Environment and Natural Resources Journal

Volume 23
Issue 3
2025

Sustainable Management of Chlorine Consumption in an Outdoor Swimming Pool: A Case Study of the Silpakorn University Swimming Pool

Umarat Santisukkasaem*

Department of Environmental Science, Faculty of Science, Silpakorn University, Nakhon Pathom, Thailand

ARTICLE INFO

Received: 25 Jun 2024
Revised: 6 Mar 2025
Accepted: 11 Mar 2025
Published online: 2 Apr 2025
DOI: 10.32526/ennrj/23/20240181

Keywords:
Outdoor swimming pool/ Chlorine management/ Environmental sustainability/ Water quality analysis/ Resource efficiency

*** Corresponding author:**
E-mail:
santisukkasaem_u@su.ac.th

ABSTRACT

The general daily maintenance of outdoor swimming pools includes the addition of chlorine for disinfection. Chlorine is a potentially hazardous chemical that is harmful to users, and its excessive addition could lead to health effects in swimmers while insufficient levels may result in inadequate disinfection. This study aimed to optimize chlorine management at the Silpakorn University swimming pool by analyzing the physical and chemical characteristics of outdoor pool water. Initial sampling revealed an unacceptably high residual chlorine concentration of 20 mg/L, exceeding regulatory standards. To address this, a chlorine management strategy was implemented. Chlorine adjustment was conducted by measuring the residual chlorine concentration and calculating the chlorine demand. Post-intervention results indicated that residual chlorine and pH levels were successfully brought within acceptable limits. Further analysis confirmed that parameters such as hardness, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, suspended and dissolved solids, and total and fecal coliform bacteria met safety standards. Recommendations were given to the pool caretaker, including the use of personal protective equipment (PPE) while handling chlorine, a precise measurement of chlorine (1 kg daily), and regular filtration tank maintenance at least twice a month. Besides improving social and environmental aspects, the optimized chlorine usage resulted in an estimated annual cost saving of $1,213.26 (1 USD ≈ 36.065 THB). This study highlights the importance of sustainable chlorine management in swimming pools, offering a practical approach that can be replicated in similar facilities.

1. INTRODUCTION

Swimming is a sport that people enjoy because it is relaxing and involves using every part of the body. Disinfection is the top priority in controlling the water quality of swimming pools. Chlorine is the most popular disinfectant used to kill germs and bacteria because it is easily available, inexpensive, easy to use, and, most importantly, very effective. However, chlorine, after mixing with pool waters, human excretions, and personal care products, has the potential to form genotoxic and carcinogenic disinfection byproducts (DBPs) (Manasfi et al., 2017). DBPs include trihalomethanes, which can exert health effects on the respiratory system. Shan et al. (2023) studied the toxicity of diethylamino hydroxybenzoyl hexyl benzoate (DHHB), a chemical that poses a major health risk, in swimming pools. They concluded that the source of the detected DHHB was the sunscreens and other personal care products worn by swimmers that were mainly oxidized by the free chlorine in swimming pools. The latest research in Thailand on swimming pools evaluated chloroform and its related health risks. Outdoor pools were found to have the highest average chloroform concentration of 63.89±12.76 µg/L, leading to an unacceptable risk for lifetime cancer in adult male and female groups (Laohapongsomboon et al., 2025).

Citation: Santisukkasaem U. Sustainable management of chlorine consumption in an outdoor swimming pool: A case study of the Silpakorn University Swimming Pool. Environ. Nat. Resour. J. 2025;23(3):256-264. (https://doi.org/10.32526/ennrj/23/20240181)

