INTERNATIONAL JOURNAL OF ENVIRONMENT

**Volume-11, Issue-2, 2022** **ISSN 2091-2854**

*Received: 26 April 2022* *Revised: 19 September 2022* *Accepted: 20 September 2022*

# EVALUATION OF THE STATUS OF WATER QUALITY OF THREE SWIMMING POOLS IN BUJUMBURA CITY, BURUNDI

Christophe Niyungeko[1]*, Jonas Ntirampeba[1], Prudence Bararunyeretse[1], Benjamin Makimilua Tiimub[2], Manassé Nihorimbere[1], Pierre Ntakiyiruta[1]

[1]Center for Research in Natural and Environmental Sciences (CRNSE), University of Burundi, Faculty of Sciences 2700, Bujumbura, Burundi

[2]Faculty of Environment and Health Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Ashanti-Mampong Campus, Ghana

*Corresponding author: christophe.niyungeko@ub.edu.bi

**Abstract**

Poor water quality is problematic for the health of public swimmers. This study focused on the water quality of three main swimming pools coded as MS, ES and HC in the city of Bujumbura, Burundi. Water samples were collected from June to the end of August 2020 and analyzed for physicochemical parameters such as pH, turbidity, conductivity, nitrates, free chlorine and microbiological parameters (total coliforms and faecal coliforms). Our results indicated that 2/3 of the sampling days showed pH >7.8 and pH<7.2 in the MS and HC pools, respectively. All these pools exhibited high turbidity whereas ES manifested very high value (6.05NTU). Free chlorine appeared very low in the MS pool with contamination by total coliforms (<1MPN $1mL^{-1}$ and $1.17x10^7$MPN $1mL^{-1}$, <1MPN $1mL^{-1}$ and $6.32x10^6$MPN $1mL^{-1}$, and < 1MPN $1mL^{-1}$ and $5x10^2$ MPN $1mL^{-1}$) for MS, ES, and HC respectively. Both MS and ES pools revealed higher thermotolerant coliforms contamination of (<1MPN $1mL^{-1}$ and $2.18x10^4$MPN $1mL^{-1}$) in MS and (<1MPN $1mL^{-1}$ and $2.32x10^4$MPN $1mL^{-1}$) in ES, but the HC pool showed a single contamination case with values of <1UFC $1mL^{-1}$ and $5UFC1mL^{-1}$ throughout the sampling period. Additionally, extreme concentrations of nitrates (104.89 $mgL^{-1}$) were observed at the ES pool. The findings showed a non-compliance with WHO standards for all three swimming pools and therefore advocates for an urgent need to monitor and treat or change the water frequently for quality assurance of swimming pools.

**Key words:** Coliforms; Contamination; Disinfection; Swimming pools; Water quality.

DOI: https://doi.org/10.3126/ije.v11i2.44652

**Introduction**

Globally people are using water for recreation and therapeutic purposes. Swimming is widely recognised for its beneficial effects on human health (Zwiener et al., 2007), whereas swimming water quality represents a crucial challenge for public health (Teo et al., 2015; Victor et al., 2019). For example, swimming during pregnancy has been shown to prevent pregnancy-related memory problems in the long term (Kim et al., 2012). Moreover, swimming remains beneficial for people with obesity, the elderly, asthmatics, and also presents few risks compared to other sports activities (Carbonnelle, 2003). Apparently, public swimming pools are one of the most visited places in the world and have ubiquitously served as a guide to good civic life and important tourist destinations in both developed and developing countries (Nag, 2017). Besides, the availability of properly designed swimming pools does not only boost pool visitor amazement but, enhances the prevention of recreational water illnesses as a multifaceted issue that requires participation from aquatics facility designers as well as pool staff, swimmers, and environmental health departments (CDC, 2016). For instance, it has been reported that, in the United States of America, 368 million people visit public swimming pools every year. In Germany, 1/3 of its population visits public pools, while in the United Kingdom, 36% of adults visit swimming pools at least once a week and 55% of children aged between 5 to 9 years swim in pools at least once a month (Zwiener et al., 2007).

In spite of its vital importance in public health, swimming pool water cannot lack health risks when its physico-chemical and microbiological quality is not preserved (Timothy et al., 2003). According to Afsset (2010), swimming pool water, like many other retention reservoirs, is susceptible to microbiological and physico-chemicals that can be harmful for humans. Therefore, to prevent or avoid the risks associated with their use, it is necessary to regularly treat the swimming pool water. In this perspective, the World Health Organization (WHO, 2003) has set up a roadmap for the sustainable management of swimming pools. It focuses on activities to be carried out to protect the health of their users, such as quality control activities, their protection through user education, their design, and construction in accordance with standards. In addition, it highlights a wide range of risks associated with swimming pools, such as water quality that can be compromised at any time due to possible pollution, inadequate treatment or even a water supply that is compromised.

In sub-Saharan countries, the numbers of swimming pools are increasing rapidly and this can be seen in their presence in recreation centers such as hotels, schools, beaches, universities etc. (Ekopai et al., 2017). Actually, there is little scientific research on pool water quality, especially in Africa, in spite of the proliferation of these infrastructures (El-Salam, 2012; Victor et al., 2019). Therefore, the finds of the above studies revealed a non-compliance with the country's standards and/or the WHO standards, which may represent a high risk to the potential users.

In Bujumbura city, Burundian swimming pools are most visited in summer time, with a high number of students and children (Kabogora, 2014). This period also happened to coincide with a school holiday period and the most sunny and hot time. The majorities of the swimming pools in the city of Bujumbura comprise an open-air system and are supplied with water from the drinking water distribution network, but others are recharged from borehole water with an operating system that is made up of static water and non-circular. Unfortunately, swimming pools, especially those built in the open air system are exposed to dust, rain, airborne, and other organic contaminants disseminated by bathers. This predisposes swimmers to microbiological hazards arising from pathogenic contaminants and chemical hazards associated with poor physicochemical quality (Victor et al., 2019). In this context, Al-Khatib et al. (2015) emphasizes water circulation, filtration, and disinfection as key concepts for achieving good water quality in swimming pools.

Until now, the assessment of water quality in swimming pools in Bujumbura city remains an unexplored topic. Kabogora (2014) assessed the quality of swimming pools and discovered that an ammonia nitrogen concentration above WHO quality standards. Consequently, swimmers with weakened immune systems in such environments may be exposed to severe sickness. To offer safe swimming pools and prevent bathers from infectious illnesses, making a safe swimming milieu free from contaminants is required. In the overall, this work objectively examined the water quality of three swimming pools in Bujumbura and specifically studied the microbiological and physicochemical quality characteristics.

