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Assessment of Ecological and Human Health Risks of Toxic Metals in Water from Public Swimming Pools within Abuja, FCT, Nigeria

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Abstract

Water in public swimming pools within Abuja, Nigeria was investigated to determine the levels of toxic metals and assess the potential ecological and human health risks. Composite water samples were collected by simple random sampling, from thirteen (13) swimming pools located in hotels and recreational centres within Abuja and a control sample from the municipal water supply line. They were analyzed for heavy metals concentration (Cr, Pb, Hg, Mn, Ni, Zn, Cu, As and Cd), using Atomic Absorption Spectrophotometry (AAS) and Atomic Emission Spectrophotometry (AES). Analytical data obtained were compared with WHO/NSDWQ standards for recreational waters. Potential human health and ecological risks from the samples were evaluated by calculating specific indices. Results showed elevated levels of Hg in all pools except RVR hotel pool, which had a threshold value of 0.0010 mg/L. The highest concentration of Hg (0.012 mg/L) was found in SH, followed by 0.011 mg/L in S-38-H. The level of Cd detected in SH was 0.0026 mg/L, an edge close to the WHO limit of 0.003 mg/L. Other levels of Cd and other toxic metals were below limit. Ecological risk index (E_r^i) for the toxic metals in the water samples was below 30, showing no overall risk of toxicity. The human health risk index (HI) was <1, indicating no overall health risk, though single toxic metal risks related to elevated levels of Hg and Cd slightly exist. It was recommended that the source of Hg in the majority of the samples should be investigated in future research. Most results from the swimming pools showed remarkable similarity in values with those from the municipal water supply line, suggesting that the swimming pools use water from the municipal water supply. Regular monitoring checks of both the municipal water supply and the swimming pools by NESREA and the Federal Ministry of Environment were recommended in this research.

Keywords

Toxic Metals, Ecological Risk, Human Health Risk, Swimming Pools, Poisoning

1. Introduction

Water is one of the most important natural resources crucial in supporting life processes in both plants and animals. Notwithstanding the importance of water to human existence, it could pose serious threats by serving as a medium for disease transmission when contaminated (Agomuo & Amadi, 2019). The recreational and environmental use of water is increasing in terms of both the nature of the activities being undertaken and the number of participants becoming involved. Recreational and environmental waters include marine and fresh waters, as well as bathing and leisure pool waters, which are frequently indoors and which often exhibit high bathing densities.

Swimming, a popular pastime activity, creates fun and is an active and a healthy way to relax and beat the heat in Africa. Swimming pools are concrete tanks, large artificial basins, or large paved holes containing water for swimming (Ajadi et al., 2016). Swimming pools have become one of the main side attractions in the marketing of tourism in Nigeria. They are found in hotels, guest houses, restaurants, club houses, tertiary institutions and individual homes, among others. Pool water and the surfaces of objects or materials at a swimming facility are exposed to contamination from body fat, toxic substances and human waste materials such as nasal secretions, saliva, sweat, faecal, urine and body lotions and creams (Saberianpour et al., 2015). Gastrointestinal, skin, eye and neurological disease conditions have all been reported to be associated with recreational and environmental water contact (Ajadi et al., 2016).

Swimming pools are increasingly patronized by people for leisure and recreational purposes, hence possible failures with their maintenance would be a matter of public health significance. According to Agomuo and Amadi (2019), the provision of quality water, amongst other benefits, enhances recreational opportunities, such as in swimming pools, that flourish as a resource-generating venture in major cities of Nigeria. Swimming pools are recreational environments that provide both social and health benefits, and as such, should not cause harm to swimmers through either toxic substances or pathogenic microbes. That notwithstanding, Addo et al. (2018) noted that the rate of injuries that occur, particularly in swimming pools, is underestimated, and greatly exceeds those in other environments. Some of these injuries include asthma, gastrointestinal issues, skin and eye irritation and other skin infections, thus requiring the establishment and enforcement of regulatory guidelines for the safety of the recreational environments (Agomuo & Amadi, 2019). Some measures, such as chlorination of the pool water and refilling swimming pools every three days using mainly borehole water, are predominantly adopted by pool owners to ensure the mitigation of health risks associated with poor sanitary conditions for the pools.

Prior to this present study, no report exists in literature regarding the ecological and human health risk assessments for swimming pools in Abuja. Therefore, it becomes paramount to fill the gap in knowledge created by the paucity of information on the present contamination status of swimming pools, especially those situated in population-dense and uncontrolled activity-laden locations. It was on this foregoing that this study was designed to determine the presence and level of water contaminants and risks associated with dermal contact and oral ingestion of these contaminants in the selected swimming pools situated in Federal Capital Territory (FCT), Abuja, Nigeria.

This study seeks to assess the toxic metal attributes of swimming pool waters in FCT, Abuja metropolis, so as to bring into light and reduce the risks of contracting disease in order to stem the incidence of recreational disease outbreaks.

The specific objectives of the study are to:

1) Determine the level of toxic metals such as Cr, Pb, Hg, Mn, Ni, Zn, Cu, As and Cd in the water samples;

2) Evaluate the potential ecological risk in the samples by calculating specific indices using the toxic metal concentrations obtained;

3) Evaluate the potential human health risk in the samples by calculating specific indices using the toxic metal concentrations obtained.

The assessment of the swimming pool water quality, particularly the potential ecological and human health risk of toxic metals, will enhance the determination of the potability of these waters, their suitability for swimming, and if humans who use the swimming pools are prone to any short-term or long-term hazard from contact with the pool water. This will guide stakeholders (individuals, hotels, government regulatory agencies like National Environmental Standards Regulation Enforcement Agency (NESREA), etc.) in the FCT to make significant changes for the safety and health of all concerned.

The study was carried out on water samples collected from thirteen (randomly selected) hotels and recreational centres in Phases I and II of Abuja, Nigeria. These Phases are the most developed parts of Abuja, located in the Abuja Municipal Area Council. The study covered the analysis of concentrations of heavy metals such as Cr, Pb, Hg, Mn, Ni, Zn, Cu, As and Cd. The results obtained were further evaluated for ecological and human health risk indices and statistical analysis of data generated was carried out.

2. Literature Review

2.1. Benefits of Using Swimming Pools

Water-based exercises confer specific advantages, as compared to land-based exercise. For this reason, water-based exercise prescription should be a key consideration for all health care clinicians, providers and commissioners. It is also emphasized that having adequate opportunities to learn to swim and have positive experiences in early life, particularly among those from disadvantaged backgrounds, may be an important step to tackle drowning as one of the causes of avoidable and tragic death (Cumming, 2017).

It is estimated that those who swim for recreational or competitive purposes are eight times more likely to meet physical activity guidelines. Long-term swim training can improve cardiorespiratory fitness or endurance in healthy pre-pubertal girls and adults, women during pregnancy, children with asthma, and adults with osteoarthritis (a condition affecting joints, causing pain and stiffness). It is however concerning to find in many areas a profound lack of robust scientific evidence in swimming as a contemporary means to: increase physical activity levels, move the inactive into swimming as a preferred physical activity, and to use a variety of community swimming venues to promote health and wellbeing at population levels (Bunn et al., 2016; Adsett et al., 2015).

The global pandemic of physical inactivity is well recognised with concomitant implications for global health (Cumming, 2017). In a nation like the United Kingdom (UK), a significant proportion of children, adolescents and adults fail to meet the national recommendations for physical activity: 90% of 2 - 4 year olds, 80% of 5 - 15 year olds, and 39% of adults. Similar patterns are seen globally (Amadi et al., 2010). Sedentary behaviour associated with adverse cardiometabolic adaptations such as insulin resistance, altered lipid trafficking, muscle fibre type alteration and ectopic fat storage was reported by Cumming (2017). Poor cardiorespiratory fitness/physical inactivity is a significant risk factor for the majority of Non-Communicable Diseases (NCDs), including cardiovascular disease, dementia, certain cancers, osteoporosis, obesity and Type 2 diabetes. It is also the strongest independent risk factor for development of post-operative morbidity and mortality (Cumming, 2017).

Of interest are the unique features that aquatic-based exercise offers, and how swimming and aquatic exercise relate to health outcomes. Swimming and other forms of aquatic exercise (aqua-jogging and aqua-aerobics, for example) are some of the most popular choices for meeting physical activity recommendations—both for the aerobic and strength/balance element (Wood et al., 2013).

Cumming (2017) maintained that exercise in an aquatic environment confers many benefits, such as minimised weight-bearing stress, a humid environment and a decreased heat load. This may offer a personalised exercise opportunity for particular populations, especially the elderly, pregnant women, and those with arthritis, type 2 diabetes, disabilities or excess adiposity (Yuan et al., 2016). The unique nature of swimming and aquatic exercise will be considered. The aquatic environment has been recognised as a place for active play and recreational exercise since the nineteenth century.

Yuan et al. (2016) compared the health aspects of swimming with alternative forms of aerobic exercise and sedentary behaviour. Participants included 10,518 women and 35,185 men aged 20 - 88 years old; the majority were Caucasian and of middle/upper socio-economic status. Screening included a formal subjective and objective history, anthropometric measurements, blood tests and a graded exercise test. Participants were categorised as "sedentary" (no participation in activity over the previous three months), "walkers" (primarily engaged in run/walk/jog at a pace ≥ 15 min/mile), "runners" (primarily engaged in run/walk/jog at a pace ≤ 15 min/mile), and "swimmers" (exclusively engaged in swimming activity). The results demonstrated that all types of physical activity produced demonstrable health benefits in comparison to a sedentary lifestyle. Of all the groups, swimming and running achieved the highest treadmill test duration/maximal metabolic equivalent (MET) levels, although the Body Mass Index (BMI) of swimmers was significantly higher than that of runners. It is worthy of note, however, that the "swimmers" category only formed approximately 1% of the total participant population, and therefore this could affect the internal validity of the study. Equally, the limited demographics of the population could adversely affect external validity. The authors, however, conclude that swimming constitutes a valuable lifetime activity that appears to produce healthy levels of cardiorespiratory fitness and, as such, is a viable alternative to other forms of exercise. This is further supported by the results of a prospective study of the health effects of physical activity and fitness in men, which concluded that swimmers had lower mortality rates than those who were sedentary, walkers or runners even after controlling for age, body mass index, smoking/alcohol and family history (Cumming, 2017; de Oliveira et al., 2014).

Similar results have been demonstrated by Oja et al. (2015); in a cohort study of over 80,000 British adults, swimming participation was associated with a significantly reduced risk of all-cause mortality of 28%, and cardiovascular disease mortality of 41%.

An increasing volume of literature supports the use of swimming and aquatic exercise in patients with impaired Left Ventricular Ejection Fractions (LVEFs), but stable symptoms (Adsett et al., 2015; Neto et al., 2015). Benefits included improvements in LVEF/6 Minute Walk Test/VO_2 peak and increased levels of plasma nitrates. Becker (2009) has proposed a clinical algorithm for aquatic activity decision-making, intended to guide healthcare practitioners in advising patients safely and appropriately. Evidence suggests that swimming and aquatic exercise are viable methods for improving cardiorespiratory fitness and may be a particularly attractive option for those individuals who are less tolerant of land-based exercise. Furthermore, swimming appears to constitute a valuable intervention for risk factor modification, especially for hypertension. Swimming and aquatic exercise appear to be safe in individuals with established cardiovascular disease, where symptoms are stable, and exercise prescription is directed by an appropriately qualified practitioner (Hallal et al., 2022; Oja et al., 2015; Prince et al., 2015).

According to the WHO (2006), the hazards from drowning and injury are probably the most obvious hazards relating to pools and similar environments. Swimming pools, however, can expose people to a variety of other health risks associated with physical, microbial and chemical hazards. Infection is a major risk in swimming pools (Bergamin et al., 2013; Oh et al., 2015; Kamioka et al., 2020).

