



International Journal of Science, Architecture, Technology and Environment

Assessment of Fluoride and Arsenic Levels in Rural Drinking Water: A Geochemical and Health Risk Perspective. A Case Study of Uromi, Edo state, Nigeria

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DOI: <https://doi.org/10.63680/ijstate0825015.44>

Abstract

Access to safe and clean drinking water is a fundamental human right and a critical determinant of public health, particularly in rural communities of developing nations. This study assessed the levels of fluoride and arsenic in groundwater sources used for drinking in Uromi, a rapidly expanding rural-urban town in Edo State, Nigeria. Ten sampling locations were selected based on spatial distribution and population dependence on borehole and hand-dug well water. Water samples were collected during the dry season and analyzed using standard geochemical methods, including ion-selective electrode and atomic absorption spectrophotometry (AAS) techniques. The results revealed that fluoride concentrations ranged from 0.76 to 2.15 mg/L, with the highest recorded at Eguare and the lowest at Efandion. Arsenic levels varied from 0.002 to 0.018 mg/L, with elevated values observed in samples from Market Square and Idumoza. Notably, 30% of the water samples exceeded the WHO permissible limit of 1.5 mg/L for fluoride, while 40% exceeded the WHO guideline value of 0.01 mg/L for arsenic, indicating significant potential for chronic exposure risks. The spatial variability of fluoride and arsenic concentrations suggests a combination of natural geochemical processes (e.g., leaching from fluoride-bearing minerals and arsenopyrite) and possible anthropogenic influences from waste disposal and agrochemical runoff. The estimated daily intake (EDI) and hazard quotient (HQ) for children and adults show a higher risk for children, particularly in areas with elevated contaminant levels. This study highlights the urgent need for continuous monitoring of groundwater quality in Uromi and similar rural regions, coupled with public health interventions such as water treatment, community education, and policy enforcement. The findings provide critical data for local authorities and environmental health planners to develop sustainable strategies for mitigating the health risks associated with fluoride and arsenic in drinking water.

Keywords: Fluoride, Arsenic, Groundwater contamination, Drinking water quality, Health risk assessment, Geochemical analysis, Rural water supply, Uromi, Nigeria, WHO standards

Introduction

Access to safe drinking water is a basic human right and a critical component of sustainable development, public health, and socioeconomic advancement. In many rural regions of developing countries, including Nigeria, groundwater sources particularly shallow wells and boreholes remain the dominant sources of domestic water. These sources, while often perceived as safe, are susceptible to contamination by naturally occurring geogenic elements such as fluoride and arsenic, both of which pose serious health risks when concentrations exceed permissible limits. In recent decades, increasing attention has been directed toward the geochemical characteristics of drinking water and their potential implications on public health, especially in under-monitored and data-scarce rural areas (Rezaei *et al.*, 2022; Khan *et al.*, 2020).

Fluoride and arsenic are naturally occurring elements that enter groundwater primarily through rock-water interactions, leaching, and anthropogenic activities such as mining, pesticide use, and industrial effluents (Smedley and Kinniburgh, 2002; Akinbile and Yusoff, 2011). Although trace levels of fluoride are essential for dental health, concentrations exceeding 1.5 mg/L can result in dental and skeletal fluorosis (World Health Organization [WHO], 2017). Similarly, prolonged exposure to arsenic even at low doses is linked with a host of chronic conditions including skin lesions, cardiovascular diseases, developmental defects, neurotoxicity, and various forms of cancer (Smith *et al.*, 2000; WHO, 2018).

In Nigeria, especially in states such as Edo where Uromi is located, rural water supplies are primarily derived from hand-dug wells and boreholes. Unfortunately, due to limited government oversight, poor infrastructure, and lack of regular water quality monitoring, the chemical composition of such drinking water remains largely undocumented (Olalekan *et al.*, 2023). Uromi, a densely populated town in Esan North-East Local Government Area of Edo State, is surrounded by weathered basement rocks and soils that may serve as geogenic sources of contaminants. While surface-level water problems like microbial contamination have received some policy attention, fluoride and arsenic contamination due to its less overt presentation has remained under-investigated in the region. Recent studies conducted in parts of northern and southwestern Nigeria have reported fluoride concentrations exceeding the WHO recommended limit, particularly in areas underlain by crystalline basement rocks (Gbadebo *et al.*, 2020; Obaje *et al.*, 2016). Similarly, elevated arsenic levels have been reported in groundwater sources located in proximity to agricultural and waste-dumping areas (Egbueri, 2020; Yusuf *et al.*, 2021). These findings underscore the need for spatially explicit studies to assess geochemical risk and identify vulnerable communities.

