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ENVIRONMENTAL IMPACT OF CHLORINE LEVELS AND PH BALANCE ON EYE AND SKIN IRRITATION AMONG OUTDOOR POOL USERS: A CASE STUDY IN GARUT REGENCY, INDONESIA

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ABSTRACT

This study investigates the correlation between chlorine levels, pH balance, and the incidence of eye and skin irritation among swimming pool users in Garut Regency, Indonesia. A total of 110 respondents were surveyed using structured questionnaires to report symptoms of irritation. Simultaneously, water samples were collected from three points (inlet, centre, and outlet) at three different times daily (08:00, 12:00, and 16:00) over one week, using a Comparator Test Kit to measure residual chlorine and pH. Statistical analysis was conducted using chi-square tests to assess associations between chemical parameters and health symptoms. Results showed that 87.3% of users reported skin irritation and 77.3% experienced eye irritation. Notably, 33.3% of chlorine measurements and 42.9% of pH readings exceeded recommended safety thresholds. A significant relationship ($p < 0.05$) was found between non-compliant chlorine and pH levels and the prevalence of irritation. These findings highlight the need for strict water quality control and real-time monitoring to ensure the safety of public swimming facilities.

Introduction

Water is an essential element for sustaining life and its availability is a crucial factor for human survival, health, and well-being. One notable use of water is recreational swimming, a popular activity known for its health benefits such as improved cardiovascular health, muscle training, and enhanced metabolism (Teo *et al*., 2015). However, swimming can also pose health risks, particularly through the transmission of waterborne illnesses. The increased popularity of swimming pools has led to greater awareness of water quality issues, particularly the presence of chemical contaminants such as chlorine, which are used to disinfect pool water and eliminate pathogenic microorganisms (Florentin *et al*., 2011).

Chlorination, a standard disinfection method, ensures water safety in swimming pools by reducing microbial contamination. However, improper chlorination levels can cause chemical by-products, which, in combination with pH imbalance, may lead to adverse health effects such as skin and eye irritation (Couto *et al*., 2021). Past research has identified Recreational Water Illnesses (RWIs) associated with poor water quality, including respiratory, digestive, and skin-related ailments (Kaydos-Daniels *et al*., 2008). Therefore, understanding the relationship between chlorine levels, pH, and health symptoms among pool users is crucial for maintaining public health standards.

The provision of safe drinking water and the management of aquatic recreational facilities depend heavily on effective disinfection methods. Chlorination remains the most prevalent approach for water treatment

due to its efficacy in eliminating pathogenic microorganisms. Chlorine primarily functions as a disinfectant through two active forms: Hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). The equilibrium between these forms shifts significantly with pH; HOCl is over 100 times more effective than OCl^- at lower pH (Dantec *et al*., 2002; Ma & Lu, 2012). This underscores the importance of maintaining pH levels within 7.2 to 7.6 in swimming pools to maximise chlorine efficacy and ensure effective disinfection (Yedeme *et al*., 2017).

Statistics indicate that in the United States alone, there are over 309,000 public swimming pools and approximately 1,500 water parks, exposing millions of people to treated water daily (Hansen *et al*., 2013). These figures highlight the urgent need for effective monitoring of water chemistry, particularly concerning the interactions between chlorine and other factors such as temperature and organic matter.

One of the significant concerns in swimming pool management is the potential for chlorine and its disinfection by-products to irritate the skin and eyes of swimmers. Studies have shown that when chlorine levels are improperly managed, by-products such as chloramines can accumulate, leading to health problems (Akinnola *et al*., 2020). Chlorine reacts with organic matter in water, forming harmful by-products that may affect users' respiratory systems, skin, and eyes (Chowdhury *et al*., 2014). Therefore, controlling residual chlorine levels and pool water pH is critical for reducing these risks.

Research indicates that several physicochemical parameters influence chlorine demand and chlorination effectiveness. Higher levels of organic matter in pool water can significantly increase chlorine demand, necessitating more rigorous treatment protocols (Naim, 2022). Additionally, temperature plays a critical role; elevated temperatures can lead to rapid chlorine loss, thus reducing the available disinfectant (Semagn *et al*., 2020). It is also noteworthy that pH fluctuations can lead to the formation of potentially harmful disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs). These compounds not only compromise water quality but may also pose health risks to patrons (Chowdhury, 2013; Hansen *et al*., 2013).

The disinfection of pool water through chlorination is widely accepted as an effective method for pathogen control, but it must be carefully regulated. According to Teo *et al*. (2015), the presence of free chlorine in water is essential for disinfection. However, excessive amounts can lead to the formation of harmful by-products such as trihalomethanes and chloramines (Teo *et al*., 2015). Chloramines, in particular, are known to cause respiratory problems and irritate the skin and eyes when they accumulate in poorly ventilated indoor pools (Kaydos-Daniels *et al*., 2008).

In addition to controlling chlorine levels, maintaining an appropriate pH is crucial for the efficacy of chlorination and user comfort. A study by Pándics *et al*. (2018) emphasised the importance of maintaining a pH range of 7.2 to 7.8, to optimise chlorine disinfection and minimise irritation risks. When the pH deviates from this range, the chlorine's effectiveness decreases, leading to insufficient disinfection or excessive chemical presence, both of which can cause health issues. This highlights the need for strict monitoring of pH and chlorine to ensure pool safety (Pándics *et al*., 2018).

