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Investigation of some disinfection chemicals and water quality parameters in swimming pools in the city center and districts of Canakkale, Turkey

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Abstract In this study, the variations in concentrations of some disinfection chemicals such as cyanuric acid (CyA), free chlorine (FC), and residual chlorine (RC), which affect human health, were investigated in the water of swimming pools. In addition, quality parameters such as temperature, pH, and total alkalinity (TA) in 44 swimming pools located in the city center and districts of Canakkale, Turkey, were examined in the summer period. While FC and RC amounts were analyzed using tablet tests with *N*-*N*-diethyl phenylenediamine (DPD 1) and potassium iodine (DPD 3) using the colorimetric method in the comparator, TA and CyA levels were measured with a photometric method. Temperature and pH were measured using YSI 556 MPS. Levels of CyA, FC, RC, pH, temperature, and TA varied between 0.00 and 725.0 mg L^{-1} (108.0 ± 111.4 mg L^{-1}), 0.00 and 5.00 mg L^{-1} (1.60 ± 0.962 mg L^{-1}), 0 and 0.55 mg L^{-1} (0.087 ± 0.059), 6.40 and 8.20 mg L^{-1} (7.30 ± 0.038 mg L^{-1}), 22.0 and 32.0 °C (27.6 ± 1.45 °C), and 0.00 and 391.0 mg L^{-1} (129.3 ± 89.0), respectively. The findings were compared to standard limit values of the Ministry of Health of the Turkish Republic and other countries. Not only maximum concentrations of CyA but also the average concentrations exceeded the standard limit values of different countries in July and August with high tourism activity in Turkey. Although there is no problem in view of average values of other quality parameters, there are some problems in view of the maximum values in pool waters compared to standard limit values.

Keywords Canakkale · Pool waters · Disinfection chemicals · CyA · Physical water quality

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Introduction

Swimming is an important sportive activity for public and athletes. But, swimming pool waters involve some risks in view of public health. Despite attempts at disinfection, some pathogens still contaminate the pool waters. In order to avoid the contamination, some disinfectants such as cyanuric acid and free and residual chlorine are commonly used for disinfection of pool waters (Canelli 1974; Kirk 1993). Chlorine and its derivatives are the most common disinfectants used in all underground and surface waters (Table 1). Despite some advantages such as easy use in large amounts of water, cheap price, and easy death of bacteria after the disinfection process, there are some disadvantages that restrict their use (US-EPA 1999). Some researches suggest that the disinfectants expose their own health hazards. Swimming pools which

Table 1 The most commonly used disinfectants in swimming pools (Ogur et al. 2004)

Disinfectant name	Free chlorine ratio (%)	Formula
Chlorine gas	100	Cl_2
Calcium hypochlorite	65.0–70.0	$Ca(OCl)_2$
Sodium hypochlorite	10.0–15.0	NaOCl
Sodium dichloroisocyanurate	56.0–63.0	$NaCl_2(NCO)_3{\cdot}2H_2O$
Trichloroisocyanuric acid	90.0	$(ClNCO)_3$

have chlorinated, particularly indoor pools, have higher risk for respiratory illnesses, including asthma and hay fever, especially for children. In addition, there are some evidences that disinfectant by-products formed when chlorinated waters are mixed with microorganisms, human body fluids, cosmetics, and sunscreen can damage DNA and increase cancer risk (US-EPA 1999; McDonald and Komulainen 2005; Richardson et al. 2007).

A pool full in humans contains all sorts of pathogens, and humans are not only affected by the pathogens, but also affect them. So, people are interacting with pathogens. Pool waters are generally polluted by organic materials such as decaying leaves, bird droppings, fungi-infected rainwater, or dead organisms. Therefore, in order to clean pool waters polluted by various pollutants, there are various methods such as chlorination, ultraviolet radiation, and treatment of water with a copper-silver solution. But the chlorination is the most popular method due to the fact that it is a cheap and relatively effective method (Loret et al. 2005). The chlorination protects swimmers from a wide range of dangerous pathogens, including (1) *Escherichia coli*, *Rotavirus*, *Salmonella*, and *Shigella* which may cause gastrointestinal symptoms and serious illness in some individuals; (2) adenoviruses which are linked with gastroenteritis, respiratory infections, eye infections, and other diseases; and (3) *Pseudomonas aeruginosa* which can cause a variety of diseases such as pneumonia and urinary tract infections.

Before the introduction of effective vaccines, the chlorination was also one of the most common protection methods for swimmers against various diseases like polio and hepatitis A. However, disinfection methods are not effective in level of 100%. Some pathogen organisms such as Giardia and Cryptosporidium which are protozoan parasites can survive even during the chlorination process, whereas others die after sitting in chlorinated water for 20 min or more. If you are unlucky enough to be in the pool just after contamination with infected child defecates of the pool water, your contracting the disease risk is very high (Kababjian 1995). Unfortunately, disposable swim diapers provide very little protection. Some researchers revealed that these child diapers release pathogen microorganisms and parasites within 5 min of hitting the water (Amburgey and Anderson 2011). This suggests that highly chlorinated pool waters would be healthy for all. But, there are some risks connected with excessive chlorination in view of public health, and the chlorination levels must be balanced against the risks of infection (Bolukbasioglu 2009; Dedeoğlu 2009; Mukherjee and Ren 2010).