## Materials and methods

### Study area

The study was carried out in Bujumbura city ($3^0\, 22'32''$ S, $29^0\, 21'\, 33''$E), the economic capital and largest city in Burundi (Fig 1). The city of Bujumbura covers an area of 145 $km^2$ with an average altitude of 820 m. The tropical climate offers year-round sunshine and an average temperature of 23°C, with peaks of 28° - 32°C during the hottest periods. Bujumbura, like the rest of the country, has four seasons: the long and short dry seasons, the long and short rainy seasons with an average precipitation of 835 mm per year.

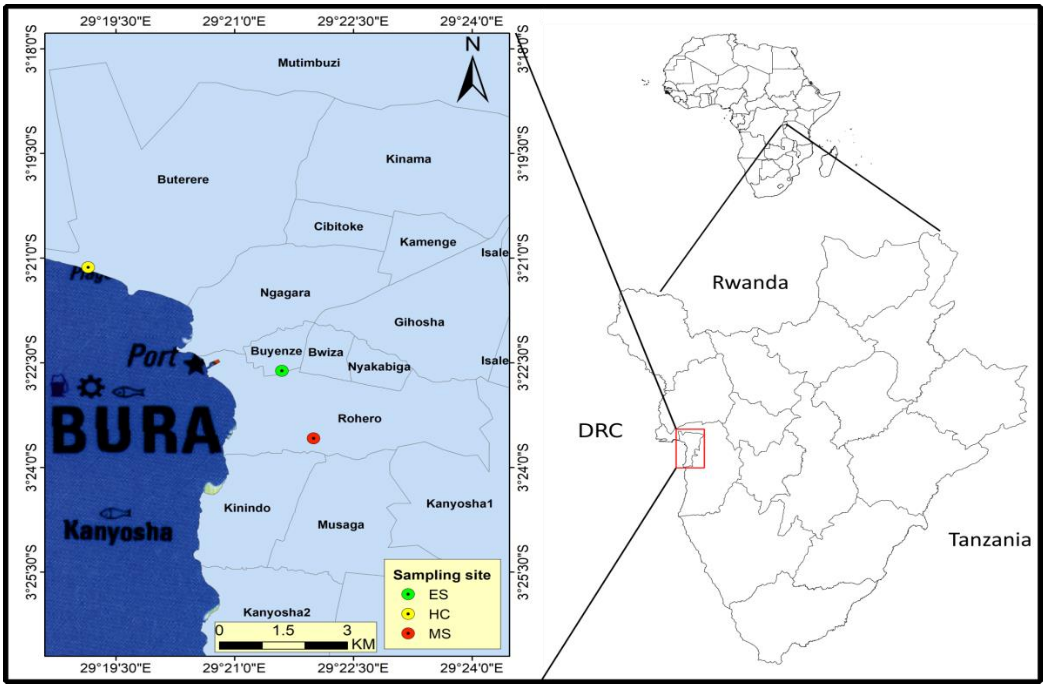


**Fig .1.** Location map of the sampling sites

The sampling sites constitute the three swimming pools most visited by the local population and some tourists. For confidential reasons, as was required by the managers, the identity of these pools has been coded. The first pool was named MS, the second ES, and the third HC. Both MS and ES pools are public while HC is semi-public (hotel). In summer, these pools can get a large number of bathers, especially children. All these pools are open-air systems and have a rectangular shape and do not have a water recirculation system except the ES pool. The managers of the HC pool use chlorine for disinfection as well as anti-algae products for the reduction of algae that can grow. Both pools (ES and HC) are supplied with borehole water. The borehole from which the HC pool is recharged also supplies the peripheral districts of the north-western part of Bujumbura city, such as the Kajaga district. The water from this borehole does not undergo any treatment other than the oxidation of $Fe^{2+}$ to $Fe^{3+}$. On the other hand, the ES pool is supplied by its own borehole which does not undergo any other treatment except disinfection and pH stabilization. Hydrochloric acid (HCl) and/or chlorine tablets are often used. The MS pool is supplied on the public water distribution network from Lake Tanganyika. Its disinfection product is sodium hypochlorite. The sampling was carried out in summer for three months, i.e. from June to August every week, on Monday morning between eight and eleven.

## Samples collection and Analysis

The pH, temperature and electrical conductivity of pool water were measured in situ by the multi-probe pH meter (Consort C6010, Belgium). The specific probe was immersed in the swimming pool and the results were displayed on the screen, then the results were noted after the values had stabilized (Rodier, 2009). The turbidity was measured by the turbidimeter (brand TURBIQUANT 1100 IR, Germany). A water sample was taken from a small, clean glass bottle for the turbidimeter and placed in the turbidimeter, turned clockwise, and the number on the display was read (Rodier, 2009).

Sampling at each pool was made from three different points, in order to consider the homogeneity of water quality throughout the pool and obtain a more representative sample matrix. Samples for chemical analysis were taken using sterilized 500 mL volumetric plastic bottle, well washed and rinsed twice by the water of this swimming pool. After removing the lid, the bottle's inverted state was pushed down to the depth of the elbow and then inverted again to fill it with water, then closed and packed with a black sachet. According to Ekopai et al. (2017), for microbiological analysis samples, the well sterilised jar provided by the laboratory was filled with sodium thiosulphate pentahydrate 10% (10mg100 $mL^{-1}$) $Na_2S_2O_3$, pushed into a pool at an angle from 45˚C and filled to a 100 mL gauge leaving about 5mm. All these samples were transported directly from the site to the laboratory in the field incubator containing ice to maintain the temperature at - 4˚C. Chemical analysis and microbiological culture were done on the same day and within six hours.

**Chemical analyses**

The nitrate concentration was analysed following the protocol of Rodier (2009). 10 mL of sample was introduced into a capsule by weakly alkalinizing with the sodium hydroxide solution, and while the water was evaporating, 1 mL of sodium salicylate was added to the residue. The content was further evaporated and 1 mL of concentrated chloridric acid added. Subsequently, 15 mL of deionised water was added, followed by 10 mL of sodium hydroxide solution. A yellow colour developed and the spectrophotometer reading was taken at a wavelength of 415 nm. Ammonia nitrogen was analysed according to the Nessler method (ASTM 2008), whereby, 50 mL of sample was placed in a vial and mixed with 2 drops of sodium and potassium tartrate while homogenizing. One mL of Nessler reagent was added to the solution, then the reading of absorbance was performed with the spectrophotometer at a wavelength of 425 nm. The total chlorine and the free chlorine were analysed using the Palintest Kit (Jaunakais et al. 2009). Free chlorine reacts with diethyl-p-phenylene diamine (DPD) in buffered solution to produce a pink coloration. The intensity of the colour is proportional to the free chlorine. After rinsing the test tube with the sample, leaving two drops in the tube, a DPD No.1 tablet was inserted, then 10 mL of sample were added and finally the free chlorine reading on the Palintest photometer was taken immediately two minutes later. While keeping the same solution, a DPD No.3 tablet was introduced into the solution and left to stand for 10 minutes after which the total chlorine reading was taken at the palintest photometer. The combined chlorine was obtained by subtracting total chlorine from free chlorine.