Recent literature suggests that improper pool maintenance practices, such as irregular chlorine application and failure to monitor pH, contribute to health complaints from swimmers. Akinnola *et al*. (2020) note that skin and eye irritation are frequently reported among users of poorly maintained pools, with symptoms increasing when chlorine levels exceed safety thresholds. Studies have shown a direct correlation between inadequate water treatment and increased health risks, reinforcing the necessity for improved pool management and regular monitoring of chemical levels (Florentin *et al*., 2011).

Although substantial research has examined the health effects of chlorine and its by-products in swimming pools, several gaps remain in understanding the specific relationship between residual chlorine, pH, and the incidence of eye and skin irritation. While studies have identified the irritant properties of chlorine by-products (Couto *et al*., 2021), there is limited data on how variations in chlorine and pH levels interact to exacerbate or mitigate these symptoms, particularly in outdoor pools.

Most studies have focused on indoor pools or controlled environments where chloramine exposure is more concentrated (Kaydos-Daniels *et al*., 2008). However, less is known about the impact of chlorination practices and pH fluctuations in outdoor settings, where factors such as sunlight and organic matter contribute to chemical degradation. Additionally, current research lacks comprehensive studies in specific regions, like Garut Regency, which has seen an increase in pool use without corresponding studies on water quality and user health.

The research will contribute to the growing body of literature on swimming pool water safety, specifically by addressing gaps in outdoor pool environments in tropical climates such as Garut. The study's novelty lies in its focus on a newly established pool facility that has not yet been the subject of similar studies, and in the inclusion of real-time chlorine and pH measurements alongside user-reported symptoms.

This study investigates the impact of chlorine and pH levels on eye and skin irritation in swimming pool users, focusing on a pool in Garut Regency. It includes monitoring residual chlorine levels and pH in the pool water and correlating these chemical parameters with reported health symptoms. The findings aim to provide insights for local pool operators and health authorities to implement more effective water-quality management practices, ensuring optimal chlorine and pH balance to mitigate chemical exposure risks and promote a safer swimming environment, ultimately enhancing public health outcomes.

Materials and Methods

Study Design and Setting

This study employed a cross-sectional design, conducted over seven consecutive days in March 2024 at Swimming Pool X, located in Maripari Village, Sukawening Subdistrict, Garut Regency, Indonesia. The site was selected based on a high frequency of user complaints regarding eye and skin irritation, as well as the absence of automated chlorine regulation systems. The facility receives approximately 3,000 visitors weekly, making it a suitable case study for public exposure analysis. Only outdoor chlorinated pools were included; indoor pools and unchlorinated facilities were excluded.

Materials

This study utilised a combination of water quality measurement tools and health monitoring questionnaires to assess the relationships among residual chlorine levels, pH, and symptoms of eye and skin irritation among swimming pool users. The materials used included a Comparator Test Kit, calibrated to measure both chlorine levels and pH in pool water, in accordance with standard guidelines for swimming pool water analysis (Wojtowicz, 2004). Additionally, observational checklists and structured questionnaires were employed to collect data on reported symptoms from pool users. These tools allowed for the systematic assessment of eye and skin irritation, aligning with established protocols in studies of the health effects of swimming pool contaminants.

Water Sampling Strategy

Water samples were collected three times daily (08:00, 12:00, and 16:00) at three spatial locations: Near the water inlet, the pool centre, and the outlet, totalling nine samples per day and 63 over the study period. Sampling was conducted on both weekdays and weekends, under varying weather conditions, including sunny and overcast days, but excluding rain. Prior to the sampling period, the last chlorination event was documented at 06:00 daily using

Trichloroisocyanuric acid (TCCA 90%). The collected water samples were immediately processed using the Comparator Test Kit to measure residual chlorine and pH. This method allowed for the detection of chlorine by-products that may have formed during pool use, aligning with procedures for studying chemical contaminants in swimming pools (Akinnola *et al*., 2020).

Instrumentation and Accuracy

Water quality parameters were assessed using the Lovibond Comparator Test Kit (Model: AF245), which has an accuracy of ± 0.1 mg/L for chlorine and ± 0.1 pH units. Chlorine levels were measured using the orthotolidine (OTO) method, and pH was measured with phenol red indicators. The test kits were calibrated weekly and operated in accordance with SNI 06-6989.22-2004 (National Standard of Indonesia).

Experimental Set-up

The experimental set-up involved measuring the residual chlorine and pH levels in the swimming pool water using the Comparator Test Kit at each sampling point and time interval. The test for chlorine was conducted using the orthotolidine (OTO) reagent, which reacts with free chlorine in the water to produce a colour change corresponding to specific chlorine concentration levels (Wojtowicz, 2004). For pH measurement, phenol red reagent was added to the water sample to assess the pool's acidity or alkalinity, which is crucial in maintaining effective disinfection and reducing irritation risks (Pándics *et al*., 2018).

Each measurement was taken in triplicate to ensure accuracy, and the results were compared against national and international standards for pool water safety such as those outlined by the World Health Organisation (Kaydos-Daniels *et al*., 2008). The experiment also involved documenting pool user demographics and exposure times, as individual susceptibility to chlorine by-products can vary (Couto *et al*., 2021).

Symptom Data Collection

Self-reported symptoms of eye and skin irritation were collected using a structured questionnaire adapted from studies by Couto *et al*. (2021) and validated through a pilot test with 10 users. A total of 110 respondents were selected via systematic random sampling from individuals exiting the pool. The sample size was calculated using the Cochran formula for finite populations, targeting a confidence level of 95% and a margin of error of 10%. Inclusion criteria included users aged ≥ 6 years who had been in the pool for ≥ 15 minutes. Respondents with pre-existing eye or dermatological conditions were excluded to minimise confounding.