Two reactions occur in succession when chlorine gas is added to water (Fig. 1). These are defined as hydrolysis and ionization:

$$\text{Hydrolysis}: Cl_2 + H_2O \rightarrow HOCl^- + H^+ + Cl^- (HOCl^- : \text{hypochlorousacid}) \quad (1.1)$$

$$\text{Ionization}: HOCl^- \rightarrow H^+ + OCl^- (OCl^- : \text{Hypochlorite}). \quad (1.2)$$

Cyanuric acid (CyA) is a chemical compound $(CNOH)_3$ which has various synonyms. Although global production of chloroisocyanurates was over 80 million kg in 1987, worldwide production was about 160 million kg in 1997 (Wojtowicz 1993; Huthmacher and Dieter Most 2005). Two thirds of this production is used in the USA alone (about 100,000 t in 1997). It is known that CyA is used as a precursor or a component of bleach, a disinfectant, and anherbicide in swimming pool waters (Huthmacher and Dieter Most 2005). CyA is also used as a chlorine stabilizer to light chlorine and as a precursor to *N*-chlorinated cyanurates. It binds to free chlorine and releases it slowly, extending the time needed to deplete each dose of sanitizer (Kowalski and Hilton 1966). The dichloro derivative is prepared by direct chlorination:

$$C(O)NH\big]_3 + 2Cl_2 + 2NaOH \rightarrow [C(O)NCl]_2[C(O)NH] \quad (1.3)$$

This derivative is typically converted to its sodium salt as known "sodium dichloro-s-triazinetrione." Further

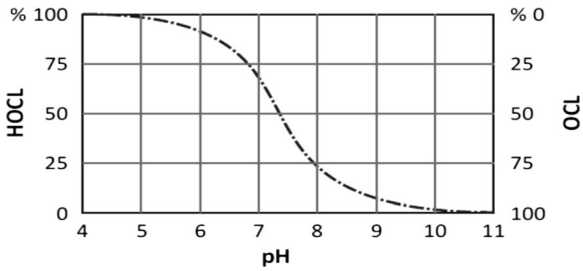

Fig. 1 $HOCl^-$ and OCl^- rates depending on pH variation (Gulluoglu 2012)

chlorination generally produces trichloroisocyanuric acid, $[C(O)NCl]_3$. These *N*-chloro compounds serve as disinfectants and algicides for swimming pool waters. It stabilizes the chlorine in the pool and prevents the chlorine from being quickly consumed by sunlight (Huthmacher and Dieter Most 2005).

Although CyA is classified as "essentially nontoxic," like all disinfectants, it is likely to cause some health problems (Huthmacher and Dieter Most 2005). There is no doubt that CyA is toxic to the liver or gastrointestinal tract (Karns 1999; Magnuson et al. 2001). It is known that CyA cause serious damage to animals by oral intake (Hammond et al. 1986). Therefore, US Environmental Protection Agency (US-EPA) and health organizations from some developing countries apply CyA standards to drinking water and swimming pool water (Anonymous 1998, 2011). These public health authorities usually limit CyA use with an upper limit of 100 ppm (Kowalsky 1992).

In order to determine levels of some disinfectants used in 44 swimming pools in the city center and districts of Canakkale, Turkey, CyA and free (FC) and residual chlorine (RC) were analyzed first time. Levels of other quality parameters such as temperature, pH, and total alkalinity (TA) which interact with these disinfectants were identified in the summer period.

Methodology

Study area and period

In this study, 44 swimming pools (Fig. 2) were selected as a study area. Pool water samples were collected monthly from sampling locations (swimming pools) in the summer of 2013 (June, July, and August, 2013) in Canakkale province and districts (Fig. 2). The sample numbers on the map are 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32:



Fig. 2 Water sampling points for swimming pools in the summer period in the province and districts of Canakkale, Turkey (Sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

Çanakkale, 33–36: Ayvacik-Assos, and 37–44: Ayvacık-Kadırga (Fig. 2).

Pool water samples were collected from special points where the water flow is the lowest or swimmers are the most intense. Moreover, special sampling depths and points were just under surface (0.20 m) and about 1 m away from the edge line of the pools. The collected samples were put in clean polythene sample bottles (1.00 L) and stored in a deep freezer at −21.0 °C until analysis. In this study, a total of 132 samples from the 44 swimming pools were analyzed for each parameter.

Analytical methods

In this study, while CyA and TA concentrations in the 44 swimming pools were determined by Lovibond Brand Checkit Direct Spectrophotometer, FC and RC were analyzed with a colorimetric method with Lovibond Comparator Brand Photometer. While DPD 1 RAPID (*N*-*N*-diethyl phenylenediamine) and DPD 3 RAPID (potassium iodide) tablets were used for FC and RC analyses, CyA test tablets were used for CyA analyses. While the device measurement range was between 2.00 and 160 mg L^{-1} for CyA, the device measurement range was between 5.00 and 200 mg L^{-1} for TA. Therefore, both CyA and TA concentrations were adjusted according to the measurement ranges. CyA samples over concentrations of 160 mg L^{-1} were diluted to suitable concentrations before measurements. Then, the CyA test tablet was added in the test tubes. The samples were spectrophotometrically measured at 528 nm wavelength. The accuracy of the CyA analyses was within the interval of ±10 mg L^{-1}.

Measurement of water quality parameters

Temperature and pH were measured with a water probe "YSI 556 MPS" in situ. Moreover, pH was also measured using a Hach apparatus HQ40D model portable multimeter pHC301 model electrode in the laboratory. TA was measured with a spectrophotometric method. As pre-treatment for the measurements, water samples of 10.00 mL were put in reaction tubes. Later, Alka-M Photometer tablets were added to the tubes. TA results were spectrophotometrically measured at 602 nm wavelength. The accuracy of the TA analysis was in the interval of ±5.00% mg L^{-1}.