## Microbiological analyses

One specific culture medium for coliforms was used, namely Violet Red Bile Lactose (VRBL) agar with peptone water. Ethyl alcohol was used to disinfect hands and other materials. The preparation of the inoculum was performed as follows: A series of tubes containing 9 mL of peptone water and cleaned Petri dishes with a diameter of 90 mm were sterilized in an autoclave for 15 minutes at 121ºC. Then, decimal dilutions were made; 1 mL of sample was added in a tube containing 9 mL of peptone water using a sterile automatic micropipette. One mL of their homogenized mixture was transferred to the center of each Petri dish (the plating). A quantity of 15 mL of VRBL medium was poured into each petri dish carefully mixed with the inoculum in the culture medium and the mixture solidified within a few minutes. All samples were made in triplicates. Petri dishes were inverted and incubated at 37 ±1ºC for total coliforms, and 44±1ºC for faecal coliforms for 48 hours. Petri dishes with 10 to 150 colonies were selected for colony counting, using a magnifying glass (ISO 16649-2 2001). Colonies with a reddish appearance were enumerated as those that appeared in the VRBL culture medium. All microbial cultures were performed in triplicates.

## Statistical analysis

Descriptive statistical analysis was applied and the Pearson correlation coefficient was performed to test the inter-relationships at $p < 0.05$ level of significance. Values of the parameters assessed are averages with standard deviation, $n = 3$.

# Results

## Chemical analyses

The results obtained for pH, turbidity and electrical conductivity for the 3 pools are shown in Fig 2**.** The turbidity values during sampling ranged from 0.67±0.0 to 6.05 ±0.8 NTU. The MS pool had a turbidity ranged from 1.49±0.0 to 2.82±0.2 NTU. For the ES pool, the values found ranged from 2.86±0.1 to 6.05±0.8 NTU. The minimum value was found in the first month of sampling and the maximum value was recorded towards the end of the 3rd month of sampling. The HC pool showed values between 0.67±0.0 and 1.82±0 NTU (Fig 2b). As for the electrical conductivity, in all the pools, the values ranged between 1036±31µScm$^{-1}$ and 1729.67±17µS cm$^{-1}$. The ES pool depicted values between 1380±30µS cm$^{-1}$ and 1729.67±17µScm$^{-1}$. The minimum value was recorded during the first month of sampling while the maximum at the end of the period.

For the HC pool, its values are between 1062±32µS $cm^{-1}$ and 1289±7µS $cm^{-1}$(Fig. 2c). The minimum value was recorded in the first month of sampling and the maximum value was recorded on the last day of sampling. Conversely, MS pool depicted oscillating values between 1085±50 and 1184.7±57µS $cm^{-1}$.

The pH values varied between 6.8±0.0 and 8.4±0.0. The values found at the MS site ranged from 7.2 ± 0.1 to 8.4±0.0. Over the entire study period, 8 days out of 12 were characterized by pH values of 7.9 to 8.4. As for the ES pool, the values found were between 7.1 and 8.18 and with the HC pool, its pH was between 6.8 and 7.1. The rate of the curve for the HC pool is almost constant but below 7.2. Conversely, other pools showed different values. ES pool showed two distinct parts. For example, from the first day of sampling to the 29th day i.e. the first month of sampling the pH was between 7.2 and 8.2 whereas the other part was characterized by an approximately constant pH oscillating around 7.2. As for the MS pool, the minimum value was recorded on the 20th day of July (Fig. 2a). The variability in electrical conductivity (Fig.2c) of the MS and HC pools was almost constant, but that of the ES pool shows a large deviation from the others. For the MS and HC pools, their electrical conductivity trended between 1062±28 µS$cm^{-1}$ and 1289±28µS$cm^{-1}$, while for the ES pool it varies between 1380.67± 30µS$cm^{-1}$ and 1729.67±1728±17 µS $cm^{-1}$.

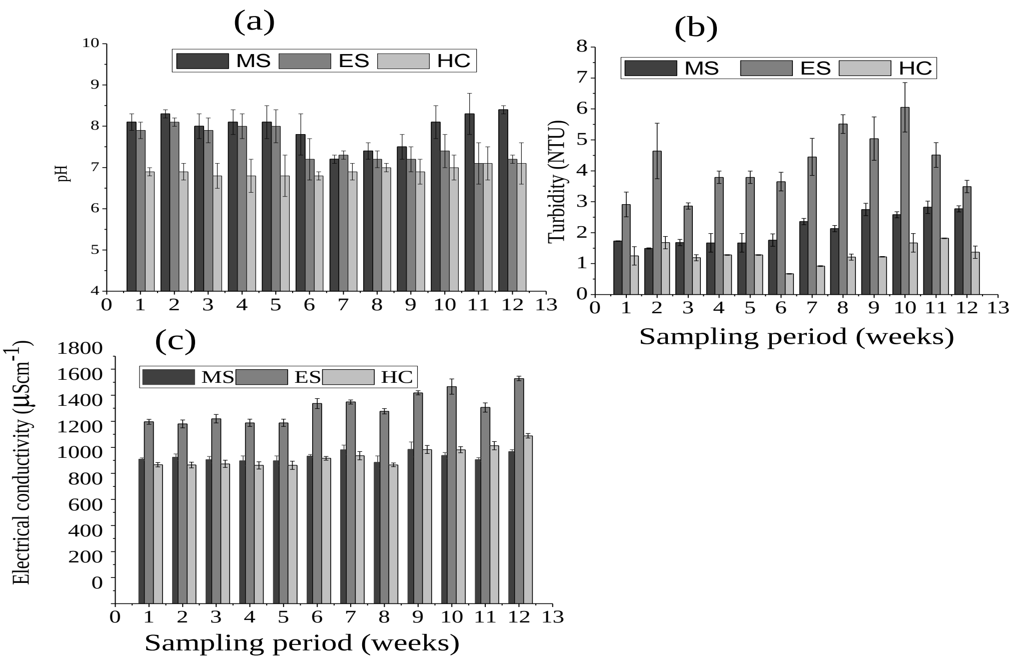


**Fig. 2.** Trend of pH **(a)**, turbidity **(b),** and electrical conductivity **(c)** for the three swimming pools.

The combined chlorine was deduced from the difference between total and free chlorine. These results are presented in Fig. 3, showing the results of the chemical parameters analyzed in the laboratory. From these results, for free chlorine, the MS pool depicted values between 0.0 $mgL^{-1}$ and 1.3±0.3 $mgL^{-1}$. In the 12 days of sampling, 9 days were characterized by values below 0.5 $mgL^{-1}$, while on 3 days, free chlorine varied from