Parameters

The primary parameters measured were the residual chlorine levels and pH of the pool water. Residual chlorine was measured in parts per million (ppm), with a target range for safe swimming conditions of 1 to 3 ppm (Wojtowicz, 2004). Chlorine levels outside this range are associated with an increased risk of chemical by-product formation, which can cause eye and skin irritation (Teo *et al*., 2015). The pH parameter was measured within a target range of 7.2 to 7.8, as deviations from this range can exacerbate the corrosive properties of chlorine or reduce its efficacy, leading to user discomfort and health risks (Chowdhury *et al*., 2014).

Bias Control and Reliability

To reduce measurement bias, all pool water samples were measured immediately after collection by trained technicians. Data collectors were blinded to the chemical test results when administering questionnaires. Symptom definitions were standardised: Eye irritation was defined as redness, itching, or burning within one hour of exposure; skin irritation included rashes, dryness, or itching on exposed areas. Triple replication of water samples ensured measurement consistency. Questionnaire internal consistency was validated using Cronbach's alpha ($\alpha = 0.84$).

Statistical Analysis

All data were analysed using Statistical Package for the Social Sciences (SPSS) software (version 26, IBM Corp., Armonk, New York, United States of America). Descriptive statistics were used to summarise demographic characteristics and symptom prevalence. Chi-square (χ^2) tests were performed to assess associations between chlorine/pH compliance and symptom occurrence (Kelsall & Sim, 2001). A *p*-value of less than 0.05 was considered statistically significant, indicating a potential health risk when chlorine and pH levels deviate from recommended ranges. Additionally, descriptive statistics were used to present the frequency and percentage of respondents reporting symptoms, in correlation with the measured chemical parameters of the pool water.

Results and Discussions

Distribution of Gender and Age of Users of Swimming Pool X, Garut Regency

The study analysed the gender and age distribution of Swimming Pool X users in Garut in 2024, as shown in Table 1. It reveals that 60.9% of the pool users were female, while 39.1% were male, indicating a higher participation of women in swimming activities at this location. In terms of age, the majority of users (54.5%) were adults aged from 19 to 45 years old, followed by adolescents aged from 6 to 18 years old (42.7%), with a smaller proportion of older adults aged from 46 to 59 years old (2.7%).

These findings provide a demographic overview of pool users, which is critical for understanding potential exposure to chemical contaminants, as chlorine and its by-products may affect different demographic groups differently (Teo *et al*., 2015). The demographic composition of Swimming Pool X users is consistent with findings in the broader literature on swimming pool use and exposure risks. Women often report higher sensitivity to chemical contaminants in swimming pools, such as chlorine by-products, which may explain their higher representation in this study. Women may also have more frequent and prolonged exposure to pool water, thereby increasing their risk of irritation from contaminants such as chloramines (Couto *et al*., 2021).

Additionally, the higher percentage of adult users corresponds with research indicating that adults are more likely to engage in regular swimming activities, which could heighten their exposure to disinfection by-products. Adolescents, who make up a significant portion of the pool user base, may be particularly vulnerable to skin and eye irritation from prolonged pool exposure, and this group emphasised the sensitivity of younger individuals to chlorine by-products (Florentin *et al*., 2011).

Understanding the gender and age distribution of Swimming Pool X users is essential for tailoring safety measures and improving water treatment practices. Given the higher proportion of female and adult users, pool management should prioritise regular monitoring of chemical contaminants, especially chlorine by-products, to mitigate health risks. As indicated, these by-products are formed when chlorine interacts with organic matter, which can increase during periods of heavy use by a diverse population (Akinnola *et al*., 2020).

Table 1: Distribution of gender and age of users of Swimming Pool X, Garut Regency (2024)

Gender	N	%	Age Group	N	%
Male	43	39.1	6 to 18 years old (youth)	47	42.7
Female	67	60.9	19 to 45 years old (adults)	60	54.5
			46 to 59 years old (elderly)	3	2.7
Total	**110**	**100**	**Total**	**110**	**100**

Moreover, public health interventions should consider the specific needs of vulnerable groups, such as adolescents and women, who may be more susceptible to the adverse effects of disinfection by-products (Rod *et al*., 2023). Implementing better ventilation systems, educating pool users on the risks of prolonged exposure, and ensuring compliance with recommended chlorine levels and pH balance will help reduce health risks (Swinarew *et al*., 2020). Chloramines are formed when chlorine reacts with organic materials (e.g., sweat, urine, skin cells) and can accumulate in indoor swimming pool environments, leading to elevated airborne levels. These compounds have been linked to respiratory issues, including asthma and allergic reactions (How *et al*., 2017). Improved ventilation systems can significantly reduce the concentration of these harmful substances by facilitating the exchange of indoor air with outdoor air. Increased air turnover helps dilute chloramines and minimise their inhalation by swimmers, thus reducing the associated health risks (Bowen *et al*., 2007). Approaches that utilise fresh air intake rather than recirculating indoor air are particularly effective at reducing chlorine compound concentrations in the air, especially in environments with high swimmer loads (Mata *et al*., 2021).

The increased sensitivity of women to chemical contaminants in swimming pools can be attributed to several biological, physiological, and environmental factors. Research indicates that women may be more susceptible to various health issues related to chemical exposure, particularly in chlorinated environments such as swimming pools. This susceptibility may be influenced by biological differences, exposure scenarios, and the interactions of chemicals used in pool water.