Results

Pool water standards in Turkey and some European countries

For the pool water analyses, although they are not used for drinking water as common legislation, the standard limit values used in water analysis of swimming pools in some European countries are presented in Table 2.

Chemical pool water quality parameters (disinfectants: CyA, FC, and RC)

Descriptive statistical analysis results of disinfectant levels (CyA, FC, and RC) in 44 swimming pools in the summer period in the province and districts of Canakkale, Turkey, are given in Table 3. Moreover, the local variations in the summer months (June, July, and August) are illustrated in Figs. 3, 4, and 5.

CyA, FC, and RC concentrations varied between 0 and 725.0 mg L^{-1} (108.0 ± 111.4 mg L^{-1}), 0 and 5.000 mg L^{-1} (1.600 ± 0.962 mg L^{-1}), and 0 and 0.550 mg L^{-1} (0.087 ± 0.059), respectively, during the sampling period. Based on both maximum and average values, disinfectant (CyA, FC, and RC) concentrations increased from June to August probably due to the increasing tourism activity from June to August during the summer (Table 3 and Figs. 3, 4, and 5).

When the findings were compared to standard limit values of the Ministry of Health of the Turkish Republic and some European countries, not only maximum concentrations of CyA (Fig. 3), but also the average concentrations were over the standard limit values for different countries, especially in July and August which have high tourism activity. During the study, based on maximum values, there were 7, 16, and 20 sample analysis results exceeding the standard limit values in June, July, and August, respectively. With regard to total samples during the study, 43 measurement results exceeded standard upper limit value (100.0 mg L^{-1}) from a total of 132 measurements (Table 3 and Fig. 3). While the ratio of unhealthy pool water samples (UHPWS) according to the standard limit value of Turkish Health Ministry increased from June (15.91%) to August (45.45%), UHPW ratio for CyA during the sampling period was calculated as 32.58% (Table 3).

FC concentrations varied between 0 and 5.00 mg L^{-1} during the sampling period (Table 3 and Fig. 4). During the study, based on maximum values, there were 6, 7, and 10 sample analysis results exceeding the standard limit values

Table 2 The standard limit values used in water analysis of swimming pools in some European countries (*TA* total Alkalinity, *CyA* cyanuric acid, *FC* free chlorine, *RC* residual chlorine) (Dallolio et al. 2013)

Parameter	Italian standard (2013)	Austrian hygiene regulation (2012)	France public health (2006)	Germany DIN 19643 (2012)	Netherlands (1969)	England (2013)
Temp. (°C)	25.0–35.0	25.0–35.0	25.0–35.0	25.0–35.0	25.0–35.0	25.0–35.0
pH	6.50–7.50	6.50–7.80	6.90–8.20	6.50–7.20 (Al) 6.50–7.50 (Fe)	7.00–7.60	7.20–7.40
TA (mg L^{-1})	0–160	0–160	0–160	0–160	0–160	0–160
CyA (mg L^{-1})						
FC (mg L^{-1})	0.70–1.50	Indoor pools pH ≤7.40'de; 0.30–1.20 pH ≥7.40'de; 0.50–1.20 Outdoor pools pH ≤7.40'de; 0.30–2.00 pH ≥7.40'de; ≤0.30	1.00–2.00	0.30–0.60	Indoor pools 0.50–1.50 Outdoor pools 0.50–3.00	0.50–1.00
RC (mg L^{-1})	≤0.40	≤0.30	≤0.60	≤0.20	–	≤1.00

in June, July, and August, respectively. In view of total samples in the study period, while 23 FC measurement results exceeded standard upper limit value (3.00 mg L^{-1}), 18 FC measurement results were under the lower standard limit value of the Health Ministry of the Turkish Republic from a total of 132 measurements (Table 3 and Fig. 4). While the FC ratio of unhealthy pool water samples (UHPWS) according to the standard limit value of Turkish Health Ministry increased from July (13.64%) to August (22.73%), UHPW ratio for FC during the sampling period was calculated as 17.42% (Table 3).

Findings revealed that RC concentrations varied between 0 and 0.550 mg L^{-1} during the sampling period (Table 3). There were 3 RC concentration values exceeding the measurements of the upper standard limit value (0.200 mg L^{-1}) of the Health Ministry of the Turkish republic. The high RC concentrations were measured in August in Ecebat (0.550 mg L^{-1}) with high values in July (0.350 mg L^{-1}) and August from Gelibolu (0.250 mg L^{-1}) (Fig. 5). UHPW ratio for RC was calculated as 2.273% (Table 3).

Physical pool water quality parameters (temperature, pH, and total alkalinity)

Physical pool water quality parameters such as temperature, pH, and total alkalinity (TA), from the study period in 44 swimming pools in the province and districts of Canakkale, Turkey, are given in Table 4 and Figs. 6, 7, and 8.

Summer average results showed that temperature, pH, and TA levels varied between 22.00 and 32.00 °C (27.60 ± 1.446 °C), 6.400 and 8.200 (7.300 ± 0.383), and 0 and 391.0 mg L^{-1} (129.3 ± 89.00), respectively (Table 4). Although there is no problem in view of average values of water quality parameters, there are some problems in view of the maximum values of pH and TA levels in pool waters according to standard limit values of the Health Ministry of the Turkish Republic and some European countries (Table 4 and Figs. 6, 7, and 8).

Temperature values from a total of 44 pools varied between 22.0 and 32.0 °C during the summer tourism period. Based on the standard values for pools of Turkish Health Ministry and the standards of some European countries, all temperature values were within standard limits except for some minimum values for sample numbers 5, 18, 26, 38, 39, 41, and 44 (Fig. 6). UHPW ratio for temperature during the summer was calculated as 5.303% (Table 4).