Therefore, several studies have focused on chlorine byproducts, specifically, their formation, exposure, and health impacts on pool users. Most of these studies were conducted on indoor swimming pools (Carter and Joll, 2017; Yang et al., 2018; Lempart et al., 2020; Abilleira et al., 2023; Zhang et al., 2023a; Zhang et al., 2023b; Peng et al., 2024). Given that chlorine is the precursor of DBPs, reducing chlorine levels will decrease DBP levels. A future study need is to minimize DBP formation (Chowdhury et al., 2014). Goma et al. (2017) proposed a new method to reduce chlorine oxidant derivatives by (1) replacing hydrochloric acid, the chemical used to reduce pH, with carbon dioxide; (2) using a low-concentration salt electrolysis system to produce hypochlorous acid ($HOCl^-$) to enhance sodium hypochlorite addition; and (3) introducing ultraviolet radiation to degrade chloramines. Studies on the application of peracetic acid (PAA) as an alternative disinfectant in outdoor swimming pools concluded that compared with chlorine, PAA is likely to produce less DBPs but has a higher price (Jia et al., 2023; Lin and Lin, 2024). Existing standards for chlorine concentrations in pool water are inconsistent and depend on the authorities of each country. For example, Dallolio et al. (2013) summarized the physical-chemical standards for swimming pool water in some European countries without considering if a pool was an indoor or outdoor pool. They found that residual chlorine values varied from 0.3 mg/L to 8.2 mg/L, and none of the countries specified the same value. The World Health Organization (WHO) recommended that the free chlorine concentration in public pools should not exceed 3 mg/L (WHO, 2006). The range of 0.6-1.0 mg/L was advised by the public health committee under the Department of Health, Ministry of Public Health of Thailand (2007) and enforced as a criterion of GREEN Health Hotel Standards in Thailand (Department of Health, 2023). Although no comprehensive legislation enforcing the amount of chlorine used exists, the free chlorine range should be set at the local level. Furthermore, considering that chlorine is inexpensive, its consumption has never been strictly controlled. Rosende et al. (2020) analyzed the cost-effectiveness of chlorine-based and unconventional disinfection products and concluded that the most affordable disinfectant agent in the pilot setup was sodium hypochlorite. Apart from the environmental and health impacts of excessive chlorine consumption, the highest expense in pool maintenance under life cycle assessment was found to be human resources (workers) and chlorine purchase (de Moura et al., 2023). Several studies emphasized chlorine consumption and transformation into DBPs, as well as alternative disinfectants, but none had pinpointed the priority of waste management: chlorine consumption reduction. This research gap exists because studies in general focused on the impacts and minimization, but not source reduction, of DBPs. Therefore, the novelty of this present study is the prioritization of the reduction of chlorine consumption to alleviate undesirable effects on sustainability. In contrast to the existing research that deployed reactive measures, which are considered as end-of-pipe treatments in environmental management, this study employed a proactive measure to avoid or prevent generating pollution at the source.

The Silpakorn University swimming pool is an outdoor pool located in the university area of the Sanamchandra Palace Campus, Nakhon Pathom, Thailand. In addition to the amount of chlorine consumed for disinfection, other factors -- such as temperature, rainfall amount, and contaminating particles, i.e., leaves and insects -- must be considered because they contribute to water quality. A preliminary investigation of the pool revealed the absence of a proper chlorine management system. The amount of chlorine added to the pool has never been properly controlled: A maintenance worker simply adds approximately 2 kg of trichloroisocyanuric acid and chlorine powder daily and adjusts the pH to neutral by adding either hydrochloric acid or basic solution. This situation is a typical issue, with researchers observing that in new checklists for swimming pool evaluation, data on chlorine use are not always recorded (Liguori et al., 2014). In the absence of a proper monitoring and recording system for chlorine consumption, the amounts of chlorine added and purchased strictly depend on the worker's experience. However, none of the customers reported health impacts, and the total cost and the amount of chlorine consumed are both negligible relative to those of other materials consumed in the university. The author would like to declare that this research was conducted only to observe the possibility of consumption reduction and identify its benefits. All findings here should not be considered offensive in any way.

The abovementioned issues lead to effects on environmental sustainability. Specifically, the overconsumption of chlorine creates unnecessary toxic pollutants. Their social impact can be seen in health effects experienced by pool users from swimming in water with excessive amounts of residual chlorine and the formation of potential DBPs, as well as those experienced by maintenance workers resulting from the inappropriate handling of chlorine. Finally, economic impact is the additional cost of chlorine purchase. All of the above issues are related. Therefore, in this research, chlorine addition was studied, and the data collected during pre- and postmanagement were considered to provide guidelines for the sustainable and safe handling of chlorine. The ultimate aim of this work is to support Sustainable Development Goal 12: Responsible Consumption and Production because reducing chlorine use can simply help achieve the sustainable management and efficient use of natural resources at the local level (Target 12.2, (UN, n.d.)), as well as promote social and economic benefits.