0.5 $mgL^{-1}$ to 1.6 $mgL^{-1}$ (Fig.3a). For the ES pool, free chlorine was between 0.00±0 $mgL^{-1}$ and 1.75±0.2 $mgL^{-1}$, while for the HC pool, the values were between 0.01±0 $mgL^{-1}$ and 2.77±0.1 $mgL^{-1}$. The total chlorine concentration ranged from 0.05±0.0 $mgL^{-1}$ to 2.81±0.1 $mgL^{-1}$ for all pools. The MS pool depicted values between 0.05±0 $mgL^{-1}$ and 1.97±0.2 $mgL^{-1}$. In the sampling period, the minimum concentration was observed in the first and 3rd month, although it peaked at the end of the second month. For the ES pool, total chlorine concentrations were between 0.05±0 $mgL^{-1}$ and 2.45±0.1 $mgL^{-1}$ (Fig.3b). The maximum and minimum values showed up first month, while in the 3rd month its values tended to stabilize between 0.22 $mgL^{-1}$ and 1 $mgL^{-1}$. The HC pool had values between 0.22±0.1 $mgL^{-1}$ and 2.81±0.1 $mgL^{-1}$. The combined chlorine values ranged from 0.04±0.0 $mgL^{-1}$ to 0.7±0.2 $mgL^{-1}$ (Fig.3c) whiles that in the MS pool was between 0.05±0.0 $mgL^{-1}$ and 0.63±0 $mgL^{-1}$. The maximum combined chlorine value was detected in the 7th week of sampling while the minimum value in the first week of sampling. For the ES pool, the combined chlorine concentration was between 0.05±0 $mgL^{-1}$ and 0.7±0.2 $mgL^{-1}$ (Fig.3c).

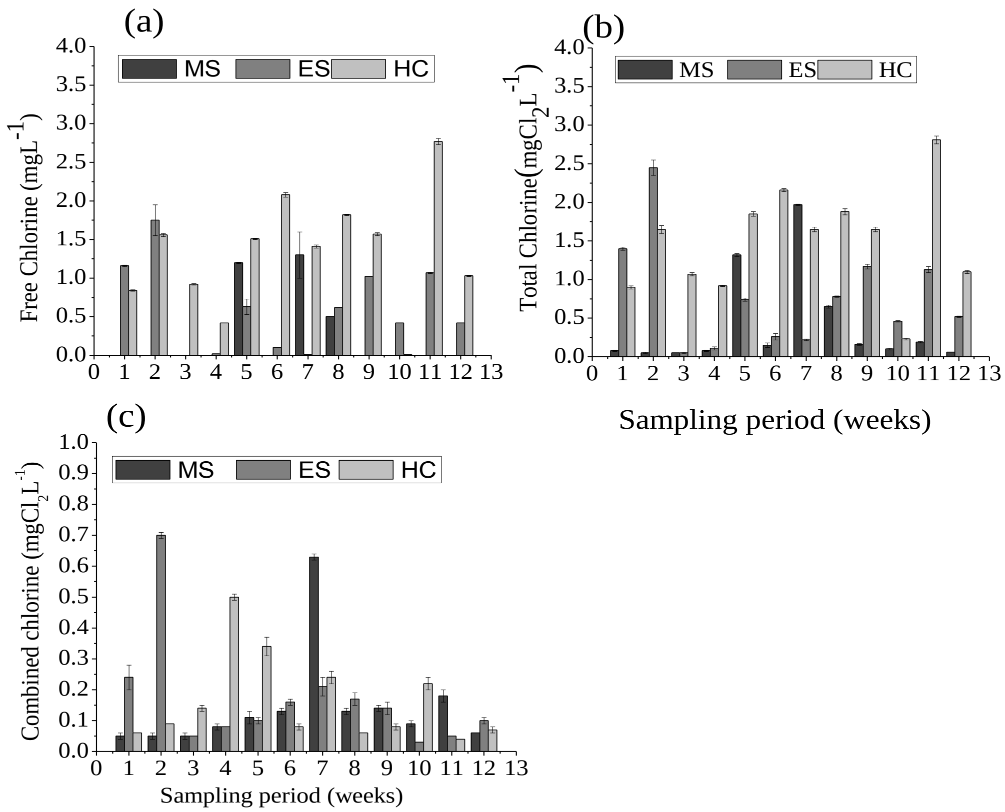


**Fig. 3.** Free chlorine **(a),** Total Chlorine **(b)**, and Combined Chlorine **(c)** concentrations in the three swimming pools

The nitrate concentration ranged from 4.19±0.1 $mgL^{-1}$ to 104.89±0.2 $mgL^{-1}$ (Fig.4a). Compared to two other pools, values from the ES pool were between 8.72±0.5 $mgL^{-1}$ and 104.89±0.2 $mgL^{-1}$. The minimum value was recorded in 1$^{st}$ month of sampling and the maximum around the last sampling month For the MS pool, its concentrations varied between 4.19± 0.1$mgL^{-1}$ and 26.1±0.4 $mgL^{-1}$. The maximum showed up at the beginning of the 2$^{nd}$ month of sampling and the minimum value in the middle of the 2$^{nd}$ month. As for the HC pool, its values were between 4.71±0.1 $mgL^{-1}$ and 26.56±0.1 $mgL^{-1}$. The minimum value was detected in the 3$^{rd}$ week of sampling while the maximum in the 4th week. Both pools (ES and HC) depicted more concentrated nitrate water. The highest nitrate concentration featured in the ES pool which reached a peak of 104.89 $mgL^{-1}$ while the lowest concentration in this pool was detected in the first month of sampling.

