Physicochemical quality, microbial load and health risk assessment of groundwater in view of the sustainable development goals 3, 6, and 11 in Osogbo, Nigeria

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Abstract

Water is abundantly available, but that of good quality for good health and well-being is not accessible thereby making cities and communities to be doubted for sustainability. Ascertaining water of good quality requires more than comparing the laboratory results with regulatory standards; exploring the multifaceted approach to check the quality of water is highly imperative and mundane to achieving the related SDGs 3, 6, and 11 to this study. The Osun Water Corporation Laboratory analysed physicochemical parameters, heavy/ toxic metals, and microbial loads of ten households' water samples across Osogbo and environs, Osun State, Nigeria. The obtained data were descriptively compared with four drinking water standards, recent works (2018-2024), and further subjected to health risk assessments (CDI, CDI_{ing}, CDI_{derm}, HQ, HI, and PLCR) using SPSS v23. The results indicated that the consumers were not free from microbial loads (total plate count, total coliform, and *Escherichia coli* in 100 % locations), cyanide (in 60 % locations), K (in 90 % locations), Cr (in 60 % locations), Cd (in 100 % locations), Mo (in 80 % locations), N-nitrate, and Free CO_2 contamination as their levels were higher than the limits of WHO, UNICEF (2014), and NIS 554 (2015) while HCO_3^- was higher that the WHO (2008) limit. The average CDI_{ing} values ranged from 3.77E-2 at location C to 8.54E-3 at location H for children and from 1.32E-1 at location C to 3.00E-2 at location H for adults. The average CDI_{derm} values ranged from 2.48E-4 at location C to 5.64E-5 at location H for children and from 4.61E-4 at location C to 1.05E-2 at location H for adults. The HQ_{ing} of Cd, Cr, and Cu were > 1, while the HQ_{derm} of Cd was > 1, thereby indicating a low non-carcinogenic risk. The adults' HI_{ing} was higher than that of the children except at locations DEC. The $PLCR_{ing}$ for adults > $PLCR_{ing}$ for children > $PLCR_{derm}$ for adults > $PLCR_{derm}$ for children. The study concluded that the health implications of the limit-exceeded parameters determined noncompliance with SDGs 3, 6, and 11. The children were more prone to ingestion and dermally-contact side effects than the adults. The HQ_{ing} is generally > HQ_{derm}. There is a need for a joint effort to make potable water available for the residents of Osogbo and its environs.

Introduction

Water is abundantly available as a natural resource specifically for human use and existence; however, its accessibility in adequate amounts for diverse uses and purposes by humans poses a major challenge, especially in developing countries like Nigeria. Safe and clean water availability and accessibility is another major hustle threatening the existentialism of man. Apart from being a major determinant of achieving the Good Health and Well-being of Sustainable Development Goal (SDG) 3, water is the driver of metabolic processes in the human body, leaving no one behind for Access to Clean and Safe Water (SDG 6). People living in the metropolis usually experience public health issues of access to clean and safe water, hence the inclusion of SDG 11: Sustainable Cities and Communities. Community remains one of the settings for health promotion and only healthy individuals can birth a healthy community. The basic provision of clean and adequate water supply remains a requisition of man to sustainably live by SDG 11.

Water is one of the scarce resources; despite its seemingly abundant occurrence on earth, its conformity to the regulatory standards determines its quality for human consumption (Malakar et al., 2019). Water of poor quality negatively impacts human life thereby jeopardising the SDG 3 campaign of good health and well-being. Water of poor quality is a result of pollutants which are traceable to the physical, chemical and microbiological parameters and whose deviations from the standards negatively obliterate the water quality (Traoré et al., 2023).

An example of the parameters is the heavy metals (HMs). The HMs are elements with derogatory effects across the spheres (biosphere, hydrosphere and lithosphere) of human existence in food chains and webs. The sources which release the HMs into the surroundings include manufacturing, agricultural, urbanisation, and nature-driven activities (Briffa et al., 2020).

Earth metal extraction with waste rock, dust and tailings releases Hg, Pb, Cd, As, and Cr into the atmosphere, hydrosphere, and lithosphere, thereby affecting their qualities. Industrial effluents, emissions, and wastes also give off Hg, Pb, Cd, Cr, Ni, and Cu to the surroundings. Wastewater sludge contains arrays of HMs, which can pose threats to the surroundings' soil, water, and air. Diffuse-associated sources, which are not limited to corrosion, erosion, abrasion, or volatilisation, can release some of their HMs, which include Pb, Cd, Hg, and Zn, into the surroundings. The most threatening points and parts of these HMs are their non-biodegradable but bio-magnification and essential metal replacement capacities with human and ecological health risks (Priya et al., 2023).

The bio-magnification health and ecological implications of the HMs are dictated by the type, dose, duration, route of exposure and contact with the HMs. Thus, water exhibits poor quality when contaminated with HMs and other pollutants, thereby affecting human health with various associated diseases and symptoms when ingested and dermally bathed with such water (Zhang et al., 2023). The indices for both ingestion and dermal contact with water were agreed for usage as indicators for assessing good water quality as an observational study had it that merely comparing analytical results with the regulatory limits hardly gives a clear idea about serious health danger that could occur from the toxic heavy metals (Omali et al., 2023); this further buttresses the fact that water of good quality is imperative to humans wherever they live. Moreover, stakeholders and scientists are craving to make risk assessment possible via various indices and simulations for the sake of modelling and prediction of water parameters for quality determination. The results of all these quality assurances no doubt contribute to good health and well-being across cities and communities for sustainable living.