Table 3 Descriptive statistical results of CyA, FC and RC concentrations in swimming pools in the summer period in the province and districts of Canakkale, Turkey (*n*: Number of samples; *l*: The number of unhealthy pool water samples according to the standard limit concentration values of Turkish Health Ministry; *UHPWS*: unhealthy pool water sample according to standard limit values of Turkish Health Ministry)

Month 2013	Parameters (mg L^{-1})	Number	Maximum values	Minimum values	Average values	Standard deviation	Analysis accuracy	Limit values	*l*	UHPWS %
June	CyA	44	603.0	0	87.00	119.6	±10.00	0.00–100	7	15.91
	FC	44	3.000	0	1.500	0.761	–	1.00–3.00	6	13.64
	RC	44	0.150	0	0.080	0.041	–	0.00–0.20	0	0.000
July	CyA	44	725.0	0	110.0	121.6	±10.00	0.00–100	16	36.36
	FC	44	5.000	0	1.700	0.968	–	1.00–3.00	7	15.91
	RC	44	0.550	0	0.080	0.083	–	0.00–0.20	1	2.273
August	CyA	44	412.0	0	127.0	92.93	±10.00	0.00–100	20	45.45
	FC	44	5.000	0	1.600	1.157	–	1.00–3.00	10	22.73
	RC	44	0.350	0	0.100	0.056	–	0.00–0.20	2	4.545

Measurements revealed that pH levels in swimming pool waters of Çanakkale region in the summer period (6.40–8.20) were generally within standard limit values. From the total of 132 pool water samples, only 12 pool samples were over or under the standard pH limit value of the Turkish Health Ministry. While only one sample measurement was under the standard limit value (sample number 19: pH 6.40), 11 sample measurements were above the Turkish standard upper limit value (Table 3). The high pH values were measured in samples 3, 6, 8, 9, 11, 13, 33, 40, and 43. UHPW ratio for pH in the sampling period was calculated as 9.840% (Table 4).

Based on the limit values for pool water standards of Turkish Health Ministry (30–180 mg L^{-1}) and the standards of some European countries (25–200 mg L^{-1}), more than one in five of the TA measurement results were outside of the lower and upper limit values (Fig. 8). During the study, from a total of 132 sample measurements while 3 TA sample measurements were under the lower standard limit values, 26 TA sample measurements exceeded the upper standard limit values (Fig. 8). UHPW ratio for TA in the sampling period was calculated as 21.2% (Table 4).

Discussion

Disinfection products (DP) and by-products (DBP) have become an important research topic for swimming pool waters especially in recent years. There are many studies

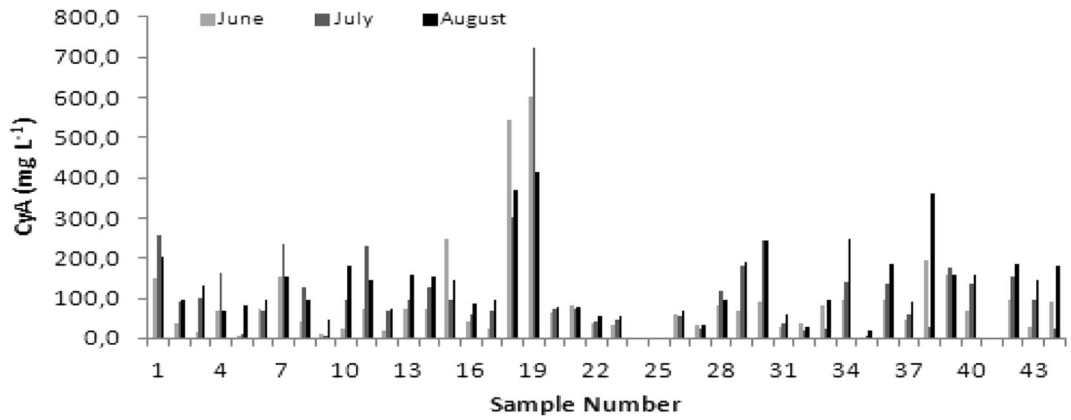

Fig. 3 Variations of CyA in 44 swimming pools in the summer period in the province and districts of Canakkale, Turkey (sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

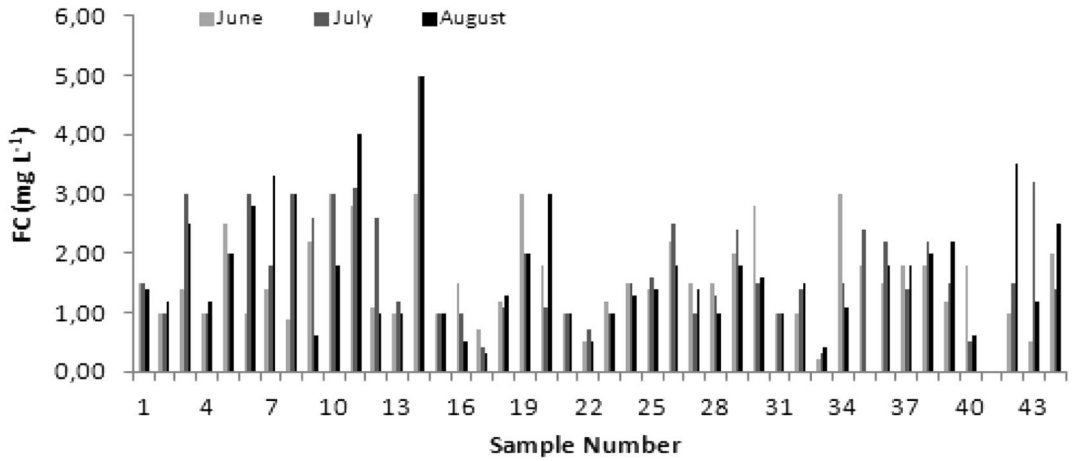

Fig. 4 Variations of FC in swimming pools in the summer period in the province and districts of Canakkale, Turkey (sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

relevant to pool water disinfection and other water quality parameters which interact with each other (Fig. 9). In this study, in view of human and animal health, levels of some important disinfection chemicals such as cyanuric acid (CyA), free (FC), and residual chlorine (RC) along with other pool water quality parameters such as temperature, pH, and total alkalinity (TA) which react with disinfectants were investigated in 44 swimming pools in the summer period in Canakkale, Turkey.