The analysis of ammonia nitrogen shows concentrations ranging between 0.12 $mgL^{-1}$ and 3.44 $mgL^{-1}$ (Fig.4b). For the MS pool, ammonia nitrogen concentrations ranged from 0.12±0.1 $mgL^{-1}$ to 2.39±0.1 $mgL^{-1}$. The minimum as well as maximum values were respectively recorded on the first sampling day and at the end of the second month. For the ES Pool, the ammonia nitrogen ranged from 0.4±0.1 $mgL^{-1}$ to 2.90±1.3 $mgL^{-1}$. The peak was detected in the second month whereas the minimum in the first week of sampling. The HC pool depicted ammonia nitrogen concentrations ranging from 0.13±0 $mgL^{-1}$ to 3.44±0.2 $mgL^{-1}$. The minimum value was found in the first month of sampling and the peak at the end of the second month. The results revealed very remarkable fluctuations in free chlorine. The MS pool significant deviated from the HC pool, probably because variations in field conditions during the different sampling periods. Minimum values as low as 0 $mgL^{-1}$ were noticed. In the ES and HC pools, the orientation of their curves appears to be somewhat constant. Total chlorine levels fluctuated, especially in ES and MS pools. Accordingly, the ES and MS pools demonstrated curves with a constant appearance except that the ES pool peaked up on the second day of sampling whiles the HC pool peaked on 20$^{th}$ of July, 2020.

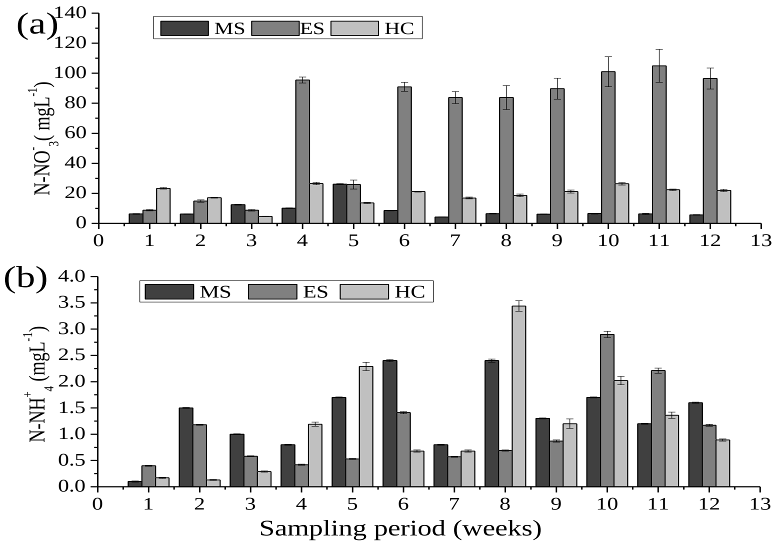


**Fig. 4.** Nitrate nitrogen ($N\text{-}NO_3^-$) **(a)** and of ammonia nitrogen ($N\text{-}NH_4^+$) **(b)** concentrations in the three swimming pools

## Microbiological analyses

The results of the microbiological analyses of the different swimming pools are shown in Table 1. In 72 samples analyzed for faecal and total coliforms, the values averaged <1MPN $1mL^{-1}$ and $1.17x10^7$ MPN $1mL^{-1}$ (Table 1). The amount of total coliforms ranged from <1 MPN $1mL^{-1}$ to $1.17x10^7$ MPN $1mL^{-1}$ in the MS pool.

**Table 1.** Microbiological Analysis Results

| | MS | | ES | | HC | |
|---|---|---|---|---|---|---|
| sampling Date | total Coliform | faecal Coliform | total Coliform | faecal Coliform | total Coliform | faecal Coliform |
| 08/06/2020 | < 1 UFC | < 1 UFC | < 1 UFC | < 1 UFC | < 1 UFC | < 1 UFC |
| 15/06/2020 | < 1 UFC | 1.00E+02 | 4.43E+03 | < 1 UFC | < 1 UFC | < 1 UFC |
| 22/06/2020 | 1.60E+03 | 1.45E+03 | 1.55E+03 | < 1 UFC | < 1 UFC | < 1 UFC |
| 29/06/2020 | 6.45E+03 | < 1 UFC | 4.43E+03 | < 1 UFC | < 1 UFC | < 1 UFC |
| 06/07/2020 | 9.00E+05 | 2.55E+02 | 5.14E+04 | 2.55E+02 | 2.05E+01 | < 1 UFC |
| 13/07/2020 | 1.17E+07 | 7.82E+02 | 6.32E+06 | 7.82E+02 | 1.36E+01 | < 1 UFC |
| 20/07/2020 | 1.36E+04 | 3.00E+02 | < 1 UFC | 2.32E+04 | < 1 UFC | < 1 UFC |
| 27/07/2020 | 3.76E+05 | 1.91E+03 | 1.33E+04 | 2.32E+04 | 1.41E+01 | < 1 UFC |
| 03/08/2020 | 2.14E+05 | 1.00E+01 | 6.00E+05 | < 1 UFC | 7.18E+01 | < 1 UFC |
| 10/08/2020 | 3.24E+05 | 8.00E+00 | < 1 UFC | 1.30E+01 | < 1 UFC | 5.00E+00 |
| 17/08/2020 | 9.23E+04 | 2.18E+04 | 1.55E+02 | < 1 UFC | 5.00E+02 | < 1 UFC |
| 24/08/2020 | 9.23E+04 | 1.00E+03 | 3.09E+03 | < 1 UFC | 1.00E+02 | < 1 UFC |

The maximum microbial numbers was noticed at the beginning of the second month of sampling when the minimum value was noticed at the beginning of the study. Faecal coliforms were between <1 MPN $1mL^{-1}$ and $2.18x10^4$ MPN $1mL^{-1}$. The maximum number of faecal coliforms was detected at the end of sampling. For the ES pool, the total coliforms were between <1 MPN $1mL^{-1}$ and $6.32x10^6$ MPN $1mL^{-1}$, knowing that the faecal coliforms, their quantity varied between <1 MPN $1mL^{-1}$ and $2.32x10^4$ MPN $1mL^{-1}$. For faecal coliforms, 7 days of sampling out of 12 were characterized by the absence or non-detection of Faecal Coliforms. On the other hand, 9 out of 12 sampling days were characterized by a significant number of total coliforms. The faecal coliforms numbers in HC pool was up to 5 MPN $1mL^{-1}$ once, whereas for the total coliforms, 6 days out of 12 were characterized by numbers between $2.05x10^1$ MPN $1mL^{-1}$ and $5x10^2$ MPN $1mL^{-1}$. This maximum value was detected in the 11th week of sampling.

## Discussion

### Physico-chemical parameters influencing swimming pool water quality

The physico-chemical parameters evaluated fluctuated around the quality standards required by the WHO ((WHO, 2006). Within a sampling period of 12 weeks, the MS pool totalled 8 days where its pH was above the WHO standards of > 7.8. The pH required by the WHO (7.2-7.8) is a key parameter for maintaining the water quality of swimming pools. The WHO recommends a pH value between 7.2 and 7.8 to facilitate the effectiveness of the disinfectant, avoid alteration of the infrastructure (pool) and also ensure the well-being of users (WHO, 2006). As for the ES pool, 5 days were characterized by a pH > 7.8, values higher than those required by WHO, which could compromise the effectiveness of disinfection.