2. METHODOLOGY

2.1 Sampling plan and locations

The pool was investigated to collect physical and chemical data. A maintenance worker was interviewed regarding chlorine handling and related details, with a disclaimer asserting that the worker will not be held responsible for any issues that may arise from providing information given that the objective of the interview is entirely to gather relevant information. The physical features of the pool surroundings were surveyed. For chemical data, chlorine sampling (Table 1) lasted for five weeks. During chlorine sampling, grab sampling was conducted daily for seven days during the first week and weekly for four weeks (21 samples at all locations per day, yielding a total of 231 samples) and 12 random days in between weeks (1 sample per day at random locations, yielding a total of 12 samples) for a total of 22 times. In the sampling strategy, the samples collected on days 1-7 represented the baseline condition. The baseline data were used in planning the amount of chlorine added. Subsequently, weekly samplings (days 14, 21, 28, and 35) were conducted during the implementation phase to observe the changes in residual chlorine concentration. Lastly, 12 samples were randomly collected to ensure the efficiency of implementation. Other related parameters in pool water quality analysis, namely, hardness (in the form of $CaCO_3$), ammonia nitrogen (NH_3), nitrate nitrogen (NO_3^-), nitrite nitrogen (NO_2^-), total dissolved and suspended solids, and total and fecal coliforms, were analyzed by using the data of the samples collected on days 1 and 35 as the pre- and postimplementation data, respectively. Figure 1 illustrates the 21 sampling points that were identified to represent the water quality of the whole pool. Given that the pool bottom is sloped with varying depths, it was divided into three zones (A-C) along the length of the pool. Each zone was further divided into three levels with respect to the pool depth. The volume of water in the pool was calculated to identify the sample volume.

Table 1. Sampling plan

Day	Sampling frequency	No. of samples
1-7	Daily (7 days in a row)	147 (21 per day)
8-13	Daily (in between week)	3 (1 per random day/location)
14	Weekly (once a week)	21
15-20	Daily (in between week)	4 (1 per random day/location)
21	Weekly (once a week)	21
22-27	Daily (in between week)	2 (1 per random day/location)
28	Weekly (once a week)	21
29-34	Daily (in between week)	3 (1 per random day/location)
35	Weekly (once a week)	21

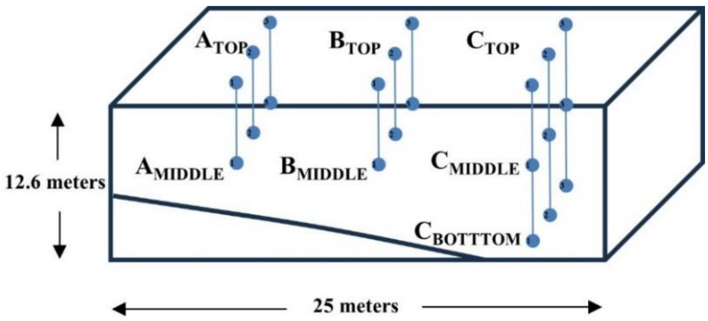

Figure 1. Sampling locations and dimensions of the pool

2.2 Sample analysis

The sample volume was approximately 2 L per sampling point. The samples were mainly analyzed for residual chlorine concentration. Remnants were combined and analyzed for other parameters. Triplicate analysis was conducted on every sample. The results were compared with Thai (Ministry of Public Health of Thailand (Public Health Committee, 2007) and international standards (WHO, 2006). The pH and temperature of the collected samples were measured with a pH meter and thermometer, respectively, and the samples were further analyzed for residual chlorine (iodometric titration) and chlorine demand (calculation). Analysis of variance (ANOVA) (α=0.05) was used to validate the homogeneity of the water throughout the pool. The difference in residual chlorine concentration was tested at three sampling points (number of samples: A=6, B=6, and C=9) on the first day (day 1) and last day (day 35) of the experiments. The additional parameters of hardness (EDTA titration), NH_3 (preliminary distillation step and titration), NO_2^- (diazotization), NO_3^- (diazotization and cadmium reduction), suspended and dissolved solids (gravimetric analysis), and bacteria (total coliform MPN test) were analyzed to ensure that the water quality complied with the standard. Given the limited number of samples (n=3 at each sampling point: A, B, and C), nonnormal distribution was assumed. The Wilcoxon test was therefore performed to verify the difference in the pre- and postcontrol data (α=0.05) for all additional parameters. All water sample analyses were conducted by following standard methods (APHA, 2017).

Chlorine adjustment was conducted simply by measuring the residual chlorine concentration and calculating the chlorine demand, which is the amount of chlorine addition required to provide sufficient residual chlorine to ensure disinfection capacity. Residual chlorine results from the chemical reaction of chlorine and organic materials. When chlorine oxidizes all organic materials, the residual chlorine then acts as a disinfectant. Therefore, the chlorine demand can be calculated by using the differences between the concentrations of the added and residual chlorine. The amount of chlorine adjustment was calculated to supply the residual chlorine concentration in accordance with the standard of the Ministry of Public Health of Thailand of 0.6-1.0 mg/L (Public Health Committee, 2007) and the WHO standard of less than 3.0 mg/L (WHO, 2006), which is the adequate concentration for disinfection.