To establish water asset proficient administration, Krishna et al. (2019) examined 120 samples of groundwater between the summer/ dry season and winter/ wet season using a combination of multivariate analyses and risk assessment in India and linked the degraded water quality to urgent attention which includes judicious land uses, proactive planning for the existing industries, designing of mitigation techniques, and effective implementation of the laws which exist. The lost qualities in the water were associated with various pollution sources while the health risk indices showed that the qualities could be restored provided treatment measures are integrated. Otherwise, the realisation of good health and well-being as well as sustainable cities and communities with respect to the assessed water might be in shambles. Monitoring in this case was suggested to be two-sided, temporal and spatial, to meticulously trace the pollution source.

Three states in India were selected for four water sources: surface water, hand pump, wells, and municipal water, while nearly 50 people were picked for As and Hg urinalysis and examined for ill health using ingestion and dermal indices for health risk assessment (Mawari et al., 2022). The researchers concluded with the need for routine water source monitoring around the sampled locations because of the determined illnesses which included gastric discomfort, abdominal pain, and stool. In another study, sixty groundwater samples of three grouped locations were explored by Rashid et al. (2023) to evaluate various metals' loads and physicochemical parameters of groundwater at Malakand, Pakistan, with respect to water quality, geochemical speciation and hydrochemistry, spatial distribution, and health risk assessment. The parameters determined exceeded the WHO guidelines, thereby suggesting geogenic, anthropogenic, mixed sources and nearly 70% severe groundwater pollution from the multifaceted approach it adopted. The water samples were said to be unwholesome for consumption, agricultural application, and even domestic demands. The possibilities of actualising either SDG 3, SDG 6 or SDG 11 are far from reality, as opined by the research overview of Rashid et al. (2023).

Moreover, Chen et al. (2021) dived into the adoption of groundwater for drinking and irrigation purposes using a water quality index, graphical technicalities and health risk assessment for ingestion and dermal in the Xinzhou Basin, Shanxi Province, North China. The adopted methods unanimously informed that the samples were nearly 70% drinking and 90% irrigation-worthy. The 30% and 10% deviations from drinking and irrigation compliance, respectively, made the study solicit reasonably remediating strategies for sustainable protection of the groundwater quality to have good health and well-being.

In addition, Nguyen et al. (2021) assessed 14 groundwater samples in wet and dry seasons for ingestion and dermal health risk in the Xuyen Moc District, Vietnam. It was discovered that the presence of F, Fe and Pb elements in the water samples subjected the residents’ (especially the children's) health to non-carcinogenic effects, thereby buttressing that good health and well-being (SDG 3) is not realisable, let alone sustainable city and community (SDG 11) for the Xuyen Moc district being studied. Two years after the study, sixty well water samples whose determined parameters' values were compared with national guidelines and computed for ingestion and dermal health risk assessment by Nguyen & Huynh (2023) at the Mekong Delta, Vietnam, showed that 30 and 26% were respectively very good and unsuitable for consumption. The kids were also said to be more at health risk danger than the adults.

Another study, which involved six multifaceted (Standard comparison, WQI: water quality index, HHI: human health index, MAS: multivariate analytical statistics, ANNM: artificial neural network models, and GIS: geographic information system) approaches, was deployed in El Kharga Oasis, Egypt by Gad et al. (2023) to assess fates of 140 groundwater samples' pollution and possible realisation of Sustainable Development Goals 3 and 11 of the United Nations, which are good health and well-being, and sustainable cities and communities respectively. The approaches unanimously observed that Fe and Mn element levels were higher than the WHO limits, most water samples belonged to poor and very poor categories, there was low risk from dermal and ingestion health assessment, and both natural- and human-induced pollution was possible. Conclusively, the research sought indulgence for cutting-edge measures to prevent possible outbreaks of water-related issues. By the following year, Mohamed et al. (2024) adopted six indices with multivariate analyses to model possible health risks associated with ground- and surface water in Siwa Oasis of Egypt. The findings showed that most assessed water samples subjected their users to various health issues, such as the carcinogenic effects from Cd, Cr and Pb in either children or adults who bathed with and consumed the water. The results made the researchers convincingly clamoured for water treatment within the vicinity of all sampled water sources to protect the environment and human health. The SDGs 3, SDG 6, and 11 were shown to yet be realised within such study locations.

Donuma et al. (2023) realised that the quality of the ten water samples analysed within the Keffi metropolis, North-central part of Nigeria, did not conform to the WHO limits, although the water quality index indicated good to excellent quality, while the two (ingestion and dermal) indices used alongside showed the water consumers were not prone to significant health risks. Failed in one and passed in the other made the researchers suggest frequent monitoring of the water sources to avert becoming of poor quality for Good Health and Well-being of SDG 3 and ascertain sustainable cities and communities with respect to water quality. Omali et al. (2023) observed that the consumers of the 27 ground- and surface-water samples across six local councils in Abuja, North-central part of Nigeria, were prone to high risk of contracting cancer as the computed index for ingestion, unlike dermal was unacceptable for both age (children and adults) groups. The researchers recommended the replacement of dumpsites with landfills to decrease health risks while ensuring the attainment of SDGs 3, 6, and 11 of the United Nations, which shall reign till 2030.