Women possess distinct physiological characteristics that can influence their sensitivity to chemical contaminants. For example, women typically have a higher body fat percentage than men, which can affect the bioaccumulation of lipophilic (fat-soluble) compounds, potentially leading to higher concentrations of harmful substances in their bodies (Mcfadden *et al*., 2014). Additionally, hormonal differences can modulate immune responses, contributing to variability in allergic reactions and sensitivities to certain chemicals, especially in the context of skin irritations caused by disinfectants such as chlorine and its by-products (Mcfadden *et al*., 2014).

In swimming environments, women are more likely to experience problems due to elevated concentrations of disinfection by-product. For instance, chloramination by-products prevalent in chlorinated pool water have been shown to exacerbate respiratory issues, skin irritations, and allergic reactions. Research indicates that female swimmers might be at a higher risk of developing such conditions due to prolonged exposure during swimming sessions. Asthma prevalence is notably high among swimmers in chlorinated pools, suggesting chronic exposure may result in long-term respiratory health complications (Romberg *et al*., 2010; Zarzoso *et al*., 2010).

Chlorine Residue Levels by Time and Location

The graph (Figure 1) illustrates the chlorine residue levels at three different pool locations (inlet, middle, and outlet) over the course of the day, measured at 08:00, 12:00, and 16:00. At 08:00, chlorine levels in all three locations were significantly above the recommended range of 1 to 1.5 mg/L, reaching 3.0 mg/L, which suggests over-chlorination and poses potential risks for swimmer irritation, particularly for the eyes and skin. By 12:00, chlorine levels decreased to the upper limit of the acceptable range (1.5 mg/L), indicating that either natural chlorine dissipation or pool management adjustments brought the levels within safe parameters. At 16:00, chlorine levels fell further to 1.0 mg/L, approaching the lower limit of the recommended range. This decline suggests that chlorine concentrations fluctuate considerably throughout the day, potentially affecting the pool's disinfection efficacy by late afternoon. The high chlorine levels in the morning and the consistent decline across the day highlight the need for more consistent chlorine monitoring and regulation to ensure optimal swimmer safety and water quality.

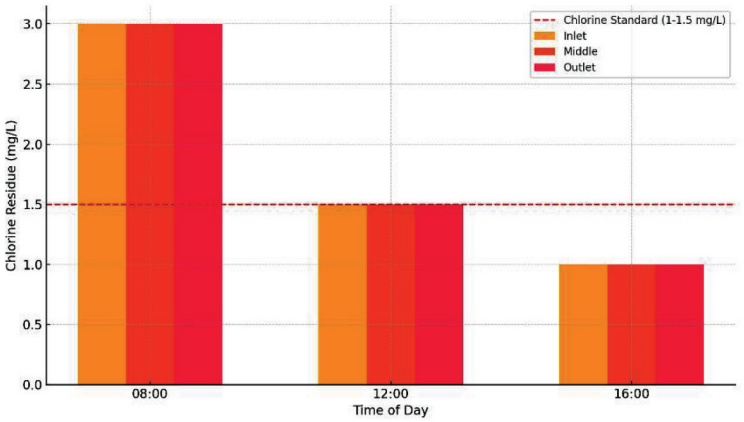

Figure 1: Chlorine residue levels by time and location

Research findings illustrate the distribution of chlorine compliance in pool water, showing the proportion of samples that met or did not meet the chlorine residue standards. Based on the results of this study, 66.7% of the samples complied with the recommended chlorine concentration range of 1 to 1.5 mg/L, ensuring effective disinfection without posing a significant risk to swimmers. However, 33.3% of the samples exceeded this range, representing instances of overchlorination. This non-compliance suggests that nearly one-third of the pool's chlorine levels exceeded the safe threshold, potentially resulting in adverse health effects, such as eye and skin irritation, among pool users. This distribution highlights the need for more consistent chlorine monitoring and regulation to minimise the frequency of non-compliant chlorine levels and maintain optimal swimmer safety throughout the day (Harjan *et al*., 2019).

pH Level by Time and Location

This graph (Figure 2) presents the pH Levels by time and location in a swimming pool, measured at three different times (08:00, 12:00, and 16:00) and at three locations (inlet, middle, and outlet). The green dashed line indicates the recommended pH range for pool water, which is between 7 and 7.8. The pH levels at all three locations began below standard at 08:00, with a consistent value of 6.8 across the inlet, middle, and outlet. By 12:00, pH levels rose

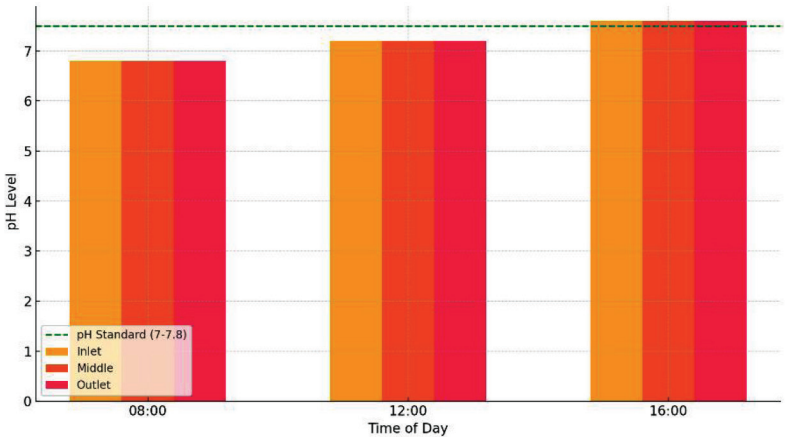

Figure 2: pH level by time and location

to 7.2, which falls within the acceptable range, indicating an improvement in water quality. At 16:00, the pH levels increased further to 7.6, still within the safe range but nearing the upper limit of the standard.