2.2. Chemical Contaminants in Swimming Pools

2.2.1. Source Water-Derived Chemicals

All source waters contain chemicals, some of which may be important with respect to pool, hot tub and spa safety. Water from a municipal drinking-water supply may contain organic materials (such as humic acid, which is a precursor of disinfection by-products), disinfection by-products from previous treatment/disinfection processes, lime and alkalis, phosphates and, for chloraminated systems, monochloramines (Fernandez-Lao et al., 2023; Cantarero-Villanueva et al., 2012). Seawater contains high bromide concentrations. In some circumstances, radon may also be present in water that is derived from groundwater. Under such circumstances, adequate ventilation in indoor pools and hot tubs will be an important consideration. WHO is considering radon in relation to drinking-water quality guidelines and other guidance (WHO 2006).

2.2.2. Bather-Derived Chemicals

Nitrogen compounds, particularly ammonia, that are excreted by bathers (in a number of ways), react with free disinfectant to produce several by-products. A number of nitrogen compounds can be eluted from the skin, as reported by the World Health Organisation. The nitrogen content in sweat is around 1 g/L, primarily in the form of urea, ammonia, amino acids and creatinine. Depending on the circumstances, the composition of sweat varies widely (Andersen et al., 2015). Significant amounts of nitrogen compounds can also be discharged into pool water through urine. The urine release into swimming pools has been variously estimated to average between 25 and 30 mL per bather and be as high as 77.5 mL per bather, although this area has not been well researched (WHO 2006).

2.2.3. Management-Derived Chemicals

A number of management-derived chemicals are added to pool water in order to achieve the required water quality. A proportion of pool water is constantly undergoing treatment, which generally includes filtration (often in conjunction with coagulation), pH correction and disinfection (Ahlskog et al., 2021). Most pools are designed for recreational use and are not to be drained, cleaned and refilled after each individual use and may consist of elements, gotten from, but not limited to, hydrojet circulation, hot water, cold water, mineral baths, air induction systems, or any combination thereof. Many studies have been conducted on public swimming pools in different areas of Nigeria (Indabawa et al., 2015; Agbagwa & Young-Harry, 2012; Eze et al., 2015).

2.3. Assessment of Toxicity in Swimming Pools

The World Health Organization (WHO 2006) held that chemicals found in pool water can be derived from a number of sources: the source water, deliberate additions such as disinfectants and the pool users themselves, as can be seen in **Figure 1**. This section describes the routes of exposure to swimming pool chemicals, the chemicals typically found in pool water and their possible health effects.

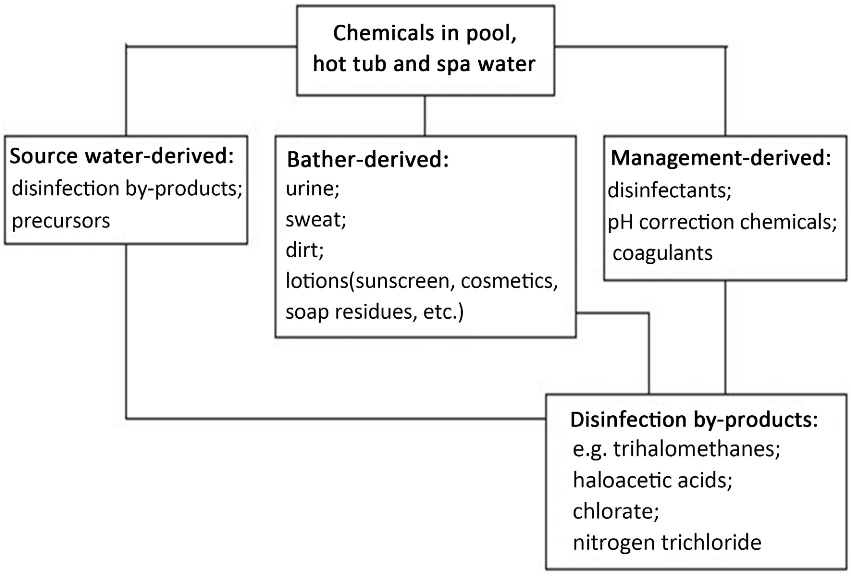

Figure 1. Possible sources of contaminants in swimming pools and similar environments (WHO 2006).

Indabawa et al. (2015) did an assessment of microbiological and physico-chemical quality of some swimming pools within Kano Metropolis, Kano, Nigeria. The result of the study showed that the swimming pools were aesthetically unsuitable for recreational purposes. The authors recommended that efforts should be put in, to enforce effective pool water treatment by the proprietors.

Agbagwa and Young-Harry (2012) worked on the quality of Selected Public Swimming Pools in Owerri, observed parameters that exceeded recommended bathing loads in several of the pools appeared to introduce many dissolved solids in water, and this in turn depleted residual chlorine sanitizer applications, and so, encouraged the growth of coliform bacteria that were also introduced by the bathers.

Eze et al. (2015) carried out a study to investigate the microbiological and physicochemical characteristics of swimming pool water in Owerri. The identification of bacterial isolates was performed using standard microbiological techniques, which included Gram staining and biochemical tests. The fungal isolates were identified using the needle mount technique. The physicochemical parameters analyzed were within WHO limit for drinking water quality, except total dissolved solid with mean values of 380 ± 10.0 mg/L and 275 ± 8.0 mg/L, respectively. The result showed that the swimming pools investigated were not contaminated with pathogenic microorganisms.

2.4. Routes of Contamination

In their report, Pasquarella et al. (2023) stated that chemical risks linked with the use of swimming pools are mainly associated with disinfectants, which can react with other chemicals in the water and give rise to Disinfection By-Products (DBPs).

There are three main routes of exposure to chemicals in swimming pools and similar environments, as reported by Hauri et al. (2015), Erdinger et al. (2004) and Fantuzzi et al. (2021).

1) Direct ingestion of water;

2) Inhalation of *volatile* or aerosolized solutes; and

3) Dermal contact and absorption through the skin.

2.4.1. Ingestion

The amount of water ingested by swimmers and pool users will depend upon a range of factors, including experience, age, skill and type of activity. The duration of exposure will vary significantly in different circumstances, but for adults, extended exposure would be expected to be associated with greater skill (e.g., competitive swimmers), and so there would be a lower rate of ingestion in a comparable time than for less skilled users (WHO 2006). The situation with children is much less clear. There appear to be no data with which to make a more detailed assessment (Erdinger et al., 2004; Fantuzzi et al., 2021).

A number of estimates have been made of possible intakes while participating in activities in swimming pools and similar environments, with the most convincing being a pilot study by Evans et al. (2001) and Fantuzzi et al. (2021). This used urine sample analysis, with 24-h urine samples taken from swimmers who had used a pool disinfected with dichloroisocyanurate and analysed for cyanurate concentrations. All the participants swam, but there is no information on the participant swimming duration. This study found that the average water intake by children (37 mL) was higher than the intake by adults (16 mL). In addition, the intake by adult men (22 mL) was higher than that by women (12 mL); the intake by boys (45 mL) was higher than the intake by girls (30 mL). The upper 95th percentile intake was for children and was approximately 90 mL.

2.4.2. Inhalation

Swimmers and pool users inhale from the atmosphere just above the water's surface, and the volume of air inhaled is a function of the intensity of effort and time. Individuals using an indoor pool also breathe air in the wider area of the building housing the pool. However, the concentration of pool-derived chemical in the pool environment will be considerably diluted in open-air pools (Strähle et al., 2000; Erdinger et al., 2004).

Inhalation exposure will be largely associated with volatile substances that are lost from the water surface, but will also include some inhalation of aerosols, within a hot tub (for example) or where there is significant splashing. The normal assumption is that an adult will inhale approximately 10 m^3 of air during an 8-h working day (WHO 2006). However, this will also depend on the physical effort involved. There will, therefore, be significant individual variation depending upon the type of activity and level of effort (Fantuzzi et al., 2021).

2.4.3. Dermal Contact

The skin will be extensively exposed to chemicals in pool water. Some may have a direct impact on the skin, eyes and mucous membranes, but chemicals present in pool water may also cross the skin of the pool, hot tub or spa user and be absorbed into the body (Pasquarella et al., 2023). Two pathways have been suggested for transport across the stratum corneum (outermost layer of skin): one for lipophilic chemicals and the other for hydrophilic chemicals (WHO 2006). The extent of uptake through the skin will depend on a range of factors, including the period of contact with the water, the temperature of the water and the concentration of the chemical (Leoni et al., 2020).

Another exposure pathway of toxic metal for swimming pool water users is through dermal absorption caused by contact with the water while swimming in a contaminated water (Agbagwa & Young-Harry, 2012). Dermal absorption pathway is significantly more important than the inhalation pathway for exposure to toxic metals. Studies evaluating health risks from heavy metals in water (such as lakes, rivers or swimming pools) often find that: the primary pathways of concern are ingestion and dermal contact and that inhalation typically contributes a much lower, often negligible amount to the overall exposure and health risk (Acarer Arat, 2025; Chaudharı et al., 2024; Guan et al., 2025).

2.5. Sampling in Swimming Pools (APHA, 2005)

Guidelines on routine sampling frequencies, along with a summary of operational guideline values, are outlined in **Table 1**. In addition to routine sampling, samples should be taken from public and semi-public facilities:

1) Before a pool is used for the first time;

2) Before it is put back into use, after it has been shut down for repairs or cleaning;

3) If there are difficulties with the treatment system, and as part of any investigation into possible adverse effects on bathers' health;

4) Samples should be taken when the pool is heavily loaded;

5) Sampling frequency should be increased if operational parameters (e.g., turbidity, pH, residual disinfectant concentration) are not maintained within target ranges;

6) Sample numbers should be determined on the basis of pool size and complexity and should include point(s) representative of general;

7) Water quality and likely problem areas;

8) Operational guidelines are shown in parentheses, e.g., when health problems associated with the pool are suspected.

The most appropriate site for taking a single sample is where the water velocity is low, away from any inlets. Depending on the size of the pool, it may be advisable to take samples from multiple sites. Many leisure pools will have additional features, such as flumes, islands and backwaters with a complex system of water flow; representative samples should be taken from the different sections (Agomuo & Amadi, 2019).

Misleading information on pool water quality could result from incorrect sampling procedures. Sample containers must be of a material that will not affect the quality of the sample either microbially or chemically. Although a good-quality glass container will meet these requirements, the risk of broken glass in the pool environment as a result of breakage has favoured the use of shatterproof plastic-coated glass containers. All-plastic containers can be used, provided they do not react with microorganisms or chemicals in the water; not all are suitable.

2.6. Water Quality Guidelines for Swimming Pools

The guidelines set by The Association of Pool & Spa Professionals are widely used, but to be certain, researchers check the health codes of the jurisdiction where they live. The chemicals a pool needs to maintain the required standards differ from pool to pool and day to day. Keeping records to "get to know" a pool can help researchers interpret its characteristics and perform the correct task (Association of Pool & Spa Professionals, 2009). **Table 2** contains the limits of some handy pool water quality parameters as stipulated by The Association of Pool and Spa Professionals, the world's oldest and largest association representing swimming pool, spa, and hot tub manufacturers, manufacturers' agents, builders, designers, installers, who are dedicated to the growth and development of their members' business and to promote the enjoyment and safety pools and spas. **Table 2** shows the WHO standard for some key parameters with respect to water in swimming pools and similar environments.

Table 1. Chemical standards for swimming pools (APHA, 2005; Association of Pool & Spa Professionals, 2009).

Parameters	Limits
Free chlorine (ppm)	2.0 - 4.0
Combined chlorine (ppm)	None
pH	7.2 - 7.8 (ideal range of 7.4 - 7.6)
Total alkalinity (ppm)	
For liquid chlorine, calcium hypochlorite, lithium hypochlorite	80 - 100
For gas chlorine, dichlor, trichlor and bromine compounds	100 - 120
Total dissolved solids (ppm)	Not to exceed 1500 greater than at pool start-up
Calcium hardness (ppm)	200 - 400
Cyanuric acid (ppm)	30 - 50

Table 2. WHO/NSDWQ limits for recreational waters (WHO 2006).