Twenty-four groundwater and ten table water samples were assessed for metal loads and risk assessment within the Nassarawa local government of Kano State, Nigeria (Salihu et al., 2019). The levels of Cd, Cr and Pb were determined to subject the water consumers to unacceptable cancer risk from the computed ingestion index. Olamilekan et al. (2018) compared the results of the borehole and hand-dug well water sampled in the Ebocha-Obrikom area of River State, Nigeria, with NAFDAC and WHO limits to which some parameters were deviated. The observations triggered suggestions for comprehensive sources' monitoring and appropriate treatment of the sampled water to help in the realisation of good health and well-being (SDG 3) and its associate (SDG 11) considered in this study. Five hand-dug wells for 30 water samples were compared with WHO limits and health risk assessment of ingestion and dermal in Omu-Aran, Kwara State, Nigeria, by Elemile et al. (2021). The results showed that 5 over 7 analysed metals exceeded the WHO limits, while ingestion but dermal index indicated non-carcinogenic effects for all the samples. So, the right of the consumers to good health and well-being (SDG 3) in a sustainable city and community (SDG 11) is infringed, i.e., not guaranteed. The study suggested community awareness of the dangers associated with its water sources.

Ibitoye & Okende (2016) adopted three-in-one visualisation (GIS: geographic information system, GPS: geographic positioning system and RS: remote sensing) techniques to spatially investigate public water supply within Osogbo and its environs. The results found and conditionally stated that optimal functionality of all the facilities would produce 30 to 35% of the total covered area water accessibility and supply. Data were gathered from three intentionally chosen residential neighbourhoods representing low, medium, and high-density areas, with a cumulative population of 134,159 and an estimated 26,829 households. Thus, the then water accessibility and supply could not meet the Millennium Development Goals. Furthermore, the recently conducted study of Adedotun et al. (2024) examined the possible sources and utilisations of water availability in Osogbo by considering the socio-economic characteristics of the randomly and systemically selected households across low, medium and high-density areas via multistage sampling techniques. The considered areas and their available water utilisation indicated a positive correlation, which was statistically significant, thereby making the study recommend necessary joint efforts of concerned groups (individuals, communities, NGOs) and government to tackle the issues of water provision across the considered areas.

The current study doubted if the outcomes of water studies had successfully been linked with the Sustainable Development Goals 3, 6 and 11 of the United Nations on the one hand, nor had there been any adoption of health risk assessment to verify the quality of the available water, particularly in Osogbo and its environs let alone Osun State in general.

Results

The physicochemical quality

The first four parameters (appearance, taste/ odour, and colour) conformed to the compared NIS 554 (2015) standards, supported by the turbidity, whose values across the ten samples did not even halve the set limit of 5. The implication was that there would not be any effect from those four parameters on the health and well-being of the consumers as they conformed to their set standards. Exact 60 % of the sampled locations had their pH values slightly acidic (6.00) and below ranges of the set limits; such slightly acidic conditions might influence the availability of heavy metals and microbial loads that feed on them. Values of the analysed temperature were higher than all the set limits of ambient (NIS 554, 2015) and 27-28 (WHO, UNICEF 2014; WHO 2008, 2017) with the implications of exothermic reactions (Table 2). The TDS of 20 % locations (H: 674.40 mg/ L and J: 548.20 mg/ L) were higher than the set limit (500 mg/ L) of NIS 554 (2015) and WHO (2017) with the possibility of the presence of dissolved substances while 80 % conformed to their values lower than 500 mg/ L. Conductivity of the same 20 % locations (H: 1044 μS/ cm and J: 1004 μS/ cm) were higher than the set limit (1000 μS/ cm) of NIS 554 (2015) to deduce the possible influence of the total dissolved solid from the dictate of the Nigerian set limit of 1000 μS/ cm for conductivity (Table 2).

Dissolved oxygen in 20 % of locations (B and G: 1.02 mg/ L) conformed to (being higher than) 0.40 mg/ L (NIS 554 2015), unlike the other 80 % of locations whose DO were lower than the expectation. Chlorine residual values were BDL and lower than the set limit of 0.30 mg/ L (NIS 554 2015), while flocculation and chemical oxygen demand had no specified values for comparison. Values of the alkalinity were lower than the NIS 554 (2015) of 200 mg/ L, while location J had its alkalinity value (120 mg/ L) higher than the WHO (2008) set limit of 100 mg/ L. For the total hardness, its values were higher at three locations (D: 110, F: 160.80, and G: 105) than the set limit of 100 mg/ L of NIS 554 (2015), while all its values were lower than the set limit: 500 mg/ L of WHO (2008). The values of Mg ions except at location C: 0.05 mg/ L were higher than the NIS 554 (2015) set limit of 2 mg/ L, while of all the locations were lower than the set limits of WHO, UNICEF (2014): 50 mg/ L and WHO (2017): 75 mg/ L. However, the determined quantities of chloride ions were lower than the set limits of WHO, UNICEF (2014): 250 mg/ L and NIS 554 (2015): 100 mg/ L. Total hardness and Mg ions implied that the water samples were fairly hard with Mg ions.