This pattern suggests the pool's pH was too acidic early in the morning, which could irritate swimmers, particularly their skin and eyes. As the day progressed, pH levels were corrected, maintaining safe water conditions by midday and later in the afternoon. The rising pH trend could indicate active pool water management such as pH adjustments or natural changes resulting from pool use. However, the low pH in the morning may require closer attention to ensure swimmers are not exposed to water that is too acidic during early pool hours. Consistent monitoring throughout the day is necessary to maintain water quality within the recommended pH range, particularly at the start of the day when pH levels are outside the safe parameters.

Research findings illustrate the pH compliance distribution in pool water samples, highlighting the percentage of measurements that either met or did not meet the recommended pH standard of 7.0 to 7.8. 57.1% of the samples were within the acceptable pH range, indicating that the majority of the pool water maintained a suitable balance for swimmer safety. However, 42.9% of the samples did not meet the standard, reflecting instances where the pH was either too low or too high, which could result in discomfort for swimmers, including skin irritation or eye discomfort. The substantial proportion of non-compliant samples underscores the need for improved pH regulation and monitoring, as deviations from the recommended range can negatively impact both swimmer health and the effectiveness of chlorine as a disinfectant. Maintaining a stable pH within the acceptable range is crucial to ensure optimal water quality and minimise risks associated with pH imbalance.

These imbalances in water chemistry, particularly excess chlorine and fluctuating pH, contribute to the formation of DBPs, which are known to have adverse health effects, including eye and skin irritation (Teo *et al*., 2015). The findings from this study correspond with previously documented cases of health effects linked to improper pool maintenance. This study found that elevated chlorine levels in swimming pools lead to the formation of chloramines and other DBPs, which can cause skin and eye irritation. This is further supported by another study, which identified that prolonged exposure to chlorination by-products can exacerbate respiratory and dermatological symptoms (Couto *et al*., 2021).

Compared with indoor pools, where chloramine exposure is more contained and problematic (Wastensson & Eriksson, 2020), outdoor pools like Swimming Pool X in Garut face different challenges. Factors such as sunlight and organic matter may accelerate the breakdown of chlorine, potentially increasing the volatility of DBPs (Wyczarska-Kokot *et al*., 2019). Although overall exposure differs, the occurrence of irritation remains a significant concern, as shown in Figure 3, over 77% of users experienced eye irritation and 87% reported skin irritation.

The breakdown products of chlorine may form new DBPs. Sunlight can enhance the volatility of certain chlorinated compounds, making them more likely to off-gas into the air. Studies have shown that exposure to chloramines and organic materials (such as those from human activity) can increase the production of volatile DBPs, including trihalomethanes (THMs) and halogenated acids (Wang *et al*., 2013; Wang *et al*., 2022). The balance between free chlorine and DBPs is critical; when chlorine levels drop due to sunlight exposure, the remaining chlorine can react with organic matter, forming more harmful, volatile DBPs (Carter & Joll, 2017; Wang *et al*., 2024).

The study underscores the importance of maintaining proper chlorine and pH levels in swimming pools to prevent health risks associated with DBPs. As shown in the results, deviations from the recommended chlorine and pH levels not only reduce disinfection effectiveness but also increase the potential for

chemical by-products to irritate (Angione *et al*., 2011; Li *et al*., 2015; Delpla *et al*., 2021). This suggests that chlorine dosing must be carefully regulated and continuously monitored, especially in outdoor pools where environmental factors complicate water quality management.

The implications of these findings are significant for public health, as poor pool maintenance can lead to widespread health issues among users. Proper regulatory practices and routine monitoring of water quality, as recommended, are necessary to minimise the formation of DBPs and ensure the safety and comfort of swimmers. Moreover, educating pool operators about the risks of improper chlorination and pH control will be critical in improving pool water quality and preventing further health problems for users (Pándics *et al*., 2018).

Distribution of Eye and Skin Irritation Symptoms

Figure 3 highlights the prevalence of eye and skin irritation symptoms among users of a public swimming pool in Garut during 2024. Of the 110 participants surveyed, 77.3% (85 individuals) reported experiencing eye irritation, while 87.3% (96 individuals) reported skin irritation. In contrast, 22.7% (25 individuals) and 12.7% (14 individuals) did not report any symptoms, respectively. These findings suggest a significant prevalence of both eye and skin irritations, likely linked to water quality issues, particularly chlorine levels and pH balance. The high rates of irritation indicate that the pool conditions may not meet recommended health standards for recreational water environments, underscoring the need for further investigation into water treatment practices and the implementation of corrective measures to ensure safe swimming conditions.

These symptoms are likely linked to chlorination by-products, which form when chlorine reacts with organic matter in the pool. As identified in previous studies, such by-products, including chloramines, are known irritants that can affect both the eyes and skin (Hrudey, 2009; Mazhar *et al*., 2020; Srivastav & Kaur, 2020).

