministry of Health regulations (TMOH Regulation 28143, 2011). However, the Turkish Standards Institution has two recommended maximum limits for swimming pool water. Oxidizability value through reduction of Mn (7+) into Mn (+2) in terms of oxygen value of filling water should be 0.75 mgL^{-1}; potassium permanganate in filling water is given as 3 mgL^{-1} (TS 11899, 2007). Taking into consideration the recommended value of 3 mgL^{-1} provided by TSI for the maximum potassium permanganate consumption, the maximum value determined in this study as 14.20 mgL^{-1} could be regarded as very high.

According to EU Council Directive, the parametric value of oxidizability used for the quality of water intended for human consumption is 5.0 mgO_2L^{-1} (EC Directive 98/83/EC, 1998). However, TS 266 regarding water intended for human consumption does not offer any information on oxidizability value (TS 266, 2005).

Being parameters representing organic matter content, DOC, NPOC and oxidizability variations in BUISPW are compiled and presented in Figure 4.23 for comparison purposes. No significant correlation between DOC and potassium permanganate consumption or NPOC and potassium permanganate consumption could be visualized. It should be also be mentioned that oxidizability method is prone to various interferences as indicated above.

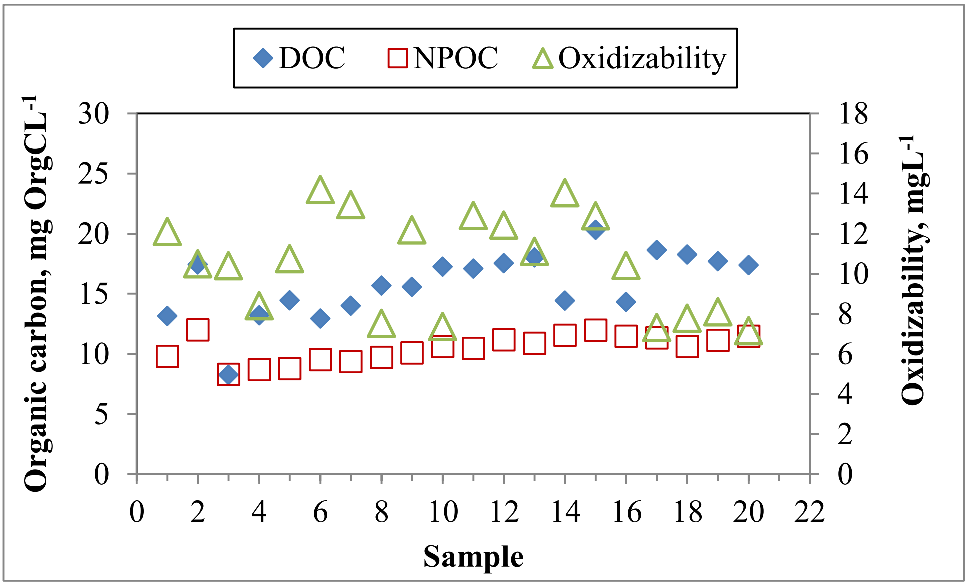

Figure 4.23. DOC, NPOC and oxidizability variations in BUISPW.

The reaction between chlorine, bromide and organic matter results in THMs. THMs are the most common DBPs and they are potential carcinogenic compounds. Temperature, pH, time, bromide and iodide concentration, chlorine dose and type, as well as characteristics and concentration of precursors affect THM formation (Symons et al., 1981; Nikolaou et al., 2007). TOC and UV_{254} absorbance are crucial parameters in the prediction of THMFP in water samples (Uyguner et al., 2007). TOC concentrations in swimming pools reported in various studies are detailed below.

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Chu and Nieuwenhuijse analyzed 44 pool water samples collected from eight indoor swimming pools in London for TOC and THMs. They reported minimum, maximum and average TOC concentration in these pools as 3.3 mgL^{-1}, 12.9 mgL^{-1} and 6.3 mgL^{-1}, respectively. They collected information on the number of people in the pool as well as temperature (water and air), pH, and turbulence during the sampling period. Minimum, maximum and average number of people in the pool is reported as 1, 16 and 7, respectively. The researchers reported that high THM concentration correlated with TOC, water temperature and the number of people in the pool (Chu and Nieuwenhuijse, 2002).

Another research conducted in France using samples from fifteen swimming pools determined minimum and maximum TOC levels as 1.80 mgL^{-1} and 7.30 mgL^{-1}, respectively (Bessonneau et al., 2011). In a further study, the mean TOC concentration of fifty municipal indoor swimming pools located in Poitiers, France was reported as 3.5 $mgCL^{-1}$ (De Laat et al., 2011).

A recent study investigated 54 municipal public pools (15 indoor and 39 outdoors) in Quebec City, Canada. Minimum, maximum and average TOC levels in the indoor swimming pools were reported as 2.16 mgL^{-1}, 8.69 mgL^{-1} and 4.53 mgL^{-1} whereas these values for the outdoor swimming pools were 2.40 mgL^{-1}, 16.70 mgL^{-1} and 8.40 mgL^{-1}, respectively (Simard et al., 2013). Parinet and colleagues reported TOC values in the range of 2.8 $mgCL^{-1}$ to 8.6 $mgCL^{-1}$ in eight indoor pools located in France but unlike the studies above, their pools were filled with seawater (Parinet et al., 2012). TOC levels were reported to be higher than the TOC levels in seawater supplying the pools. The reason was attributed to the presence of organic matter brought in by users.

Seredyńska-Sobecka and colleagues investigated two pools — one warm water pool and one cold water pool — in terms of water quality and organic contamination by fluorescence excitation emission matrix with parallel factor analysis (PARAFAC). They reported values of non-volatile organic carbon in the warm water pool ranging from 2.2 $mgCL^{-1}$ to 3.2 $mgCL^{-1}$ and in the cold water pool from 1.8 $mgCL^{-1}$ to 1.9 $mgCL^{-1}$ (Seredyńska-Sobecka et al., 2011).

In BUISPW samples, minimum, maximum and average values of non-volatile organic carbon were calculated as 8.258 mg $OrgCL^{-1}$, 11.98 mg $OrgCL^{-1}$ and 10.45 mg $OrgCL^{-1}$, respectively. Compared with the values observed in the study above, the values obtained in BUISPW were high.

Lee and colleagues examined 183 indoor swimming pools in Korea for THM production and associated health risk assessment. Seventy two of those pools were treated with chlorine, 86 with ozone/chlorine and 25 with EGMOs. In the pools that were treated with chlorine, the TOC range reported was 0.25-70.6 mgL^{-1}. TOC range in pools treated with ozone/chlorine was 0.25-82.3 mgL^{-1} in; and in those treated with EGMOs it was 0.43-12.3 mgL^{-1}. The average values of TOC in filtered samples taken from these three types of pools were 4.4 mgL^{-1}, 3.7 mgL^{-1} and 3.5 mgL^{-1}, respectively. The researchers also reported potassium permanganate consumption in filtered samples collected from pools treated with chlorine in the range of 0.5 mgL^{-1} to 10.2 mgL^{-1}, with an average of 4 mgL^{-1}. Filtered samples from pools treated with ozone/chlorine had a range of 0.3 mgL^{-1} to 16.0 mgL^{-1}, with an average of 3.5 mgL^{-1}; the range in pools treated with EGMOs was 1.7 mgL^{-1} to 14.5 mgL^{-1} with an average of 7.7 mgL^{-1} (Lee et al., 2009).

TOC studies mentioned above gave no information about filtration of samples (Chu and Nieuwenhuijse, 2002; Bessonneau et al., 2011; De Laat et al., 2011; Simard et al., 2013; Parinet et al., 2012; Seredyńska-Sobecka et al., 2011). However, Lee and colleagues analyzed filtered samples and reported TOC ranges of 0.25-70.6 mgL^{-1} in pools treated with chlorine, which were higher than the levels reported in other studies (Lee et al., 2009). Like the samples of Lee and co-workers, BUISPW samples were filtered and high DOC values were obtained: minimum 8.258 mg $OrgCL^{-1}$, maximum 20.31 mg $OrgCL^{-1}$, and an average of 15.78 mg $OrgCL^{-1}$. The difference between the results may be due to the use of filtration in the samples. Lee and colleagues reported the range of potassium permanganate consumption as 0.5 mgL^{-1} to 10.2 mgL^{-1}, with an average of 4.0 mgL^{-1} in filtered samples collected from pools treated with chlorine. Potassium permanganate consumption in non-filtered samples from BUISPW were higher than the study of Lee and colleagues (Table 4.8) (Lee et al., 2009).

BU indoor swimming pool was filled with drinking water from Kağıthane Treatment Plant, which receives raw water from Terkos and Alibeykoy reservoirs. Ates and colleagues reported the annual average DOC of raw water from Terkos and Alibeykoy reservoirs in 2004. The DOC values for these two reservoirs were 3.85 mgL^{-1} and 4.29 mgL^{-1}, respectively (Ates et al., 2007). Suphandag and colleagues examined tap waters coming from different reservoirs supplying water for Istanbul and they reported minimum, maximum and average values of DOC as 1.86 mg CL^{-1}, 3.66 mg CL^{-1} and 2.55 mg CL^{-1}, respectively (Suphandag et al., 2007).

Two publications that focus on water processed in the Kağıthane Treatment Plant give information about the quality of water delivered to the water distribution system. Uyak and colleagues in their study on monitoring and modeling of trihalomethanes (THMs) at Kağıthane Treatment Plant (Çelebi Mehmet Han) in Istanbul used temperature, pH, alkalinity, chlorine level, TOC, UV_{254} and THM as raw and processed water quality parameters in 120 samples during a 12-month sampling program in 2003. They reported the minimum, maximum and average TOC as 4.20 mgL^{-1}, 6.20 mgL^{-1} and 4.86 mgL^{-1}, respectively. Although filtration through 0.45µm filter is a crucial step in determining and expressing the organic content, no information was given about sample filtration (Uyak et al., 2005). In the publication of Kitis and colleagues, characteristics of raw water from Kağıthane Treatment Plant were presented in terms of pH, alkalinity, turbidity, conductivity, TDS, total hardness, DOC, UV_{254} and $SUVA_{254}$. They reported DOC average as 2.8 mgL^{-1} in their samples (Kitis et al., 2007). Since DOC was reported, samples were subjected to the filtration prior to the analysis.

Furthermore, possibility of a correlation between TKN and DOC was investigated (Figure 4.24). The source of TKN as organic nitrogen might be related to the presence of

DOC either coming from source water or introduced to the pool water by users. As depicted in Figure 4.24, no significant relationship could be visualized.

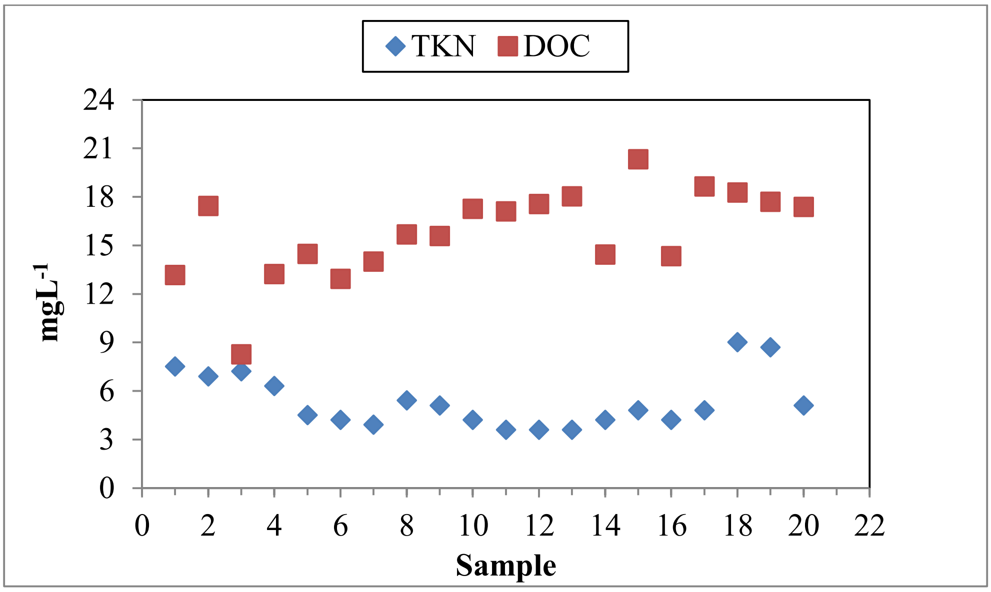

Figure.4.24. TKN and DOC variations in BUISPW.

Moreover, the presence of IC could also be related to conductivity. As presented by Figure 4. 2, no correlation could be assessed.

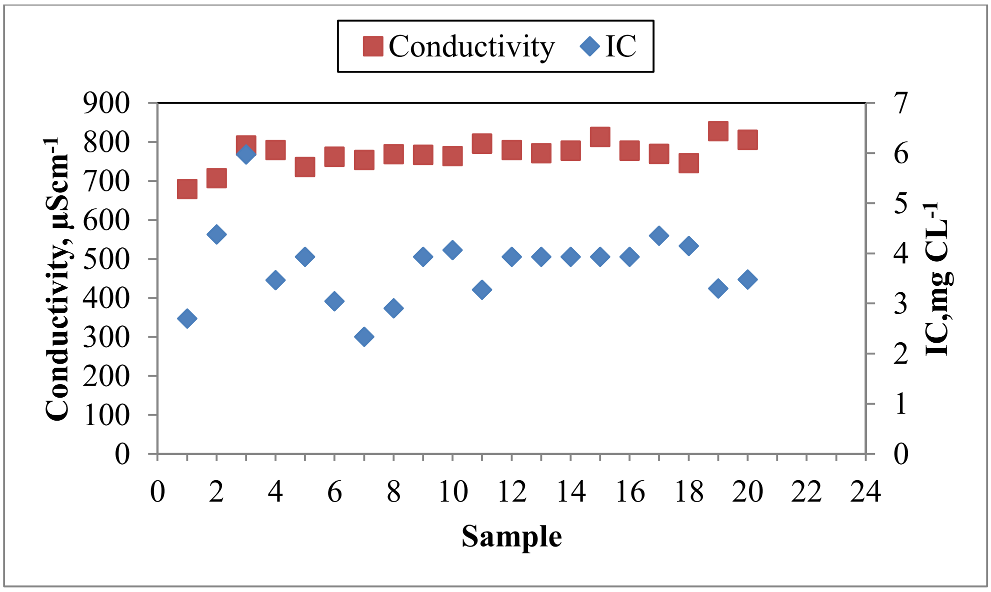

Figure.4.25. Conductivity and IC variations in BUISPW.