Parameters	Maximum Allowable Limit
Zinc	50 mg/L
Nickel	0.07 mg/L
Manganese	8.0 mg/L
Lead	0.2 mg/L
Cadmium	0.003 mg/L
Chromium	0.05 mg/L
Copper	2.0 mg/L
Arsenic	0.01 mg/L
Mercury	0.001 mg/L
Temperature	22˚C - 26˚C
Turbidity	6 NTU
pH	7.0 - 7.8
Nitrate	1 - 5 mg/L
Phosphate	0.01 - 0.02 mg/L
Conductivity	1000 µ/cm
Total Hardness	150 mg/L
Total Dissolved Solid	500 mg/L
Dissolved Oxygen	9 - 10 mg/L
Biological Oxygen Demand	1 - 2
Free residual chlorine	1 - 3 mg/L
Heterotrophic plate count	≤200 cfu/mL
Escherichia coli	≤1/100 mL
Staphylococcus aureus	≤100/100 mL

2.7. Ecological Risk Indices

Pollution indices seem to be promising and beneficial in assessing the metal enrichment and/or contamination in the water-sediment system (Pobi et al., 2019). There are several methods to assess water sediment quality and describe the contamination adverse effects (Ridgway & Shimmield, 2022).

2.7.1. Ecological Risk Index (RI)

The potential ecological risk index (RI) evaluation method proposed by Håkanson (1980) remains a classic method to evaluate the potential ecological risk of heavy metals in substances (Etuk et al., 2026; Bwede et al., 2021).

$$C_f^i = \frac{C_i}{B_n} \tag{1}$$

$$E_{ir} = T_r^i \times C_f^i \tag{2}$$

$$RI = \sum_{i=1}^{n} E_{ir} \tag{3}$$

where,

C_f^i is the contamination factor for a given toxic metal;

C_i is the measured concentration of toxic metal;

B_n is the background/reference value of toxic metal;

E_{ir} is toxic metal ecological risk factor for a single toxic metal *I*;

T_r^i is the toxic response factor for a single toxic metal contamination, and *RI* is the total potential ecological risk index for heavy metals. The world background/reference values for the selected toxic metals, as documented by Turekian and Wedepohl (1961) and used by Wuana et al. (2020), were applied. The background values are Zn, 95; Ni, 68; Mn, 850; Pb, 20; Cd, 0.3; Cr, 90; Cu, 45; As, 13; Hg, 0.4 mg/mL, respectively.

When $RI < 150$, the risk level is low; when $150 \leq RI < 300$, the risk level is medium; when $300 \leq RI < 600$, the risk level is high; and when $RI \geq 600$, the risk level is very high (Turekian & Wedepohl, 1961).

2.7.2. Pollution Load Index (PLI)

The Pollution Load Index (PLI), introduced by Tomlinson et al. in 1980, is calculated as the *n*-th root of the product of *n* Contamination Factors (CFs) for various pollutants.

The formula is:

$$\text{PLI}\left(CF_1 \times Cf_2 \times Cf_3 \times Cf_4 \times Cf_n\right)^{1/n} \tag{4}$$

When PLI = 0 (background concentration), 0 < PLI ≤ 1 (unpolluted), 1 < PLI ≤ 2 (unpolluted to moderately), 2 < PLI ≤ 3 (moderately polluted), 3 < PLI ≤ 4 (moderately to highly polluted), 4 < PLI ≤ 5 (highly polluted) and PLI > 5 (very highly polluted).

2.8. Human Health Risk Index Evaluation

The human health risk models, including carcinogenic and non-carcinogenic models raised by USEPA, (2009), have proven successful and adopted worldwide. The USEPA model and their threshold values to assess the potential human health risks posed by heavy metal pollution were employed in this present study.

2.8.1. Chronic Daily Intake (CDI) Indices

The CDI through water ingestion is calculated according to the modified equation:

$$CDI = \frac{C \times DI}{BW} \tag{5}$$

where,

C, *DI* and *BW* represent the concentration of toxic metal (mg/L), average daily intake rate (2 L/day) and body weight (70 kg), respectively (USEPA, 2009).

2.8.2. Hazard Quotient (HQ) Indices

The HQ for non-carcinogenic risk can be calculated by the following equation

(USEPA, 2009):

$$HQ = \frac{CDI}{RfD} \tag{6}$$

where, the non-cancer Hazard Quotient (*HQ*) is the ratio of exposure to hazardous substances, and *RfD* is the chronic reference dose of the toxicant ($mg \cdot kg^{-1} \cdot d^{-1}$).

According to the USEPA-Database (USEPA, 2009), the oral toxicity reference dose values (RfD) are Cr, Zn, Ni, Cu, As, Cd, Pb and Hg are 0.0003, 0.3, 0.02, 0.04, 0.0005, 0.001, 0.004 and 0.0005mg/kg, respectively.

2.8.3. Chronic Hazard Index (CHI)/Non-Cancer Risk

Mathematically,

$$\text{Chronic Hazard Index (CHI/CHQ)} = \sum_{i=1}^{n} = \frac{CDI}{RfD} \tag{7}$$

where, the chronic Hazard Index (HI) is the sum of more than one hazard quotient for multiple substances or multiple exposure pathways, *CDI* is the daily intake of a toxic metal (*k*) and *RfD* is the chronic reference dose for the heavy metal *n*.

An $HQ < 1$ is assumed to be safe and taken as noncarcinogenic (Singh & Hussian, 2016), but $HQ > 1$ indicates a potential health risk to those exposed to the medium of contamination. HI > 1 shows that exposure could have a potential adverse effect on human health generally (Li & Zhang, 2020).

2.8.4. Cancer Risk

Cancer risk can be evaluated from

$$\text{Cancer risk (CR)} = \text{CDI} \times \text{SF} \tag{8}$$

where, Cancer Risk (CR) represents the probability of an individual's lifetime health risk from carcinogens;

CDI is the chronic daily intake of carcinogens (mg/kg/d);

SF is the slope factor of hazardous substances (mg/kg/d).

Slope factor values for the carcinogens As, Ni, Cd and Cr are given as 1.5, 0.91, 15 and 0.5, respectively (USEPA, 2009). Cu, Zn, Hg and Pb, being non-carcinogens, have no assigned value for Slope Factor (SF).

The cumulative cancer risk will be calculated from:

$$\text{Total Cancer Risk (TCR)} = \sum_{i=1}^{k} = CDI_k \times SF_k \tag{9}$$

where,

CDI_k is the chronic daily intake (mg/kg/d) of a single toxic metal *k*;

SF_k is the slope factor for the toxic metal *k* (mg/kg/d).

The acceptable or tolerable maximum limit for TCR, for regulatory purposes, is within the range of 10^{-6} - 10^{-4} (USEPA, 2001). Toxic metals like Cd, As, Pb and Ni, which have potential cancer risks, were considered in the carcinogenic risk evaluation of the studied swimming pools. Risk assessment model documented in Chen et al. (2022), USEPA (2010), and Mohammadi et al. (2019) was used to estimate the cancer risk coefficient ($Risk_{car}$) associated with exposure through skin contact and accidental ingestion. When the $Risk_{car}$ value of any metal considered is lower than 1.0×10^{-6}, which is equivalent to the probability of cancer occurring in one out of 1,000,000 people, the risk can be considered to be **negligible**, and when it is higher than 1.0×10^{-4}, it is recognized that the carcinogenic risk is high and unacceptable.

3. Materials and Methods

3.1. Materials

3.1.1. Chemicals and Reagents

The chemicals and media used were of analytical reagent grade (99.9% purity) and they were obtained from reputable chemical distribution companies. The following reagents were used for the analyses: Trioxonitrate (V) acid (analytical grade), hydrogen peroxide, tetraoxosulphate (VI) salts of Cr, Pb, Cu, As, Mn, Zn, Hg, Ni and Cd. Doubly distilled, deionized water was used in the preparation of all solutions in the experiments.

3.1.2. Equipment/Instruments and Apparatus

An AA 6800 SHIMADZU Atomic Absorption Spectrophotometer (AAS) was used for Cr, Pb, Cu, Mn, Zn, Ni, and Cd determinations while an Agilent 4210 MP-AES Atomic Emission Spectrophotometer (AES) was used for As and Hg determinations.

Other pieces of apparatus used include plastic sample bottles, weighing scale, thermometer, Whatman No 41-filter paper, funnels, beakers, measuring cylinders, stirring rod, dropping pipette, standard volumetric flasks (for preparing reagents) and a time piece.

3.1.3. Study Area

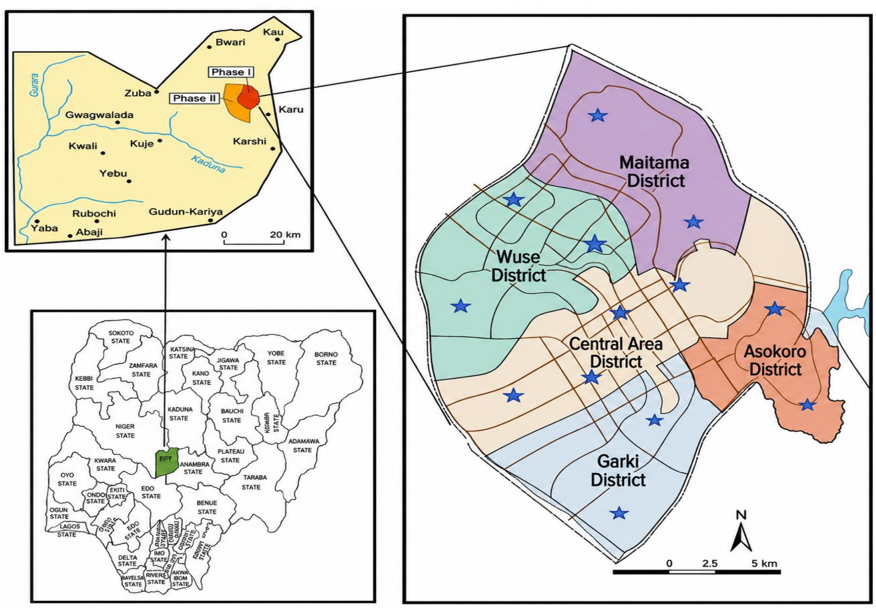

Figure 2. Map of Abuja, showing districts of sampling locations.

This study was carried out within the Abuja Municipal Area Council (AMAC) of the Federal Capital Territory (Figure 2). The Federal Capital Territory (FCT) Abuja serves as the capital of Nigeria. It is one of the wealthiest urban areas in Africa, playing home to some of the richest people on the continent. The presence of numerous governmental institutions, foreign embassies and its strategic location in the heart of the nation has led to significant investment in the city. This has resulted in Abuja ranking among the fastest-growing cities globally.

3.2. Methods

3.2.1. Sampling

A total of thirteen (13) swimming pools were selected by Simple Random Sampling (SRS), based on popularity and frequency of usage, from the AMAC districts, for sampling in this study, as shown in Table 3. Consideration was given to the swimming pools that have high patronage of swimmers as discovered from visitors' logs and interactions with pool managers. A composite of four (4) water samples was collected per location, into sterile 250 mL plastic bottles with airtight caps, labelled appropriately, which were washed thoroughly, rinsed with distilled water and rinsed with the samples thrice, before collection. In all the pools, sampling was done at dusk during weekends, when the pools were mostly in use. The container was opened and immersed bottom-side up into the pool at four different spots to approximately "elbow depth" (about 20 - 45 cm below the surface), which is far enough down that sunlight cannot penetrate and affect the sample. At the proper depth, the container was turned right-side up to fill and when completely full, the container was brought to the surface and the cap was immediately replaced. The sample was then sent to the laboratory in an ice box within 4 hours of sampling. About 0.25 mL of 3% sodium thiosulphate ($Na_2S_2O_3$) solution was added to neutralize residual chlorine after sampling, following the procedure described by WHO (2006).

One composite sample was collected at the municipal supply line as control. All bottles containing the water samples were immersed in ice boxes and transported to the laboratory for analysis.

Table 3. Selected swimming pools for water sampling.