The findings of eye and skin irritation in Swimming Pool X users are consistent with established literature. Exposure to high levels of chlorine and its by-products in swimming pools often leads to irritation of mucous membranes, including the eyes, due to the formation of chloramines (Teo *et al*., 2015). Prolonged exposure to these disinfection by-products significantly increases the risk of eye and skin discomfort, particularly in environments where chlorine levels are not adequately regulated (Couto *et al*., 2021).

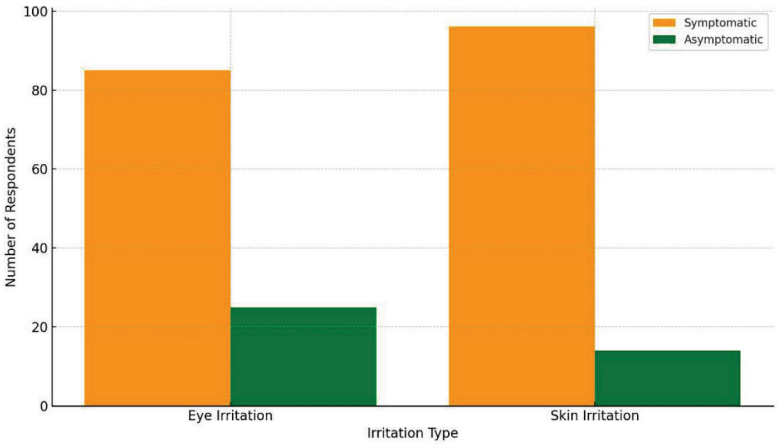

Figure 3: Distribution of eye and skin irritation symptoms

While the study by Kaydos-Daniels *et al*. (2008) focused on the health impacts of chloramines in indoor pools, where air quality is also a concern, the results from Swimming Pool X indicate that outdoor pools are similarly affected. Although environmental factors, such as sunlight, may mitigate some indoor air quality issues, they can accelerate chlorine breakdown in outdoor pools, thereby increasing the risk of skin and eye irritation (Chowdhury *et al*., 2014).

Sunlight, particularly ultraviolet (UV) radiation, plays a significant role in degrading chlorine in pool water. Chlorine is susceptible to photodegradation when exposed to sunlight, which involves the absorption of UV light, leading to the chemical breakdown of chlorine molecules into various by-products, reducing its disinfectant efficacy (Choo *et al*., 2022). The rapid decay of chlorine not only results in inadequate disinfection but also compromises the chemical balance of pool water, allowing pathogens to thrive and creating an environment that can cause skin and eye irritations for swimmers.

The high incidence of eye and skin irritation among Swimming Pool X users underscores the need for stricter management of chlorine levels and pH. These findings are consistent with the understanding that residual chlorine, while essential for disinfecting pool water, must be carefully balanced to avoid the formation of harmful by-products (Fish *et al*., 2020; Kwio-Tamale & Onyutha, 2024). The observed irritation symptoms indicate that improper water treatment practices are a public health concern, as excessive chlorination and improper pH levels can significantly affect swimmers' well-being.

From a regulatory perspective, these results suggest that pool operators should implement regular monitoring systems to maintain optimal chlorine and pH levels (Pándics *et al*., 2018). In addition, public health authorities should ensure that pool management protocols include comprehensive guidelines to prevent overchlorination, thereby reducing the risk of by-product formation (Akinnola *et al*., 2020). This will improve the safety and comfort of pool environments, reducing the incidence of irritation and other health-related issues.

Analysis of the Relationship Between Residual Chlorine Levels in Swimming Pool Water and Eye and Skin Irritation Symptoms Among Users of Swimming Pool X in Garut Regency in 2024

Table 2 presents an analysis of the relationship between residual chlorine levels in swimming pool water and eye irritation symptoms among users in Garut in 2024. Out of the total 110 respondents, 77.27% (85 individuals) reported eye irritation, while 22.73% (25 individuals) did not experience symptoms. The data further reveal that 36.36% (40 individuals) of participants exposed to chlorine levels below the health standard reported eye irritation, whereas none remained symptom-free. In contrast, among those exposed to acceptable chlorine levels, 40.91% (45 individuals) experienced eye irritation, while 22.73% (25 individuals) reported no symptoms. A chi-square test indicated a statistically significant relationship

Table 2: Analysis of the relationship between residual chlorine levels in swimming pool water and eye irritation symptoms among users of Swimming Pool X in Garut Regency in 2024

Chlorine Residue Level	Eye Irritation Symptoms				Total		*p*-value
	Symptomatic		Asymptomatic				
	Count	%	Count	%	Count	%	
Not meeting standard	40	36.36	0	0	40	36.36	
Meeting standard	45	40.91	25	22.73	70	63.64	< 0.001
Total	**85**	**77.27**	**25**	**22.73**	**110**	**100**	

between residual chlorine levels and eye irritation (p-value < 0.001). This suggests that higher chlorine concentrations may increase the likelihood of eye irritation among pool users.

Table 3 presents the analysis of the relationship between residual chlorine levels in swimming pool water and skin irritation symptoms among pool users in Garut in 2024. Of the 110 respondents, 87.27% (96 individuals) reported experiencing skin irritation, while 12.73% (14 individuals) did not exhibit any symptoms. The analysis shows that among those exposed to chlorine levels below the recommended health standard, 36.36 (40 individuals) reported skin irritation, while none remained symptom-free. On the other hand, among respondents exposed to chlorine levels meeting the standard, 50.91% (56 individuals) experienced skin irritation, and 12.73% (14 individuals) did not report symptoms. A chi-square test confirmed a statistically significant relationship between residual chlorine levels and skin irritation (p-value = 0.006). These results indicate that elevated chlorine concentrations may increase the risk of skin irritation among swimming pool users.