4.4.10. Spectroscopic parameters

Characterization and specification of organic matter in the pool water were determined by UV-vis absorption and fluorescence spectra. Instruments and methods used were presented in the previous Methodology section.

4.4.10.1. Characterization of organic content by UV-vis absorption spectral features

UV-vis absorption spectra of the BUSPW samples were recorded in the wavelength range of 200-600 nm. Specified absorbance values measured at wavelengths 254 nm, 280 nm, 365 nm and 436 nm were assessed as UV-vis parameters designated as UV_{254}, UV_{280}, UV_{365}, and $Color_{436}$ as indicated previously. UV-vis absorbance spectra of the samples are presented in Figure 4.26. Since no substantial absorbance values were recorded at wavelengths longer than 450 nm, the wavelength range was selected as 200-450 nm in Figure 4.26.

UV-vis spectra of the samples expressed a logarithmic declining trend as generally observed for humic substances (Uyguner and Bekbolet, 2005). Samples 1 and 5 displayed a peak in wavelength region 200-230 nm beyond which decreasing profile could also be visualized. It should also be indicated that inorganic constituents, mainly nitrate, could significantly affect the UV-vis absorbance spectrum in 200-300 nm wavelength region. Moreover, all of the spectra displayed an overlapping behavior in the wavelength region of 250-450 nm, representing minor changes in the respective UV-vis parameters. Based on the UV-vis spectral features, sample dependent variations of the specified UV-vis spectral parameters of pool water samples are given in Figure 4.27. Since nitrate mainly displays absorbance at wavelength λ=220 nm, in the presence of organic matter a nitrate concentration equivalent correction with respect to the absorbance measured at λ=275 nm could be made for the elucidation of the contribution of nitrate absorbance to the UV-vis spectrum. The presence of nitrite could also interfere; however, non-existence of nitrite excludes this interference (Table 4.6). However, the samples did not reveal any linear correlation (R^2<0.30) between the nitrate concentration and $UV_{220corr}$ (UV_{220}-UV_{275}) expressing the possible contribution of UV absorbing other species present in the pool water samples.

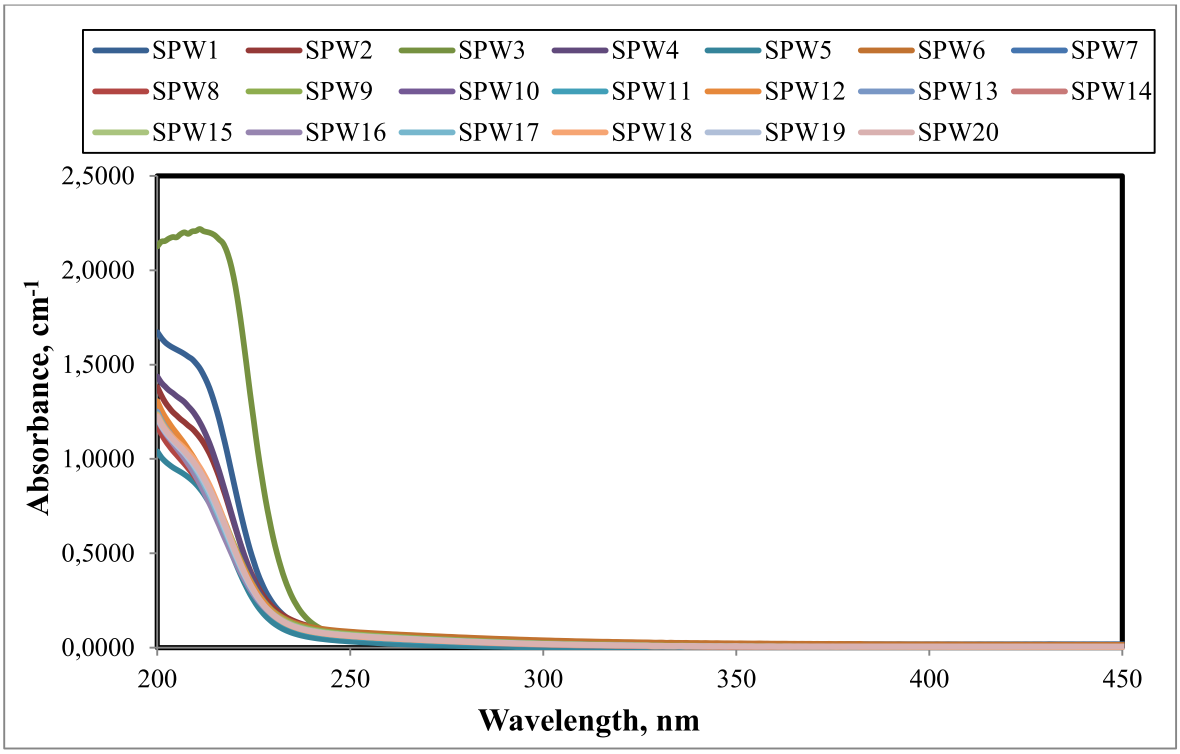

Figure 4.26. UV-vis scan absorbance spectra of BUISPW samples.

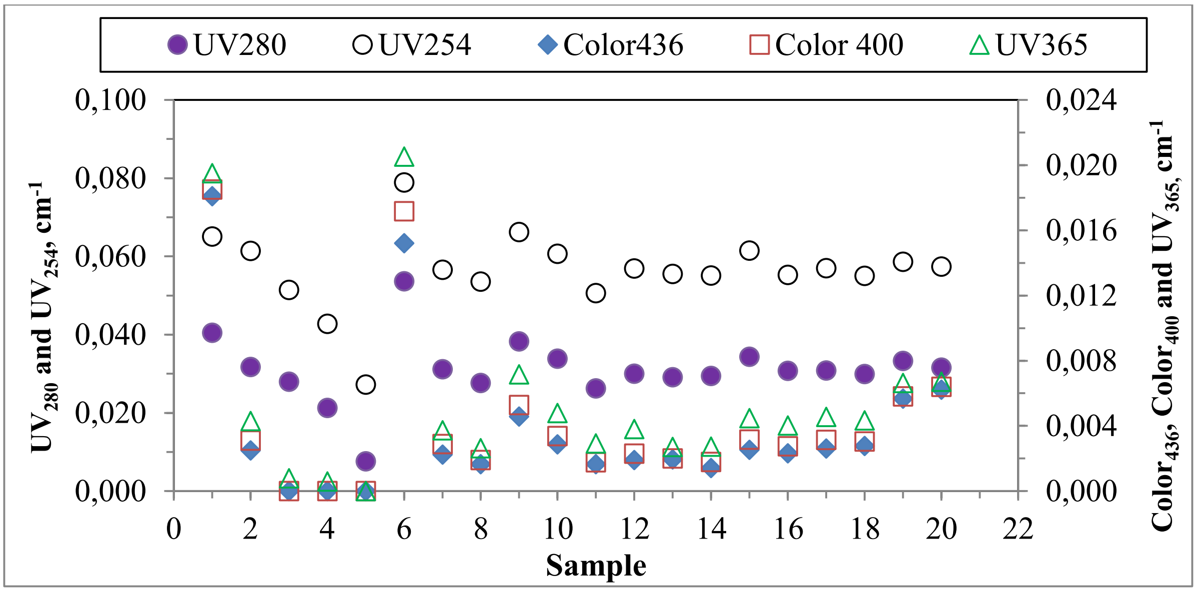

Figure 4.27. Specific UV-vis spectral parameters of BUISPW samples.

Moreover, since the UV-vis spectral features are directly related to the chemical and compositional characteristics of the organic matrix present in the samples, further evaluations are based on the organic matter contents (DOC and/or NPOC). Since no significant variations could be assessed for the specified parameter as $Color_{400}$ and $Color_{436}$, only UV_{254}, UV_{280} and UV_{365} parameters were considered. Specific UV-vis spectral parameters (UV_{254}, UV_{280} and UV_{365}), DOC and NPOC of the pool water are given in Figure 4.28.

As indicated previously, dependence of the UV-vis parameters on the organic carbon contents reveals the significance of the specific UV-vis parameters (DOC normalized UV-vis parameters, $m^{-1}mg^{-1}L$) as $SUVA_{254}$, $SUVA_{280}$, $SUVA_{365}$. $SCoA_{400}$ and $SCoA_{436}$. Thus, minimum, maximum and average values of spectral parameters and specific UV-vis parameters are presented in Table 4.9. It should also be mentioned that both $Color_{400}$ and $Color_{436}$ parameters as well as their respective $SCoA_{400}$ and $SCoA_{436}$ values could be used interchangeably to indicate the color of the water samples.

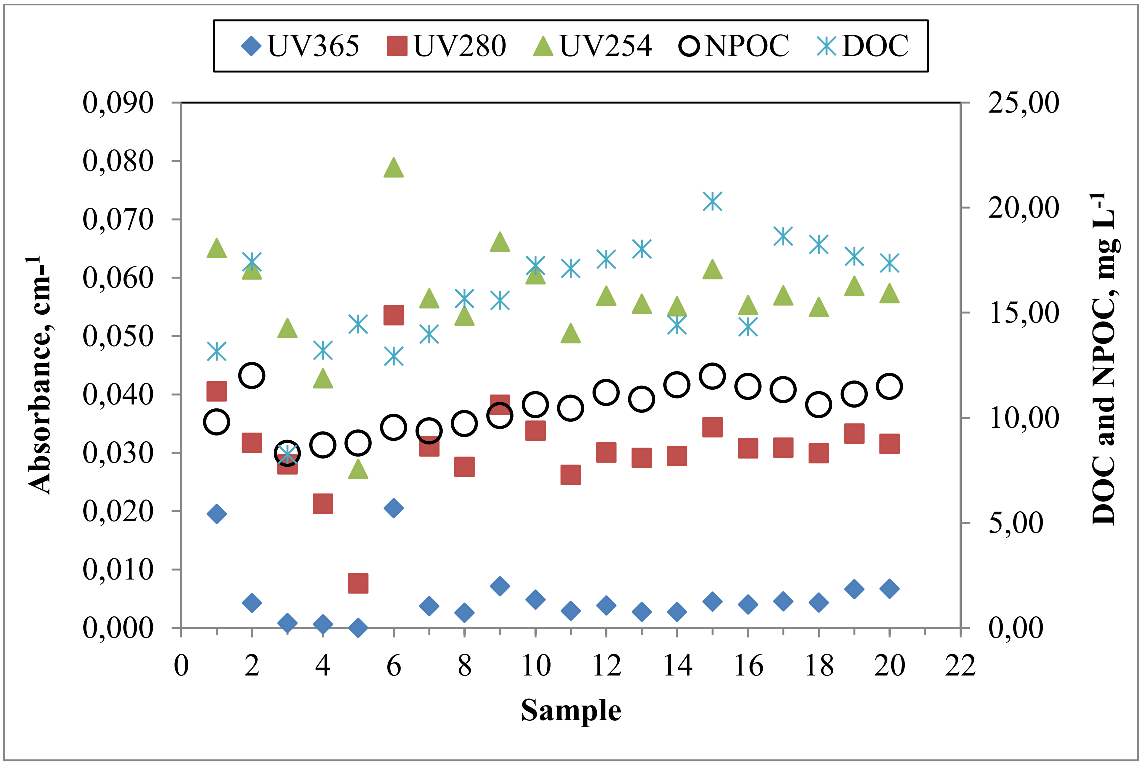

Figure 4.28. Specific UV-vis parameters, DOC and NPOC of BUISPW samples.

Table 4.9. Minimum, maximum and average values of the specified and specific UV-vis parameters of BUISPW samples.

Specified UV-vis parameters, m^{-1}					
	UV_{254}	UV_{280}	UV_{365}	$Color_{400}$	$Color_{436}$
Minimum	2.73	0.762	0.00	0.00	0.00
Maximum	7.89	5.36	2.05	1.81	1.85
Average	5.63	3.10	0.532	0.385	0.423
Specific UV-vis parameters, $m^{-1}mg^{-1}L$					
	$SUVA_{254}$	$SUVA_{280}$	$SUVA_{365}$	$SCoA_{400}$	$SCoA_{436}$
Minimum	0.188	0.0526	0.00	0.00	0.00
Maximum	0.622	0.415	0.159	0.141	0.138
Average	0.369	0.204	0.0355	0.0281	0.0254

Absorption in the near UV wavelength region of 200-380 nm is generally due to the presence of conjugated aromatic systems (Weishaar et al., 2003). Therefore, specified UV-vis parameters could express the presence of organic matter mainly composed of aromatic sub-units as expected for the humic material present in the pool water. It is widely accepted that $SUVA_{254} < 2$ indicated the presence of organic matter more aliphatic in nature, as non-humics, low hydrophobicity, low molecular weight (Edzwald and Tobiason, 1999). Since all of the water samples exhibited $SUVA_{254}$ even <1, contribution from natural organic matter mainly composed of humic substances present in incoming water could be considered as insignificant.

4.4.10.2. Characterization of organic content by fluorescence spectral features

In addition to UV-vis absorbance spectroscopic properties of BUISPW samples, fluorescence spectroscopic properties of are also determined. Two types of fluorescence spectra, emission scan and synchronous scan fluorescence spectra were measured by Perkin Elmer LS 55 Luminescence Spectrometer as explained in the Materials and Methods section.