S/No	Codes for Sampling Locations
1.	D-ER
2.	C-H
3.	SITWP
4.	RVR
5.	NOSP
6.	SCWP
7.	AH
8.	S-38-H

Continued

9.	SH
10.	N-H
11.	NPL
12.	AJH
13.	THH

3.2.2. Sample Pre-Treatment

Digestion of the water samples was done in triplicate using concentrated nitric acid (Analytical Grade) according to the method described by Anake et al. (2014). The concentrated acid (5 mL) was added to 50 mL of sample water in a 100 mL beaker, and then heated over a water bath, on a hot plate to boil until its volume reduced to 20 mL. Another 5 mL of concentrated HNO_3 was added and then heated for 10 minutes and allowed to cool. About 5 mL of nitric acid was used to rinse the sides of the beaker and the solution filtered using Whatman 0.42 μm filter paper into a 50 mL volumetric flask and topped up to the mark with distilled water. A blank solution was similarly prepared with distilled water. This is critical in order to destroy the organic matrix capable of trapping the trace metals, and thus making them unavailable for the instrumental analysis (Anake et al., 2014).

3.2.3. Preparation of Stock and Standard Solutions

Stock standard solutions containing 1000 $mg \cdot L^{-1}$ of Cu, Pb, Hg, As, Cd, Cr, Fe, Mn and Zn were prepared from the metal salts (Analytical Grade) using nitric acid. Working standards for all the metals were prepared from the stock solutions by serial dilutions in distilled water.

3.2.4. Preparation of Calibration Curves

To determine the instrument signal response to changes in concentration, calibrations were done using working standard solutions of known and increasing concentrations for each analyte element of interest. By measuring the signals of the working standards, the AAS constructed a suitable calibration curve of response/absorbance versus concentration. The AAS used this suitable graph to determine concentrations of the unknown analytes of interest.

3.3. Heavy Metal Analysis

Heavy metals such as Cu, Pb, Cd, Ni, Mn, Zn, and Cr were determined using Atomic Absorption Spectroscopy (AAS), while Hg and As were determined using an Atomic Emission Detector (AED) because of its occurrences in trace amount. Prior to metal ion analyses, calibration solutions of the target metal ions were prepared from standard stock by serial dilution and the operating conditions of the instruments were set according to the manufacturer's specifications.

3.4. Human Health Risk Assessment

3.4.1. Non-Carcinogenic Risks

The health risk assessment models provided by the USEPA were used in this study to evaluate non-carcinogenic risk (USEPA, 2004). This model considers different exposure pathways and the effects of different exposure frequencies. Adults in the swimming pool environment are mainly affected by the following two exposure pathways: 1) inadvertent inhalation of heavy metals from the pool water; and 2) dermal absorption caused by contact with the water while swimming (Oni et al., 2022; Chen et al., 2022). The chronic daily intake of heavy metals under the two exposure pathways can be calculated using Equations (10) and (11).

$$CDI_{inhale} = \frac{C_{metal} \times IR_{inh} \times ED \times EF}{PEF \times BW \times AT} \tag{10}$$

$$CDI_{dermal} = \frac{Cmetal \times SA \times SL \times ABS \times ED \times EF}{BW \times AT \times CF} \tag{11}$$

where, CDI_{inhale} and CDI_{dermal} represent the chronic daily intake of heavy metals under two exposure pathways of inhalation and dermal contact, respectively, in mg·(kg·d)$^{-1}$; CDI_{metal} is the concentration of a single heavy metal in a single sample of pool water (mg·kg^{-1}); IR_{inh} is the weight of inhalation toxic metal intake (mg); other parameters used in this study are shown in **Table 4**.

Table 4. Exposure parameters used to characterize the Chronic Daily Intake (CDI) of heavy metals (Chen et al., 2022).

Symbol	Parameter		Value	Unit
IR_{ing}	Ingestion rate		100	mg·day^{-1}
IR_{ing}	Inhalation rate		12.8	m^3·day^{-1}
EF	Exposure frequency	Farmland and mining land	350	day·a^{-1}
		Industrial and mining land	250	
		Forestland and other types	40	
ED	Exposure duration	Non-carcinogenic risk	24	a
		Carcinogenic risk	69.5	
SA	Exposed skin area		5700	cm^2
Sl	Skin adherence factor		0.07	mg·(cm^2·day)$^{-1}$
ABS	Dermal absorption factor		0.03 (As), 0.001 (Cd), 0.04 (Cr), 0.10 (Cu), 0.05 (Hg), 0.35 (Ni), 0.006 (Pb), 0,02 (Zn)	unitless
PEF	Particle emission factor		1.36 × 10^9	m^3·kg^{-1}
AT	Average exposure time		ED × 365	days
BW	Average bodyweight		62	kg
CF	Conversion factor		1.0 × 10^{-6}	unitless

In this study, the HI represents the health risks of chronic diseases in humans caused by the two exposure pathways of the nine heavy metals, including As, Cd, Cr, Mn, Cu, Hg, Ni, Pb, and Zn. Chronic diseases may occur when the HI is greater than 1, and the risk of diseases increases with an increasing HI (USEPA, 2004). The HI/HQ and CHI/CHQ of the heavy metals were evaluated using Equations

(6) and (7) as previously explained in Section 2.7.

3.4.2. Carcinogenic Risk Assessment

Toxic (heavy) metal carcinogenic risk is characterized by the probability that an individual will experience cancer through lifelong exposure to carcinogens in the environment, and this value is obtained by establishing a Cancer Slope Factor (CSF) through the individual exposure to toxic metal carcinogens by various exposure pathways in the water, as shown in Table 5. The carcinogenic risk is calculated for the carcinogens As, Cd, Ni, Cr and Pb using:

$$\text{Risk}_{\text{car}} = \text{CDI} \times \text{CSF} \quad (12)$$

where,

Risk_{car} is the carcinogenic risk from the exposure pathway, CDI_j is the chronic daily intake of a carcinogen under the exposure pathway (mg·(kg·day)$^{-1}$); and CSF is the carcinogenic slope factor of the carcinogen under the exposure pathway. Commonly, when the cancer risk coefficient (Risk_{car}) is lower than 1.0 × 10^{-6}, which is equivalent to the probability of cancer occurring in one out of 1,000,000 people, the risk can be considered to be negligible, and when it is higher than 1.0 × 10^{-4}, it is recognized that the carcinogenic risk is unacceptable (Chen et al., 2022, USEPA, 2010, Mohammadi et al., 2019).

3.5. Ecological Risk Indices (RI)

The potential ecological risk (RI) method proposed by Håkanson (1980) and reported in Izah et al. (2018), Liu et al. (2020) and Wuana et al. (2020) was applied. Table 6 shows the grading for E_f^i and R_i values.

Table 5. Reference Dose (RfD) and Carcinogenic Slope Factor (CSF) of heavy metals (Chen et al., 2022; Huang et al., 2016).

Heavy Metals	RfD/mg·(kg·d)$^{-1}$			CSF/mg·(kg·d)$^{-1}$		
	RfD_{ingest}	RfD_{inhale}	RfDdermal	CSF_{ingest}	CSF_{inhale}	CSF_{dermal}
As	3.00 × 10^{-4}	1.50 × 10^{-5}	1.23 × 10^{-4}	1.50 × 10^{0}	1.51 × 10^{1}	1.50 × 10^{-0}
Cd	1.00 × 10^{-3}	1.00 × 10^{-5}	1.00 × 10^{-5}	6.10 × 10^{0}	1.47 × 10^{1}	2.44 × 10^{2}
Cr	1.50 × 10^{0}	1.50 × 10^{0}	1.50 × 10^{0}	0.5 × 10^{0}	4.20 × 10^{1}	0.5 × 10^{0}
Cu	4.00 × 10^{-2}	4.00 × 10^{-2}	1.20 × 10^{-2}			
Hg	3.00 × 10^{-4}	3.00 × 10^{-4}	2.10 × 10^{-5}			
Ni	2.00 × 10^{-2}	9.00 × 10^{-5}	5.40 × 10^{-3}			
Pb	3.50 × 10^{-3}	3.50 × 10^{-3}	5.25 × 10^{-4}	8.50 × 10^{-2}	4.20 × 10^{-2}	8.50 × 10^{-3}
Zn	3.00 × 10^{-1}	3.00 × 10^{-1}	6.00 × 10^{-2}			

Table 6. Risk grade indices and grades of potential ecological risk of heavy metal pollution (Håkanson, 1980).

E_f^i	Risk Grade	R_i Value	Risk Level	Risk Degree
E_f^i < 30	Slight	R_i < 40	A	Slight

Continued

$30 \leq E_f^i < 60$	Medium	$40 \leq R_i < 80$	B	Medium
$60 \leq E_f^i < 120$	Strong	$80 \leq R_i < 160$	C	Strong
$120 \leq E_f^i < 240$	Very strong	$160 \leq R_i < 320$	D	Very strong
$E_f^i \geq 240$	Extremely strong	$R_i \geq 320$	E	Extremely strong

3.6. Statistical Treatment of Data and Test of Significance

Descriptive statistics was conducted to determine the average, range, mean and standard deviations of investigated toxic metal concentrations in the water samples. One-sample t-test was used to compare the trace metals against the WHO/NSDWQ guidelines and one-way ANOVA was used to test the variations across the thirteen (13) sites sampled.

4. Results

4.1. Results of Toxic Metal Concentrations

The toxic metal concentration results determined for the nine (9) toxic metals: Zn, Ni, Mn, Pb, Cd, Cr, As and Hg, in the swimming pool water samples from the thirteen study locations: D-ER, C-H, SITWP, RVR, NOSP, SCWP, AH, S-38-H, SH, N-H, NPL, AJH, THH and Municipal water supply are presented in Tables 7-20, respectively.

Table 7. D-ER swimming pool.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0241	0.0022	50
Nickel	0.0023	0.0020	0.07
Manganese	0.0032	0.0001	8.0
Lead	0.0105	0.0058	0.2
Cadmium	0.0019	0.0011	0.003
Chromium	0.0000	0.0001	0.05
Copper	0.0117	0.0001	2.0
Arsenic	0.0010	0.0050	0.01
Mercury	0.0011	0.0030	0.001

Table 8. Toxic metal concentrations in C-H.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0370	0.0011	50

Continued

Nickel	0.0011	0.0014	0.07
Manganese	0.0026	0.0007	8.0
Lead	0.0127	0.0089	0.2
Cadmium	0.0000	0.0000	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0016	0.0005	2.0
Arsenic	0.0110	0.0010	0.01
Mercury	0.0020	0.0020	0.001

Table 9. Toxic metal concentrations in SITWP.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0187	0.0009	50
Nickel	0.0014	0.0010	0.07
Manganese	0.0021	0.0005	8.0
Lead	0.0006	0.0097	0.2
Cadmium	0.0000	0.0000	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0014	0.0004	2.0
Arsenic	0.0010	0.0010	0.01
Mercury	0.0040	0.0050	0.001

Table 10. Toxic metal concentrations in RVR.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0304	0.0006	50
Nickel	0.0016	0.0009	0.07
Manganese	0.0027	0.0002	8.0
Lead	0.0020	0.0123	0.2
Cadmium	0.0000	0.0016	0.003
Chromium	0.0000	0.0001	0.05
Copper	0.0019	0.0002	2.0
Arsenic	0.0060	0.0030	0.01
Mercury	0.0010	0.0020	0.001

Table 11. Toxic metal concentrations in NOSP.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0189	0.0006	50
Nickel	0.0022	0.0013	0.07
Manganese	0.0010	0.0004	8.0
Lead	0.0077	0.0061	0.2
Cadmium	0.0008	0.0005	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0012	0.0001	2.0
Arsenic	0.0040	0.0030	0.01
Mercury	0.0030	0.0010	0.001

Table 12. Toxic metal concentrations in SCWP.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0278	0.0019	50
Nickel	0.0021	0.0013	0.07
Manganese	0.0038	0.0002	8.0
Lead	0.0055	0.0082	0.2
Cadmium	0.0003	0.0014	0.003
Chromium	0.0000	0.0001	0.05
Copper	0.0022	0.0006	2.0
Arsenic	0.0020	0.0010	0.01
Mercury	0.0050	0.0010	0.001