These findings are consistent with previous research linking high chlorine exposure to eye and skin irritation in pool users. Improper chlorination often leads to the formation of chloramines, which can irritate the eyes and skin. Interestingly, while many users with compliant chlorine exposure reported irritation (Teo *et al*., 2015), even small amounts of chloramines formed during normal chlorination processes can cause discomfort (Couto *et al*., 2021).

The persistence of irritation symptoms, even at recommended chlorine levels, suggests that pool users exposed to standard chlorine levels can still develop symptoms due to the accumulation of disinfection by-products. This suggests that factors beyond just chlorine concentration, such as water quality management and pH levels, contribute to irritation risks (Kaydos-Daniels *et al*., 2008).

The findings underscore the importance of not only adhering to recommended chlorine levels but also considering other variables, such as pH and organic load, that contribute to by-product formation. While maintaining proper chlorine levels is crucial, this study shows that even within these ranges, users can still experience health issues, likely due to the presence of chloramines or other disinfection by-products (Chen & Hung, 2017; Pérez *et al*., 2022).

These results imply that pool operators need to implement more comprehensive water treatment protocols, including regular monitoring of both chlorine and by-product levels. Enhanced ventilation or alternative disinfection methods could reduce these health risks (Wojtowicz, 2000). Public health interventions should also focus on educating users about potential risks and symptoms of irritation associated with chlorine exposure.

Table 3: Analysis of the relationship between residual chlorine levels in swimming pool water and skin irritation symptoms among users of Swimming Pool X in Garut Regency in 2024

Chlorine Residue Level	Skin Irritation Symptoms				Total		*p*-value
	Symptomatic		Asymptomatic				
	Count	%	Count	%	Count	%	
Not meeting standard	40	36.36	0	0.00	40	36.36	0.006
Meeting standard	56	50.91	14	12.73	70	63.64	
Total	**96**	**87.27**	**14**	**12.73**	**110**	**100**	

Analysis of the Relationship Between pH Levels in Swimming Pool Water and Eye and Skin Irritation Symptoms Among Users of Swimming Pool X in Garut Regency in 2024

Table 4 provides an analysis of the relationship between pH levels in swimming pool water and eye irritation symptoms among pool users in Garut in 2024. Out of 110 respondents, 77.27% (85 individuals) reported experiencing eye irritation, while 22.73% (25 individuals) did not. The data indicate that among those exposed to pH levels not meeting health standards, 40.91% (45 individuals) reported eye irritation, with only 4.55% (5 individuals) not experiencing symptoms. Conversely, among participants exposed to acceptable pH levels, 36.36% (40 individuals) reported eye irritation, while 18.18% (20 individuals) did not. A chi-square test confirmed a statistically significant relationship between pH levels and eye irritation (p-value = 0.007). The calculated PR-value of 1.350 suggests that users swimming in water with non-compliant pH levels have a 1.35 times higher likelihood of experiencing eye irritation compared to those swimming in water with compliant pH levels.

Table 5 analyses the relationship between pH levels in swimming pool water and skin irritation symptoms among pool users in Garut in 2024. Out of 110 respondents, 87.27% (96 individuals) reported experiencing skin irritation, while 12.73% (14 individuals) did not exhibit any symptoms. The data show that among those exposed to pH levels below the recommended standard, 43.64% (48 individuals) reported skin irritation, and only 1.82% (2 individuals) were symptom-free. In contrast, among participants exposed to pH levels meeting the standard, 43.64% (48 individuals) reported skin irritation, while 10.91% (12 individuals) did not. A chi-square test indicated a statistically significant relationship between pH levels and skin irritation (p-value = 0.026). The PR-value of 1.537 suggests that individuals swimming in water with non-compliant pH levels are 1.537 times more likely to develop skin irritation than those exposed to water with compliant pH levels.

Table 4: Analysis of the relationship between pH levels in swimming pool water and eye irritation symptoms among users of Swimming Pool X in Garut Regency in 2024

pH Level	Eye Irritation Symptoms				Total		*p*-value
	Symptomatic		Asymptomatic				
	Count	%	Count	%	Count	%	
Not meeting standard	45	40.91	5	4.55	50	45.45	0.007
Meeting standard	40	36.36	20	18.18	60	54.55	
Total	**85**	**77.27**	**25**	**22.73**	**110**	**100.00**	

Table 5: Analysis of the relationship between pH levels in swimming pool water and skin irritation symptoms among users of Swimming Pool X in Garut Regency in 2024

pH Level	Skin Irritation Symptoms				Total		*p*-value
	Symptomatic		Asymptomatic				
	Count	%	Count	%	Count	%	
Not meeting standard	48	43.64	2	1.82	50	45.45	0.026
Meeting standard	48	43.64	12	10.91	60	54.55	
Total	**96**	**87.27**	**14**	**12.73**	**110**	**100.00**	

The findings align with existing literature on the health impacts of imbalanced pH levels in swimming pools. pH is a critical factor in maintaining chlorine efficacy and preventing irritation, as imbalanced pH can increase the formation of chlorination by-products such as chloramines (Teo *et al*., 2015), which are known irritants to the eyes and skin. Similarly, it is emphasised that maintaining proper pH levels is essential to reduce the risks posed by disinfection by-products, as non-optimal pH conditions exacerbate the irritant effects of chlorine (Couto *et al*., 2021).