Emission scan fluorescence spectra were acquired in the emission wavelength range of 360-600 nm and 380-600 nm at 350 and 370 excitation wavelengths, respectively. Comparison with the previously reported research findings on the emission scan fluorescence spectral features of various humic substances indicated the possible use of both excitation wavelengths (Uyguner et al., 2007). The emission fluorescence spectra of the pool water are presented in Figure 4.29 and Figure 4.30. It should be indicated that emission scan fluorescence spectral features of the BUISPW samples expressed an almost similar trend with a broad peak formation at around λ_{emis}=450 nm irrespective of the excitation wavelength as λ= 350 nm and λ=370. BUISP water sample 5 expressed a rather different emission spectrum in the emission wavelength of λ< 380 nm and λ <400 nm for excitation wavelengths of λ= 350 nm and λ=370 nm respectively. The maximum fluorescence intensity was recorded for Sample 1 as FI=9.3 at λ_{exc}=350 nm and λ_{emis}=450 nm whereas as FI=5.8 at λ_{exc}=370 nm and λ_{emis}=440 nm. From a general perspective emission scan fluorescence spectral features could not be regarded as discriminative between samples due to overlapping rather broad peak formation. It should also be indicated that the recorded FI variations in the emission wavelength of 350 nm-570 nm could only resemble a humic acid solution < 5 mgL^{-1} (NPOC~3.5 mgL^{-1}) whereas samples displayed NPOC range of 8.29-11.98 mgl^{-1} with an average of 10.45 mgl^{-1} (Table 4.8).

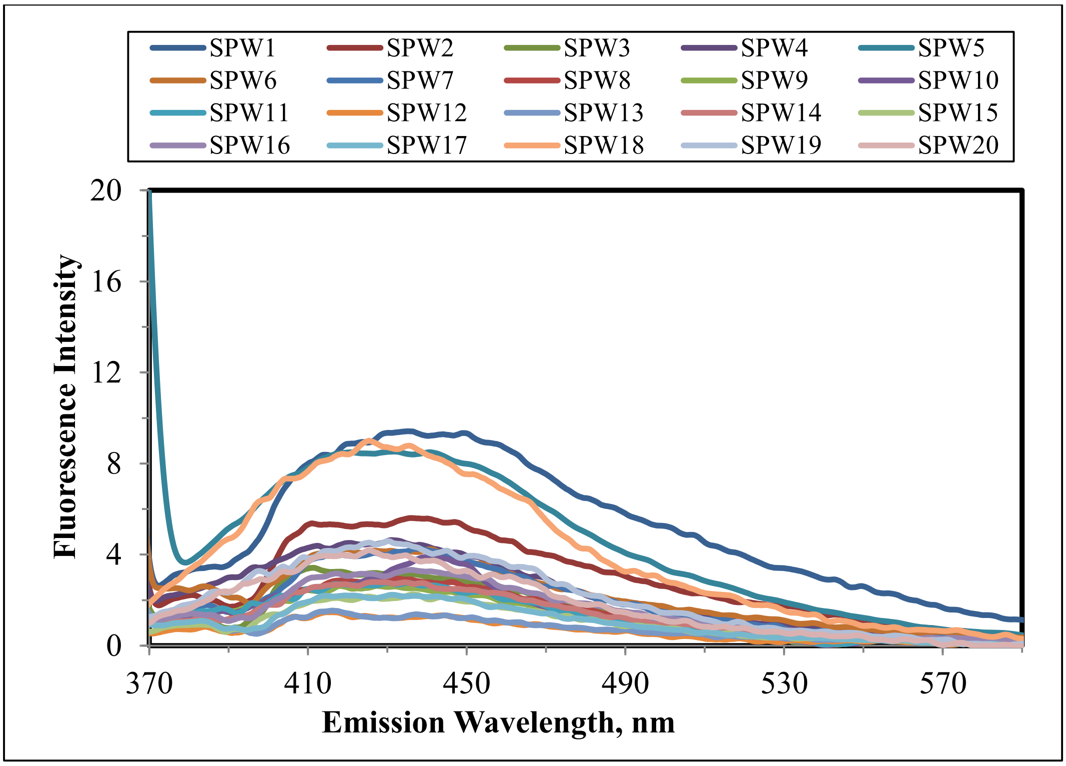

Figure 4.29. Emission scan fluorescence spectra of BUISPW samples at λ_{exc}=350 nm.

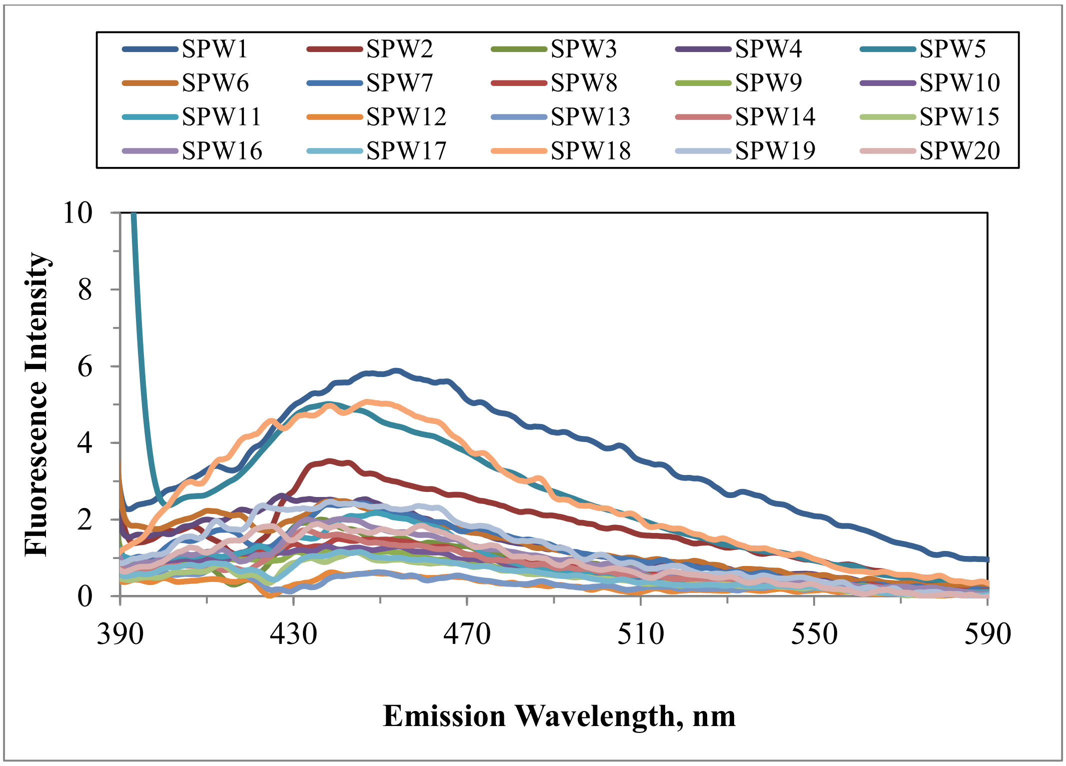

Figure 4.30. Emission scan fluorescence spectra of BUISPW samples at λ_{exc}=370 nm.

Synchronous scan fluorescence spectra were scanned in the 200-600 nm with the bandwith of $\Delta\lambda$=18 nm (Figure 4.31). Samples showed a rather sharp peak around emission wavelength region of 360 nm-430 nm. Some sample dependent minor peaks were also detected in longer wavelength region of 400 nm-500 nm. The maximum synchronous scan fluorescence intensity as FI=49 was recorded for Sample 5 and a minimum FI was recorded as 0.35 for sample 15 at emission wavelength of λ_{emis}=380 nm. Variations in FI_{syn} could resemble a humic acid solution of < 5 mgL^{-1} as was also observed in emission scan fluorescence spectra (Figure 4.29 and Figure 4.30) (Uyguner and Bekbolet, 2005). Since all the samples expressed a peak formation at λ_{emis}=380 nm, NPOC normalized specific fluorescence intensity (SFI_{syn}) values were calculated. NPOC dependent FI values and respective specific fluorescence values (SFI_{syn}) are presented in a comparative manner (Figure 4.32). NPOC distribution profiles of both FI_{syn} and SFI_{syn} values demonstrated that synchronous scan fluorescence intensity values could well be used as an indicator parameter for NPOC contents of the swimming pool waters that is organic matter in the presence of various chemical compounds as well as microbiological species.

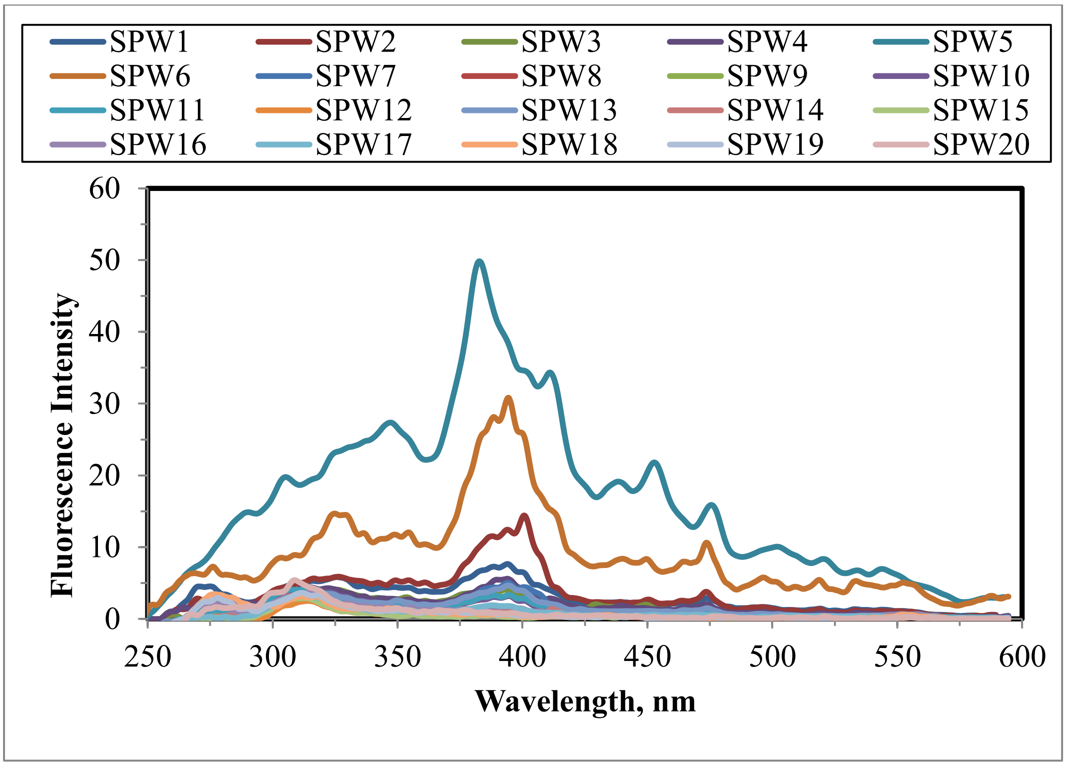

Figure 4.31. Synchronous scan fluorescence spectra of BUISPW samples.

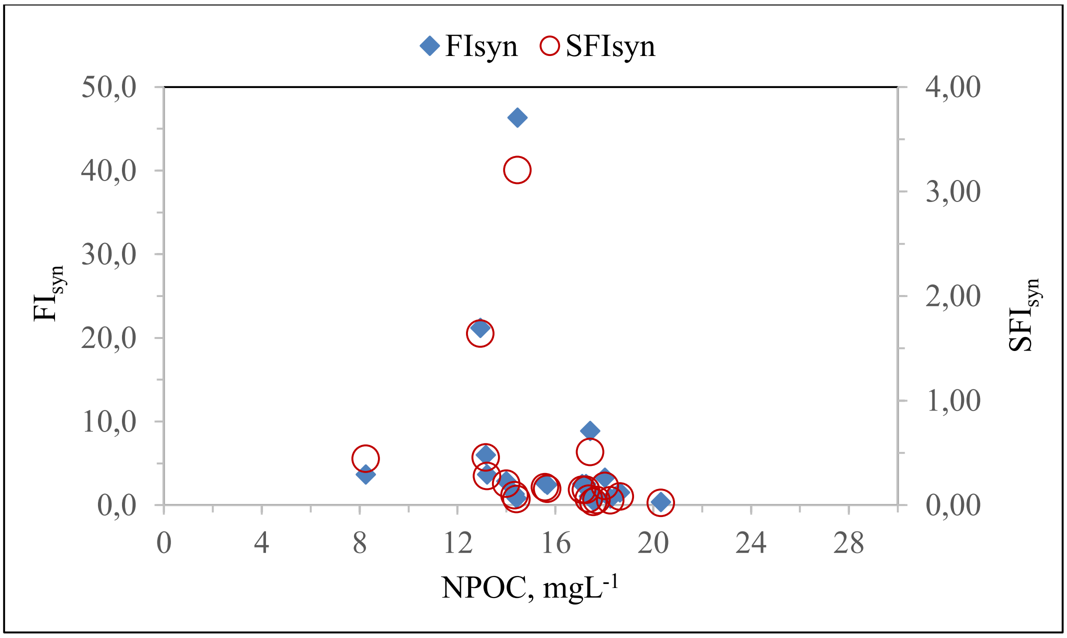

Figure 4.32. NPOC dependent variations of synchronous fluorescence intensity (FI_{syn}) and specific fluorescence intensity (SFI_{syn}) values of the BUISPW samples.

4.5. Microbiological parameters of BUISPW samples

The microbiological parameters analyzed in this study included heterotrophic plate count, total coliforms, fecal coliforms, fecal streptococci, *P. aeruginosa* and *E. coli*. The culture medium and technique used are given in the Materials and Methods section. Colonies were confirmed in accordance with the conventional methods (Natara et al., 2011; Vaneechoutte et al., 2011; Wauters et al., 2011; Henry and Speert, 2011; Lipuma et al., 2011; Teixeira et al.,2011; Abbott, 2011; Becker and von Eiff, 2011). API ID32 GN test system detailed in the Materials and Methods section was used to identify unidentified colonies when necessary (Bio Mérieux, France).

Microbiological parameters concerning swimming pool water quality according to TSI standards, Turkish Ministry of Health Department regulations, WHO Guidelines and UK PWTAG are presented in Table 2.9. Turkish Standards Institution provided information regarding general rules for preparation of water, as well as technical construction, maintenance and management of swimming pools (TS 11899, 2007). In 2012, this standard was withdrawn and since then two new standards (TS EN 15288-1 and 2) have come into force. These new standards do not include microbiological parameters. Hence, microbiological parameters in the previous standard (TS 11899, 2007) were taken into account.

Swimming pool water is expected to have the same characteristics as potable water (PWTAG, 2014a). Consequently, in addition to these recommendations, TSI's standards for water intended for human consumption is also taken into account (TS 266, 2005). The assessment of the microbiological quality of BU swimming pool water was carried out according to the recommended values of bacteria issued by the authorities (Table 2.9).