Table 13. Toxic metal concentrations in AH.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0346	0.0008	50
Nickel	0.0031	0.0010	0.07
Manganese	0.0036	0.0002	8.0
Lead	0.0069	0.0100	0.2
Cadmium	0.0002	0.0018	0.003
Chromium	0.0001	0.0001	0.05
Copper	0.0060	0.0003	2.0

Continued

Arsenic	0.0020	0.0010	0.01
Mercury	0.0020	0.0020	0.001

Table 14. Toxic metal concentration S-38-H.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0187	0.0013	50
Nickel	0.0018	0.0014	0.07
Manganese	0.0031	0.0003	8.0
Lead	0.0053	0.0024	0.2
Cadmium	0.0016	0.0003	0.003
Chromium	0.0000	0.0001	0.05
Copper	0.0400	0.0005	2.0
Arsenic	0.0020	0.0040	0.01
Mercury	0.0110	0.0040	0.001

Table 15. Toxic metal concentrations at SH.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0192	0.0010	50
Nickel	0.0037	0.0013	0.07
Manganese	0.0045	0.0004	8.0
Lead	0.0022	0.0033	0.2
Cadmium	0.0026	0.0005	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0038	0.0003	2.0
Arsenic	0.0080	0.0010	0.01
Mercury	0.0120	0.0040	0.001

Table 16. Toxic metal concentrations at N-H.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0215	0.0008	50
Nickel	0.0024	0.0007	0.07
Manganese	0.0020	0.0005	8.0

Continued

Lead	0.0068	0.0083	0.2
Cadmium	0.0000	0.0000	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0018	0.0003	2.0
Arsenic	0.0010	0.0010	0.01
Mercury	0.0060	0.0040	0.001

Table 17. Toxic metal concentrations in NPL.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0292	0.0010	50
Nickel	0.0033	0.0011	0.07
Manganese	0.0045	0.0004	8.0
Lead	0.0051	0.0153	0.2
Cadmium	0.0015	0.0009	0.003
Chromium	0.0003	0.0000	0.05
Copper	0.0024	0.0003	2.0
Arsenic	0.0010	0.0020	0.01
Mercury	0.0050	0.0050	0.001

Table 18. Toxic metal concentrations in AJH.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0310	0.0015	50
Nickel	0.0004	0.0013	0.07
Manganese	0.0015	0.0002	8.0
Lead	0.0042	0.0034	0.2
Cadmium	0.0000	0.0005	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0014	0.0000	2.0
Arsenic	0.0050	0.0030	0.01
Mercury	0.0020	0.0010	0.001

Table 19. Toxic metal concentrations in THH.

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0350	0.0021	50

Continued

Nickel	0.0028	0.0003	0.07
Manganese	0.0017	0.0003	8.0
Lead	0.0043	0.0084	0.2
Cadmium	0.0018	0.0009	0.003
Chromium	0.0022	0.0002	0.05
Copper	0.0017	0.0001	2.0
Arsenic	0.0020	0.0010	0.01
Mercury	0.0030	0.0040	0.001

Table 20. Toxic metal concentrations in municipal water supply (control).

Toxic Metals	Mean Concentration (mg/L)	SD	NSDWQ/WHO Limit (mg/L)
Zinc	0.0660	0.0002	50
Nickel	0.0270	0.0005	0.07
Manganese	0.0450	0.0009	8.0
Lead	0.0041	0.0008	0.2
Cadmium	0.0000	0.0000	0.003
Chromium	0.0000	0.0000	0.05
Copper	0.0495	0.0001	2.0
Arsenic	0.0070	0.0009	0.01
Mercury	0.0003	0.0001	0.001

4.2. Non-Carcinogenic Risk Assessment

The hazard index calculations for the non-carcinogenic risk assessment are presented for the two exposure pathways considered in this study, namely, inadvertent inhalation of heavy metals from the pool water, and dermal absorption caused by contact with the water while swimming.

4.2.1. Hazard Index by Inhalation

The hazard index by inhalation evaluated for the various swimming pool water samples is summarized in Table 21.

Table 21. Summary of human non-carcinogenic risk index by inhalation.

S/No	Pool/Hotel	Hazard Inde × (HI)	Interpretation
1.	D-ER	5.18683×10^{-9}	No risk
2.	C-H	1.05569×10^{-8}	No risk
3.	SITWP	-6.5173×10^{-1}	No risk
4.	RVR	6.50658×10^{-9}	No risk

Continued

5.	NOSP	6.4971×10^{-9}	No risk
6.	SCWP	3.86278×10^{-9}	No risk
7.	AH	3.69975×10^{-9}	No risk
8.	S-38-H	6.2338×10^{-9}	No risk
9.	SH	1.5095×10^{-8}	No risk
10.	N-H	-2.33438×10^{-9}	No risk
11.	NPL	5.05328×10^{-9}	No risk
12.	AJH	5.43157×10^{-9}	No risk
13.	THH	6.12162×10^{-9}	No risk

Note: Chronic diseases may occur when the HI is greater than 1, and the risk of diseases increases with an increasing HI (USEPA, 2001).

4.2.2. Hazard Index by Dermal Contact

The hazard index by dermal contact evaluated for the swimming pool water samples from the study areas (D-ER, C-H, SITWP, RVR, NOSP, SCWP, AH, S-38-H, SH, N-H, NPL, AJH and THH) is summarized in Table 22.

Table 22. Summary of human non-carcinogenic risk index by dermal contact.

S/No	Pool/Hotel	Hazard Inde × (HI)	Interpretation
1.	D-ER	3.22×10^{-6}	No risk
2.	C-H	6.11×10^{-7}	No risk
3.	SITWP	7.50×10^{-6}	No risk
4.	RVR	3.60×10^{-6}	No risk
5.	NOSP	6.26×10^{-6}	No risk
6.	SCWP	1.01×10^{-5}	No risk
7.	AH	5.05×10^{-6}	No risk
8.	S-38-H	2.023×10^{-5}	No risk
9.	SH	2.328×10^{-5}	No risk
10.	N-H	1.084×10^{-5}	No risk
11.	NPL	1.025×10^{-5}	No risk
12.	AJH	4.72×10^{-6}	No risk
13.	THH	6.20×10^{-6}	No risk

Note: Chronic diseases may occur when the HI is greater than 1, and the risk of diseases increases with an increasing HI (USEPA, 2001).

4.3. Carcinogenic Risk Evaluation

The results for the carcinogenic risk evaluation for the swimming pool water samples D-ER, C-H, SITWP, RVR, NOSP, SCWP, AH, S-38-H, SH, N-H, NPL, AJH and THH, evaluated for Ni, Pb. Cd, Cr and As, are presented in Tables 23-35.

Table 23. Carcinogenic risk evaluation for D-ER.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	2.84×10^{-10}	0.84	2.38×10^{-10}	No threat
Lead	2.23×10^{-11}	0.0085	1.90×10^{-13}	No threat
Cadmium	6.86×10^{-13}	15	1.03×10^{-11}	No threat
Chromium	5.65×10^{-12}	0.5	-2.82×10^{-12}	No threat
Arsenic	1.06×10^{-11}	1.5	1.59×10^{-11}	No threat

Table 24. Carcinogenic risk evaluation for C-H.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	1.36×10^{-10}	0.84	1.14×10^{-10}	No threat
Lead	2.70×10^{-11}	0.0085	2.29×10^{-13}	No threat
Cadmium	5.05×10^{-13}	15	7.58×10^{-12}	No threat
Chromium	8.47×10^{-12}	0.5	4.23×10^{-12}	No threat
Arsenic	1.16×10^{-10}	1.5	1.75×10^{-10}	No threat

Table 25. Carcinogenic risk evaluation for SITWP.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	1.73E−10	0.84	1.45×10^{-10}	No threat
Lead	1.27E−12	0.0085	1.08×10^{-14}	No threat
Cadmium	5.41E−13	15	8.12×10^{-12}	No threat
Chromium	8.47E−12	0.5	4.23×10^{-12}	No threat
Arsenic	1.06E−11	1.5	1.59×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 26. Carcinogenic risk evaluation for RVR.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	1.73E−10	0.84	1.45×10^{-10}	No threat
Lead	1.27E−12	0.0085	1.08×10^{-14}	No threat
Cadmium	5.41E−13	15	12×10^{-12}	No threat
Chromium	8.47E−12	0.5	4.23×10^{-12}	No threat
Arsenic	1.06E−11	1.5	1.59×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 27. Carcinogenic risk evaluation for NOSP.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	2.72E−10	0.84	2.28×10^{-10}	No threat
Lead	1.64E−11	0.0085	1.39×10^{-13}	No threat

Continued

Cadmium	2.89E−13	15	4.33×10^{-12}	No threat
Chromium	8.47E−12	0.5	4.23×10^{-12}	No threat
Arsenic	4.23E−11	1.5	6.35×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 28. Carcinogenic risk evaluation for SCWP.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	2.59E−10	0.84	2.18×10^{-10}	No threat
Lead	1.17E−11	0.0085	9.93×10^{-14}	No threat
Cadmium	1.08E−13	15	1.62×10^{-12}	No threat
Chromium	0.00E+00	0.5	0.00 × 10+00	No threat
Arsenic	2.12E−11	1.5	3.18×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 29. Carcinogenic risk evaluation for AHs.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	3.83E−10	0.84	3.21×10^{-10}	No threat
Lead	1.47E−11	0.0085	1.25×10^{-13}	No threat
Cadmium	7.22E−14	15	1.08×10^{-12}	No threat
Chromium	1.41E−12	0.5	7.06×10^{-13}	No threat
Arsenic	2.12E−11	1.5	3.18×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 30. Carcinogenic risk evaluation for S-38-H.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	2.22E−10	0.84	1.87×10^{-10}	No threat
Lead	1.13E−11	0.0085	9.57×10^{-14}	No threat
Cadmium	5.78E−13	15	8.66×10^{-12}	No threat
Chromium	0.00E+00	0.5	$0.00 \times 10^{+00}$	No threat
Arsenic	2.12E−11	1.5	3.18×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 31. Carcinogenic risk evaluation for SH.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	4.57E−10	0.84	3.84×10^{-10}	No threat
Lead	4.67E−12	0.0085	3.97×10^{-14}	No threat
Cadmium	9.38E−13	15	1.41×10^{-11}	No threat

Continued

Chromium	1.41E−12	0.5	7.06×10^{-13}	No threat
Arsenic	8.47E−11	1.5	1.27×10^{-10}	No threat

Note: Hint: E = Exponent (10).

Table 32. Carcinogenic risk evaluation for N-H.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	2.96E−10	0.84	2.49×10^{-10}	No threat
Lead	1.44E−11	0.0085	1.23×10^{-13}	No threat
Cadmium	9.75E−13	15	1.46×10^{-11}	No threat
Chromium	7.06E−12	0.5	3.53×10^{-12}	No threat
Arsenic	1.06E−11	1.5	1.59×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 33. Carcinogenic risk evaluation for NPL.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	4.07E−10	0.84	3.42×10^{-10}	No threat
Lead	1.08E−11	0.0085	9.21×10^{-14}	No threat
Cadmium	5.41E−13	15	8.12×10^{-12}	No threat
Chromium	4.23E−12	0.5	2.12×10^{-12}	No threat
Arsenic	1.06E−11	1.5	1.59×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 34. Carcinogenic risk evaluation for AJH.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	4.94E−11	0.84	4.15×10^{-11}	No threat
Lead	8.92E−12	0.0085	7.58×10^{-14}	No threat
Cadmium	1.08E−13	15	1.62×10^{-12}	No threat
Chromium	8.47E−12	0.5	4.23×10^{-12}	No threat
Arsenic	5.29E−11	1.5	7.94×10^{-11}	No threat

Note: Hint: E = Exponent (10).