Other studies focused primarily on indoor pools, where volatile chloramines pose a significant health risk. However, the findings from Swimming Pool X demonstrate that even in outdoor pools, pH deviations can lead to substantial discomfort. These results support the idea that pH levels play a crucial role in preventing irritant symptoms, even when chlorine levels are within acceptable limits (Aoi & Marunaka, 2014; Proksch, 2018; Dewangan *et al*., 2023).

The findings underline the importance of maintaining both chlorine and pH levels within recommended standards to prevent eye and skin irritation among swimming pool users. Deviations in pH not only reduce the effectiveness of chlorine as a disinfectant but also contribute to the formation of harmful by-products that increase the risk of irritation (Akinnola *et al*., 2020). These results suggest that pool operators need to monitor pH levels as rigorously as they monitor chlorine levels to mitigate the health risks associated with swimming in chemically imbalanced water.

In practical terms, this study highlights the need for comprehensive water quality management protocols that address both chlorine concentration and pH balance (Wojtowicz, 2004). Public health interventions should focus on educating pool operators about the critical role of pH in preventing irritant symptoms and encouraging the adoption of real-time water quality monitoring systems to ensure consistent compliance with safety standards (Pándics *et al*., 2018; McGill *et al*., 2021). By doing so, the risks of eye and skin irritation can be significantly reduced, leading to safer swimming environments.

Effective Dose of Chlorine Use

Details:

- Pool size = 30 m² × 50 m² × 1 m
- Pool volume = 1500 m³
- Chemical used for chlorination = Trichloroisocyanuric acid (TCCA – 90%)
- Desired chlorine dose = 1.5 mg/L

According to WHO (2006), the correct amount of chlorine can be calculated using the following formula:

$$\frac{D}{1.000.000} \text{ x } ppm \text{ x } \frac{1.000}{x} = gram$$

Explanation:

- D = Amount of water to be disinfected in millilitres
- ppm = Desired amount of residual chlorine in mg per litre
- x = Active chlorine content of the disinfectant used for pool water disinfection

$$\frac{1.500.000.000}{1.000.000} \text{ x } 1.5\ ppm \text{ x } \frac{1.000}{90} = 2.500\ gram$$

Based on the calculated chlorine requirement for Swimming Pool X in Garut, a volume of 1,500 m³ requires 2.5 kg of TCCA to achieve a desired chlorine concentration of 1.5 mg/L. TCCA, containing 90% active chlorine, is widely used as a swimming pool disinfectant due to its effectiveness in maintaining safe, hygienic water conditions. The calculated dosage ensures that the pool maintains optimal chlorine levels within the recommended range, effectively killing harmful microorganisms while minimising the risk of irritation for pool users.

The formula provided by WHO allows for precise calculation of the chlorine needed, taking into account the pool's volume and the chemical's active chlorine content (WHO,

2017). This ensures that the correct amount of disinfectant is used, which is crucial for maintaining both water quality and public health. By applying 2.5 kg of TCCA, the pool management can ensure that the chlorine concentration stays within the recommended 1.5 mg/L, aligning with health standards to provide safe swimming conditions.

Overall, this calculation demonstrates the importance of controlled and accurate dosing in pool maintenance. Proper dosing not only ensures effective disinfection but also reduces the likelihood of overchlorination, which can lead to health concerns such as skin and eye irritation. Regular monitoring and adjustment of chlorine levels are essential to maintain this balance and ensure the pool environment is safe and comfortable for all users.

Implications and Limitations of the Study

The health implications stemming from compromised water quality in swimming pools are significant. Public health authorities need to enforce stricter regulations on chlorine levels in public pools to safeguard against potential irritations and long-term health impacts, particularly in vulnerable populations such as children and individuals with pre-existing respiratory conditions. Moreover, community awareness programmes should educate pool users about the importance of personal hygiene and its impact on water quality, aiming to reduce organic loads and ongoing chemical reactions.

While this study provides valuable insights, it is important to acknowledge certain limitations. Reliance on self-reported symptoms may introduce bias, as individuals may underreport or overreport their symptoms based on personal perceptions. Furthermore, the cross-sectional design limits our ability to infer causality. A longitudinal study design would facilitate a clearer understanding of the long-term effects of continuous exposure to varying chlorine levels.

Future Research Directions

Future research is set to explore the mechanistic pathways of chlorine exposure and its impact on health, potentially utilising controlled laboratory settings to simulate varying chlorine concentrations and their effects on human cell cultures. Investigating alternative disinfection methods, such as ozone or UV light, could also yield insights into effective strategies to reduce the health risks associated with chlorinated swimming pools. Additionally, studies should examine the cumulative effects of long-term exposure to disinfection by-products, particularly in young swimmers and aquatic professionals.

Conclusions

This study successfully demonstrated a clear link between improper chlorine and pH levels and the incidence of eye and skin irritation among outdoor swimming pool users. It highlights that maintaining standard chlorine and pH levels alone may not eliminate health risks, emphasising the role of disinfection by-products as contributing factors. The findings underscore the importance of adopting a more comprehensive water quality management approach that includes real-time monitoring, proper chlorination practices, user hygiene, and public awareness. Additionally, the study provides valuable recommendations for pool operators to adapt their disinfection strategies to environmental conditions, and it lays a foundation for future research exploring safer, more effective water treatment alternatives.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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