According to the Turkish Ministry of Health Regulations on swimming pool water (TMOH Regulation 27866, 2011), the maximum limit value for total colony count is 200 CFU per mL (24 hours at 37ºC). The regulation was later revised but the maximum limit value did not change. *E.coli, P. aeruginosa* and total coliforms are the other recommended microbiological parameters (TMOH Regulation 28143, 2011).

According to the previous standards of TSI, recommended colony count at both 20±2ºC and 36±1ºC was 100 CFU per mL. *E. coli* and *P. aeruginosa* should be absent in 100 mL swimming pool water. In addition, L*egionella pneumophila* should not be present in hot whirlpools and in pools where water is ≥ 23ºC (TS 11899, 2007). However, the new standards TS EN 15288-2 on swimming pool safety requirements for operation do not include information about microbiological quality parameters (TS EN 15288-2, 2012).

Indicator microorganisms are used for monitoring potential hazards in swimming pools and similar environments according to WHO Guidelines (WHO, 2006). These organisms are heterotrophic plate count, thermotolerant coliforms *E. coli, P. aeruginosa, Legionella* spp., and *S. aureus*. Table 2.9 shows operational level of these parameters. WHO guidelines about swimming pools and similar environments recommend periodic monitoring of *Legionella* spp. and set the acceptable operational level at less than 1 per 100 mL (WHO, 2006). Like WHO, TSI also recommends monitoring of *Legionella pneumophila* for swimming pools (TS 11899, 2007). However, *Legionella* spp. was not investigated in this study.

Another microbiological parameter, *S. aureus* in pool water should be less than 100 per 100 mL (WHO, 2006). However, routine monitoring of this parameter is not recommended unless there are health problems associated with the swimming pool. In this study, *S. aureus* was not used as a parameter but coagulase negative staphylococci was identified in the differentiation of the strains. According to Turkish Standards 266, *E.coli* and enterococci should not be present in 100 mL of Class 2 Type 2 water. There is no information about colony count (at 22ºC and 37ºC) or *P. aeruginosa* (TS 266, 2005).

4.5.1. Microbiological parameters

4.5.1.1. Heterotrophic plate count (HPC). Minimum, maximum and average HPC were 0, 130 CFU/mL and 27 CFU/mL, respectively (Figure 4.33). Two random microbiological samplings were taken in this study and their average HPC results were 14 CFU/mL.

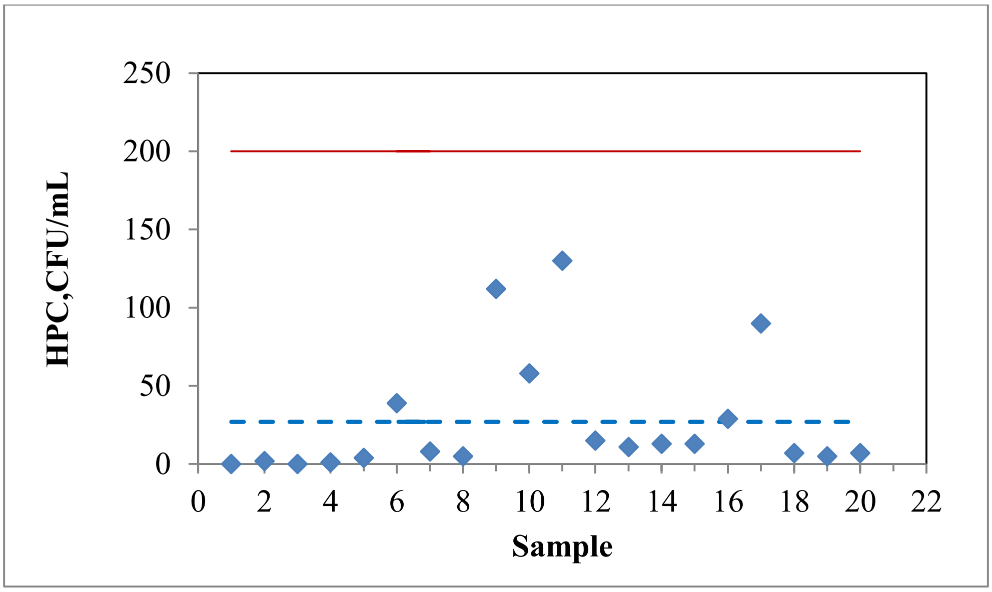

Figure 4.33. HPC variations in BUISPW.

(Dashed line indicates average level, straight line indicates recommended value)

According to Turkish Ministry of Health regulations, the limit value of total colony count at 36°C and 22°C is 200 CFU/mL (TMOH Regulation 28143, 2011). The acceptable value according to TSI is 100 CFU/mL (TS 11899, 2007) (Table 2.9). WHO's recommended operational level at 37°C for 24 hours is less than 200 CFU/mL in disinfected semipublic and public swimming pools. Moreover, the total colony count value should be less than 10 CFU/mL according to PWTAG Code of Practice; a colony count of more than 100 CFU/mL is unacceptable. By these criteria, HPC of 27 CFU/mL observed in this study was low. BUISPW conformed to the microbiological limits for colony count set by Turkish Ministry of Health, TSI and WHO. In terms of PWTAG Code of Practice, the pool water is acceptable.

According to WHO guidelines, HPC is a useful parameter for operational monitoring, evaluation of cleanliness, integrity of distribution system, effectiveness of disinfection and the presence of biofilms. HPC provides information about total number of viable bacteria. It is an important indicator for disinfection efficacy (WHO, 2011). Normal skin flora bacteria such as *Staphylococcus and Pseudomonas* shed by pool users causes swimming pool related illnesses (WHO, 2006).

In this study, BUISPW conformed to the microbiological limits for colony count set by regulations of Turkish Ministry of Health, standards of TSI and WHO guidelines. In terms of PWTAG Code of Practice, the pool water is satisfactory (Table 2.9).

4.5.1.2. Total coliforms. Total coliform bacteria are defined as Gram-negative, non-spore-forming aerobic and facultative anaerobic rod-shaped bacteria. They can ferment lactose within 24 hours at 35-37ºC and produce acid or aldehyde. They also produce β-galactosidase enzyme. Coliform group bacteria survive in the gut and feces of warm-blooded animals and can produce gas from lactose at 44.5 ± 0.2ºC. This ability is a very valuable criterion for defining fecal members of the coliform group (Standard Methods, 2005). This group includes the genera *Escherichia, Klebsiella, Enterobacter and Citrobacter.* Fecal and environmental species belong to this group because total coliforms can survive in water and soil. The presence of total coliform in drinking water is an indication of inadequate treatment, which may result in regrowth, biofilm formation and contamination (WHO, 2011).

Total coliforms were not observed in 500 mL, 750 mL and 1 L sample volume taken from BUISPW. Total coliform should not be present in 100 mL pool water according to swimming pool water regulations and guidelines (TMOH Regulation 28143, 2011; PWTAG, 2015). This group of bacteria is not mentioned as a parameter in standards of TSI or WHO Guidelines on swimming pools (Table 2.9) (TS 11899, 2007; WHO, 2006).

4.5.1.3. Fecal coliforms. Fecal coliform bacteria (thermotolerant coliforms) are a subset of coliform bacteria and they can ferment lactose at 44-45ºC by producing acid and gas. However, coliforms are able to ferment lactose at 37ºC. *Escherichia, Klebsiella, Enterobacter and Citrobacter* are thermotolerant bacteria. *E. coli* is an important parameter in water quality and it can be distinguished from thermotolerant bacteria by an indol test or its production of enzyme β-galactosidase.

Fecal coliforms were not observed in 500 mL, 750 mL and 1 L swimming pool water samples in this study. However, *Klebsiella pneumonia* was isolated in 15 L sample volume whereas *Enterobacter* spp. was identified in 1 L microbiological random sampling. The standards, regulations and guidelines about swimming pools do not mention fecal coliforms (TS 11899, 2007; TMOH Regulation 28143, 2011; PWTAG, 2015). However, WHO indicates that thermotolerant coliforms (fecal coliforms) and *E. coli* are indicators of fecal contamination, so less than one in 100 mL is the recommended operational level for these bacteria (Table 2.9) (WHO, 2006).

Klebsiella spp. are a member of the family *Enterobacteriaceae* and Gram-negative non-motile rod-shaped bacteria. They are found in water environments and drinking water distribution systems as well as human intestines and feces. Nearly 80% of all *Klebsiella* spp. excreted in the clinical specimens and feces are *Klebsiella pneumoniae*. *Klebsiella* spp. cause hospital-acquired infection (nosocomial infection) and they have antimicrobial resistance. *Klebsiella* spp. in distribution systems are associated with biofilm growth and inadequate treatment. Among strategies for minimizing biofilm growth are optimizing organic carbon removal, limiting the residence time of water in distribution systems, and maintaining disinfectant residuals. Like *Klebsiella*, *Enterobacter* spp. are thermotolerant. There is no other detailed information in WHO guidelines regarding *Enterobacter* spp. in swimming pools and drinking water (WHO, 2006; WHO, 2011).

<u>4.5.1.4. Fecal streptococci.</u> Fecal streptococci were not observed in 500 mL, 750 mL and 1 L BUISPW samples. However, the presence of enterococci was observed only in the 10L and 15L pool water samples. There is no data about this bacterium in pool water guidelines (TMOH Regulation 28143, 2011; TS 11899, 2007; WHO, 2006; PWTAG, 2015). According to European Union Council directive 98/83/EC on the quality of water intended for human consumption, the accepted parametric value for enterococci is 0 per 100 mL. In addition, standards of TSI on water intended for human consumption recommend enterococci value of 0 per 100 mL (Table 2.9) (TS 266, 2005).

Recommended limits for fecal streptococci (enterococcus) in swimming pool water are not set by regulations of Turkish Ministry of Health, standards of TSI, WHO guidelines or PWTAG recommendations. Fecal streptococci were not observed in the small samples (volumes 500 mL, 750 mL and 1 L) from BUISPW whereas enterococci were detected in big samples (volumes 10 L and 15 L). This study indicates that using more pool water in the samples can increase the probability of isolation of fecal streptococci.

Enterococci are human specific pathogens in the fecal streptococcus group. *Enterococcus faecalis, E. faecium, E. durans* and *E. hirae* are important pathogens in this group. These intestinal enterococci have been isolated from feces of humans and other warm-blooded animals and indicate fecal contamination. Their ability to survive long-term in water, their resistance to chlorination and drying enable this group of bacteria to survive longer than *E. coli* (WHO, 2011).

4.5.1.5. *Pseudomonas aeruginosa.* Two *P. aeruginosa* and eight *Pseudomonas* spp.were identified in 1 L samples taken per bacterium whereas 3 *P. aeruginosa* and 3 *Pseudomonas* were identified in the 15 L samples collected per bacterium.

P. aeruginosa should not be observed in 100 mL swimming pool water according to regulations and guidelines (TMOH Regulation 28143, 2011; WHO, 2006; PWTAG, 2015). There is no information concerning *P. aeruginosa* in TSI standards (TS 11899, 2007). Microbiological compliance with TMOH Regulation 28143 in this study was very high with 90% when only *P. aeruginosa* identification is considered.

4.5.1.6. *Escherichia coli.* *E. coli* and thermotolerant bacteria are the most important indicators of fecal contamination in swimming pool water as well as in potable water (WHO, 2006; WHO, 2011). In this study, *E. coli* was not observed, as suggested by all guidelines (Table 2.9). However, standards of TSI do not mention this indicator (TS 11899, 2007). Presence of *E.coli* indicates recent fecal contamination.

As indicated previously, the highest Org-N of 8.61 mgL^{-1} and 8.46 mgL^{-1} were observed in samples 18 and 19 (Figure 4.16). An examination of the measurements of other parameters in these two samples indicates the presence of *Pseudomonas* spp. in Sample 18 and *P. aeruginosa* in Sample 19. The free chlorine levels in these samples were recorded as 0.21 mgL^{-1} and 0.19 mgL^{-1}, respectively. These levels were much lower than the recommended level. This indicates inadequate disinfection of BUISP on those days.

As mentioned before, when even trace amounts of organic nitrogen are present in water, some strains of *Yersinia* spp. can replicate at low temperatures (WHO, 2011).

Yersinia was not identified in this study although organic nitrogen was determined in the samples.

As stated previously, organic matter provides food source for bacteria. However, an assessment of the DOC levels in samples where bacterial growth was observed did not indicate any correlation between the level of organic matter and bacterial growth. Furthermore, some samples that had similarly high DOC levels did not have any bacterial growth.

A total of 35 strains were identified in the BU indoor swimming pool water. Distribution of these bacteria is presented in Table 4.10.

Table 4.10. Distribution of all bacteria identified in BUISPW.

Bacteria	**Strain number**	**Percentage (%)**
Pseudomonas aeruginosa	7	20
Pseudomonas spp. (except PA)	12	34
Acinetobacter spp.	3	8.6
Stenotrophomonas maltophilia	3	8.6
Elizabethkingia meningoseptica	2	5.7
Fecal streptococci (Enterococcus)	2	5.7
Delftia acidovorans	1	2.9
Enterobacter spp.	1	2.9
Sphingobacterium multivorum	1	2.9
Klebsiella pneumoniae	1	2.9
Myroides spp.	1	2.9
Coagulase Negative Staphylococci	1	2.9
Total	35	100

Pseudomonas spp. were the most frequently isolated bacteria (34%) in BUISPW in this study. As indicated previously, *Pseudomonas* spp. are potential microbial hazards in pools and similar environments for bathers (Table 2.5) (WHO, 2006). Moreover, 20% of isolated strains were *P. aeruginosa*, followed by various bacteria such as *Acinetobacter spp.*, *Stenotrophomonas maltophilia*, *Elizabethkingia meningoseptica, Delftia acidovorans*, *Enterobacter spp.*, *Sphingobacterium multivorum, Klebsiella pneumoniae*, *Myroide spp.,* and coagulase negative staphylococci. General information regarding these opportunistic bacteria is presented below:

Acinetobacter spp. belong to the family *Moraxellaceae* whereas the members of *Elizabethkingia*, *Myroides* and *Sphingobacterium* are in the family *Flavobacteriacae*, which include environmental bacteria. Members of the genus *Acinetobacter* exist in soil and water. However, *Acinetobacter* species are opportunistic pathogens and cause hospital-acquired infections including ventilator-associated pneumonia, bloodstream infections, urinary tract infections, wound infections, skin and soft tissue infections as well as secondary meningitis (Vaneechoutte et al., 2011).