3. RESULTS AND DISCUSSION

3.1 Preliminary experiments

Theoretically, the amount of added chlorine can be simply calculated from the pool area. However, the outdoor pool investigated in this work may contain interferences, such as rain, sunlight, and leaves, which might affect the amount of residual chlorine. An experiment must then be conducted to reassure that the amount of chlorine added is adequate. Given that the preliminary measurement indicated that the amount of residual chlorine was approximately 20 mg/L, which significantly exceeded the standard of 0.6-3.0 mg/L, experiments were conducted along with daily and weekly sampling to avoid whole-pool water replacement. The pH value reflects the hydrogen ion concentration in water and thus directly affects the structure of the residual free chlorine. A high pH is associated with low hypochlorite (OCl^-) ion levels, implying low disinfectant efficiency given that OCl^- is negatively charged and thus has the tendency to bond with the suspended solids in water and become inactive. However, some OCl^- ions are converted into hypochlorous acid ($HOCl^-$), which has a high disinfectant efficiency. Moreover, even though high temperatures result in high dissolved chlorine levels, an increase in water temperature causes a reduction in $HOCl^-$ and thus, in-efficiency. Temperature is therefore a concern for outdoor pools in Thailand. Nonetheless, it exerts a negligible impact on the pH. As shown in Figure 2, even when the temperature increased, the pH did not decrease. This situation indicates that the controlled amount of added chlorine worked at the typical ambient temperature, causing the pH to meet the standard values of 7.20-7.80 (WHO, 2006), which are not only safe for swimmers but also provide sufficient disinfectant capacity.

3.2 Control of chlorine addition

Given that the residual chlorine concentration exceeded the limit, the amount of chlorine added was controlled and the residual chlorine concentration was measured throughout the experiment. Figure 3 provides the residual chlorine concentration at every sampling point from days 1 to 35. The daily data showed that during the first week, the chlorine concentration gradually decreased from approximately 19 mg/L to 9 mg/L. The weekly data indicated a similar trend, and chlorine concentration remained constant within the range of 3-5 mg/L during the last weeks of the experiment. ANOVA verified that there is no difference among sampling locations A, B, and C. Therefore, the