None of the N-ammonia contents was lower than the set limit: 0.01 mg/ L of the NIS 554 (2015), the N-nitrate contents across the sampled locations were higher than 10 mg/ L stipulated by the NIS 554 (2015) but of location A: 62 mg/ L, F: 84 mg/ L, and G: 52 mg/ L were higher than the 50 mg/ L stipulated by the WHO, UNICEF (2014). The N-nitrite contents across the sampled locations were lower than 0.10 mg/ L stipulated by the NIS 554 (2015). The determined contents of Free CO_2 across the sampled locations except at G: 10 mg/ L were higher than the NIS 554 (2015) limit of 12 mg/ L. The values of hydrogen sulphide were lower and higher in 50 % of locations than the set limit: 0.05 mg/ L of the NIS 554 (2015) (Table 2).

The determined contents of SO_4^{2-} were lower than the set limits of all the compared standards (WHO, UNICEF (2014): 500 mg/ L; WHO (2017): 250 mg/ L; NIS 554 (2015): 100 mg/ L). The determined values of the PO_4^{3-} ranged from 0.22 mg/ L at location H to 0.68 mg/ L at location E with no comparable set limit of any standard. The values of CO_3^{2-} were lower than the set limit of 100 mg/ L of NIS 554 (2015) except at location J: 160 mg/ L, but generally lower than the set limit of 350 mg/ L of WHO (2017). For the HCO_3^-, its contents across the sampled locations were lower than 500 mg/ L of the WHO, UNICEF (2014), lower than 250 mg/ L of NIS 554 (2015) except at location J: 378.20 mg/ L, and higher than 120 mg/ L of the WHO (2017). The fluoride contents of all the sampled locations were lower than the set limit of 1.50 mg/ L (WHO, UNICEF 2014; NIS 554 2015).

Microbial loads

The chlorine serves as a disinfectant, and it is not naturally present or sometimes present in small amounts in groundwater but it is majorly a result of human activities. In all the test samples there is no presence of chlorine to act as a disinfectant against the pathogenic coliform bacteria. The three microbial indicators assessed for their loads were worrisomely higher than the set limits of 10, nil, and nil for total plate count, total coliform, and E. coli, respectively (NIS 554, 2015) (Table 3).

The total plate count of the groundwater samples of locations B, C, D, H, and I revealed cluster formation, i.e., too numerous to count when compared with the standard value, while groundwater samples of locations A, E, F, G, and J were numerically higher when compared to the value of the standard. In a nutshell, all the tested samples showed higher significant values than the standard. For the total coliform test using the Most Probable Number (MPN) test, the groundwater sample of location C showed the highest numerical value when compared with every other test sample. In the same vein, the groundwater samples of locations B and H have the same numerical values likewise a sample of location F. The location I also have the same value, and there is no difference to the sample of location D.

In contrast, the sample of location E has the lowest numerical value when compared with every other water sample. *E. coli* is an indicator for all the coliform bacteria, and there was visible growth in all test samples when cultured on selective media (EMB).

Heavy/ toxic metals

The amount of the determined cyanide across four sampling locations (B, C, E, and G) exceeded the NIS 554 (2015) limit of 0.01 mg/ L, while the silica contents were lower than the set limit of 0.10 mg/ L (NIS 554 2015). Levels of the determined K-content exceed the limits of WHO, UNICEF (2014) and NIS 554 (2015) except at location A, where it was below the detection limit of the analytical instrument (BDL) (Table 3).

For the heavy metals, levels of Fe, Cu, Mn, Al, Zn, and Br were lower than their respective compared standards. Levels of Pb and As were below the detection limit of the analytical instrument (BDL). The Cr-content of four locations (B to E) was lower than the set limit of WHO, UNICEF (2014): 0.05 mg/ L, while none of the ten locations was lower than the set limit of NIS 554 (2015): 0.01 mg/ L. The Cd-content was higher than the set limits of WHO, UNICEF (2014): 0.005 mg/ L and NIS 554 (2015): 0.003 mg/ L. Levels of Mo were higher than the set limit of NIS 554 (2015): 0.001 mg/ L across the sampling locations except at D and E (Table 3). The implication was that the consumers were not free from cyanide (in 60 % locations), K (in 90 % locations), Cr (in 60 % location), Cd (in 100 % locations), Mo (in 80 % locations) contamination for being higher than the compared set limits of WHO, UNICEF (2014), and NIS 554 (2015) unlike silica, Fe, Cu, Mn, Al, Zn, Br, Pb, and As which were lower than the limits.

Human health risk assessment

Tables 4 to 6 indicated chronic dose index (CDI), ingested dose of water (CDI_{ing}), and dermally contacted dose (CDI_{derm}), respectively, of water considered to elicit non-carcinogenic health risk for the water consumers: children and adults. The average CDI were determined to follow households C > D > E > B > G > J > E > A > I > H, ranging from 1.62E-3 at location H to 7.16E-3 at location C for the children while 1.16E-4 to 5.11E-4 for the adult. The average CDI_{ing} showed that its values gradually ranged from 8.54E-3 at location H to 3.77E-2 at location C for the children and from 3.00E-2 at location H to 1.32E-1 at location C for the adults. The average CDI_{derm} showed that its values progressively ranged from 5.64E-5 at location H to 2.48E-4 at location C for the children and from 1.05E-4 at location H to 4.61E-1 at location C for the adults.