When compared to standard limit values of the Ministry of Health of the Turkish Republic and some European countries (Table 2), not only maximum concentrations of CyA (725.0 mg L^{-1}), FC (5.000 mg $L^{-}1$), and RC (0.550 mg L^{-1}) (Table 3 and Figs. 3, 4, and 5), but also the average concentrations (108.0 ± 111.4 mg L^{-1}, 1.600 ± 0.962 and 0.087 ± 0.059 mg L^{-1}, respectively) were above the standard limit values of different Europian countries especially in July–August during the peak period in terms of tourism. Concentrations of CyA, FC, and RC increased from June to August (Table 3 and Figs. 3, 4, and 5).

During the study, concentrations of 43, 23, and 3 samples in CyA, FC, and RC respectively exceeded the standard limit values of the Health Ministry of the Turkish Republic and other European countries (Table 2). Based on total samples for each parameter (132 samples), 32.6% of CyA samples (43 samples), 17.4% of the FC samples (23 samples) and 2.27% of the

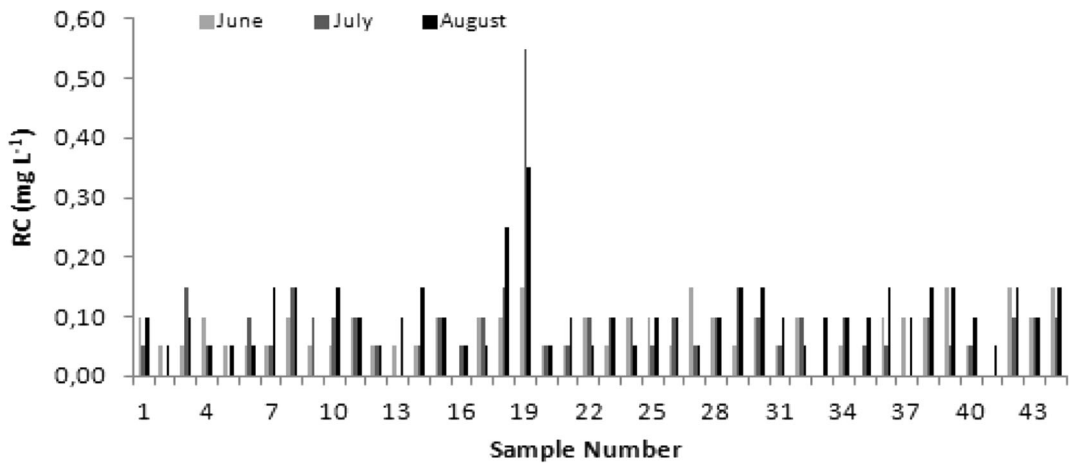

Fig. 5 Variations of RC in swimming pools in the summer period in the province and districts of Canakkale, Turkey (sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

Table 4 Descriptive statistical results of TA concentration, pH and temperature in swimming pools in the summer period in the province and districts of Canakkale, Turkey (*n*: Number of samples; *TA*: Total alkalinity; *l*: The number of unhealthy pool water samples according to the standard limit concentration values of Turkish Health Ministry; *UHPWS*: unhealthy pool water sample according to standard limit values of Turkish Health Ministry)

Month 2013	Parameters	Number	Maximum values	Minimum values	Average values	Standard deviation	Analysis accuracy	Limit values	*l*	UHPWS %
June	Temp. (°C)	44	30.00	22.50	26.40	1.463	–	26.0–38.0	6	13.64
	pH	44	8.100	6.500	7.300	0.428	±0.10	6.50–7.80	4	9.090
	TA (mg L^{-1})	44	364.0	0.000	131.0	100.7	±%5	30.0–180	12	27.27
July	Temp. (°C)	44	30.50	22.00	27.60	1.578	–	26.0–38.0	1	2.272
	pH	44	8.200	6.400	7.400	0.391	±0.10	6.50–7.80	5	11.36
	TA (mg L^{-1})	44	391.0	0.000	137.0	90.23	±%5	30.0–180	9	20.45
August	Temp. (°C)	44	32.00	26.50	28.70	1.296	–	26.0–38.0	0	0.000
	pH	44	8.000	6.600	7.200	0.331	±0.10	6.50–7.80	3	6.818
	TA (mg L^{-1})	44	50.77	33.00	120.0	76.05	±%5	30.0–180	7	15.91

RC samples (3 samples) were outside the standard limit values, also stated as unhealthy pool water samples (UHPWS) (Table 3 and Figs. 3, 4, and 5). However, UHPWS ratios varied from 15.9% (June) to 45.5% (August), from 13.6% (July) to 22.7% (August), and from 0.25% (August, Gelibolu) to 0.55% (August, Ecebat), respectively, for the three parameters (Table 3). Looking at the UHPWS ratios, it is clear that there were CyA and FC problems in the pools located around Canakkale, Turkey. Moreover, there was an important regression (R^2 = 0.7009) between CyA and FC (Fig. 9). When similar studies in other Europian countries were examined, the UHPWS ratios were generally lower than in our country.