Table 35. Carcinogenic risk evaluation for THH.

Toxic Metal	CDI	CSF	$Risk_{car}$	Interpretation
Nickel	3.46E−10	0.84	2.90×10^{-10}	No threat
Lead	9.13E−12	0.0085	7.76×10^{-14}	No threat
Cadmium	6.50E−13	15	9.75×10^{-12}	No threat
Chromium	3.10E−11	0.5	1.55×10^{-11}	No threat
Arsenic	2.12E−11	1.5	3.18×10^{-11}	No threat

Note: Hint: E = Exponent (10).

4.4. Ecological Risk Index Results

The results for the ecological risk index assessment and pollution load index for the pool water in the study areas are summarized in Table 36.

Table 36. Summary of ecological risk index and pollution load index results.

S/No	Pool/Hotel	Ecological Risk Index	Rating	Pollution Load Index	Rating
1.	D-ER	2.75	Excellent	0.000	Unpolluted
2.	C-H	0.072	Excellent	0.000	Unpolluted
3.	SITWP	0.251	Excellent	0.000	Unpolluted
4.	RVR	0.225	Excellent	0.000	Unpolluted
5.	NOSP	1.468	Excellent	0.000	Unpolluted
6.	SCWP	1.268	Excellent	0.000	Unpolluted
7.	AH	0.534	Excellent	0.000	Unpolluted
8.	S-38-H	0.653	Excellent	0.000	Unpolluted
9.	SH	0.333	Excellent	0.000	Unpolluted
10.	N-H	0.056	Excellent	0.000	Unpolluted
11.	NPL	0.386	Excellent	0.000	Unpolluted
12.	AJH	0.175	Excellent	0.000	Unpolluted
13.	THH	0.483	Excellent	0.000	Unpolluted

4.5. Result of Statistical Analysis

Table 37 and Table 38 show the results of descriptive statistics and t-test analysis.

Table 37. Descriptive statistics of toxic metals.

Metal	N	Minimum (mg/L)	Maximum (mg/L)	Mean (mg/L)	Std. Deviation	Skewness	Kurtosis
Zinc (Zn)	13	0.0187	0.0350	0.0266	0.0068	0.2431	−0.3184
Nickel (Ni)	13	0.0004	0.0037	0.0022	0.0009	0.3597	−0.5262
Manganese (Mn)	13	0.0010	0.0038	0.0027	0.0010	−0.2219	−0.3771
Lead (Pb)	13	0.0020	0.0127	0.0057	0.0032	−0.4883	−0.8210
Cadmium (Cd)	13	0.0000	0.0022	0.0004	0.0017	0.4205	−0.3567
Chromium (Cr)	13	0.0000	0.0000	−0.0001	0.0008	0.1876	−0.1932
Copper (Cu)	13	0.0012	0.0400	0.0059	0.0106	0.2342	−0.4673
Arsenic (As)	13	0.0010	0.0080	0.0026	0.0021	0.3849	−0.6245
Mercury (Hg)	13	0.0010	0.0060	0.0037	0.0030	0.2921	−0.4889

Note: Source: SPSS Output, Version 28 (2025).

Table 38. t-test results of swimming pool waters and NSDWQ/WHO guideline.

	t	df	Sig. (2 Tailed)	Mean Difference	95% Confidence Interval of the Difference Lower → Upper
POOLS	2.095	15	0.045	90.02056	−1.5623 → 181.6034
NSDWQ/WHO	2.044	15	0.047	137.5563	−5.885 → 280.997

t-test result of municipal water supply and NSDWQ/WHO guidelines.

Test Value = 0					
95% Confidence Interval					
	t	df	Sig. (2 Tailed)	Mean Difference	95% Confidence Interval of the Difference Lower → Upper
Municipal Waters Supply Line	3.384	15	0.004	10.062188	3.72447 → 16.39990
NSDQW/WHO	2.055	14	0.059	145.3267	−6.313 → 296.966

t-test result of municipal water supply and WHO/USEPA.

	t	df	Sig. (2 Tailed)	Mean Difference	95% Confidence Interval of the Difference Lower → Upper
Municipal Waters Supply Line	3.384	15	0.004	10.062188	3.72447 → 16.39990
WHO/USEPA	2.059	14	0.059	146.7267	−6.139 → 299.592

5. Discussion

5.1. Toxic Metal Concentrations

The results obtained for the toxic metal concentrations in the studied swimming pools within Abuja, Nigeria, as well as the toxic metal concentration in the municipal water supply, are presented in Tables 7-20.

The levels of all but two toxic metals analyzed in the various swimming pool water were below the WHO and NSDWQ guidelines, with the exceptions being Hg and Cd. Notably, the levels of Hg in all the swimming pools were higher than the WHO limit, except the pool in RVR, which had a low value. The highest concentration of Hg (0.012 mg/L) was recorded for the swimming pool in SH, followed by 0.011 mg/L in S-38-H.

The concentration of Hg in a specific pool can be influenced by local environmental factors, such as proximity to industrial areas or dust release from rock blasting and even improper handling of products containing mercury, making some pools more susceptible to contamination than others (Agomuo & Amadi, 2019).

There appears to be a source of Hg getting into the pool waters from surrounding underground soils, substances used for constructing the pools or a chemical used in treating the pool water or pool maintenance. Further investigation will be required in this regard.

The level of Cd detected in SH was 0.0026 mg/L, an edge close to the WHO limit of 0.003 mg/L. Other levels of Cd were below limit.

The municipal water supply gave all values of toxic metal concentration significantly lower than the regulatory limits (**Table 20**). Toxic metal concentrations in the municipal water supply showed remarkably low levels, giving evidence that the treatment process in the Lower Usuma Treatment Plant is being properly done in the period under study. Appropriate regulatory agencies need to monitor and ensure that this is maintained because the municipal water supply is used as the primary source of water in swimming pools within Abuja, among other users.

5.2. Potential Human Health Risk

An individual risk pathway as a result of human exposure to trace metals contamination could be through inhalation via the nose and mouth and dermal absorption through the skin (Agbagwa & Young-Harry, 2012). The hazard index calculations for the non-carcinogenic risk assessment are presented for the two exposure pathways considered in this present study: inadvertent inhalation of heavy metals from the pool water, and dermal absorption caused by contact with the water while swimming.

5.2.1. Human Non-Carcinogenic Risk Assessment by Inhalation

Table 21 summarized the hazard index by inhalation evaluated for the various swimming pool water samples. The HI results obtained for the various pool waters are highlighted thus; D-ER (HI = $5.18683 \times 10^{-9)}$, C-H (HI = 1.05569×10^{-8}), SITWP (HI = -6.5173×10^{-1}), RVR (HI = 6.50658×10^{-9}), NOSP (HI = 6.4971×10^{-9}), SCWP (HI = 3.86278×10^{-9}), AH (HI, = 3.69975×10^{-9}), S-38-H (HI = 6.2338×10^{-9}), SH (HI = 1.5095×10^{-8}), N-H (HI = -2.33438×10^{-9}), NPL (HI = 5.05328×10^{-9}), AJH (HI = 5.43157×10^{-9}) and THH (HI = 6.12162×10^{-9}). In this study, all the thirteen (13) swimming pools sampled presented values less than 1 for the hazard index by inhalation, indicating no risk of any chronic disease by inhaling the pool waters. Wuana et al. (2020) reported no cancer risk for the water from the Abuja municipal water raw water source. They opined that even without further treatment, users of water from the municipal water supply are not at any risk of chronic diseases. The treated raw water (municipal water supply), being most likely the major source of water for the sampled pools, there is probably no risk of getting chronic diseases from inhalation by swimmers.

5.2.2. Human Non-Carcinogenic Risk by Dermal Contact

The hazard index by dermal contact evaluated for the various swimming pool water samples is summarized in **Table 22**. The Hazard Index (HI) by USEPA (2001) was also used to represent the health risks of chronic diseases in humans caused by the considered exposure pathways of the nine (9) heavy metals, including As, Cd, Cr, Mn, Cu, Hg, Ni, Pb, and Zn. For HI values greater than 1, chronic diseases are said to occur, and the risk of diseases increases with an increasing HI (USEPA, 2001). The HI values for these heavy metals obtained for the various pool waters on the non-carcinogenic risk index by dermal contact include: D-ER (HI = 3.22×10^{-6}), C-H (HI = 6.11×10^{-7}), SITWP (HI = 7.50×10^{-6}), RVR (HI = 3.60×10^{-6}), NOSP (HI = 6.26×10^{-6}), SCWP (HI = 1.007×10^{-5}), AH (HI = 5.05×10^{-6}), S-38-H (HI = 2.023×10^{5}), SH (HI = 2.328×10^{-5}), N-H (HI = 1.084×10^{-5}), NPL (HI = 1.025×10^{-5}), AJH (HI = 4.72×10^{-6}) and THH (HI = 6.20×10^{-6}). The thirteen pool water samples presented the HI values less than 1, which indicates no risk of the chronic disease, thus the swimming pool waters sampled are safe for use for recreational activities in accordance with the USEPA (2004) report.

5.2.3. Results for Carcinogenic Risk Assessment

The results for the carcinogenic risk evaluation for the studied swimming pools evaluated for Ni, Pb, Cd, Cr and As are presented in **Tables 23-35**. The $Risk_{car}$ value for the various swimming pools indicates no threat. D-ER (1.90×10^{-13} - 2.38×10^{-10}), C-H (-4.23×10^{12} - 1.14×10^{-10}), SITWP (-8.12×10^{-12} - 1.45×10^{-10}), RVR (-8.12×10^{-12} - 1.45×10^{-10}), NOSP (-4.23×10^{12} - 2.28×10^{-10}), SCWP (0.00 × 10 + 00 - 2.18×10^{-10}), AH (7.06×10^{-13} - 3.21×10^{-10}), S-38-H ($0.00 \times 10^{+00}$ - 1.87×10^{-10}), SH (-7.06×10^{-13} - 1.27×10^{-10}), N-H (-3.53×10^{-12} - 2.49×10^{-10}), NPL (9.21×10^{-14} - 3.42×10^{-10}), AJH (-4.23×10^{-12} - 4.15×10^{-11}) and THH (7.76×10^{-14} - 2.90×10^{-10}). Agomuo and Amadi (2019) also reported an $Risk_{car}$ values lower than 1.0×10^{-6}, for the swimming pools in Owerri. Therefore, there is no cancer threat for the swimmers in the studied swimming pools in FCT, Abuja.

5.3. Potential Ecological Risk Evaluation

The process of computation of the Ri values for the various pool water, involved the determination of the Ecological Risk Assessment (E_f^i) values for individual metal and their respective contamination factors (C_f^i), which described their contamination level. The results for the potential ecological Risk Index (RI) and pollution load (PLI) results for the studied area are summarized in **Table 36**. The water pollution load index (PLI) was also presented to assess pollution in the various samples.

The RI values of the sampled pool water ranged in the order: $0.056 < 0.072 < 0.175 < 0.225 < 0.251 < 0.333 < 0.386 < 0.483 < 0.534 < 0.653 < 1.268 < 1.468 < 2.75$, respectively, for RVR, C-H, AJH, AH, SITWP, N-H, NOSP, THH, SCWP, NPL, S-38-H, SH and D-ER. Meanwhile, pool water samples from D-ER, C-H, SCWP, NPL, NOSP, AJH and THH recorded an Excellent Rating, while the rest pools recorded a Good Rating on Ecological Risk Index Evaluation.

Contamination factor (C_f^i) was below one for all the toxic metals under study, in the water samples from the sampled swimming pools in FCT. This means there is generally low possibility of contamination from these metals through analyzed samples.

Ecological risk index (E_r^i) values for all the toxic metals in the water samples were all far below 30, showing no risk of toxic metal poisoning from any ingestion route of the studied waters. This indicates safety; hence, water from the various swimming pools studied poses no ecological hazard to aquatic life or humans that come in contact with them.