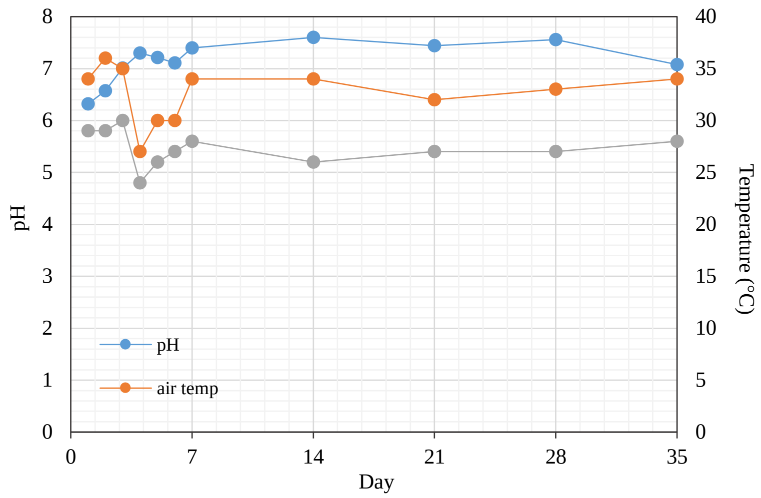

Figure 2. pH and temperature of the pool

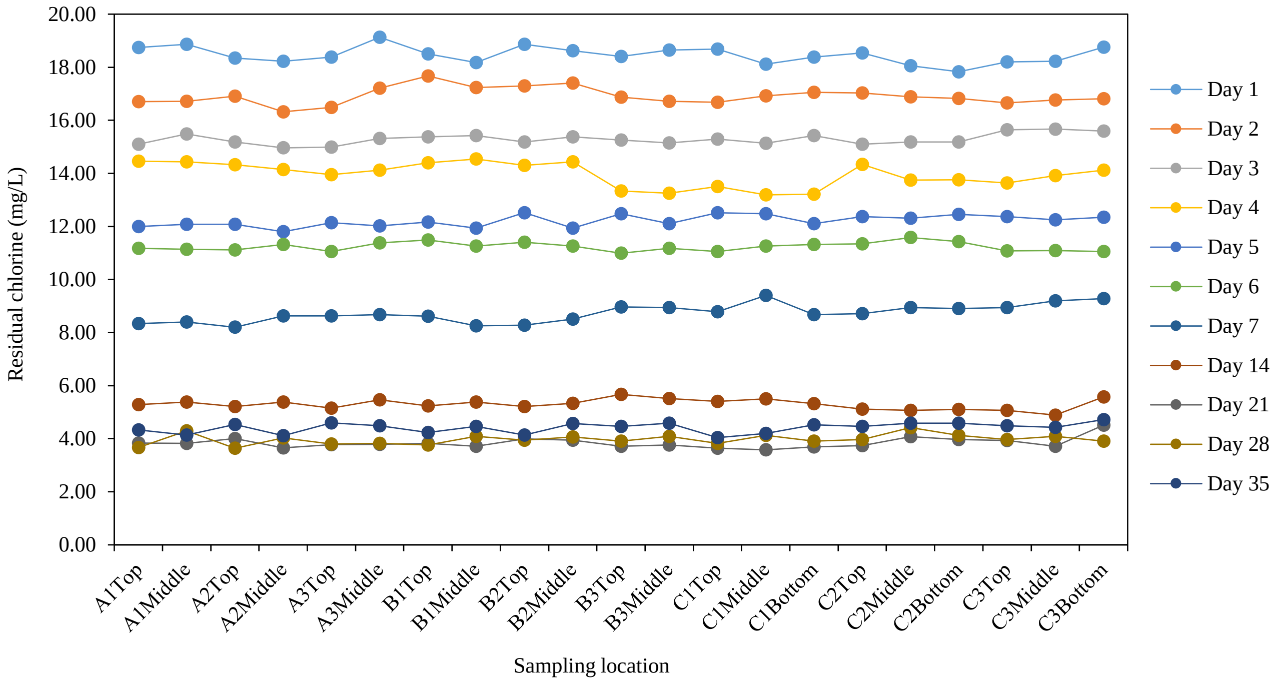

Figure 3. Residual chlorine concentration

pool water is assumed to have mixed homogeneously, enabling the diffusion of the added chlorine throughout the pool. Overall, the control provided a significant reduction in residual chlorine concentration. However, the residual chlorine concentration still exceeded the standard of the Ministry of Public Health of Thailand of 0.6-1.0 mg/L and the WHO standard of less than 3.0 mg/L due to the uncontrolled factors of precipitation; sunlight; temperature; dust particles, debris, and leaves that had fallen into the pool; and the number of pool users. These factors are the main limitations for operating outdoor pools, making pinpointing the exact amount of added chlorine inconvenient. This finding is also confirmed by the fluctuation of the residual chlorine concentration, which ranged from 3.01 mg/L to 7.61 mg/L. The data for the residual chlorine concentration were obtained from random sampling during the experiment. Therefore, the chlorine demand was calculated by using the residual chlorine data from the last four weeks, as shown in Figure 4. The average chlorine demand fell within the range of 1.15±0.39-3.52±0.10 mg/L. In the identification of the amount of chlorine added to provide sufficient disinfection while complying with the standard limit, the data from the day (day 28) that provided the optimum residual chlorine concentration (1.63-3.51 mg/L) that was closest to the standard were selected. The calculation conducted in accordance with the volume of pool water showed that the amount of added chlorine should be 1.10-2.30 kg. The addition of the minimum amount of 1.10 kg of chlorine resulted in the residual chlorine concentration of 1.63 mg/L. Therefore, in theory and practice, the addition of 1 kg of chlorine results in adequate disinfection. In addition, a study conducted on Northeastern Ethiopia outdoor swimming pools, which had similar characteristics as the pool in this study, i.e., similar ranges of temperature, pH, and residual chlorine concentrations, indicated that most pool water samples did not meet the WHO standard limit (Natnael et al., 2024). Therefore, the results of this study could possibly be applied to other swimming pools operated in a similar manner.