Stenotrophomonas maltophilia is an environmental bacterium which is aerobic, nonfermentative, motile and Gram-negative rod. It exists in aqueous environments, animals, food and plants and it is related to respiratory infections in people. This multi-drug resistant opportunistic pathogen causes various infections such as respiratory and urinary tract infections, soft tissue infections, eye infections and bacteremia (Brooke, 2012).

Elizabethkingia meningoseptica (formerly *Chryseobacterium meningosepticum*) is an enviromental Gram-negative bacterium and causes various infections such as bacteremia, endocarditis and nosocomial infections (Shinha and Ahuja, 2015; Bomb et al., 2007; Ratnamani and Rao, 2013; Pereira et al., 2013).

Delftia acidovorans (formerly *Comamonas acidovorans*) is an aerobic, non-fermentative, non-spore-forming Gram negative rod-shaped environmental bacterium. Although it is related to plants or microbial diversity and biodegredation, Bilgin and colleagues indicated that it is a significant pathogen for immunocompetent and immunocompromised patients as it is resistant to aminoglycosides (Bilgin et al., 2015).

Sphingobacterium is a genus which includes nonmotile Gram-negative rod-shaped bacteria that produce yellow pigment. *S. multivorum* (formerly known as *Flavobacterium multivorum*) is widespread among people. Moreover, *S. spiritivorum, S. thalpophilum* and *Flavobacterium mizutaii* are frequently encountered species of the genus (Vaneechoutte et al., 2011).

Myroides species (formerly referred to as *Flavobacterium odoratum*) are nonfermentative, aerobic, yellow-pigmented, Gram-negative non-motile rod shaped bacteria. Colonies produce fruity odor and they are isolated from various clinical specimens such as urine, blood, wounds, sputum and ear secretion. Two species, namely *Myroides odoratimimus* and *Myroides odoratus,* belong to this genus (Vaneechoutte et al., 2011). Some case reports associated with *Myroides* spp. have been reported (Ferrer et al., 1995; MacFarlane et al., 1985; Maraki et al., 2012). In addition, an outbreak of central venous catheter-associated bloodstream infections due to contaminated commercially produced ampoules of water with *Myroides odoratus* and *Burkholderia cepacia* in Ecuador has been reported (Douce et al., 2008).

Staphylococci are non-motile, non-spore-forming Gram-positive cocci, observed as single cocci, in pairs, tetrads, short chains and form irregular cluster similar to bunch of grapes. Skin and mucous membranes of mammals and birds are major habitats of the Staphylococcus. S. *aureus, Staphylococcus epidermidis, Staphylococcus haemolyticus* and *Staphylococcus saprophyticus* subsp. *saprophyticus* are significant strains for humans. The most important coagulase-negative staphylococci observed in people is *S. epidermidis,* which colonizes the moist areas of the body surface, especially axillae, inguinal and perineal area, anterior nare and toe webs. Other bacteria in this group include *S. auricularis*, *S. capitis, S. haemolyticus, S. hominis and S. saprophyticus subsp. Saprophyticus),* which exist in various parts of the body (Becker and von Eiff, 2011).

With regard to sample volume, 500 mL is the minimum official microbiological sample volume recommended by Turkish Ministry of Health regulations for microbiological parameters (TMOH Regulation 28143, 2011). No bacteria were isolated in the 500 mL and 750 mL sample volumes in BUISPW. 1 L sample volume was used per bacteria (TC, FC, FS, PA and EC) in a total of 20 samplings. In addition, 15 L sample volume per bacteria (TC, FC, FS, PA and EC) was used in this study and the bacteria identified are given in Table 4.11. Moreover, different random samples (1 L, 5 L, 10 L and 15 L) were taken for only the examination of microbiological parameters.

Table 4.11. Bacteria identified in BUISPW using 1 L and 15 L sample volumes.

1 L sample volume		**15 L sample volume**	
Identification	**Strain number**	**Identification**	**Strain number**
Pseudomonas. aeruginosa	2	*Pseudomonas. aeruginosa*	3
Pseudomonas spp.	8	*Pseudomonas* spp.	3
Acinetobacter spp.	2	*Stenotrophomonas maltophilia*	3
Delftia acidovorans	1	Enterococci	1
Total	13	*Klebsiella pneumoniae*	1
		Sphingobacterium multivorum	1
		Total	12

Table 4.12 shows bacteria identified in different random samples (1 L, 5 L, 10 L and 15 L). Briefly, data shows that increasing sample volume also increased identification of fecal streptococcus.

Table 4.12. All bacteria identified in random samples.

Sample volume, L	**Identification**	**Strain number**
1	*Acinetobacter* spp.	1
	Enterobacter spp.	1
5	*Pseudomonas aeruginosa*	2
	Elizabethkingia meningoseptica	2
10	Enterococci	1
	Pseudomonas spp.	1
	Myroides spp.	1
15	Coagulase negative staphylococci	1
		Total=10

Some points were observed regarding identified bacteria. Bacteria were identified in samples where the water temperature ranged between 23.3°C-27.1°C and pH between 6.05-7.51. In samples where *P. aeruginosa* was identified, the range of free chlorine observed was 0.07 mgL^{-1}-1.41 mgL^{-1}. At the highest free chlorine level of 1.70 mgL^{-1}, Enterococci, *Sphingobacterium multivorum*, and *Stenotrophomonas maltophilia* were identified.

Various studies were conducted on microbiological quality of different types of pools. These are presented below:

Rigas and colleagues examined water quality of 11 indoor and outdoor swimming pools in Athens area and reported 45-91% microbiological compliance with German standards DIN 19643 (91% for total count, 64 % for total coliforms, 82 % for *E.coli,* 45% for *S. aureus* and 73% for *P. aeruginosa*), which indicated that *P. aeruginosa* and *S. aureus* were the most important parameters (Rigas et al., 1998).

Three indoor swimming pools (a teaching pool, a competition pool and a hydrotherapy pool) and two outdoor swimming pools (a hotel semi-public pool and a private swimming pool) in Greece were investigated by Papadopoulou and co-workers. 462 water samples were collected during 8 years and presence of bacteria, protozoa, and fungi were checked. In addition, susceptibility tests for bacterial isolates were performed. The study indicated that the hydrotherapy pool was the poorest in microbiological quality (total hetetrophic count was $\geq$ 500 CFU mL^{-1} in 12.1% of the samples) and it had the highest prevalence of multi-resistant isolates (73.6%). *P. aeruginosa* was investigated and *Pseudomonas* species were not isolated in the competition pool and the private pool. They isolated 107 bacterial strains from 5 swimming pools and 38 isolates in 107 showed resistance to one or more antibiotics; the other 69 isolates were susceptible to all tested antibiotics (Papadopoulou et al., 2008).

In an earlier study, 100 swimming pools (30 public and 70 private) in South Australia were monitored and total colony count, total coliforms, E.coli and *P. aeruginosa* were used for the assessment of their microbiological quality. 18 % of the pools were reported to have unacceptable bacteriological quality. A strong positive association of free chlorine with microbiological quality was shown by multiple logistic regression analyses. By using a mathematical model derived from multiple logistic regression analyses, they estimated an acceptable bacteriological quality of 1.0 mg L^{-1} in 99% of the pools (Esterman et al., 1984).

Al-Khatib and Salah investigated 46 swimming pools in West Bank of Palestine in 2000 in terms of microbiological quality by using coliforms, streptococci, *Salmonella* and *Staphylococcus*. They reported that all pools were microbiologically contaminated. They indicated that increasing of public awareness, training of governmental pool management and operators, and monitoring of swimming pool water is required for improving water quality (Al-Khatib and Salah, 2003).

Guida and colleagues investigated microbiological quality of the water collected from 4 recreational and 3 rehabilitation pools in Naples, Italy, in a 2-year survey. They observed *P. aeruginosa* contamination and microbial mesophilic contamination in the seven pools (Guida et al., 2009).

Ibarluzea and co-workers conducted a study in 12 indoor swimming pools to determine the relationship between disinfection and parameters: 7 pools using chlorination as disinfectant method and 5 using electrolytically disinfected system, copper and silver ions generation. The study highlighted that 2.6 mgL^{-1} of free chlorine was sufficient for 90% microbial acceptance of bathing water. *P. aeruginosa* was isolated in 18.8% of the samples collected from chlorinated pools. The predominant species of *Pseudomonas* was *Pseudomonas acidovorans* with 51.9 % and *P. aeruginosa* in the pools (Ibarluzea et al., 1998).

Only *P. aeruginosa* was identified in BUISPW whereas other Pseudomonas species were not distinguished. This study indicated that the prevalence of *Pseudomonas spp*. was more widespread than *P. aeruginosa* in the BUISPW.

Rabi and colleagues examined 85 public swimming pools (34 indoors and 51 outdoors) in Amman and reported total coliform contamination in 43.5% of the samples (Rabi et al., 2008).

Itah and Ekpombok surveyed 10 swimming pools in Nigeria and the pools were not in compliance with WHO standards for recreational water due to high percentage of bacterial isolation: *E coli* (20%), *P. aeruginosa* (70%), *S. aureus* (100%), *S. epidermidis* (50%), *Enterococcus faecalis* (30%), *Clostridium perfringens* (30%) and *Bacillus cereus* (80%) (Itah and Ekpombok, 2004).

Microbiological quality of water in 11 public swimming pools (7 outdoors and 4 indoors) in Tehran were investigated over a one-year period by using the parameters HPC, total coliforms, fecal coliforms, *E. coli* and *P. aeruginosa.* The study revealed that nine of the pools (indoors and outdoors) were contaminated with P. *aeruginosa* (81.8 %), and 2 indoor pools were not contaminated with any of the investigated parameters. In addition, P. *aeruginosa*, HPC, TC and FC were observed in 2 pools. Since the presence of *P. aeruginosa* in pool water is associated with ear infection, particularly otitis externa, ear swabs were collected from bathers and from the control group to determine if the swimming pool posed any risk of ear infection. A high rate of P. *aeruginosa* (79.3%) was isolated from ear swabs collected from bathers whereas this rate was very low in the control group (4%) (Hajjartabar, 2010).

Rodríguez-Morales and colleagues assessed the microbiological quality of water in 60 recreational swimming pools in central Venezuela and the antimicrobial susceptibility patterns of the isolated bacterial strains. They reported that 19 pools were contaminated and 35 strains were isolated: 13 strains of *P. aeruginosa* (68%), 12 strains of *Streptococcus* spp. (63%) and 10 of *Staphylococcus* spp. (53%) (Rodríguez-Morales et al., 2008). Tirodimos and colleagues monitored the prevalence and antibiotic resistance of *P. aeruginosa* isolated in 4 hydrotherapy pools, 4 jacuzzis/spas and 21 swimming pools in Greece. Prevalence of *P. aeruginosa* was reported as 25%, 8.2% and 18.2%, respectively. In addition, the prevalence of HPC, TC, and *E. coli* was 64.5%, 7.0 and 2.3%, respectively. The rate of microbiological compliance of samples collected from swimming pools was 90.7 % (Tirodimos et al., 2010).

Dallolio and co-workers monitored 144 pools (75 outdoor, 69 indoor) in Bologna, Italy in a three-year period to evaluate microbiological and chemical water quality. Some of the samples collected from pool water for HPC, *E. coli*, enterococci, *P. aeruginosa* and *S. aureus* displayed the rates of 8.1%, 0.0%, 1.4%, 2.6% and 1.0%, respectively. These samples did not comply with Italian Standards for swimming pools (Dallolio et al., 2013).

Moore and colleagues collected a total of 3510 samples from 13 hydrotherapy pools, 51 Jacuzzis/spas and 68 swimming pools in Ireland over a two-year period to assess incidence of *P. aeruginosa* in these waters. *P. aeruginosa* contamination in these pools was 30.8%, 72.5% and 38.2%, respectively. The results indicated that Jacuzzis/spas were contaminated heavily with *P. aeruginosa* (Moore et al., 2002).

To sum up, microbiological results indicate that;

- The result of HPC values were within the microbiological limits set by Turkish Ministry of Health, TSI, WHO and PWTAG Code of Practice. However, other parameters were also detected. Only HPC is not enough to check water quality.

- Presence of total coliforms or fecal coliforms was not observed in BUISPW samples of 500 mL, 750 mL and 1 L volume. However, *K. pneumonia* was isolated in 15 L sample volume whereas *Enterobacter* spp. were identified in 1 L microbiological random samples.

- *E.coli* was not observed, as suggested by all guidelines (Table 2.9) whereas enterococci, which are more resistant bacteria than *E.coli* and indicate fecal contamination, were identified only in big sample volumes (10 L and 15 L). Data shows that increasing sample volume also increased identification of enterococci (fecal streptococcus).
- *Pseudomonas* spp. was the most frequently isolated bacteria in the indoor swimming pool water in this study (Table 4.10). Twenty percent of isolated strains were *P. aeruginosa,* followed by various bacteria such as *Stenotrophomonas maltophilia, Elizabethkingia meningoseptica, Delftia acidovorans, Enterobacter* spp., *Sphingobacterium multivorum, K. pneumoniae*, *Myroide* spp., and Coagulase negative staphylococci.

- The most frequently identified bacteria in BUISPW were nonfermentative Gram-negative bacteria.

Presence of bacteria in the pool water is closely related with hygienic habits of pool users. Detailed information obtained from the questionnaire given to pool users about habits that contribute to all potential hazards related to pool water are presented in the following section.

4.6. Survey result: Information provided by pool users

A questionnaire was used to survey users of the Boğaziçi University indoor swimming pool. The questionnaire was designed after those used by Fantuzzi and Schoefer (Fantuzzi et al., 2001; Schoefer et al., 2008). Questions aim at gathering information on user profile, time and frequency of pool use, knowledge and observance of pool rules, health problems encountered following pool use (Appendix C). Data obtained from the survey revealed statistics on user profile and habits.