The results showed that children's susceptibility to the possible side effects of chronic dose through ingestion (CDI_{ing}) and dermal contact (CDI_{derm}) over time was more than the adults' (Table 7). The HQ_{ing} of Cd, Cr, and Cu were >1 in that order; Fe and Zn were < 1 across the study locations, while Mn was < 1 at 60 % of locations. Order of the HI_{ing} followed D > E > C > J > F > G > A > H > I > B, and higher for the adults than for the children. The HQ_{derm} of Mn, Cu, Zn, Fe, and Cr were < 1 in that order, while Cd > 1. The HQ_{derm} of Cd and Zn > 1 for adults, while Cd > 1 for children. Order of the HI_{derm} followed D > E > C > J > B > F > H > A > I > G > C for the children, D > E > C > B > A > F > I > G > H > J for the adults; the adults' HI_{derm} were higher than of the children (Table 8). Order of the PLCR was observed to follow the $PLCR_{ing}$ for adults > $PLCR_{ing}$ for children > $PLCR_{derm}$ for adults > $PLCR_{derm}$ for children (Table 9).

Discussion

Water parameters are used in determining water quality, important indices requiring serious attention, and monitoring as one of the key factors in which attainment Good Health and Well-being (SDG 3), clean and safe water access, and sanitation for all (SDG 6), and sustainable cities and communities (SGD 11) is hinged. The comparison of the analysed parameters and their ranged values in the current study with other related studies (Table 10) determined the relatedness, reliability, and validity of their outcomes; this comparison purposely affirmed the earlier comparison with the regulatory agencies' limits: WHO (2008, 2017), WHO, UNICEF (2014), and NIS 554 (2015) to know how the current households' drinking water quality faired for their consumers' health.

Comparing the current study's turbidity value (1.02-2.08 NTU) with the studies of Olalekan et al. (2018): 0.00-50.00 NTU and Rashid et al. (2023): 2.4-14.00 NTU signified a close relatedness. The WHO recommendation stipulated that the turbidity value for safe and quality drinking water should be less than 1 NTU while not exceeding 5 NTU, to which the current study's range of values complied. Thus, in line with one of the eight targets of SDG 6, the households' water sample with turbidity value of 1.02-2.08 recorded in this study was in the right direction of achieving SDGs 3, 6 and 11. According to the US Water Science School (2018), the relative clarity of water due to the suspended particles' amount is measured by the turbidity. Hence, the higher the turbidity of water, the higher the level of disease-causing microorganisms (bacteria, viruses, and parasites) and inorganic chemicals available in it. Frequent consumption of high turbid water is a risk factor for the occurrence of diseases like cholera, diarrhoea, endemic gastrointestinal illness, and accumulation of toxins from inorganic chemicals, which are usually detrimental to human health (Olalekan et al., 2018) and environmental sustainability, SDG 3, 6, and 11.

Comparing the pH of the households' water (6.0-7.5) in the current study with other studies showed there was a relative comparativeness in their values aside from that of Olalekan et al. (2018): 3.21-10.32 and also fell in the range with the compared WHO standard. The pH of most drinking water is between 6.5 and 8.5, although it can be affected by factors like temperature, humidity, and other dissolved particles available in the water. The significance of the pH of the water is in determining the corrosiveness of the water, i.e. the acidity or alkalinity of the water, with no direct relationship with human health but rather in association with other determinants of water quality. According to WHO (2008, 2017), the pH of water measures an acid-base equilibrium system and is controlled by the carbon dioxide–bicarbonate–carbonate (i.e., CO_2-$HCO_3^-$$CO_3^{2-}$) equilibrium in most natural waters. As an important water quality parameter, it is imperative to monitor the water pH level to prevent adverse effects on the odour, taste, and appearance of the water (WHO, 2007). The temperature of the water sampled in this current study with other studies revealed a divergent value for the lower limit when compared to the upper limit. It measures the kinetic energy of water. Temperature determines how hot or cold the water is; its value depends on location, season, and time of the day/ year. The WHO (2008, 2017) recommended that the water temperature must neither be too low nor too high to prevent microorganism growth.

The Total Dissolved Solid (TDS) is another important index for water quality. Comparing the current study's TDS (302.20 - 674.40 mg/ L) with other studies revealed an unequal distribution of a lower limit range of 203.00 – 1120.00 mg/ L and an upper limit of 904.07 – 153589.00 mg/ L. A value below 500 mg/ L is generally recommended. The TDS describes either the inorganic salts or small amounts of organic matter present in solution or water (WHO, 1996). The relatively high levels of TDS and total hardness moved near the assertion of Herojeet et al. (2013) to indicate groundwater abstraction with groups of salts; the high levels of K^+, Mg^{2+}, HCO_3^-, and free CO_2 supported the views of salts abstraction from the underground water (Laar et al., 2011; Dinka et al., 2015). While the USEPA recommended a conductivity value of less than 1000 μS/ cm for drinking water, Bilewu et al. (2022) used a standard of 300 μS/ cm to compare the physicochemical parameters of the households' water sampled in their study. Only the conductivity value (480-1500) reported by Rashid et al. (2023) was within the range of the conductivity value of the water sampled in the current study (682 - 1004).

Comparing the current households' water dissolved oxygen (DO) with the values determined by Olalekan et al. (2018) showed major variation while being in range with the values determined by Mawari et al. (2022) together with the flocculation value. The 80 % of households whose water DO values were lower than the set limit of 0.40 mg/ L (NIS 554 2015) could influence dead of the water body and organisms in the hydrosphere, according to Chukwu (2008) and Ejenolu et al. (2011). The total alkalinity value was higher than the value reported in the Olalekan et al. (2028) study, and Dami et al. (2012) informed of possible acidic substance intrusion into the sources of the sampled water, thereby contributing to the high level of alkalinity, especially at the location J. The total hardness was higher than the ranged values of Olalekan et al. (2018) but within those of Chen et al. (2021) and Nyengen et al. (2021).