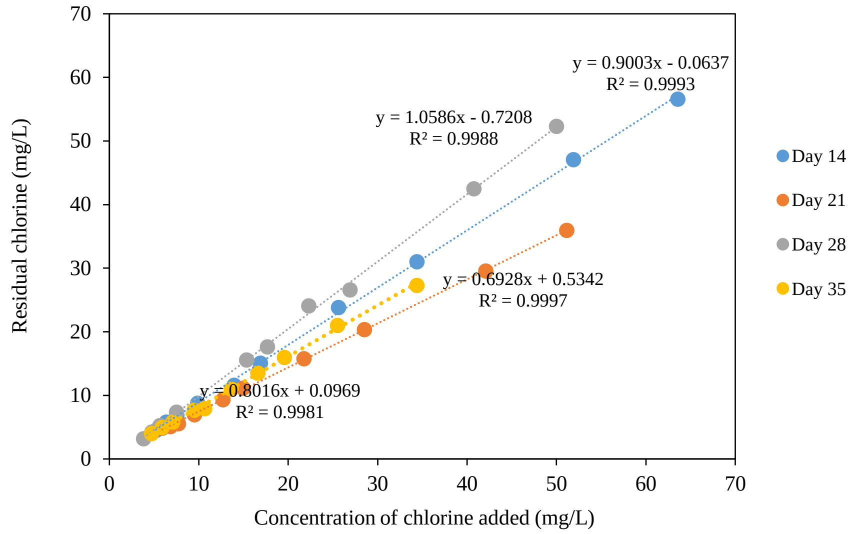

Figure 4. Relationship between residual chlorine and chlorine demand

3.3 Water quality analysis

Other related parameters were also measured to ensure the safety of pool users. All values fell within standard limits. The pre- and postimplementation data were sampled and analyzed (Figure 5) to confirm that reducing the amount of chlorine added would neither interfere with the disinfection efficiency nor create any toxic byproducts. Hardness is the amount of dissolved calcium (in the form of $CaCO_3$) in water. An excessively low hardness level can result in corrosion, causing in the tearing off of sealants, whereas an excessively high hardness level can cause precipitation, thus disturbing system operation. The levels of hardness (in the form of $CaCO_3$) reduced from an average value of 441 mg/L to 415 mg/L before and after the experiment, respectively. The values of hardness (in the form of $CaCO_3$) recommended by the Thai Public Health Committee (2007) are 250-600 mg/L. The average pre- and postexperimental NH_3 levels were 0.34 and 0.07 mg/L, respectively. The standard for NH_3 is less than 20 mg/L. NO_2^- had an average value of 0.0008 mg/L and was undetectable after treatment. The latter effect is typical because NO_2^- does not tend to accumulate in water but is rather converted into nitrate rapidly. The average NO_3^- also declined from 3.55 mg/L to 3.17 mg/L. The standard for NO_3 is less than 50 mg/L. NO_3 values were distributed equally in each zone, indicating that the water had mixed homogeneously throughout the pool. Total suspended solids (TSS) decreased from 2.10 mg/L to nondetectable levels (no standard limit), whereas the total dissolved solids (TDS) nonsignificantly increased (≈18.11%) from 836.28 mg/L to 1,021.28 mg/L without exceeding the standard of 1,000-2,000 mg/L. The last but most important parameters are total coliform bacteria and fecal coliform bacteria, which were confirmed to be both negative. In addition, the Wilcoxon test validated the absence of a statistically significant difference between the pre- and postexperimental concentrations in this work. The data on NO_2^- and TSS were excluded due to the lack of detectable data. Therefore, although the amount of chlorine added was reduced by half, the disinfection efficiency remained the same.