Furthermore, the pollution load indices for all the studied pool water recorded a non-significant value of 0.000, indicating an unpolluted aquatic environment. This report is in agreement with Wuana et al. (2020), who reported the Ecological risk index (E_r^i) values below 30 for water and catfish from Lower Usuma Dam water, showing slight risk of toxic metal poisoning from ingestion of water or catfish from Lower Usuma Dam Water in Abuja, the primary source of most of the studied swimming pool water.

5.4. Statistical Analysis Results

Table 36 presents the descriptive analysis results of the heavy metals concentration in the studied swimming pool water samples. The descriptive analysis revealed that mean concentrations of toxic metals varied across the 13 sampling sites but remained within the range for all the metals, indicating a spatial consistency. Zn (0.0266 mg/L), Ni (0.0022 mg/L), Mn (0.0027 mg/L), Pb (0.0057 mg/L), Cd (0.0004 mg/L), Cr (−0.0001 mg/L), Cu (0.0059 mg/L), As (0.0026 mg/L) and Hg (0.0037 mg/L). These mean values obtained for the heavy metals in the study area are below the WHO/NSDWQ guideline limits for the various metals (Zn (3 mg/L), Ni (0.02 mg/L), Mn (0.2 mg/L), Pb (0.01 mg/L), Cd (0.003 mg/L), Cr (0.05 mg/L), Cu (1 mg/L), As (0.01 mg/L) and Hg (0.006 mg/L)). Their low variability (SD), ranging between 0.0009 to 0.0106, supports stable natural background concentrations, consistent with essential trace-metal status rather than pollution, thereby indicating similarity in chemical composition across the pools. This is in affirmation with the indices used for human health risk assessments (HQ and HI) for the various exposure pathways, which showed acceptable values of <1 and the ecological risk assessments indices (E_r^i) showing acceptable values of <40 for the various trace metals across the sampled swimming pools. This implies no health risk on the users of these pool waters and no potential ecological risk. Meanwhile, the skewness and kurtosis near zero confirm normality, implying no outliers distorted the dataset.

The ANOVA result for D-ER shows that the observed differences among the eight groups are not statistically significant, $F(7, 1) = 3.148$, $p = 0.409$, indicating that the groups essentially share the same D-ER values, and when compared with the WHO/NSDWQ standard, all group means fall within the acceptable limit, showing that the D-ER levels are safe and compliant with the recommended guidelines.

The t-test results provide additional insight by comparing the results of the measured water parameters directly with established national and international standards. For the municipal water supply, the t-test revealed a statistically significant difference ($p = 0.004$), indicating that there is significant relationship between the municipal water quality parameters and the guideline values. Similarly, the t-tests comparing pool water samples with the same standards showed statistically significant difference, as reflected by *p*-values below 0.05 ($p = 0.045$ for swimming pool waters versus baseline; $p = 0.047$ for the swimming pool waters versus NSDWQ/WHO and WHO/USEPA standards) and indicated in the measured parameters with values occurring below these standard limits, as such indicating no possible contaminations in the water serving as water source for most of the swimming pool water in the studied recreational centres.

6. Conclusion and Recommendations

6.1. Conclusion

This study was based on assessing the levels of some water quality parameters, particularly toxic metal concentrations. Carcinogenic, non-carcinogenic risks, as well as ecological risk indices, were evaluated and interpreted. Heavy metal concentrations of Zn, Ni, Mn, Pb, Cd, Cr, Cu, As and Hg in the studied pool water samples were determined using Atomic Absorption Spectroscopy and Atomic Emission Spectroscopy for the metals such as arsenic and mercury because of their occurrences in trace amounts. Human health and ecological risk indices were evaluated using the toxic metal concentrations obtained and the index values were equally interpreted.

The human health risk index (HI) was <1 across board, indicating no overall health risk, though specific risks related to elevated levels of Hg and Cd slightly exist in some pools. Human health and ecological risk assessments revealed that there is no overall non-cancer risk by the two absorption pathways and that cancer risk is non-existent, while the overall ecological risk showed no overall risk of toxic metal poisoning to aquatic life or other forms of life that come in contact with the waters. In addition, the pollution load indices for all the studied pool water recorded a non-significant value of 0.000, indicating an unpolluted aquatic environment.

6.2. Recommendations

Further research needs to be carried out to examine some of the activities or sources of elevated Hg levels in all the study sites, particularly SH. Treatment chemicals and rock blasting activities around the recreation environment that raise dust that might contain certain elemental contaminants need careful regulations. Considering that Cd is carcinogenic, the relatively high level of Cd in the swimming pool at SH should be investigated and controlled. The researcher strongly recommends a routine regulatory monitoring of public swimming pools within Abuja in order to mitigate possible heavy metal contamination and resultant ecological and human health risks that may arise from poor treatment or other anthropogenic activities. Furthermore, the need for the development of a localized guideline for recreational water quality in Nigeria is emphasized.

Further research may be carried out to:

1) Determine the concentration of other swimming pool water pollutants such

as chloramines and trihalomethanes (THMs), which form when disinfectants like chlorine react with organic matter from swimmers, such as sweat and urine;

2) Find out the concentration of Disinfection By-Product (DBPs) like Halo-Acetic Acids (HAAs) and chemicals like cyanuric acid that are capable of polluting the pool waters;

3) Investigate the source of elevated Hg in the majority of the swimming pools within Abuja.

6.3. Contribution to Knowledge

The study verified the heavy metal toxicity status of thirteen (13) swimming pools in some recreational centres in FCT, Nigeria. Results from the study established that:

1) The potential ecological risk evaluation for the various water samples is below the threshold of 40, ranging in the order: 0.056 < 0.072 < 0.175 < 0.225 < 0.251 < 0.333 < 0.386 < 0.483 < 0.534 < 0.653 < 1.268 < 1.468 < 2.75, showing no risk of toxic metal poisoning from any ingestion route of the studied pool water.

2) The findings from this study will provide baseline data for toxic metals in these recreational centres as no such study had been done on the swimming pools in the past, and would stir up similar research on other swimming pools not covered in the study.

3) The findings from the study will assist in monitoring the safety status of the swimming pool waters in the FCT and debunk the wrong impressions of some individuals on the safety of swimming pools in recreational centres in FCT, Abuja.

4) The study would serve as a reference point for the regulatory bodies towards establishing or reviewing a national standard for swimming pool water quality in Nigeria.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Acarer Arat, S. (2025). Health Risk Assessment of Oral and Dermal Exposure to Metal-Contaminated Groundwater: A Case Study from Hatay, Türkiye. *Science of the Total Environment, 1006,* Article ID: 180932. https://doi.org/10.1016/j.scitotenv.2025.180932

Addo, M. G., Tee, J., & Larbi, J. A. (2018). Recreational Water Quality Assessment of Some Selected Swimming Pools in the Asuogyaman District, Ghana. *Microbiology Research Journal International, 26,* 1-8. https://doi.org/10.9734/mrji/2018/v26i530079

Adsett, J. A., Mudge, A. M., Morris, N., Kuys, S., & Paratz, J. D. (2015). Aquatic Exercise Training and Stable Heart Failure: A Systematic Review and Meta-Analysis. *International Journal of Cardiology, 186,* 22-28. https://doi.org/10.1016/j.ijcard.2015.03.095

Agbagwa, O. E., & Young-Harry, W. M. (2012). Health Implications of Some Public Swimming Pools Located in Port Harcourt, Nigeria. *Public Health Research, 2,* 190-196. https://doi.org/10.5923/j.phr.20120206.03

Agomuo, E. N., & Amadi, P. U. (2019). Swimming Pools Quality Risk Assessment for Heavy Metal Deposition and Intake via Oral and Dermal Exposure. *Environmental Analysis Health and Toxicology, 34,* e2019008. https://doi.org/10.5620/eaht.e2019008

Ahlskog, J. E., Geda, Y. E., Graff-Radford, N. R., & Petersen, R. C. (2021). Physical Exercise as a Preventive or Disease-Modifying Treatment of Dementia and Brain Aging. *Mayo Clinic Proceedings, 86,* 876-884. https://doi.org/10.4065/mcp.2011.0252

Ajadi, F. A., Bakare, M. K., & 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,* 831-843.

Amadi, A. N., Olasehinde, P. I., Okosun, E. A., & Yisa, J. (2010). Assessment of the Water Quality Index of Otamiri and Oramiriukwa Rivers. *Physics International, 1,* 102-109.

Anake, W. U., Benson, N. U., Akinsiku, A. A., Ehi-Eromosele, C. O. and Adeniyi, I. O. (2014). Assessment of Trace Metals in Drinking Water and Groundwater Sources in Ota, Nigeria. *International Journal of Scientific and Research Publications, 4,* 1-4.

Andersen, L. K., Backhausen, M., Hegaard, H. K., & Juhl, M. (2015). Physical Exercise and Pelvic Girdle Pain in Pregnancy: A Nested Case-Control Study within the Danish National Birth Cohort. *Sexual & Reproductive Healthcare, 6,* 198-203. https://doi.org/10.1016/j.srhc.2015.04.004

APHA (2005). *Standard Methods for the Examination of Water and Waste Water* (21st ed.). American Public Health Association.

Association of Pool & Spa Professionals (2009). *American National Standard for Water Quality in Public Pools and Spas (ANSI/APSP-11-2009).* American National Standards Institute.

Becker, B. E. (2009). Aquatic Therapy: Scientific Foundations and Clinical Rehabilitation Applications. *PM&R, 1,* 859-872. https://doi.org/10.1016/j.pmrj.2009.05.017

Bergamin, M., Ermolao, A., Tolomio, S., Berton, L., Sergi, G., & Zaccaria, M. (2013). Water-versus Land-Based Exercise in Elderly Subjects: Effects on Physical Performance and Body Composition. *Clinical Interventions in Aging, 8,* 1109-1117. https://doi.org/10.2147/cia.s44198

Bunn, C., Wyke, S., Gray, C. M., Maclean, A., & Hunt, K. (2016). 'Coz Football Is What We All Have': Masculinities, Practice, Performance and Effervescence in a Gender-Sensitised Weight-Loss and Healthy Living Programme for Men. *Sociology of Health & Illness, 38,* 812-828. https://doi.org/10.1111/1467-9566.12402

Bwede, D. D., Wuana, R. A., EGAH, G. O., Itodo, A. U., Ogah, E., Yerima, E. A. et al. (2021). Characterization and Evaluation of Human Health Risk of Heavy Metals in Tin Mine Tailings in Selected Area of Plateau State, Nigeria. *Journal of the Nigerian Society of Physical Sciences, 3,* 406-413. https://doi.org/10.46481/jnsps.2021.262

Cantarero-Villanueva, I., Fernandez-Lao, C., Cuesta-Vargas, A. I., Del Moral-Avila, R., & Fernandez-de-Las-Penas, C. (2012). Effectiveness of Core Stability Exercises and Recovery Myofascial Release Massage on Fatigue in Breast Cancer Survivors: A Randomized Controlled Clinical Trial. *Evidence-Based Complementary and Alternative Medicine, 2012,* Article ID: 620619.

Chaudharı, M., Chotalıya, R., Ali, G., Pandya, A., & Shrivastav, P. (2024). Assessment of Heavy Metal Contamination in the Groundwater of Gujarat, India Using the Heavy Metal Pollution Index. *Environmental Research and Technology, 7,* 471-488.

https://doi.org/10.35208/ert.1433696

Chen, Z., Xu, J., Duan, R., Lu, S., Hou, Z., Yang, F. et al. (2022). Ecological Health Risk Assessment and Source Identification of Heavy Metals in Surface Soil Based on a High Geochemical Background: A Case Study in Southwest China. *Toxics, 10,* Article 282. https://doi.org/10.3390/toxics10060282

Cumming, I. (2017). *The Health and Well-Being Benefits of Swimming.* https://www.aquaticsgb.com/media/documents/1._The_Health_and_Wellbeing_Benefits_of_Swimming_June_2017.pdf

de Oliveira, M. R., da Silva, R. A., Dascal, J. B., & Teixeira, D. C. (2014). Effect of Different Types of Exercise on Postural Balance in Elderly Women: A Randomized Controlled Trial. *Archives of Gerontology and Geriatrics, 59,* 506-514. https://doi.org/10.1016/j.archger.2014.08.009

Erdinger, L., Kuhn, K. P., Kirsch, F., Feldhues, R., Frobel, T., Nohynek, B., & Gabrio, T. (2004). Pathways of Trihalomethane Uptake in Swimming Pools. *International Journal of Hygiene and Environmental Health, 207,* 571-575.