Some relevant studies showed that there was correlation not only between CyA and FC, but also FC and other chloride species. For instance, Yue et al. (2016) reported that there were linearly correlated with chloride concentration between three volatile DBPs (NCl_3, $CHCl_3$, and $CNCHCl_2$). In other word, they indicated that free chlorine consumption was also observed increase with increase of chloride concentration. This relation was explained to be attributable to shifts in speciation of free chlorine, with higher chloride resulting in higher concentration of molecular chlorine (Cl_2), which is much more reactive than HOCl by Yue et al. (2016). On the other hand, another study showed that there was chlorine competition between different pioneers from natural organic matters which in pool water sources and body fluids of swimmers such as ure, uric acid, citric acid, and hippuric acid (Yang et al. 2016).

Simard et al. (2013) performed an annual study in Quebec City (Canada) in 15 indoor and 39 outdoor pools, including a total of 54 public municipalities and city mains water from 5 different locations. Sampling was performed once a month throughout the year from the indoor swimming pools, and at intervals of 2 weeks during the summer months (June, July, and August) from the outdoor swimming pools. DBP (THMs, HAAs, chloramines), FC, RC, pH, conductivity, and temperature values were compared. In the analysis, calorimetry, UV/VIS spectrophotometry, 0.25 μm thick column gas chromatography, ECD detectors, and portable multimeter were used. In the outdoor swimming pools, FC was in the range of 0.74–2.75 (Avg. 1.66 mg L^{-1}), RC was in the range of 0.04 to 0.43 (Avg. 0.16 mg L^{-1}), pH in the range of 7.44 to 8.33 (Avg. 7.85), and temperature was in the range 20.6 °C–26.2 °C (Avg. 23.2 °C). Gas chromatography (GC-MS)

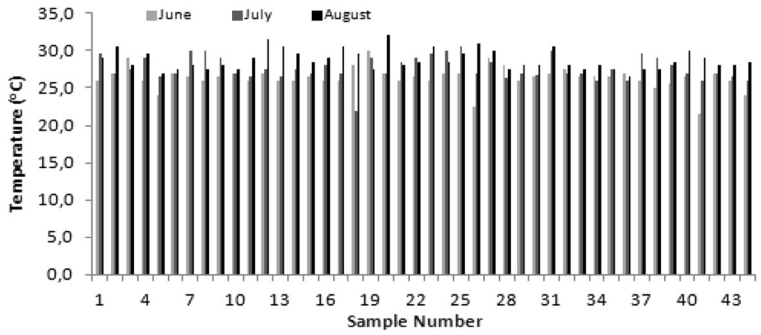

Fig. 6 Variations of temperature in swimming pools in the summer period in the province and districts of Canakkale, Turkey (sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

measurements made for chloramines determined a rate of about 55.0% NH_2Cl, 12.0% $NHCl_2$, and 33.0% NCl_3.

In our study, FC was in the range of 0–5.00 (Avg. 1.60 mg L^{-1}), RC was in the range of 0–0.55 (Avg. 0.087 mg L^{-1}), pH was in the range of 6.40–8.20 (Avg. 7.30), and temperature was in the range of 22.0 °C–32.0 °C (Avg. 27.6 °C). If we compare the two studies, average values were close to each other, apart from temperature. The reason for the difference in water temperature may be due to the climatic differences between Canada and Turkey. Another important point between the two studies is that although average pool temperatures were different, FC and RC averages were very close together. The comparison of swimming pools in the two countries showed both use stabilized chlorine compounds for disinfection as indicated by the FC levels.

In other investigation, Yang et al. (2016) studied formations of DBPs by alternative disinfectants for swimming pool disinfection in tropical conditions. They revealed that outdoor pools usually negatively affect by the dense sunlight which degradates the free chlorine rapidly. On the other hand, sunlight also increases temperature in pool waters. It is known that higher temperature enhances the DBP formation, because reaction rates depend on the temperature. Therefore, temperature control pool waters, especially which have higher temperature in view of DBP levels. It is known that most people prefer pool waters which have higher temperatures for hydrotherapy (Yang et al. 2016). Therefore pool waters should be took into consideration in view of sunlight and temperature. Because, both sunlight and temperature increase indirectly affects potential DBP formation in pool waters.

Summer average results showed that temperature, pH, and TA levels varied between 22.00 and 32.00 °C (27.60 ± 1.446 °C), 6.400 and 8.200 (7.300 ± 0.383), and 0 and 391.0 mg L^{-1} (129.3 ± 89.00), respectively. Although there is no problem in view of average values of water quality parameters, there are some problems in view of the maximum values of pH and TA levels in pool waters according to standard limit values of the Health Ministry of the Turkish Republic and some European countries (Table 4 and Figs. 6, 7, and 8).