The magnesium and chloride ions values were lower than the values in other studies. Nitrate was within the range of other studies. The sulphate value was perfectly fitted with the values determined by Rashid et al. (2023). Phosphate and carbonate were equally within the range of available studies. The Fluoride contents were lower in this study than the compared agencies' set limits, within the determined values of Krishna et al. (2019), Chen et al. (2021), and Nguyen et al. (2021), but lower than that of Mawari et al. (2022). The determined high levels of N-nitrates across the household water samples indicated possible human health risks with marked natural contamination (Gopalkrushna, 2011; Donkor et al., 2015).

Combined consumption of water with high presence/ high contents of N and F were said to possibly influence cancer of the stomach (Zhang et al., 2018), skeletal and dental fluorosis (Adimalla et al., 2019), methemoglobinemia (Karunanidhi et al., 2019). The source of N and F were said to have been from faecal leakage-percolation and water-rock interface, respectively.

The presence of N-nitrate could be worsened by the absence of chlorine across the households' water, thereby posing significant health risks and affecting the water supply's overall quality and safety. There are also possible severe implications of increased risk of waterborne diseases, microbial contamination, and shortened water shelf life (Salehi, 2022; Wu, 2020; Islam *et al.,* 2021). The presence of clusters or numerous colonies in the total plate count of a groundwater sample is great contamination from sources that include sewage, animal waste or other forms of pollution (Karri *et al.,* 2021), with an indication of potential health implications (Vasudevan *et al.,*2021). Drinking water withhighlevels of bacteria subjects humans to health issues ranging from gastrointestinal problems, diarrhoea, and nausea to other waterborne illnesses (Kristanti *et al.,* 2022). The surface of coliform in the water sample has a significant health implication. So, the total coliforms found across the households' water samples suggested that the water supply/ quality had been compromised and the chance of posing health risks to those (children and adults) who consume it (Sarkar *et al.,* 2022). Coliforms are a group of bacteria found in the environment and intestines of warm-blooded animals (Some *et al.,* 2021). Coliform presence in households' drinking water indicates potential contamination from faecal matter or other sources (Daly & Harris, 2022). An *Escherichia coli* presence in water samples indicates contamination by faecal matter, either from humans or animals; this can have serious health implications with symptoms such as diarrhoea, fever, and abdominal pain. Dehydration and kidney failure are among the cases at the severe level (Some *et al.,* 2021).The K-content aligned with the values determined by Krishna et al. (2019) and Chien et al. (2021) while lower than those of Rashid et al. (2023), Gad et al. (2023), and Mohamed et al. (2024).

The toxic/ heavy metals were within the ranges of values in comparison with other studies. Their (toxic/ heavy metals') ingested (CDI_{ing}) and dermally-contacted (CDI_{derm}) doses averagely varied across the households' water samples under consideration in Osogbo and its environs; the children were more prone to the assessed health risks than the adults augmented by the previous studies (Nguyen et al., 2021; Nguyen & Huynh, 2023) unlike as they were stated to be unacceptable to both sets of the consumers (children and adult) in the studies of Omali et al. (2023) in Nigeria and Mohamed et al. (2024) in Egypt.

He et al. (2021) and Li et al. (2021) affirmed the usage of HQ_{ing}, HQ_{derm} and their associated HI_{ing} and HI_{derm} for the non-carcinogenic human health risk assessment. Non-determination of HQ_{ing} and HQ_{derm} across 40 % of the study locations with no non-carcinogenic health risk effects from ingestion and dermally contact with the sampled water took to the study of Elemile et al. (2021). As the HQ_{ing} of Cd, Cr, and Cu were >1 for children and adults while the HQ_{derm} of Cd and Zn > 1 for adults and Cd > 1 for the children, there were low risks (HQ >1≤5) of non-carcinogenic risk (USEPA, 2005). The order of HI_{ing} and

HI_{derm} were higher for the adults than the children. Order of the progressive lifetime cancer risk (PLCR) followed $PLCR_{ing}$ for adults > $PLCR_{ing}$ for children > $PLCR_{derm}$ for adults > $PLCR_{derm}$ for children with all greater than 1 for low risk, which Nguyen et al. (2021) warned against that low risk is not even acceptable.

Conclusion and recommendations

The premier health risk water assessment study in Osogbo and its environs, determined 44 water parameters which cut across physicochemical, microbial, and toxic/ heavy metal loads across ten households. The results were compared with four sets of standards: WHO (2008, 2017), WHO, UNICEF (2014), and NIS 554 (2015), and with ten recently (2018 to 2024) published works across Nigeria, Egypt, India, Pakistan, and Vietnam showed that

- the determined contents of silica, Fe, Cu, Mn, Al, Zn, Br, Pb, and As were lower than the compared limits,
- the cyanide (in 60% of locations), K (in 90% of locations), Cr (in 60% of locations), Cd (in 100% of locations), and Mo (in 80% of locations) were higher than the compared limits, and
- no household's water sample was spared of high loads of total plate counts, total coliform and *E. coli*.

The order of the average values of the computed CDI, CDI_{ing}, and CDI_{derm} indicated that the health risks followed C > D > E > B > G > J > F > A > I > H, with the children being more prone than the adults.