The questionnaire was answered by forty-one swimming pool users on a voluntary basis, during the period of May 4th to June 27th, 2013. A greater percentage of participants were male (63%), with females making up 37% of the respondents. The average age of the respondents is 31.7; thus a higher proportion of users consists of young people. The graph below shows the age distribution of BUISP users (Figure 4.34). It should be noted that none of the users who answered the questionnaire was under the age of 18.

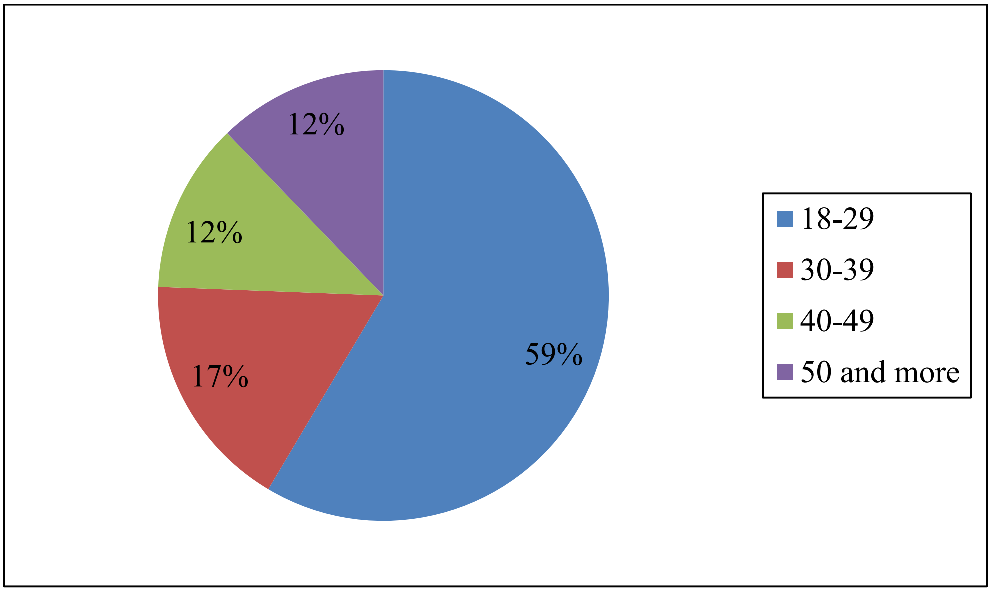

Figure 4.34. Age profile of indoor swimming pool users.

According to the survey data, swimming pool users are divided into five main groups: BU students, academicians employed by BU (Acad), BU staff, graduates of Boğaziçi University (BU grad), spouses and children of academicians and staff members (sp/ch)

(Figure 4.35). Students seem to be the predominant pool users (58%) while employees of BU (academicians and staff) constitute the second largest group (total 27%).

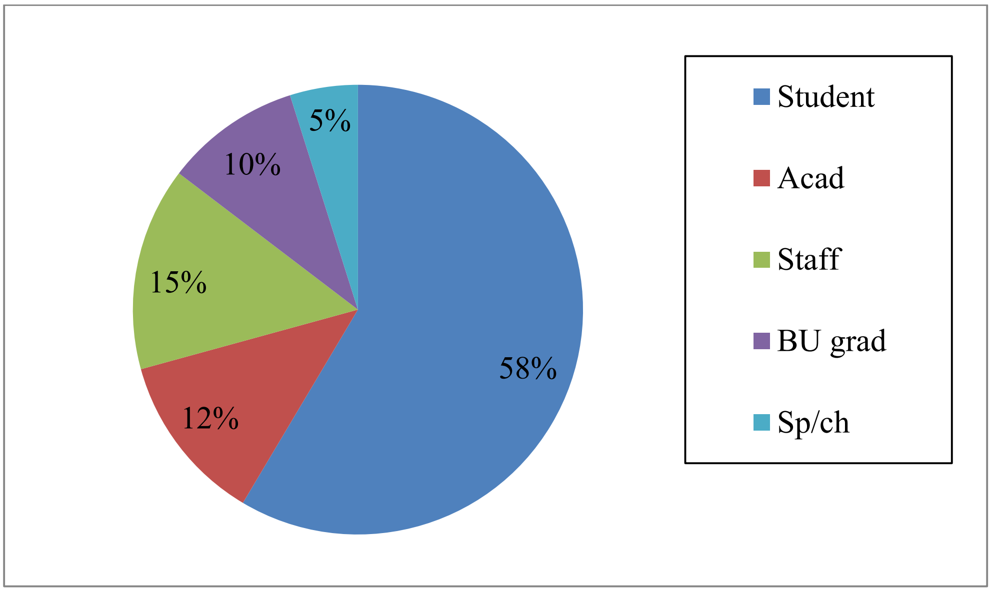

Figure 4.35. Profile of indoor swimming pool users.
(Acad: Academician, BU grad: Boğaziçi University Graduate, Sp/ch: Spouse and/or children of academicians and staff members).

Data on the educational background of the respondents indicate that 65% of pool users are current undergraduate, Master's or PhD students. Of graduates, fifteen percent hold undergraduate degrees, whereas 7% have Master's and 8% have doctorate degrees. (Figure 4.36). As for frequency of use, the questionnaire revealed that 7% of the respondents use the pool every day. Just over a quarter (27%) of the respondents use the pool twice a week and 23% use the facility three times a week. A quarter of the participants (25%) come to the pool at least once a month (Figure 4.37).

Mondays, Wednesdays and Thursdays are the most popular days for swimming pool usage. Interestingly, weekends are the least preferred days. The pie chart below shows frequency of swimming pool use (Figure 4.38). The survey also indicates that the use of the pool during the mid-term break is quite high (80%).

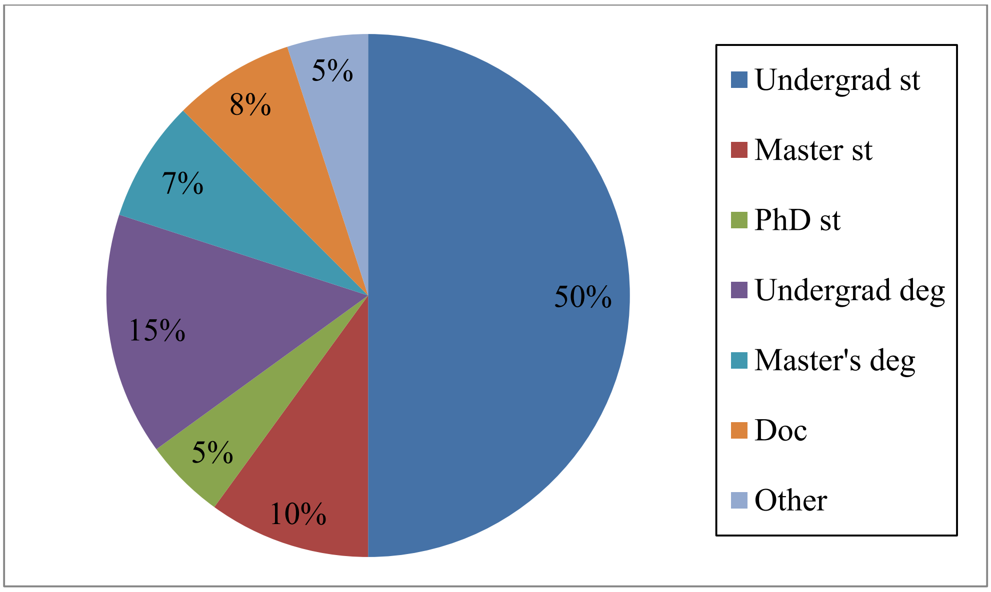

Figure 4.36. Educational background of participants.
(Undergrad st: Undergraduate student, Master st: Master’s student,
PhD st: Doctoral student, Undergrad deg: Undergraduate Degree,
Master’s deg: Master’s degree, Doc: Doctoral degree).

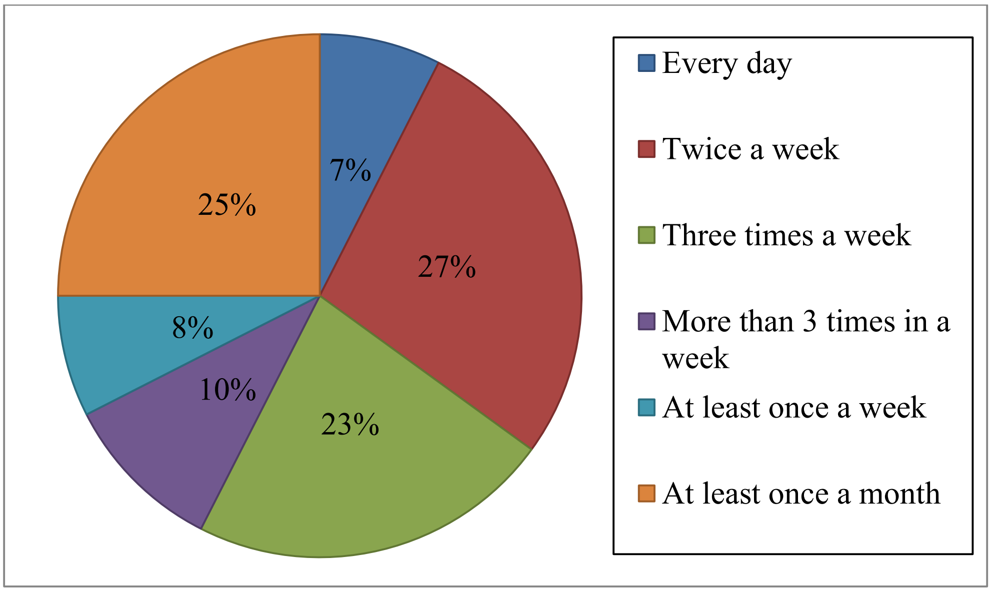

Figure 4.37. Frequency of pool usage.

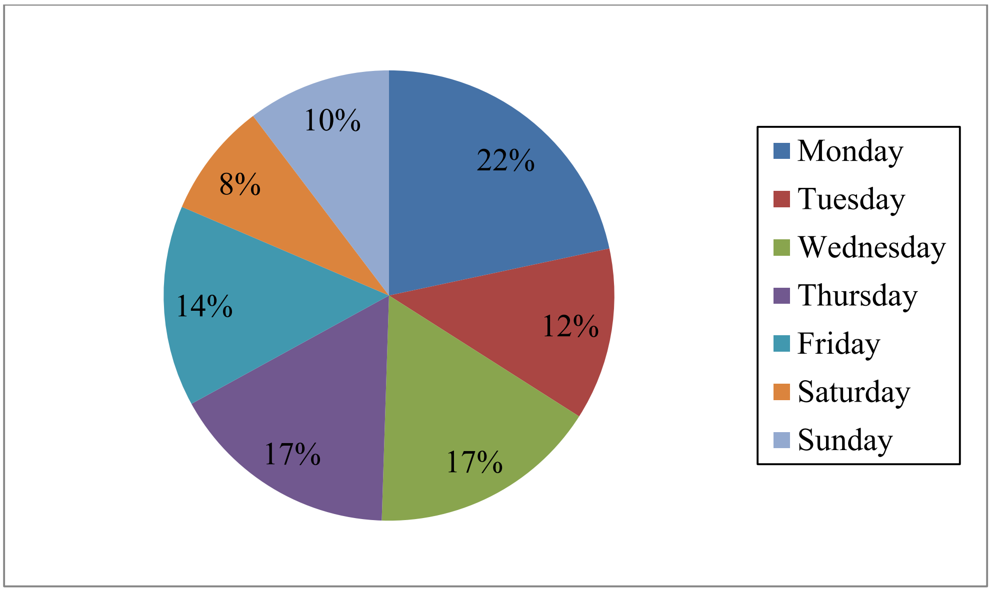

Figure 4.38. Pool usage by day of the week.

The survey reveals that the most popular time period for pool users is from 17:00 to 19:00 hours. For 18% of the users, the preferred period was 12:00-14:00 hours. Figure 4.39 gives information about favorable hours.

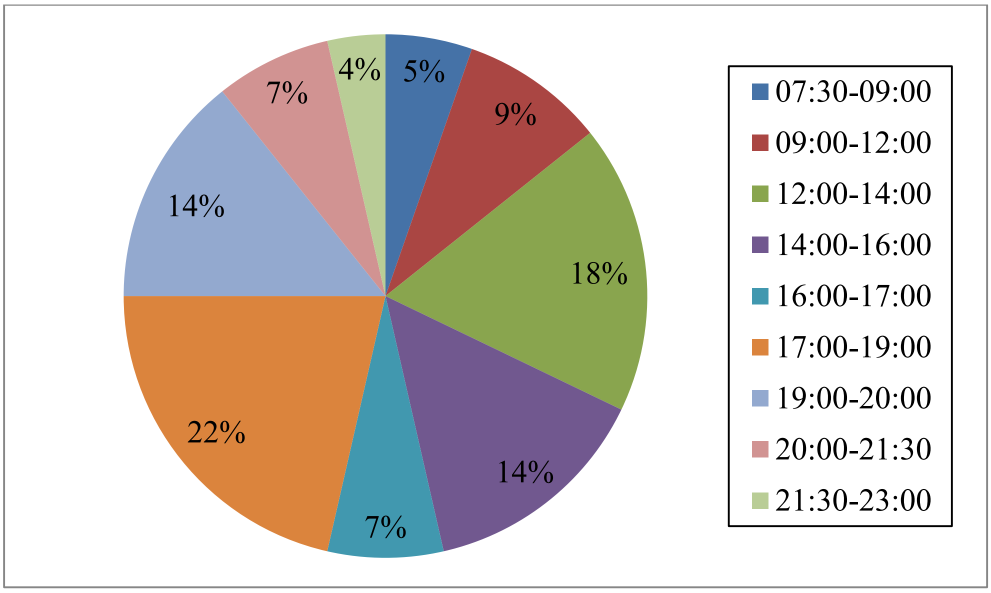

Figure 4.39. Favorable hours of pool use.

The survey revealed information on not only the popular hours and days of pool use but also the length of time spent on swimming or other pool activities as well as the time spent around the pool. Swimming seems to be the most popular activity; it constitutes 92%

of pool use. Activity time for participants who answered the relevant question includes a minimum of five minutes because of the distance between pool and locker room. According to questionnaire results, participants spend fifty two minutes on average for swimming. The average amount of time spent on other pool activities is thirty seven minutes while the average time spent around the pool was calculated as thirty three minutes.