Concerning turbidity, in all the swimming pools evaluated, none of them confirmed to the WHO standards that recommend values between 0.5 and 1NTU before and after swimming (Victor et al., 2019). The HC pool greatly varied in turbidity level as compared to the other pools evaluated. The MS pool depicted turbidity exceeding the WHO standards by more than one unit. The ES pool was characterized by high turbidity compared to the other 2 pools. Since MS and ES are public pools, organic matter caused by many of the bathers that they receive may account for their high turbidity. On the other hand, the HC pool, which is semi-public, is mainly visited by tourists and public access is limited, which may justify its turbidity closer to the required quality limits. Among the pools evaluated, the ES pool manifested a high turbidity compared to the others, i.e. >5NTU. The results ascertained are similar to those presented by Shittu et al. (2008) who indicated values above 5.5NTU. Turbidity represents dissolved solids and colloidal matter in the water, which hampers disinfection. This turbidity could also be explained by a lack of treatment of raw water from the borehole. Coagulation/flocculation and filtration processes should be considered prior to disinfection as Amor et al.

(2015) strongly suggested that pre-treatment with coagulation/flocculation is an essential process to reduce the significant amount of dissolved solids (organics) to improve subsequent treatment.

Electrical conductivity was very high, the entire results were above the WHO recommended values and the significant positive correlation ($R^2 = 0.621$) with nitrates (Table 2) for the ES pool. This is also associated with high turbidity because the electrical conductivity is a function of the mineral matter dissolved in the water in the form of carbonates, nitrates, sulphates, etc. Thus, Simard (2009) found a similarly high conductivity of 1698±665µScm$^{-1}$ as an indicator of water contamination by dissolved solids (Farooq et al. 2008). The evolution of these parameters during the study period could be explained by the increasing number of bathers during holidays because, according to Yeh et al. (2014), during sports competitions, incremental organic matter in sports pools was observed. Compared to a recent study (Robles et al. 2019), they found a high electrical conductivity of up to 6300 µS cm$^{-1}$. These swimming pools in Bujumbura are more visited during vacation periods (in summer), hence the increase in organic matter. The pools evaluated have a high concentration of nitrates. While swimming, humans can accidently ingest some quantities of water. In the same vein, the WHO suggests nitrate limits of 10.2 mgL$^{-1}$ in drinking water (Alan et al. 1980). For this reason, Suthar et al. (2009) intimated that the nitrate content of swimming pool water should be the same as that of drinking water. This study indicates that the nitrates concentrations were very high, considering the disadvantages that are associated with it. This is particularly evident in the ES pool which, over the entire study period manifested a nitrate peak of 104.89 mgL$^{-1}$. In this study, the first 3 weeks were a pre-vacation period, and the peak observed as of the 29$^{th}$ of June 2020 could be explained by a swimming earlier competition that occurred prior to sampling. The extreme nitrate concentration from the 13$^{rd}$ of July, 2020 to the end of the study could be explained by organic matter introduced by swimmers. Sadikoglu (2017) found values ranging between 0.003 mgL$^{-1}$ and 0.999 mgL$^{-1}$ for ammonia nitrogen, 0.04192 mgL$^{-1}$ and 76.844 mgL$^{-1}$ for nitrates. Contrary to the explanation on nitrates, the pools with excessive nitrate values in the present study may have a source of borehole water supply. Therefore, these excessive nitrate concentrations could also be explained by the fact that this groundwater could be polluted with nitrates. Indeed, in a monitoring of borehole water in Burkina-Faso, Ibrahimou (2017) found that sites with concentrations up to 469.9 mgL$^{-1}$ were associated with anthropogenic activities in their surroundings such as livestock rearing, archaic toilets and garbage lixiviates. Another study conducted in India by Suthar et al. 2009) which typically assessed the nitrate contamination of borehole water discovered a concentration ranging from 7.10 mgL$^{-1}$ to 162 mgL$^{-1}$ attributed to anthropogenic activities. A specific study is necessary to shed light on this point in view of the present results in relation to nitrate concentration.

**Table 2.** Pearson correlation obtained between the physicochemical and microbiological parameters of the ES pool

| | pH | Electrical Conductivity | Turbidity | Free chlorine | Combine chlorine | $NO_3$-N | Total coliform | Faecal coliform |
|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | |
| Electrical Conductivity | -0.609** | 1 | | | | | | |
| Turbidity | -0.348** | 0.345* | 1 | | | | | |
| Free chlorine | NS | NS | NS | 1 | | | | |
| Combine chlorine | 0.369* | NS | NS | 0.587** | 1 | | | |
| $NO_3$-N | -0.693** | 0.621** | 0.476** | -0.332* | -0.438* | 1 | | |
| Total coliform | NS | NS | NS | NS | NS | NS | 1 | |
| Faecal coliform | NS | NS | NS | NS | NS | NS | NS | 1 |

*The data are significantly different at $P < 0.05$; ** the data are significantly different at $P < 0.01$; NS: not significant

**Microbiological quality**

A significant correlation was observed between total coliforms and ammonia nitrogen ($p = 0.52$) (Table 3) and a low significant correlation between faecal coliforms and turbidity. This relationship could be related to the fact that turbidity in the network creates a deposit of particles and promotes the growth of algal biofilms with the potential presence of pathogens. Ammonia nitrogen is the nutrient of the algae which in turn facilitated their growth (Jung et al., 2014). The results show a relatively significant microbiological contamination especially for both total coliforms and faecal coliforms and this was more evident particularly in MS and ES pools. These two pools have a large number of total and faecal coliforms compared to the HC pool. The microbiological contamination of both pools (MS and ES) could be explained by the absence of free chlorine in the pools, an absence noticed during analyses of this parameter.