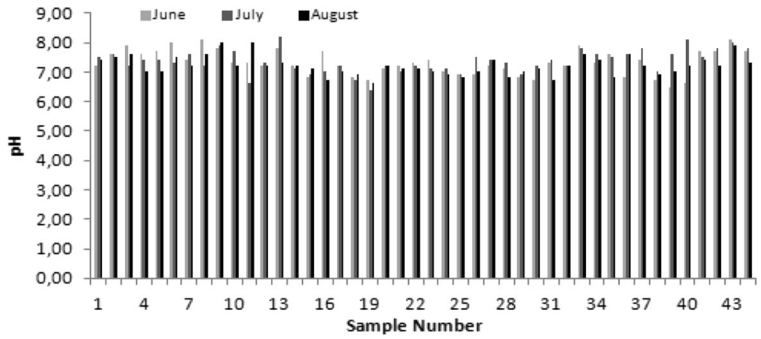

Fig. 7 Variations of pH in swimming pools in the summer period in the province and districts of Canakkale, Turkey (sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

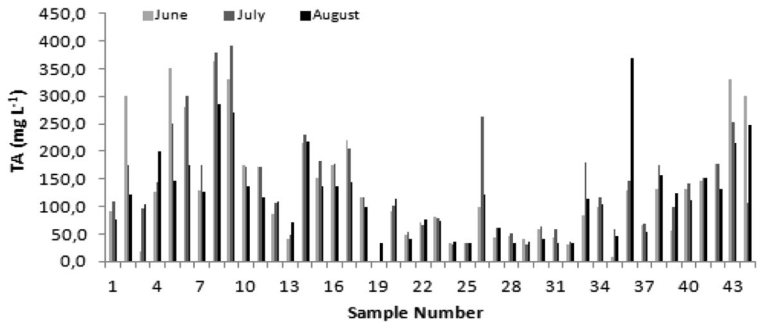

Fig. 8 Variations of TA in swimming pools in the summer period in the province and districts of Canakkale, Turkey (sample numbers 1–13: Ayvacik-Kucukkuyu, 14–16: Bozcaada, 17: Ezine, 18: Eceabat, 19: Gelibolu, 20–21: Çan, 22–23: Yenice, 24–25: Biga, 26–32: Çanakkale, 33–36: Ayvacik-Assos, 37–44: Ayvacık-Kadırga)

Temperature values from a total of 44 pools varied between 22.0 and 32.0 °C during the summer tourism period. Based on the standard values for pool waters of Turkish Health Ministry and the standards of some European countries, all temperature values were within standard limits except for some minimum values from samples numbered 5, 18, 26, 38, 39, 41, and 44 (Fig. 6). UHPW ratio for temperature during the summer was calculated as 5.303% (Table 4).

Measurements revealed that pH levels from swimming pools in the Çanakkale region in the summer period (6.40–8.20) were generally within standard limit values. From the total of 132 pool water samples, only 12 pool water samples were over or under the standard pH limit value of the Turkish Health Ministry. While only one sample measurement was under the standard limit value (sample number 19: pH 6.40), 11 sample measurements were above the Turkish standard upper limit value (Table 3). The high pH values were measured in samples 3, 6, 8, 9, 11, 13, 33, 40, and 43. UHPW ratio for pH in the sampling period was calculated as 9.840% (Table 4).

Based on the limit values for pool water standards of Turkish Health Ministry (30–180 mg L^{-1}) and the standards of some European countries (25–200 mg L^{-1}), more than one in five of the TA measurement results were outside of the lower and upper limit values (Fig. 7). During the study, from a total 132 sample measurements, while 3 TA sample measurements were under the lower standard limit values, 26 TA sample measurements exceeded the upper standard limit values (Fig. 6). UHPW ratio for TA in the sampling period was calculated as 21.21% (Table 4).

Compared to other types of disinfection, CyA has several advantages. Clasen and Edmondson (2005) used NaOCl (sodium hypochlorite) with NaDCC (sodium dichlorocyanurate) in their study for water disinfection and compared results. In both NaOCl and NaDCC, although $HOCl^{-}$ was used as active agent for disinfection, there are significant differences in performance of the two compounds. In environments where the pH is high or variable, NaDCC provides some advantages compared to NaOCl. $HOCl^{-}$ loses effectiveness to disinfect water at higher pH levels and is known to undergo dissociation. $HOCl^{-}$' releases a significant amount while NaDCC works in a wider pH range. Also NaDCC tablets tend to reduce the pH of the water, as in acidic solutions. This situation is also observed to support the formation of $HOCl^{-}$. Hypochlorites are alkali, and this situation tends to increase the pH value which is considered undesirable. Another difference relates to the storage conditions. The recommended period of use for a tightly closed opaque NaOCl bottle is 6 months after opening. NaDCC has a shelf life of 5 years in temperate and tropical climates, which is another advantage. Liquid NaCl contains approximately 5.00% available chlorine, while anhydrous NaDCC contains about 62.0% chlorine which is a big advantage. A single 67.0 mg NaDCC tablet can disinfect 20.0 L of water with 2.00 ppm FC dosing. Moreover, researchers have found NaDCC and THMs to be advantageous for the formation of NaOCl. In this study, isocyanate containing chlorine was found to be slightly toxic and less corrosive.

The findings of both our study and of others which discussed above suggest that variations in swimming