The (Cd, Cr and Cu) HQ_{ing} were higher than the (Cd and Zn) HQ_{derm}, with their HQ > 1 indicating low non-carcinogenic health risk. The order of HI_{ing} and HI_{derm} were higher for the adults than the children.

Progressive lifetime cancer risk of ingestion ($PLCR_{ing}$) was higher for adults than children, while dermal contact ($PLCR_{derm}$) was higher for adults than for children.

Therefore, the study suggested that the Osun State Water Corporation see to community water provision and, at the same time, pay attention to purification of the water sources for Cr, Cd, Mo, and microbial loads. The government should do health education intervention and non-governmental organisations among the community members to forestall further pollution by human activities by human activities. Such an awareness would promote behavioural change in line with water sanitation and hygiene (WASH). Conclusively, the authors are aware that households across the study locations consume packaged (PET and satchel) water, whose quality is not yet ascertained. So, there is a need for further research on such water samples.

Materials and Methods

Study Area

Osogbo is the capital city of Osun State, Nigeria. It belongs to the rainforest agroecological zone. The state is known as the land of virtue by the national slogan, while the Osogbo yearly celebrates the traditional festival of the Osun River with respect to the water deity. People fly into the capital city from far and wide for this yearly celebration. The study of Ibitoye & Okende (2016) comprehensively described the geographical location of Osogbo, Osun State, Nigeria. It further made speculation on the population of the city capital to have nearly 221,000 from the 3.5% growth rate of the United Nations as of 2016. Deductively, the population of Osogbo is nearly 291,059 as at the time of conducting this study (February, 2024) using the quoted figure of 156,694 by the National Population Census of 2006 in the following formula

$P_n = P_o (1 + (3.5/100))^n$ ----- (Ibitoye and Okende, 2016) ---------- (1)

where n = 2024 – 2006 = 18 years from 2006. Po = Osun population of 156,694 (NPC, 2006) -------- (2)

Water Samples Collection and Analysis

Residences of the environmental health science students of the Fountain University Osogbo, Osun State, were purposively chosen with the thought that they were living across Osogbo and its environs. Each designated student used a prewashed and well-drained plastic bottle of 2.5-litre capacity. The sampling bottles were washed with detergent, rinsed five times, followed by rinsing with distilled water, soaked in acidified water for 24 hours, and finally rinsed with the water to be taken at the sampling point.

The GPS of the residences were taken while collecting the water samples to make a map (Fig. 1). The water samples were collected at the doorsteps of the students on Friday, 23rd day of February 2024 and immediately taken in ice-chest to the Osun State Water Regulation Commission, Department of Quality Control and Laboratory Services, State Secretariat, Abere, Osogbo, Osun State for analyses using standard methods for 44 parameters that included physical, chemical and microbiological parameters. The results were issued with NIS (Nigeria Industrial Standards) limits of 2015. The certificates had ref. no.: OSWRC/QC2/94 and OSWRC/QC2/95; each containing five results.

Statistical Analysis

The data from the laboratory analysis were descriptively compared with the NIS (National Industrial Standards 2015), WHO, UNICEF (2014), and WHO (World Health Organisation 2008, 2017) standards, and ranged values of ten recently conducted research between 2018 and 2024 to comparatively know how fair the determined parameters were. The toxic/ heavy metal data were further subjected to human health risks assessment.

Human Health Risk Assessment (HHRA)

Chronic daily index (CDI), hazard quotient (HQ), hazard index (HI), and progressive lifetime cancer risk (PLCR) were computed using the USEPA (2022) and various applicable coefficients.

$$CDI = C * ((IR/BW)) \text{ ———————— } (3)$$

$CDI_{ing} = (C_{water}*IR*EF*ED)/ (BW*AT)$ ------------------ (3a)

$CDI_{der} = (C_{water}*SA*KP*ET*CF*EF*ED)/ (BW*AT)$ ------------------ (3b)

HQ = CDI/ RfD ---------------------- (4)

PLCR = CDI/ CSF ———————— (5)

The HHRA of each analysed heavy/ toxic metal was verified through quantification of its risk level. For the CDI to be well related to either the ingested quantity or dermally contracted quantity, this study adopted both equations 3a for ingestion risk and 3b for dermal risk.

Sun et al. (2015) expressed the result to either be cancer or non-cancer health risk from ingested (1a) and dermally-contacted (1b) available/ potable water. Kavcar et al. (2009) computed the chronic daily intakes (CDI in mg/kg/day) of heavy/ toxic metals. Where C is the contaminant value determined in the potable water, IR is the one-time ingestion rate (child: 1 L/day while adult: 2 L/day), and BW is the national average body weight (70 kg for adult) in Nigeria. However, the National Standards (2020) put the Nigerian mean daily water quantity per person at 9 L, though the acceptable quantity is between 12 and 16 L.

Nguyen et al. (2021) mentioned in their study that CDI_{ing} represents ingested dose/ quantity of water (mg/kg/day) while CDI_{der} represents dermally absorbed dose/ quantity of water (mg/kg/day); Cwater: the determined heavy/ toxic metal in water (mg/L); IR: the assumed water ingestion rate (L/day); EF: contact frequency with water (days/year); ED: contact duration with water (years); BW: the assumed mean body weight (kg); AT: averaging time (days); SA: area of the exposed skin (cm^2); KP: the coefficient of dermal absorptivity, (0.001 cm/h for Mn, Fe, F and 0.004 cm/h for Pb); ET: time of exposure (h/day) and CF: unit conversion factor (0.001 L/ cm^3).