**Table 3.** Pearson correlation obtained between the physicochemical and microbiological parameters of the MS pool

| | pH | Electrical Conductivity | Turbidity | Free chlorine | Combine chlorine | $NO_3$-N | Total coliform | Faecal coliform |
|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | |
| Electrical Conductivity | -0.353* | 1 | | | | | | |
| Turbidity | NS | 0.44* | 1 | | | | | |
| Free chlorine | -0.50** | NS | NS | 1 | | | | |
| Combine chlorine | -0.60** | 0.38* | NS | 0.56** | 1 | | | |
| $NO_3$-N | NS | -0.36* | -0.43* | 0.42* | NS | 1 | | |
| Total coliform | NS | NS | NS | NS | NS | NS | 1 | |
| Faecal coliform | NS | 0.42* | NS | NS | NS | NS | NS | 1 |

*The data are significantly different at $P < 0.05$; ** the data are significantly different at $P < 0.01$; NS: not significant

In one pool where the disinfection service was ineffective, bacterial multiplication was a direct consequence. The large numbers of bacteria observed in the ES pool could be related to a concentration of free chlorine measured below the WHO limits (WHO, 2006). When disinfecting, this normally targets bacteria (microorganisms) that are pathogenic to humans. The parameters that guide the well-being of the bathers are pH, turbidity, and free chlorine, among others. The significant microbial contamination detected in swimming pools (MS and ES) almost every day (except one day) could be explained by a low quantity of disinfectant in the pools or by ineffective disinfection process (Badiee and Rouein, 2019). This was evident from the concentrations of free chlorine found in the tests. For the MS pool, 9 days out of 12 were characterized by non-detective free chlorine with many microbiological contaminants. This suggests that a small amount of disinfectant was introduced into the water loaded with many microorganisms that negatively affect the disinfection by making it ineffective (Abdel-Salam, 2012). On the other hand, disinfection would have been hindered by other factors such as pH and turbidity. Despite that, these pools were characterized by turbidity above the quality standards; the water in these pools may contain a lot of organic matter, which would require a high concentration of chlorine. The disinfectant would have reacted with the organic matter forming chloramines and its quantity would be finished without being consumed by the target microorganisms. The HC pool manifested a slight contamination over the entire study period. A similar pattern was discovered in the study of Abdel-Salam (2012) in Egypt, where a high contamination by pathogenic bacteria was attributed to a large number of bathers but also to a low concentration of free chlorine in swimming pools.

The results of this study corroborate with those of Ekopai et al. (2017) who reported a total number of mesophilic aerobic flora exceeding the WHO limits for swimming pools microbial quality (less than $5x10^2$ MPN $1mL^{-1}$). Lack of frequent disinfectant for the treatment of swimming pools makes them an important source of microbiological contaminants (Badiee and Rouein, 2019). This was confirmed in a recent study (Victor et al. 019) in Nigeria, where before and after swimming, 86% of samples were contaminated with total coliforms and faecal coliforms. This study revealed greater contamination of two pools (MS and ES) with total coliforms at 69.4% (n=25/36) and faecal coliforms at 52.2% (n=19/36). Contrarily, the HC pool had low faecal coliform contamination where 1/12 days had 5 MPN $1mL^{-1}$, when total coliforms were $1.36x10^1$ MPN $1mL^{-1}$ to $5.00x10^2$ MPN $1mL^{-1}$.

**Table 4.** Pearson correlation obtained between the physicochemical and microbiological parameters of the HC pool

| | **pH** | **Electrical Conductivity** | **Turbidity** | **Free chlorine** | **Combine chlorine** | **$NO_3$-N** | **Total coliform** | **Faecal coliform** |
|---|---|---|---|---|---|---|---|---|
| **pH** | 1 | | | | | | | |
| **Electrical Conductivity** | 0.74** | 1 | | | | | | |
| **Turbidity** | 0.51** | 0.34* | 1 | | | | | |
| **Free chlorine** | NS | NS | NS | 1 | | | | |
| **Combine chlorine** | -0.40** | NS | NS | -0.47** | 1 | | | |
| **$NO_3$-N** | 0.38* | 0.33* | NS | NS | NS | 1 | | |
| **Total coliform** | -0.34* | NS | -0.59** | 0.36* | NS | NS | 1 | |
| **Faecal coliform** | NS | NS | NS | 0.55* | NS | 0.36* | NS | 1 |

*The data are significantly different at $P < 0.05$; ** the data are significantly different at $P < 0.01$; NS: not significant

Statistical analyses of the data for this pool (HC) showed an inverse correlation ($R^2$ = - 0.552) (Table 4) between free chlorine and faecal coliforms. This is substantiated by the fact that optimization of chlorine disinfection can significantly reduce the number of coliforms. Among the pools evaluated, the MS and ES were contaminated with pollution indicator bacteria. Since these two public swimming pools receive a significant number of bathers, especially during the vacation season, their quality is of great health concern. Consequently, HC is a semi-public swimming pool (hotel) which has a lower number of bathers than the other two (MS and ES), which could justify this difference in its microbiological contamination.

## Conclusion

In the present study, the physical and chemical properties of the three swimming pools were not optimally the same in the entire pools analyzed. Valuable management of these three studied swimming pools and suitable control of disinfectant levels, turbidity, pH and microbiological property may generate satisfactorily water safety plans for public recreational activities. This study generally demonstrated that none of the three swimming pools met the expected WHO quality standard.There is an urgent need to decrease introduction of contaminants into these swimming pools. It is necessary to adopt and sustain appropriate water quality measures to avoid transmission of the potential infectious, facultative pathogens that are introduced by swimmers.

## Author's contribution statement

Christophe Niyungeko: Project design, Methodology design, Writing-review and editing , Correspondence
Jonas Ntirampeba: Experiment , Writing-review and editing
Prudance Bararunyeretse:  Experiment, Writing and editing
Benjamin Makimilua Tiimub: Writing-review and editing
Manassé Nihorimbere:  Writing-review and editing
Pierre Ntakiyiruta: Writing-review and editing

## Conflict of interest

The authors declare that there is no conflict of interest.


## Acknowledgment

We are grateful for research and teaching support given by the VLIR-UOS project (P1).

## References

Afsset 2010. Risques sanitaires liés aux piscines : évaluation des risques sanitaires liés aux piscines – Partie 1 piscines réglementées, Edition Scientifique - Eau et Agents Biologiques, Juin 2010, 244p.

Ajadi, F. A., Bakare, M. K., and Oyedeji, O., 2016. Assessment of the physicochemical and microbiological qualities of swimming pools in selected hotels in osogbo metropolis, Southwestern Nigeria. Ife Journal of Science, 18(4), 831– 843.

Alan, J.B., Diaz, R., Ordaz, C., and Palomeque B., 1980. Nitrates , Chlorates and Trihalomethanes In Swimming Pool Water. American journal of public health, 70(1), 79 – 82. doi: 10.2105/ajph.70.1.79.

Al-khatib, I., and Salah, S., 2015. Bacteriological and chemical quality of swimming pools water in developing countries : A case study in the West Bank of Palestine, International Journal of Environmental Health Research, 13, 17– 22.