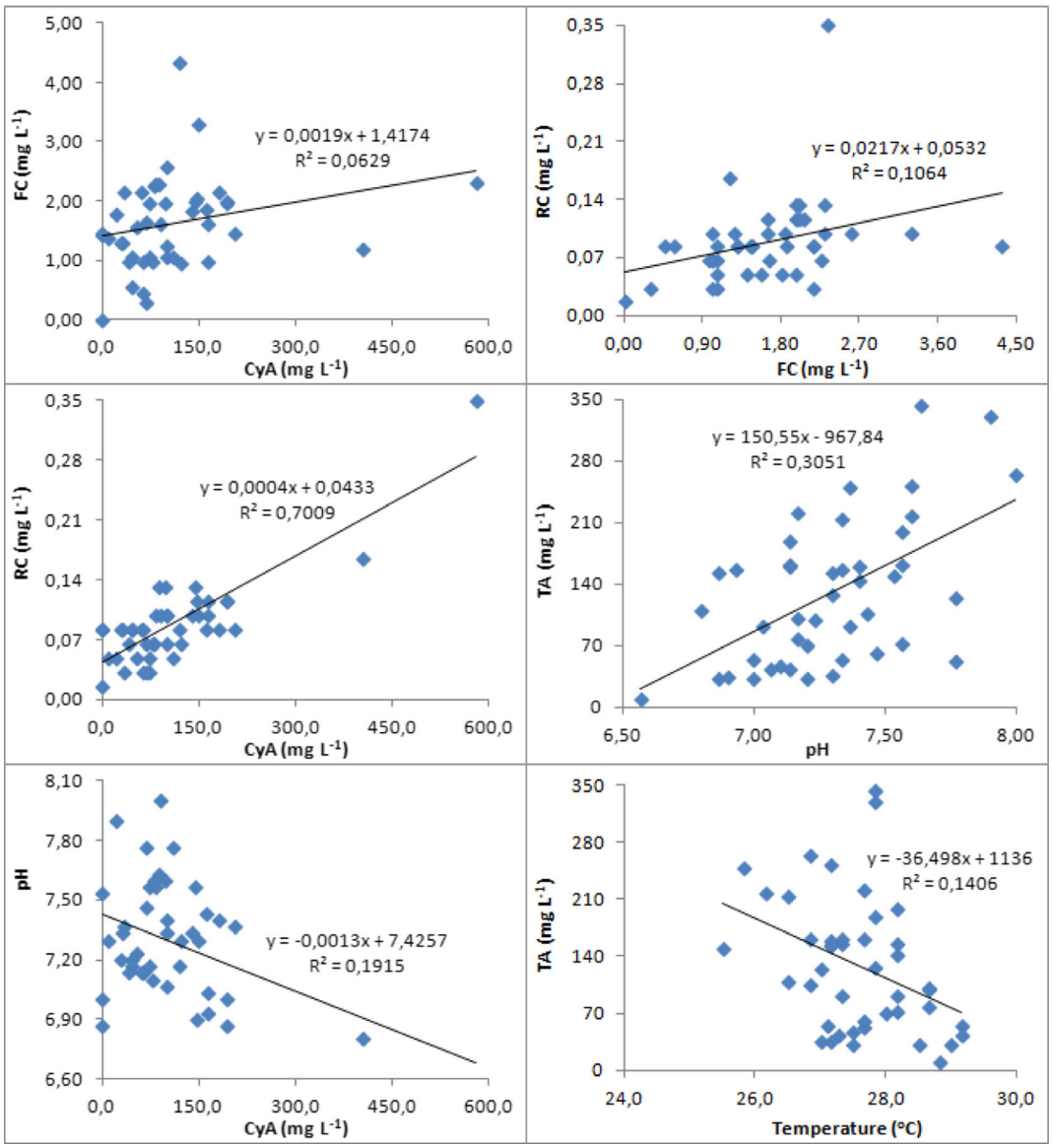

Fig. 9 Relationships between pool water disinfectants (FC, RC, and CyA) and other water quality parameters (temperature, pH, and TA) in the summer period in the province and districts of Canakkale, Turkey. The coefficients of determination (R^2) and the equation (y) are shown for each regression

pool management strategies to support low chloride level could be important for check of volatile disinfection by-products (DBPs) in swimming pools and in order to decrease free chlorine use.

Conclusion

- NaDCC, as shown in other studies carried out on swimming pool disinfectants, is a stabilizer that offers many advantages for disinfection.
- A high level of CyA indicates frequent changes of water were made. Generally, high concentration of total alkalinity due to the hardness of the pool water was estimated to have a negative effect on disinfection by increasing the pH of pool water.
- From a single pool, high RC values (sample 19) were measured (0.55 and 0.35 mg L^{-1}). CyA measurements with very high concentration were obtained in this pool at Gallipoli (603, 725, and 412 mg L^{-1}). pH measurements in the same pool

of 6.70, 6.40, and 6.60 were close to the lower limit value (6.50) and TA (0.00, 0.00, and 33.0 mg L^{-1}) was under the lower limit. The low alkalinity and high CyA were effective in decreasing the pH. High concentration measurements of RC and CyA clearly reveal that insufficient changes were made to water in the pool.

- There were seven (7) measurements under the lower limit value for temperature (26.0 °C) measurements, with 6 of them in June. This may be due to the lower temperature and less use of the pool in this month.
- High pH measurements were observed together with the highest value of overall TA (samples 6, 8, 9, 10, and 43). This was also supported by regression results between pH and TA (Fig. 9).
- pH values were identified near the lower limit, generally together with high CyA values (samples A 18, 19, 29, 30, 36, 38, 39, and 40).
- The stabilizer used as a disinfectant was shown to be affected by water temperature and FC concentration level consisting of chlorine compounds.
- pH limit values of Turkey and other countries (avg.) are close to each other with a small gap to the limit value in England (7.20 to 7.40).
- FC has low range values in European countries (median), while, in Turkey, it has a wider range (1.00 to 3.00 mg L^{-1}). But contrarily, RC is low in Turkey and Germany (0.20 mg L^{-1}), while other countries are more tolerant (≤0.30, ≤0.40, ≤0.60, and ≤1.00 mg L^{-1}).
- The wide range of values in Turkey for FC (1.00 to 3.00 mg L^{-1}) provides tolerance to the user in terms of the amount of disinfectant (CyA) used. These results from 44 pools have an average of 14, resulting in high levels of concentration of CyA.

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