Etuk, B. A., Effiong, J. O., Ekop, U., & Mbong, E. (2026). Contamination Indices and Ecological Risk Assessment of Trace Metals in Soil from Selected Dumpsites in Uyo Metropolis, Nigeria. *Asian Journal of Applied Chemistry Research, 17,* 118-129. https://doi.org/10.9734/ajacr/2026/v17i1379

Evans, O., Cantú, R., Bahymer, T. D., Kryak, D. D., & Dufour, A. P. (2001). A Pilot Study to Determine the Water Volume Ingested by Recreational Swimmers. In *2001 Annual Meeting of the Society for Risk Analysis.*

Eze, V. C., Onwuakor, C. E., & Ikwuegbu, A. L. (2015). Microbiological and Physicochemical Characteristics of Swimming Pool Water in Owerri, Imo State, Nigeria. *Journal of Applied & Environmental Microbiology, 3,* 6-10.

Fantuzzi, G., Righi, E., Predieri, G., Ceppelli, G., Gobba, F., & Aggazzotti, G. (2021). Occupational Exposure to Trihalomethanes in Indoor Swimming Pools. *Science of the Total Environment, 264,* 257-265. https://doi.org/10.1016/s0048-9697(00)00722-1

Fernandez-Lao, C., Cantarero-Villanueva, I., Ariza-Garcia, A., Courtney, C., Fernández-de-las-Peñas, C., & Arroyo-Morales, M. (2023). Water versus Land-Based Multimodal Exercise Program Effects on Body Composition in Breast Cancer Survivors: A Controlled Clinical Trial. *Supportive Care in Cancer, 21,* 521-530. https://doi.org/10.1007/s00520-012-1549-x

Guan, Y., Lu, H., Dong, J., Ge, Y., Zhang, W., & Deng, Y. (2025). A Novel Groundwater Pollution Risk Assessment Method for Producing-Enterprises Sites: Integrating Scenario-Specific Pollution Evaluation with Gaussian Mixture Model Clustering. *Process Safety and Environmental Protection, 195,* Article ID: 106760. https://doi.org/10.1016/j.psep.2025.01.014

Håkanson, L. (1980). An Ecological Risk Index for Aquatic Pollution Control. A Sedimentological Approach. *Water Research, 14,* 975-1001. https://doi.org/10.1016/0043-1354(80)90143-8

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., & Ekelund, U. (2022). Global Physical Activity Levels: Surveillance Progress, Pitfalls, and Prospects. *The Lancet, 380,* 247-257. https://doi.org/10.1016/s0140-6736(12)60646-1

Hauri, A. M., Schimmelpfennig, M., Walter-Domes, M., Letz, A., Diedrich, S., Lopez-Pila, J. et al. (2015). An Outbreak of Viral Meningitis Associated with a Public Swimming Pond. *Epidemiology and Infection, 133,* 291-298. https://doi.org/10.1017/s0950268804003437

Huang, J., Liu, W., Zeng, G., Li, F., Huang, X., Gu, Y. et al. (2016). An Exploration of Spatial Human Health Risk Assessment of Soil Toxic Metals under Different Land Uses Using

Sequential Indicator Simulation. *Ecotoxicology and Environmental Safety, 129,* 199-209. https://doi.org/10.1016/j.ecoenv.2016.03.029

Indabawa, I. I., Ali, S., & Mukhtar, M. D. (2015). Assessment of Microbiological and Physico-Chemical Quality of Some Swimming Pools within Kano Metropolis, Kano Nigeria. In *3rd International Conference on Biological, Chemical & Environmental Sciences (BCES-2015)* (pp. 21-22). IICBEE.

Izah, S. C., Bassey, S. E., & Ohimain, E. I. (2018). Ecological Risk Assessment of Heavy Metals in Cassava Mill Effluents Contaminated Soil in a Rural Community in the Niger Delta Region of Nigeria. *Molecular Soil Biology, 9,* 1-11. https://doi.org/10.5376/msb.2018.09.0003

Kamioka, H., Tsutani, K., Okuizumi, H., Mutoh, Y., Ohta, M., Handa, S. et al. (2020). Effectiveness of Aquatic Exercise and Balneotherapy: A Summary of Systematic Reviews Based on Randomized Controlled Trials of Water Immersion Therapies. *Journal of Epidemiology, 20,* 2-12. https://doi.org/10.2188/jea.je20090030

Leoni, E., Legnani, P. P., Sabattini, M. A., & Righi, F. (2020). Prevalence of *Legionella* spp. in Swimming Pool Environment. *Water Research, 35,* 3749-3753. https://doi.org/10.1016/s0043-1354(01)00075-6

Li, S., & Zhang, Q. (2020). Spatial Characterization of Dissolved Trace Elements and Heavy Metals in the Upper Han River (China) Using Multivariate Statistical Techniques. *Journal of Hazardous Materials, 176,* 579-588. https://doi.org/10.1016/j.jhazmat.2009.11.069

Liu, J., Wu, J., Feng, W., & Li, X. (2020). Ecological Risk Assessment of Heavy Metals in Water Bodies around Typical Copper Mines in China. *International Journal of Environmental Research and Public Health, 17,* Article 4315. https://doi.org/10.3390/ijerph17124315

Mohammadi, A. A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M. H. et al. (2019). Carcinogenic and Non-Carcinogenic Health Risk Assessment of Heavy Metals in Drinking Water of Khorramabad, Iran. *MethodsX, 6,* 1642-1651. https://doi.org/10.1016/j.mex.2019.07.017

Neto, G., Pereira-Junior, P., Mura, G., Carta, M., & Machado, S. (2015). Effects of Different Types of Physical Exercise on the Perceived Quality of Life in Active Elderly. *CNS & Neurological Disorders—Drug Targets, 14,* 1152-1156. https://doi.org/10.2174/1871527315666151111130045

Oh, S., Lim, J., Kim, Y., Kim, M., Song, W., & Yoon, B. (2015). Comparison of the Effects of Water- and Land-Based Exercises on the Physical Function and Quality of Life in Community-Dwelling Elderly People with History of Falling: A Single-Blind, Randomized Controlled Trial. *Archives of Gerontology and Geriatrics, 60,* 288-293. https://doi.org/10.1016/j.archger.2014.11.001

Oja, P., Titze, S., Kokko, S., Kujala, U. M., Heinonen, A., Kelly, P. et al. (2015). Health Benefits of Different Sport Disciplines for Adults: Systematic Review of Observational and Intervention Studies with Meta-Analysis. *British Journal of Sports Medicine, 49,* 434-440. https://doi.org/10.1136/bjsports-2014-093885

Oni, A. A., Babalola, S. O., Adeleye, A. D., Olagunju, T. E., Amama, I. A., Omole, E. O. et al. (2022). Non-Carcinogenic and Carcinogenic Health Risks Associated with Heavy Metals and Polycyclic Aromatic Hydrocarbons in Well-Water Samples from an Automobile Junk Market in Ibadan, SW-Nigeria. *Heliyon, 8,* e10688. https://doi.org/10.1016/j.heliyon.2022.e10688

Pasquarella, C., Veronesi, L., Napoli, C., Castaldi, S., Pasquarella, M. L., Saccani, E. et al. (2023). Swimming Pools and Health-Related Behaviours: Results of an Italian Multicentre Study on Showering Habits among Pool Users. *Public Health, 127,* 614-619. https://doi.org/10.1016/j.puhe.2013.01.014

Pobi, K. K., Satpati, S., Dutta, S., Nayek, S., Saha, R. N., & Gupta, S. (2019). Sources Evaluation and Ecological Risk Assessment of Heavy Metals Accumulated within a Natural Stream of Durgapur Industrial Zone, India, by Using Multivariate Analysis and Pollution Indices. *Applied Water Science, 9,* Article No. 58. https://doi.org/10.1007/s13201-019-0946-4

Prince, M., Wimo, A., Guerchet, M., Ali, G. C., Wu, Y., & Prina, M. (2015). *World Alzheimer Report 2015: The Global Impact of Dementia: An Analysis of Prevalence, Incidence, Cost and Trends.* Alzheimer's Disease International (ADI).

Ridgway, J., & Shimmield, G. (2022). Estuaries as Repositories of Historical Contamination and Their Impact on Shelf Seas. *Estuarine, Coastal and Shelf Science, 55,* 903-928. https://doi.org/10.1006/ecss.2002.1035

Saberianpour, S., Momtaz, H., Ghanbari, F., & Mahmodi, F. (2015). Assessment of Bacterial and Fungal Contamination in Public Swimming Pools in Shahrekord, Iran. *Journal of Tropical Diseases, 4,* Article ID: 1000190.

Singh, S., & Hussian, A. (2016). Water Quality Index Development for Groundwater Quality Assessment of Greater Noida Sub-Basin, Uttar Pradesh, India. *Cogent Engineering, 3,* Article ID: 1177155. https://doi.org/10.1080/23311916.2016.1177155

Strähle, J., Sacre, C., Schwenk, M., Jovanovic, S., Gabrio, T., & Lustig, B. (2000). *[Risk Assessment of Exposure of Swimmers to Disinfection By-Products Formed in Swimming Pool Water Treatment].* Final Report on the Research Project of DVGW 10/95, Landesgesundheitsamt Baden-Württemberg. (In German)

Turekian, K. K., & Wedepohl, K. H. (1961). Distribution of the Elements in Some Major Units of the Earth's Crust. *Geological Society of America Bulletin, 72,* 175-192. https://doi.org/10.1130/0016-7606(1961)72[175:doteis]2.0.co;2

United State Environmental Protection Agency (USEPA) (2001). *Risk Assessment Guidance for Superfund, Volume III: Part A, Process for Conducting Probabilistic Risk Assessment (EPA/540-R-02-002).* Office of Emergency and Remedial Response, U.S. Environmental Protection Agency.

United State Environmental Protection Agency (USEPA) (2004). *Risk Assessment Guidance for Superfund, Volume I. Human Health Evaluation Manual. (Part E, Supplemental Guidance for Dermal Risk Assessment).* Office of Superfund Remediation and Technology Innovation U.S. Environmental Protection Agency.

United State Environmental Protection Agency (USEPA) (2009). *Guidelines for Carcinogen Risk Assessment (EPA/630/P-03/001F).* Risk Assessment Forum.

United State Environmental Protection Agency (USEPA) (2010). *Integrated Risk Information System.* https://www.epa.gov/iris/

Wood, B., van der Mei, I., Ponsonby, A., Pittas, F., Quinn, S., Dwyer, T. et al. (2013). Prevalence and Concurrence of Anxiety, Depression and Fatigue over Time in Multiple Sclerosis. *Multiple Sclerosis Journal, 19,* 217-224. https://doi.org/10.1177/1352458512450351

World Health Organization (WHO) (2006). *Guidelines for Safe Recreational Water Environments. Volume 2: Swimming Pools and Similar Environments.*

Wuana, R., Ogbodo, C., Itodo, A. U., & Eneji, I. S. (2020). Ecological and Human Health Risk Assessment of Toxic Metals in Water, Sediment and Fish from Lower Usuma Dam, Abuja, Nigeria. *Journal of Geoscience and Environment Protection, 8,* 82-106.

https://doi.org/10.4236/gep.2020.85006

Yuan, W. X., Liu, H. B., Gao, F. S., Wang, Y. X., & Qin, K. R. (2016). Effects of 8-Week Swimming Training on Carotid Arterial Stiffness and Hemodynamics in Young Overweight Adults. *BioMedical Engineering OnLine, 15,* Article No. 151. https://doi.org/10.1186/s12938-016-0274-y