The relative of the CDI with respect to chronic reference dose (RfD) amounts to the non-cancer hazard quotient, or the quantity of daily exposure level for the human population during a lifetime, expressed as the (HQ) (Bamuwamye et al., 2015). The scale of HQ indicated no risk: ≤ 1, low risk: $>1 \leq 5$, medium risk: $>5 \leq 10$, and high risk: >10 (USEPA, 2005). Nguyen et al. (2021) indicated that low risk is not even acceptable.

For the progressive lifetime cancer risk PLCR, the CDI is related to the cancer slope factor (CSF in $mg/kg/day)^{-1}$, as the probability of developing cancer before reaching age 70 due to daily exposure to a cancerous hazard. Omali et al. (2023) gave CSF of ingested doses of 0.5, 1.5 and 6.1 for Cr, As, and Cd. Mohamed et al. (2024) gave CSF an ingested dose of 0.5 for Pb. The factors and their values are shown in Table 1.

Statements and Declarations

Availability of data and material data will be sent upon request from the department of the corresponding author.

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Ethics declarations It is not applicable here.

Consent for publication All the authors gave consent to publish the work.

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Tables

Tables 1 to 10 are available in the Supplementary Files section

Figures

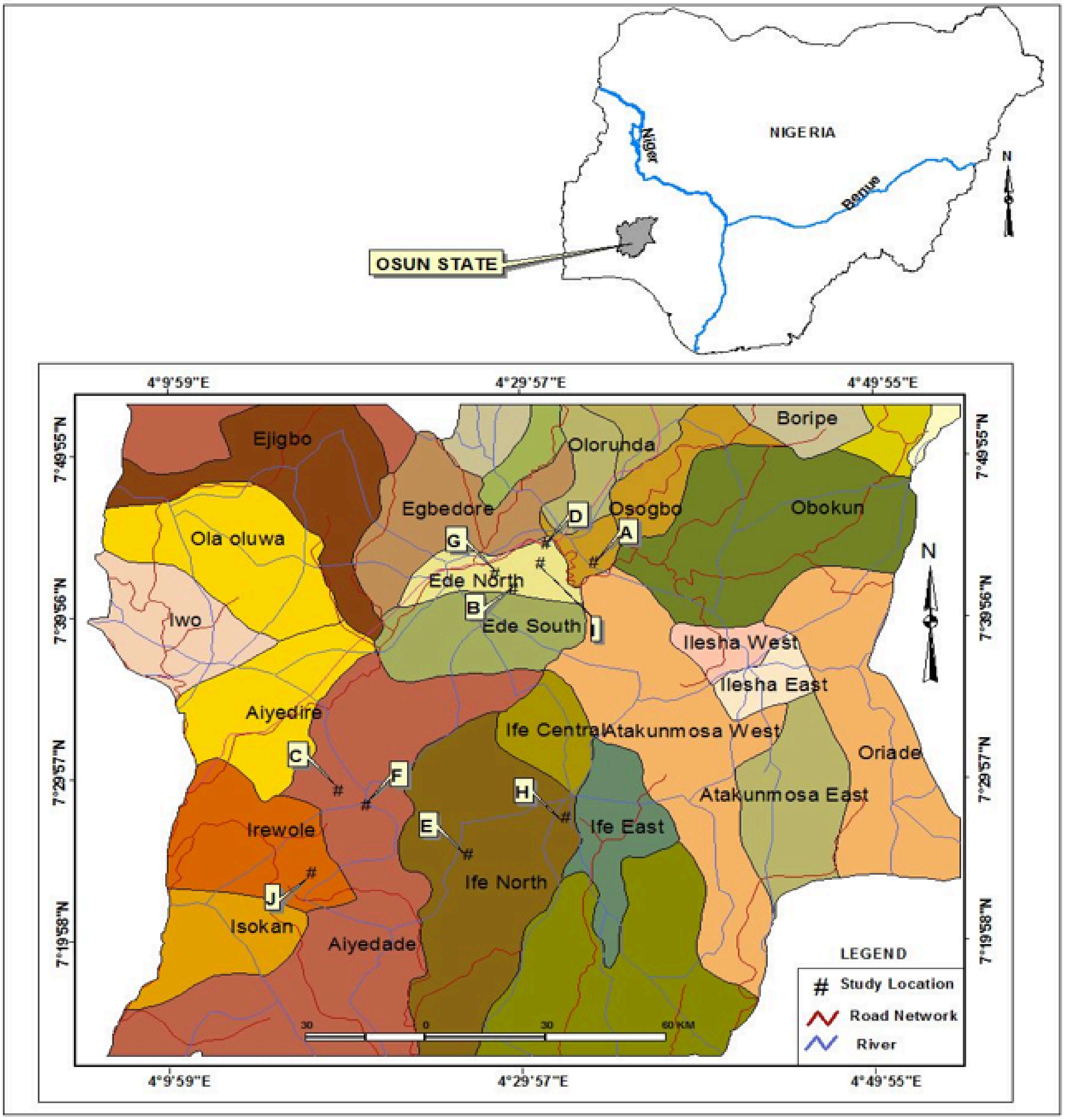

Figure 1

Map of the sampling and study locations

Supplementary Files

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