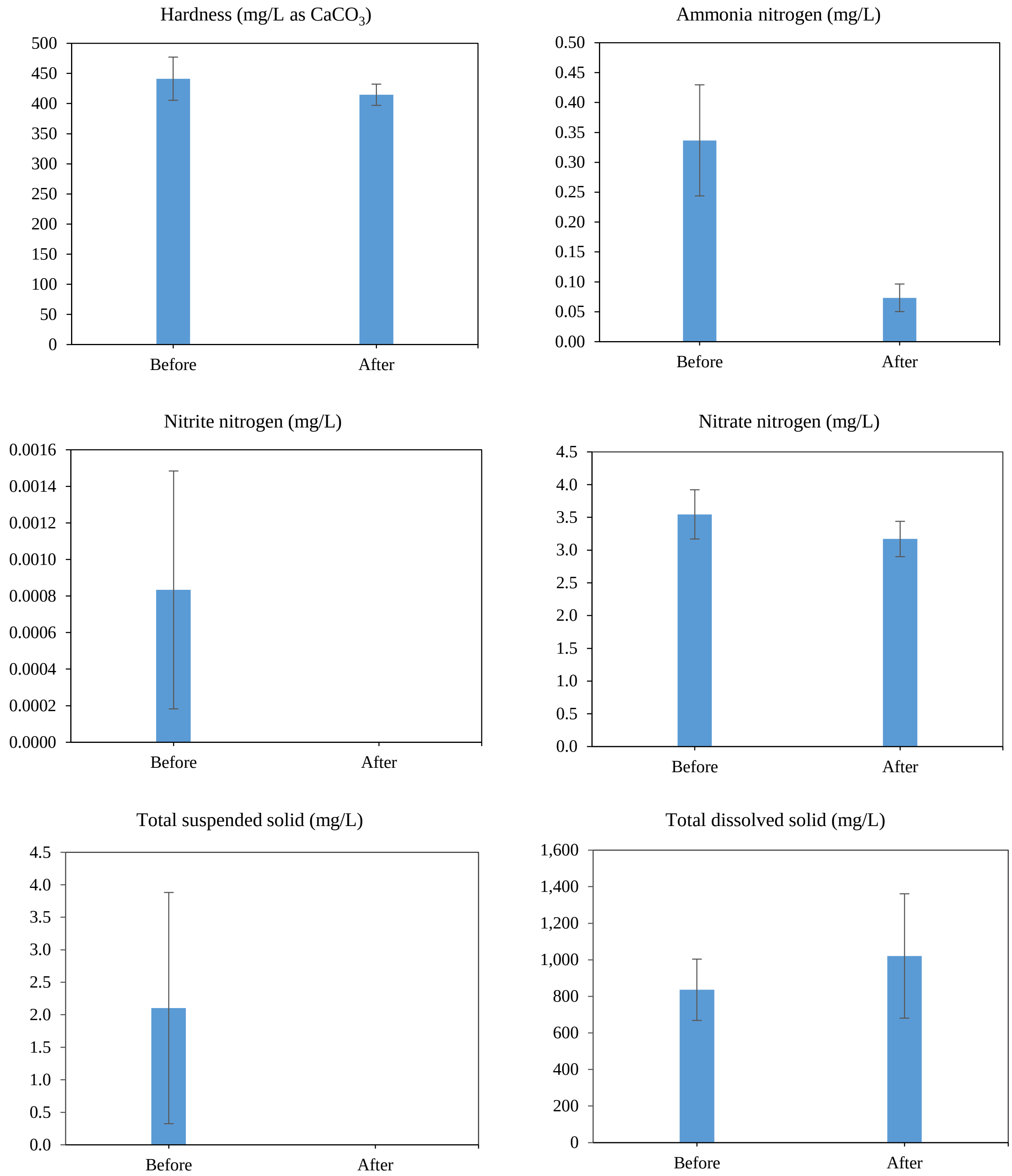

Figure 5. Pre- and postexperimental data on pool water quality

4. CONCLUSION

The experimental results showed that reducing chlorine consumption yielded a similar disinfection efficiency. This research technically supports the practices of SDG12: Sustainable Consumption and Production and partly supports Subtarget 3.9 (Mortality from Environmental Pollution) of SDG3: Good Health and Well-being. The avoidance of excessive chlorine can contribute to sustainability as follows: From an environmental perspective, the values of all related parameters comply with the standard. The underlying point is that the amount of chlorine added is reduced by 50%, i.e., from 2 kg to 1 kg daily. Even though chlorine is not a greenhouse gas, reducing chemical consumption is the first principle in environmental management and circular economy because it can decrease natural resource consumption and prevent pollution throughout the chlorine life cycle. From an economic perspective, reducing chlorine consumption by half has monetary value because using only 1 kg of chlorine daily is equivalent to a reduction of 365 kg of chlorine yearly, resulting in annual cost savings of approximately $1,213.26 (1 USD ≈ 36.065 THB). This figure was calculated by using an average cost of chlorine of $3.33 per kg and a preimplementation consumption rate of 2 kg per day. Therefore, adding 2 kg of chlorine per day for 365 days per year results in the consumption of 730 kg of chlorine or cost of $2,430.90 per year. As mentioned previously, the postimplementation consumption of chlorine reduced by half. The above values may slightly vary due to currency conversion. From a social perspective, excess chlorine can cause damage to the health of pool caretakers and swimmers. Therefore, reducing chlorine additions decreases exposure risk. The results of this research can act as baseline information in the formulation of local policies related to sustainable environmental management and can be further utilized by any corporation with outdoor swimming pools operated in a similar manner. Nevertheless, this work has some limitations, and the following possible future recommendations should be considered: (1) the long-term microbial risks due to the reduced amount of chlorine added should be monitored; (2) biotic and abiotic interferences, such as rain, sunlight, and pool user behavior, should be clearly identified and studied thoroughly; (3) applicability to other pools under different climatic conditions or different pool types should be explored; and (4) potential hidden costs, such as increased maintenance time and worker behavioral changes, should be observed.

ACKNOWLEDGEMENTS

The author would like to acknowledge the financial support from the Research Grant for PhD Graduated Scholars (grant number SRF-PRG-2561-06) from the Faculty of Science, Silpakorn University. Parts of the sampling and analysis were performed by the author’s colleagues and students who provided expertise that assisted the research; their support is greatly appreciated.

REFERENCES

Abilleira E, Goni-Irigoyen F, Aurrekoetxea JJ, Cortes MA, Ayerdi M, Ibarluzea J. Swimming pool water disinfection by-products profiles and association patterns. Heliyon 2023;9:e13673.

American Public Health Association (APHA), American Water Works Association, Water Environment Federation. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC, United States of America: American Public Health Association; 2017.

Carter RAA, Joll CA. Occurrence and formation of disinfection by-products in the swimming pool environment: A critical review. Journal of Environmental Sciences 2017;58:19-50.

Chowdhury S, Alhooshani K, Karanfil T. Disinfection byproducts in swimming pool: Occurrences, implications and future needs. Water Research 2014;53:68-109.