Amor, C., Torres-Socías, E. De, Peres, J. A., Maldonado, M. I., Oller, I., Malato, S., and Lucas, M. S., 2015. Mature landfill leachate treatment by coagulation/flocculation combined with Fenton and solar photo- Fenton processes. Journal of Hazardous Materials, 286, 261–268.

ASTM. 2008. Standard Test Methods for Ammonia Nitrogen in Water, https://doi.org/10.1520/D1426-08.

Badiee, P. and Rouein, S., 2019. The Best Commercial Chemical Disinfectant for Swimming Pools Environments Contaminated With Fungi. Mohammad Rasul Allah Research Tower, Khalili St., Shiraz, 7193635899, IRAN, 22p, https://orcid.org/0000-01-5587-4336.

Carbonnelle, S., 2003. Les risques sanitaires des produits dérivés de la chloration des eaux de bassins de natation », *VertigO - la revue électronique en sciences de l'environnement* [En ligne], Volume 4 Numéro 1, mis en ligne le 01 mai 2003, consulté le 16 novembre 2021. URL: http://journals.openedition.org/vertigo/4638 ; DOI : https://doi.org/10.4000/vertigo.4638.

CDC, 2016. Designing Public Swimming Facilities. Health Swimming, Healthy Water. Centers for Disease Control and Prevention, May, 4. Available online at: edge://settings/content/siteDetails?site=https%3A%2F%2Fwww.cdc.gov

Ekopai, J.M., Musisi, N.L., Onyuth, H., Namara, B.G., and Sente, C., 2017. Determination of Bacterial Quality of Water in Randomly Selected Swimming Pools in Kampala City,Uganda, New Journal of Science Volume 2017 |Article ID 1652598 https://doi.org/10.1155/2017/1652598.

El-Salam, M.M. A., 2012. Assessment of water quality of some swimming pools: A case study in Alexandria, Egypt. Environmental Monitoring and Assessment, *184*(12), 7395–7406. https://doi.org/10.1007/s10661-011-2508-6.

Ibrahimou, M.N., 2017. Évaluation de la qualité physico-chimique et bactériologique des eaux des forages a usage particulier et semi-industriels a ouagadougou (Burkina Faso).

Jaunakais, I., Hill, R., and Anand, S.M., 2009. United States Patent Date of Patent : In Reagent delvery and photometric chlorine analysis (Vol.1).

Jung, A. V., Cann, P. Le, Roig, B., Thomas, O., Baurès, E., and Thomas, M. F., 2014. Microbial contamination detection in water resources: Interest of current optical methods, trends and needs in the context of climate change. International Journal of Environmental Research and Public Health, *11*(4), 4292– 4310. https://doi.org/10.3390/ijerph110404292

Kabogora, M., 2014. Etude de la qualité et de la traitabilité de l'eau souteraine de la ville de Bujumbura: cas de l'eau de puit et de piscine située à kinindo (M Sc Thesis), Université du Burundi, Bujumbura, 56p.

Kim, K., Chung, E., Kim, C. J., and Lee, S., 2012. Swimming exercise during pregnancy alleviates pregnancy-associated long-term memory impairment. Physiology and Behavior, 107(1), 82–86. https://doi.org/10.1016/j.physbeh.2012.06.004.

Nag, O.S., 2017. Top Tourists Destinations in the World. Accesed online at : edge://settings/content/siteDetails?site=https%3A%2F%2Fwww.worldatlas.

Robles, E., Ramírez, E., Sáinz, M. D. G., Martínez, B., Ayala, R., González, M. E., and Olmos, M., 2019. Microbiological and Physico-chemical Study of Swimming Pool Water. International Research Journal of Advanced Engineering and Science, 4(4), 15–20.

Rodier, J., 2000. L'analyse de l'eau 9e Ed.1529 p.

Sadikoglu, M., 2017. Variations in Nitrogen ($NH_4^+$, $NO_2^-$, $NO_3^-$) and Heavy Metal (Al and Cu) Levels of Water from Swimming Pools in the City Center and Districts of Canakkale, Turkey. Environmental Analytical Chemistry, 4(2), 2 – 6. https://doi.org/10.4172/2380-2391.1000198

Farooq, S., Hashmi, I.,Ishtiaq, A., Sara, Q., and Rasheed, S. , 2008. Monitoring of Coliforms and chlorine residual in water distribution network of Rawalpindi, Pakistan. Environmental Monitoring and Assessment 140, 339 – 347, https://doi.org/10.1007/s10661-007-9872-2.

Shittu, O.B., Olaitan, J.O. and Amusa, T.S., 2008. Physicochemical and bacteriological analyses of water used in drinking and swimming purposes in Abeokuta, Nigeria. African Journal of Biomedical Research, 11, 285 – 290.

Simard, S., 2009. Occurrence des sous-produits de la désinfection dans l ' eau des piscines. Québec, 52p.

Suthar, S., Bishnoi, P., Singh, S., Mutiyar, P. K., Nema, A. K., and Patil, N. S., 2009. Nitrate contamination in groundwater of some rural areas of Rajasthan , India. Journal of Hazardous Materials, 171, 189 –199. https://doi.org/10.1016/j.jhazmat.2009.05.111.

Teo, T. L.L., Coleman, H. M., and Khan, S. J., 2015. Chemical contaminants in swimming pools: Occurrence, implications and control. Environment International, 76, 16 –31.

Timothy, J., Wade, N.P., Joseph, N.S. E., John, M., and Colford, J., 2003. Do U.S. Environmental Protection Agency water quality guidelines for recreational waters prevent gastrointestinal illness? A systematic review and meta-analysis. Environmental Health Perspectives, 111(8), 1102–1109. https://doi.org/10.1289/ehp.6241.

Victor, T. O., Doosuur, N.T., and Stephen, E., O., 2019. Studies on the physicochemical and bacteriological properties of some semi-public Swimming pools in Makurdi, Nigeria. African Journal of Microbiology Research, 13(14), 264 – 272. https://doi.org/10.5897/ajmr2019.9053.

WHO. 2006. Guidelines for safe recreational water environments., Swimming pools and similar environments, Geneve, 118p .

Yeh, R. Y. L., Farré, M. J., Stalter, D., Tang, J. Y. M., Molendijk, J., and Escher, B. I., 2014. Bioanalytical and chemical evaluation of disinfection by-products in swimming pool water. Water Research, 59, 172–184. https://doi.org/10.1016/j.watres.2014.04.002.

Zwiener, C., Richardson, S. D., De Marini, D. M., Grummt, T., Glauner, T., and Frimmel, F. H., 2007. Drowning in disinfection byproducts? Assessing swimming pool water. Environmental Science and Technology,41(2),363–372.https://doi.org/10.1021/es062367.