Boğaziçi University indoor swimming pool has a specific set of rules pertaining to pool use. The rules consist of seven items (Appendix E). These rules are posted on the notice board in the reception area. The survey indicated that 97% of the respondents knew the rules, which is a very high rate. One of the seven rules is observed by all pool users: wearing a swim cap. One of the pool rules requires showering before stepping in the pool; this rule is practiced by 95% of the pool users. 83% of the respondents indicated they used the toilet before swimming and all of them washed their hands after toilet usage. The disinfecting foot-bath was used by 67% of the respondents**.** The proportion of respondents wearing goggles or contact lenses while swimming was 17% and 78%, respectively. The questionnaire also included the use of swimming equipment; however, 73% of respondents did not answer this question. According to the observations of researchers kickboards were the most commonly used equipment.

Another piece of information the questionnaire sought to get was the aim for which the pool was used. Nearly half of the participants (49%) used the pool for health reasons. 31% used the pool as a hobby. The use of the pool for weight control was aimed by nearly 15% of the respondents (Figure 4.40). Interestingly, none of the respondents marked "compulsory" as a reason for pool use even though attendance in swimming classes is compulsory for students.

The respondents were also asked to indicate if they developed any medical problems following pool use. 66% of the respondents chose not to answer this question. Among those who did answer the question, the most common medical problems reported were ear and eye related, followed by coughs. Another question asked respondents to name the chronic illnesses they suffered from, if any. This question was answered by only four of the respondents, the illnesses mentioned being cancer, herniated disc, and arthritis. One respondent mentioned beginning to use the pool one month after their chemotherapy ended.

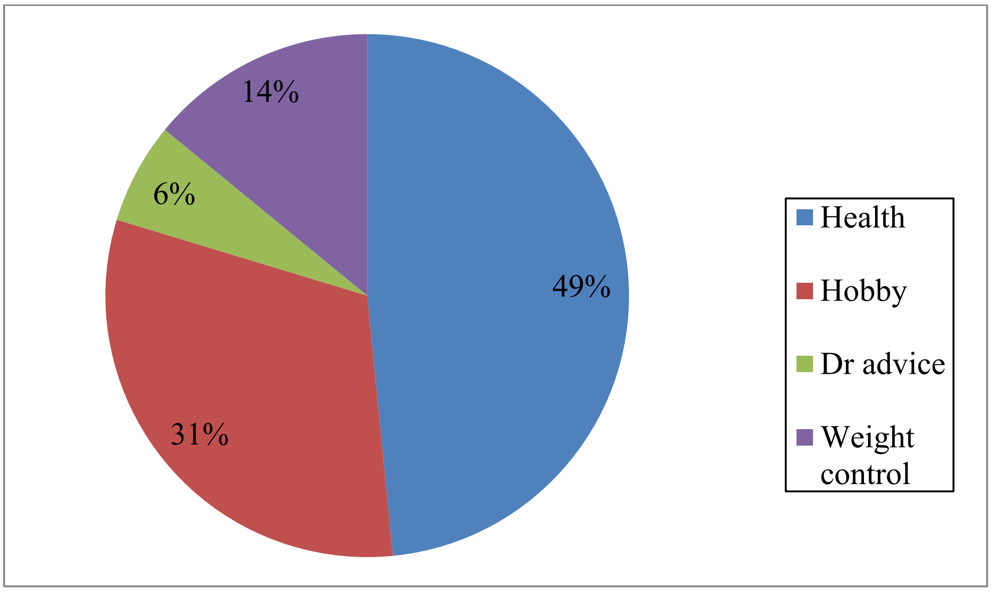

Figure 4.40. Aim of the pool usage.
(Dr advice: Medical advice)

Researches have commonly employed questionnaires to collect information about pool users.

A study by Schoefer and colleagues focused on early pool attendance of children. They conducted parental-administered questionnaires to gather data on the children, including the age of the child's first pool attendance, doctor diagnosed diseases, socioeconomic factors, medical history and lifestyle factors (Schoefer et al., 2008).

The study conducted by Schet and colleagues collected information on bathing water exposure of 8000 adults on the Internet. Beside age, gender, postal code, socioeconomic status and family composition, data was collected on frequency of bathing, duration of bathing, the amount of water swallowed while bathing, and head submersion while bathing (Schet et al., 2011).

On the other hand, behaviors and personal hygiene habits of bathers are also investigated since they influence chemical and microbiological quality of water in the swimming pool, which is closely related with potential recreational water illnesses and outbreaks.

A new study evaluated 4315 questionnaires in Italy and the researchers concluded that 41.7% of the respondents never read the swimming pool rules. The rate of pool users taking showers before entering the swimming pool was 70.9%, whereas the rate of bathers who urinated in the pool at least once was reported as 13.5%. The study showed that the rate of improper behaviors among pool users was very high, and that the majority of pool users were not aware that reading pool rules could reduce certain health risks (Pasquarella et al., 2014).

On the other hand, a study conducted by Bernard and colleagues indicated that regular chlorinated indoor pool attendance was associated with an increase in lung epithelium permeability, and that it increased the risk of a lung disease, asthma (Bernard et al., 2003).

Some studies also employed questionnaires to gather information about pool staff. Jacobs and colleagues conducted a questionnaire for indoor swimming pool workers on lifestyle, work-related conditions; health related and work related symptoms to assess exposure to trichloramine and respiratory symptoms in swimming facilities. They indicated that the risk of developing respiratory symptoms, especially asthma, was quite high for swimming pool staff (Jacobs et al., 2007).

Fantuzzi and colleagues defined the personal characteristics of thirty two subjects through questions on gender, age, amount of time worked, main job location and type and duration of swimming activity (Fantuzzi et al., 2001).

Similarly, in this study, a questionnaire was conducted to analyze the profile of the pool staff used by Fantuzzi and colleagues (Fantuzzi et al., 2001). The main headings used in the questionnaire on BU swimming pool staff were gender, age, job description and location, education, work experience, frequency of pool use, time spent at different points at the pool location and smoking habits similar to those in the Fantuzzi study. Some questions were added about certificates received on relevant topics such as pool operation and first-aid.

Moreover, in the BU swimming pool water study, another questionnaire was given to the users of indoor swimming pool to gather information on bather profile and bather awareness. BU swimming pool users answered on a voluntary basis the questions related to the user profile, time and frequency of pool use, knowledge of pool rules and health problems associated with pool usage.

To summarize, the questionnaire provided the following information on BU pool users:

- Nearly 60% of the pool users are under the age of 30; students use the pool more frequently than other groups of pool users.
- The maximum frequency of pool usage is twice a week. However, Mondays, Wednesdays and Thursdays are the most popular days for swimming pool usage. The most popular time period is 17:00-19:00.
- The average swimming time is 52 minutes.
- The rate of awareness of BUSP rules is very high-97%.
- The rate of wearing a swim cap is 100% because it is a pool rule.
- Showering before stepping in the pool is practiced by 95% of the pool users.
- The rate of toilet usage before swimming is 83%.
- The rate of foot-bath usage is low, with 67%.
- Nearly half of the participants (49%) use the pool for health reasons.
- Ear and eye problems are the most common health problems associated with pool usage.
- The rate of wearing goggles or contact lenses while swimming are 17% and 78%, respectively.

The questionnaires indicated bather behavior and habits as summarized above. The results obtained in this research seem to be closely related to these behaviors and habits. Specifically, taking a shower before getting in the pool removes traces of sweat, urine, fecal matter, cosmetics, suntan oil and other potential water contaminants. Pre-swim showering contributes to cleaner pool water, decreases the amount of chemical disinfectants needed to clean the pool, providing savings on cost and reducing potential chemical hazards.

The crucial point in preventing these problems is education of bathers. The responsibility on this issue belongs as much to pool operators as the bathers themselves. Parents of children, the elderly and immune-suppressed individuals need to be informed about the risks they may encounter.

5. CONCLUSION

Boğaziçi University indoor swimming pool water quality was assessed in terms of physical, chemical and microbiological parameters. Turkish Ministry of Health regulations, TSI standards and WHO directives on swimming pool water were taken into account in evaluating the results obtained on these parameters. On the other hand, some parameters specified for drinking water but not for swimming pool water were also evaluated since pool water quality should be compatible with the quality standards of drinking water.

Physical parameters examined in BUISPW were temperature, color, turbidity, conductivity, TDS and salinity. Water temperatures recorded at the pool area were within recommended limits. The average values observed for color and turbidity in BUISPW were lower than the values set by the Turkish Ministry of Health regulations. Ministry of Health regulations and standards (TMOH Regulation 28143, 2011; TS 11899, 2007) do not mention conductivity, TDS or salinity in pool water. However, these parameters were examined and drinking water quality standards were considered in evaluating their results. The average values of conductivity and TDS were lower than values indicated for drinking water. No recommended values of salinity in pool water were provided by the Ministry of Health regulations or TSI standards (TMOH Regulation 28143, 2011; TS 11899, 2007). The salinity values observed in the samples used in this study showed consistency: the salinity values of the samples were 0.1. In only one sample was a value of 0.2 observed.

Chemical parameters examined in this study were pH, alkalinity, hardness, free chlorine as residual disinfectant, nitrogen containing species, common anions (phosphate, sulfate, nitrite, nitrate, chloride, fluoride and bromide), metals (copper, iron, manganese and aluminum), oxidizability, parameters related to organic content, and spectroscopic parameters (UV-vis and fluorescence). The average value of pH obtained in BUISPW complied with the recommended range set by the Turkish Ministry of Health regulations, standards of TSI and WHO directives on swimming pool water (TMOH Regulation 28143, 2011; TS 11899, 2007; WHO, 2011). Hardness range of 250-300 $mgCaCO_3L^{-1}$ conformed to the recommended range of 150-1000 $mgCaCO_3L^{-1}$. More than thirty percent (31.5%) of the free chlorine level results fell within the range of 1.0 to the 1.5 mgL^{-1} set by Turkish

Ministry of Health for swimming pool water (TMOH Regulation 28143, 2011). 58% of the results were lower than the minimum free chlorine level of 1 mgL^{-1}; on the other hand, 10.5% were higher than the maximum free chlorine level.

The average levels of chloride, fluoride, sulfate levels recorded in BUISPW were lower than contaminant levels specified by the authorities (Table 4.7). All measurements of bromide ions in BUISPW samples were below 0.014 mgL^{-1}, the lowest detectable level for bromide in the instrument used. No information is provided as to the recommended level of phosphate in pool water or in drinking water. However, the average phosphate level in BUISWP was recorded as 7.80 mgL^{-1}.

As for the results observed for metals, the average values of copper and aluminum were below the levels recommended for both pool water and drinking water. Similarly, the average iron level was recorded lower than the recommended levels. Manganese level in BUISPW, on the other hand, was below the drinking water standards mentioned.

Bathers are the major source of nitrogen containing species in pool water. By means of sweat and urine, these compounds enter into the swimming pool water. For this reason, nitrogen containing species were assessed in BUISPW: these were nitrite, nitrate, ammonia, ammonium, TKN, nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen, ammonium nitrogen, total inorganic nitrogen, total organic nitrogen and total nitrogen. There are no studies published on pool water quality or nitrogen containing species in swimming pools in Turkey. Nitrite and nitrate are important parameters in drinking water quality in terms of the risk of methaemoglobinemia. The average nitrite and nitrate levels of BUISPW were lower than the indicated limits for both swimming pool and drinking water. The average ammonia and ammonium values observed in BUISPW were 0.41 and 0.44 mgL^{-1}, respectively. Regulations and standards about swimming pool water stipulate ammonium value (0.5 mgL^{-1}) but no recommendation is made for ammonia in swimming pools. Only 25% of the results exceeded the recommended limit for ammonium. Morevover, the average TKN was determined as 5.34 mgL^{-1}. The two highest TKN values observed in sample 18 and sample 19 were 9.0 mgL^{-1} and 8.7 mgL^{-1}, respectively. Free chlorine levels in these samples were very low: 0.21 mgL^{-1} and 0.19 mgL^{-1}, respectively. Regulations and standards about swimming pool water do not include any information on recommended TKN levels in pool water. Sample 18 and sample 19 also displayed the two highest org-N levels of 8.61 and 8.46 mgL^{-1}, respectively. Presence of high organic nitrogen may indicate microbial contamination. The high organic nitrogen levels in these two samples indicated microbiological contamination by *Pseudomonas* spp. and *P. aeruginosa.*

Organic content of the BUISPW was determined by using TC, DOC, NPOC, VOC, IC as well as oxidizability. Sample number 15 was the only sample where nitrite could be measured; in the same sample TC, IC, DOC, NPOC and VOC amounts were determined as 20.63 mgL^{-1}, 0.3198 mgL^{-1}, 20.31 mgL^{-1}, 11.980 mgL^{-1} and 8.33 mgL^{-1}. The TC, DOC and VOC results were the highest results obtained in this study. No microbial contamination was observed in sample number 15. Oxidizability is determined by potassium permanganate consumption. Maximum potassium permanganate consumption in BUISPW samples were recorded as 14.20 mgL^{-1} and found to be higher than the recommended level.

Characterization and specification of organic matter in the pool water were determined by UV-vis absorption and fluorescence spectra.

On the subject of microbiological results, HPC values complied with the microbiological limits set by Turkish Ministry of Health, TSI, WHO and PTWAG Code of Practice. However, other parameters also were detected. The results indicated that only HPC is not enough to check water quality.

Total coliforms or fecal coliforms were not detected in BUISPW samples of 500 mL, 750 mL and 1 L volume. However, *K. pneumonia* was isolated in 15 L sample volume, and *Enterobacter* spp. were identified in 1 L microbiological random sampling. As suggested by all guidelines, *E.coli* was not observed, whereas enterococci were identified only in big sample volumes (10 L and 15 L). These are more resistant bacteria than *E.coli* and indicate fecal contamination. Data shows that increasing sample volume also increased identification of enterococci (fecal streptococcus). 2 of the 20 samples (10%) of 1000 mL volume per bacteria displayed the presence of *P. aeruginosa,* and 6 of these samples (30%) contained other species of *Pseudomonas* spp. In all, presence of *Pseudomonas* spp. was verified in 40% of the samplings. The most frequently isolated bacteria in the indoor swimming pool water in this study was *Pseudomonas* spp. Twenty percent of the isolated strains were *P. aeruginosa,* followed by various bacteria such as *Stenotrophomonas maltophilia, Elizabethkingia meningoseptica, Delftia acidovorans, Enterobacter* spp., *Sphingobacterium multivorum, K. pneumoniae*, *Myroide* spp., and Coagulase negative staphylococci. Considering all bacteria identified in the pool water, the most frequently identified bacteria in BUISPW were nonfermentative Gram-negative bacteria.