Dallolio L, Belletti M, Agostini A, Teggi M, Bertelli M, Bergamini C, et al. Hygienic surveillance in swimming pools: Assessment of the water quality in Bologna facilities in the period 2010-2012. Microchemical Journal 2013;110:624-8.

de Moura IEMO, Neto JMM, da Silva EA. Residential swimming pools maintenance under an environmental perspective. Science of the Total Environment 2023;903:Article No. 166612.

Department of Health, Ministry of Public Health, Thailand. GREEN Health Hotel Standard [Internet]. 2023 [cited 2024 Feb 21]. Available from: https://ghh.anamai.moph.go.th/storage/app/uploads/public/64d/312/75c/64d31275c7242198337016.pdf.

Goma A, de Lluis R, Roca-Ferrer J, Lafuente J, Picado C. Respiratory, ocular and skin health in recreational and competitive swimmers: Beneficial effect of a new method to reduce chlorine oxidant derivatives. Environmental Research 2017;152:315-21.

Jia M, Chen X, Liu B, Hur K, Dong S. Persistence kinetics of a novel disinfectant peracetic acid for swimming pool disinfection. Journal of Hazardous Materials 2023;457:Article No. 131792.

Laohapongsomboon C, Youdee K, Suma Y, Kiattisaksiri P. Health risk assessment of chloroform in swimming pools: A case study in Lampang province, Thailand. EnvironmentAsia 2025;18(1):138-49.

Lempart A, Kudlek E, Dudziak M. The potential of the organic micropollutants emission from swimming accessories into pool water. Environment International 2020;136:Article No. 105442.

Liguori G, Capelli G, Carraro E, Di Rosa E, Fabiani L, Leoni E, et al. A new checklist for swimming pools evaluation: A pilot study. Microchemical Journal 2014;112:181-5.

Lin H, Lin A. Peracetic acid as an alternative disinfectant for micropollutants degradation and disinfection byproducts control in outdoor swimming pools. Journal of Hazardous Materials 2024;464:Article No. 132988.

Manasfi T, Coulomb B, Boudenne JL. Occurrence, origin, and toxicity of disinfection byproducts in chlorinated swimming pools: An overview. International Journal of Hygiene and Environmental Health 2017;220(3):591-603.

Natnael T, Hassen S, Desye B, Woretaw L. Physicochemical and bacteriological quality of swimming pools water in Kombolcha Town, Northeastern Ethiopia. Frontiers in Public Health 2024;11:Article No. 1260034.

Peng F, Wang Y, Lu Y, Yang Z, Li H. Formation and control of disinfection by-products during the trichloroisocyanuric acid disinfection in swimming pool water. Environmental Pollution 2024;346:Article No. 123536.

Public Health Committee, Department of Health, Ministry of Public Health, Thailand. Public Health Committee

Recommendations No.1/2550 (2007) on the Control of Swimming Pool Operations or any other Similar Business [Internet]. 2007 [cited 2024 Feb 21]. Available from: https://laws.anamai.moph.go.th/th/recommendation/download/?did=193119&id=41427&reload=.

Rosende M, Miro M, Salinas A, Palerm A, Laso E, Frau J, et al. Cost-effective analysis of chlorine-based and alternative disinfection systems for pool waters. Journal of Environmental Engineering 2020;146(1):Article No. 04019094

Shan P, Lin J, Zhai Y, Dong S, How ZT, Qin R. Transformation and toxicity studies of UV filter diethylamino hydroxybenzoyl hexyl benzoate in the swimming pools. Science of the Total Environment 2023;881:Article No. 163498.

United Nations (UN). The 17 Goals [Internet]. n.d. [cited 2024 Feb 21]. Available from: https://sdgs.un.org/goals.

World Health Organization (WHO). Guidelines for Safe Recreational Water Environments. Volume 2, Swimming pools and similar environments [Internet]. 2006 [cited 2024 Feb 21]. Available from: https://iris.who.int/bitstream/handle/10665/43336/9241546808_eng.pdf?sequence=1&isAllowed=y.

Yang L, Chen X, She Q, Cao G, Liu Y, Chang VWC, et al. Regulation, formation, exposure, and treatment of disinfection by-products (DBPs) in swimming pool waters: A critical review. Environment International 2018;121:1039-57.

Zhang D, Craven CB, Shen Q, Chu W, Li XF. Swimming pool disinfection byproducts: Analytical characterization of precursors, formation and occurrence, health risks and future needs. TrAC Trends in Analytical Chemistry 2023a; 169:Article No. 117385.

Zhang D, Dong S, Chen L, Xiao R, Chu W. Disinfection byproducts in indoor swimming pool water: Detection and human lifetime health risk assessment. Journal of Environmental Sciences 2023b;126:378-86.