Hygienic habits of bathers determine the presence of bacteria in the pool water to some extent. For this reason, a questionnaire was designed to gather information about users of BUISP. Detailed information was obtained about user profile, time and frequency of pool use, knowledge of and observance of pool rules, and health problems encountered. The survey indicated that the pool is generally used by young people (under the age of 30), especially students. Mondays, Wednesdays and Thursdays are the most popular days for swimming pool usage, and the most popular time period is 17:00-19:00. The maximum frequency of pool usage is twice a week. The average swimming time is 52 minutes. The questionnaire indicated that 97% of the users were aware of BUISP rules and 95% took a shower before entering the pool; these are very high rates. Similarly, the rate of wearing a swim cap is 100% because it is a pool rule. However, the rates of using the foot-bath or toilet before swimming are low: 67% and 83%, respectively. In addition, only 17% of the users wear goggles and 78% wear contact lenses while swimming. Nearly half of the participants (49%) use the pool for health reasons whereas ear and eye problems are the most common health problems associated with pool usage.

Maintaining good hygiene habits and avoiding sharing personal items such as towels, swim suits, goggles, and water toys are important in preventing the transmission of non fecally derived microbial hazards.

The results of this study have indicated that a survey conducted in semi-public and municipal pools where usage is intensive will be beneficial in revealing the habits and behaviors of pool users and directing future research on pool water quality.

A further point to be noted is that *Enterococci* are not recommended as a microbiological parameter to be used in assessing pool water. However, *Enterococci* and *E. coli* are recommended parameters for drinking water quality in TSI (TS 266). As the results of this study suggest, since pool water is expected to have the same quality as drinking water, *Enterococci* should be recommended as a parameter for the evaluation of pool water quality.

Education is crucial to preventing several health risks caused by pool water and air quality as well as bather behaviors and habits. Swimming pool safety and reduction of water related infections and outbreaks can only be possible through public education.

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APPENDIX A

Questionnaire given to BU Indoor Swimming Pool Management

Date: ________________________

A. General information about the pool

Name of swimming pool: ____

Type of pool: ____

Dimensions (length, width and depth): ____

Volume of the pool (m^3): ____

Capacity: ____

Person volumetric load ($pe/m^3/d$): ____

Age of Facility: ____

Number of employees: ____

Working days and hours:____

B. Information about swimming pool water source characteristics and disinfection practices

Source of water: ____

Method of disinfection: ____

Method of Chlorination:

- ☐ Powder
- ☐ Liquid
- ☐ Gas

Dosing system:

- ☐ Automatic dosing
- ☐ Manual dosing

Shock chlorination application:

- ☐ Yes
- ☐ No

Use of algicides:

- ☐ Yes
- ☐ No

Name of algicide used: ____

Hardness prevention:

- ☐ Yes
- ☐ No

Name of product used: ____

Use of flocculants:

- ☐ Yes
- ☐ No

Name of product used: ____

pH control system:

- ☐ Yes
- ☐ No

Safety measures for accidental release of feces and vomit into the swimming pool:

- ☐ Yes If yes how? ____
- ☐ No

C. Information about maintenance and management of the pool

Cleaning program of the swimming pool:

Cleaning agents used and their suppliers: ______________________________________

Disinfection agents used and their suppliers: ____________________________________

Authority responsible for control of pool chemicals: ______________________________

Cleaning program of the building:

Frequency of cleaning of the swimming pool: ___________________________________

Frequency of cleaning of pool apparatus: ______________________________________

Frequency of cleaning of toilets and showers: ___________________________________

Frequency of cleaning of lockers: ____

Frequency of floor cleaning: ____

Frequency of cleaning of glass surfaces: _______________________________________

Frequency of cleaning and disinfection of pool deck: ____________________________

Disposal of garbage: ____

Authorities responsible for the control of the pool:

- ☐ University
- ☐ Municipal officials
- ☐ Ministry of Health
- ☐ Hızzısıhha Institute
- ☐ Accredited laboratory

D. Information on amenities available to bathers

Availability of a locker for each pool user:

- ☐ Yes
- ☐ No

Total number of lockers: ____

Availability of a notice board:

- ☐ Yes
- ☐ No

Total number of notice boards: ____

Availability of instructions for emergencies:

- ☐ Yes
- ☐ No

Emergency contact number posted:

- ☐ Yes
- ☐ No

Availability of first aid kits:

- ☐ Yes
- ☐ No

Special rules for pool users (Boğaziçi University Swimming Pool Rules):

- ☐ Yes
- ☐ No

Channels used to post/announce this information?

- ☐ Boğaziçi University website
- ☐ Application forms
- ☐ Personal interviews
- ☐ Notice Boards at the Reception Area

E. Information about the monitoring of pool water

Records of water quality control:

- ☐ Yes
- ☐ No

Starting year of monitoring records: ____

Name of the person responsible for record keeping: ________________________________

Any serious problems concerning the indoor swimming pool water:

- ☐ Yes
- ☐ No

Has the pool ever been closed for serious problem water?

- ☐ Yes
- ☐ No

Parameters usually used for monitoring:

- ☐ Turbidity
- ☐ pH
- ☐ Free chlorine
- ☐ Combined chlorine
- ☐ Residual disinfectant

Frequency of monitoring tests: ____

Microbiological control of water quality:

- ☐ Yes
- ☐ No

Parameters used for microbiological control of water quality: _______________________

Frequency of microbiological water quality control: ______________________________

Control of residual disinfectant concentration:

- ☐ Yes
- ☐ No

Time of sample collection from pool water: ______________________________

Number of samples used for analysis: ______________________________

Sample type: ______________________________

F. Information on various other variables

Average number of pool users per year: ______________________________

Average number of pool users day:______________________________

Heavy use days: ______________________________

Maximum number of pool users per day:______________________________

Heavy use hours: ______________________________

Maximum number of pool users per hour: ______________________________

APPENDIX B

Questionnaire given to pool staff

Date: ____________________

Gender:

- ☐ Female
- ☐ Male

Age (years):

- ☐ < 30
- ☐ 30-39
- ☐ 40+

Main job location:

- ☐ Reception
- ☐ Pool
- ☐ Pool side
- ☐ Engine room

Job description: ____

Education: ____

Work experience (years):

- ☐ 1-5
- ☐ 6-10
- ☐ 10+

How often do you use the swimming pool?

- ☐ Cannot swim
- ☐ Never
- ☐ Occasionally
- ☐ Daily

Number of hours/day spent in different areas of the swimming pool:

- ☐ Reception: ______________ hours/day
- ☐ Pool side: ______________ hours/day
- ☐ Engine room: ___________ hours/day

Do you have any certificates on swimming pool operations?

- ☐ Yes
- ☐ No

Name and date of the certificate: ____

Do you have any certificates on first aid?

- ☐ Yes
- ☐ No

Name and date of the certificate: ____

Smoking habit:

- ☐ Non-smoker
- ☐ Smoker for _________ years
- ☐ Ex-smoker

APPENDIX C

Questionnaire given to the Department of Construction and Technical Affairs

Date:______________________

Flow rate of water pumped into the pool: ____

Flow rate of water sucked out of the pool: _______________________________________

Flow rate of water in low-gradient drain pipes: ____________________________________

Water turnover rate (h): ____

Retention time (h): ____

Circulation (m^3h^{-1}): ____

Make-up water (m^3/d): ____

Make-up water flow rate (Ld^{-1}): ____

Filter types:

- ☐ Cartridge filters Number: ________
- ☐ Sand filters Number: ________
- ☐ Ultrafine filters Number: ________
- ☐ Precoat filters Number: ________

Filter area (m^2): ____

Filter run time: ____

Backwash frequency (d): ____

Backwash time (min): ____

Water Heating System: ____

Availability of a coagulation system: ____

Ventilation: ____

Air conditioning: ____

Air flow rate (m^3h^{-1}): ____

Air turnover time (h): ____

Water detention time: ____

Saturation Index: ____

Overflow water circulation: ____

Hair catchers:

- ☐ Yes Number: ________
- ☐ No

In-pool lighting:

- ☐ Yes Number: ________
- ☐ No

Sewage disposal:

- ☐ Yes Number: ________
- ☐ No

Inlets and outlets: ____

Frequency of chlorine measurements: ____

Average chlorine level: ____

Average pH level: ____

Average number of pool users per day: ____

APPENDIX D

Questionnaire given to Boğaziçi University Indoor Swimming Pool Users

Date: ____________________

Name and Surname: ____

Gender:

- ☐ Female
- ☐ Male

Age (years): ____

Contact number and e-mail address: ____

Profile of pool user:

- ☐ Academician
- ☐ Student
- ☐ Staff
- ☐ Graduate of Boğaziçi University
- ☐ Retired (academician or staff)
- ☐ Member's spouse and/or children
- ☐ Guest
- ☐ Other
  (please specify)____

Occupation and occupation location: ____

Education: ____

Frequency of pool use:

- ☐ Every day
- ☐ Twice a week
- ☐ Three times a week
- ☐ More than three times a week
- ☐ At least once per week
- ☐ At least once per month

Type of user activity in the pool:

- ☐ Swimming classes
- ☐ Training for swimming team
- ☐ Training for water polo
- ☐ Individual swimming
- ☐ Water polo match
- ☐ Water polo match of BU graduates
- ☐ Children's swimming lessons
- ☐ "DIVING IS FREEDOM" Project - Special class for handicapped users
- ☐ Other (please specify): ____

Time spent swimming:____

Time spent on other pool activities: ____

Time spent in the swimming pool area: ______________________________________

Times and days you use the pool most:

☐ Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐ Saturday ☐ Sunday	☐ (07:30- 09:00) ☐ (09:00-12:00) ☐ (12:00-14:00) ☐ (14:00- 16:00) ☐ (16:00-17:00) ☐ (17:00- 19:00) ☐ (19:00-20:00) ☐ (20:00- 21:30) ☐ (21.30-23:00)

Do you use the pool during the mid-term break?

- ☐ Yes
- ☐ No

Do you use the toilet before stepping in the pool?

- ☐ Yes
- ☐ No

Do you wash your hands after using the toilet?

- ☐ Yes
- ☐ No

Do you take a shower before stepping in the pool?

- ☐ Yes
- ☐ No

Do you use the disinfecting foot-bath before stepping in the pool?

- ☐ Yes
- ☐ No

Do you wear contact lenses while in the pool?

- ☐ Yes
- ☐ No

Do you use a swim cap?

- ☐ Yes
- ☐ No

Do you use goggles?

- ☐ Yes
- ☐ No

Do you knowing the swimming pool rules?

- ☐ Yes
- ☐ No

Existence of a medical condition

- ☐ Cancer
- ☐ Cystic fibrosis
- ☐ Special cases (pregnancy, disability)
- ☐ Other (please specify): ____

Do you use any equipment while swimming?

- ☐ Kickboard
- ☐ Snorkel
- ☐ Weights
- ☐ Hand paddles
- ☐ Flippers
- ☐ Other (please specify): ____

Aim of pool use

- ☐ Health
- ☐ Hobby
- ☐ Doctor’s recommendation
- ☐ Weight control
- ☐ Compulsory attendance at lessons
- ☐ Other (please specify): ____

Health problems encountered following pool use

- ☐ None
- ☐ Urinary tract infections
- ☐ Ear problems
- ☐ Eye irritation/burning
- ☐ Diarrhea
- ☐ Bronchitis and pneumonia
- ☐ Cough
- ☐ Conjunctivitis
- ☐ Allergic reactions
- ☐ Skin problems

APPENDIX E

Boğaziçi University Indoor Swimming Pool Rules

- Do not step in the pool if you cannot swim
- Take a shower before entering the pool
- Do not enter the water without a swim cap
- Swim along the lane
- Do not jump or dive into the pool
- Do not disturb others
- Observe the warnings of the pool attendant

APPENDIX F

Laboratory instruments used in this study

Parameter	Instrument
Physical parameters	
Temperature	Eutech Insruments pH 5500 Dual Channel pH/Ion meter
Color	Hach portable datalogging spectrometer Model: HACH DR 2010
Turbidity	2100P Turbidimeter- HACH 46500-00
Conductivity, Salinity, TDS	WTW LF 320 Conductivity meter
Chemical parameters	
pH	Eutech Insruments pH 5500 Dual Channel pH/Ion meter.
Free chlorine	Hach portable datalogging spectrometer Model: HACH DR 2010
Nitrogen species	
Ammonia and TKN	Hach portable datalogging spectrometer Model: HACH DR 2010
Organic matter	
TC, DOC, NPOC, IC	Shimadzu TOC Vwp total organic carbon analyzer
Anions and metals	
Anions	Dionex ICS-3000 Ion Chromatography
Metals	Perkin Elmer Optima 2100 DV optical emission spectrometer
Spectroscopic parameters	
UV-vis	Perkin Elmer Lambda 35 UV-vis double beam spectrophotometer
Fluoresence	Perkin Elmer LS 55 Luminescence Spectrometer
Microbiological parameters	
Heterotrophic Plate Count Total coliforms Fecal coliforms Fecal streptococci *Pseudomonas aeruginosa* *Escherichia coli*	Gallenkamp Cooled Incubator (42ºC)
	Fisher Isotemp Incubator Senior Model (35ºC)
	Fisher Scientific Darkfield Quebec Colony Counter
	Nüve steamArt-OT 40L
	Memmert –UM 400 Sterilizer (35 ºC)
	Elektro.mag M 6040B Sterilizer
	Sanyo MDF-U73V Ultra –low temperature feezer (-70ºC)
	Heraeus Hera Freeze HFU 686 Basic (-70ºC)
	Olympus CX21 microscope
	Mini API bioMerieux