Health risk assessments that focus on lifetime exposure and dose-response relationships are becoming increasingly important tools for quantifying the public health implications of contaminated water supplies. The integration of Geographic Information Systems (GIS) and geostatistical modeling in recent water quality studies has proven effective in identifying contamination hotspots and guiding remediation efforts (Ugbaja *et al.*, 2023). Yet, such methodological rigor is seldom applied in many rural Nigerian studies due to lack of technical capacity or funding constraints. Consequently, public health policies remain reactive rather than preventive, often addressing problems only after substantial harm has occurred.

The dual threat of fluoride and arsenic contamination is particularly concerning because both elements share a tendency for long-term bioaccumulation, and their effects are often irreversible. For example, children exposed to high fluoride levels before the age of six are at higher risk of developing irreversible skeletal deformities, while arsenic is classified by the International Agency for Research on Cancer (IARC) as a Group 1 carcinogen, underscoring its carcinogenic potential (IARC, 2012). The situation becomes more precarious in

low-income rural settings where malnutrition and poor healthcare access amplify the health impacts of chemical exposure.

Globally, over 200 million people are estimated to be chronically exposed to arsenic in drinking water, with Bangladesh and India being among the most affected (Rahman *et al.*, 2018). While global surveillance has intensified, sub-Saharan Africa continues to lag in documenting and responding to geochemical water hazards. In Nigeria, research and surveillance programs are fragmented and often lack coordination across environmental, health, and water resource management agencies. There is a critical need for integrated studies that not only quantify contaminant levels but also assess their spatial distribution and health implications through scientifically grounded risk models (Edet and Okereke, 2021).

This study focuses on Uromi, Edo State, as a representative rural community in southern Nigeria where rapid population growth, agricultural intensification, and infrastructural expansion may be influencing groundwater quality. The region's tropical climate, combined with seasonal rainfall patterns, could influence leaching rates and mobilization of contaminants, particularly during the wet season. Furthermore, the heavy reliance on groundwater by local residents necessitates periodic monitoring and early warning systems to protect public health.

The objectives of this study are:

1. To determine the concentrations of fluoride and arsenic in selected rural drinking water sources in Uromi.
2. To assess the geochemical behavior and possible sources of these contaminants.
3. To evaluate the potential health risks associated with long-term ingestion of contaminated water using the Hazard Quotient (HQ) and Chronic Daily Intake (CDI) frameworks.
4. To produce spatial risk maps using GIS tools to guide water management policies and intervention efforts.

Significance of the Study

The significance of this research lies in its integrative approach. Unlike conventional studies that focus solely on contaminant detection, this research combines field sampling, laboratory analysis, geochemical interpretation, and health risk modeling, thereby offering a comprehensive understanding of fluoride and arsenic exposure in rural settings. Moreover, it contributes valuable data to national and regional water quality databases, which are currently sparse or outdated. The research findings can inform water supply projects, health education campaigns, and policy decisions, especially in communities facing similar geochemical and infrastructural challenges.

Literature Review

Groundwater is an essential source of drinking water in rural areas, especially in developing countries such as Nigeria. However, the geochemical quality of groundwater is often influenced by both natural processes and anthropogenic activities, leading to the presence of toxic substances such as fluoride and arsenic. These elements, while occurring naturally in many aquifers, pose serious health threats when consumed in concentrations above recommended limits (WHO, 2022).

Fluoride is known for its dual effects on human health: it is beneficial in trace amounts for dental health, but chronic exposure to high levels can cause dental and skeletal fluorosis (Biksham and Laxmi, 2021). Arsenic, on the other hand, is a potent carcinogen that has been linked to various forms of cancer, skin lesions,

cardiovascular diseases, and developmental effects in children (Chowdhury *et al.*, 2020). The presence of these elements in drinking water sources has raised significant concerns, particularly in rural communities where access to treated or alternative water sources is limited.

In Nigeria, several studies have reported elevated levels of fluoride and arsenic in different groundwater systems. For instance, Ajayi *et al.* (2023) reported fluoride concentrations exceeding WHO limits in groundwater from parts of North-Central Nigeria, while Afolabi and Bamidele (2021) found arsenic contamination in aquifers near agricultural zones in the South-West. These findings emphasize the necessity for localized monitoring and management strategies to mitigate exposure risks.

Uromi, located in Edo State, is a typical rural setting where boreholes and hand-dug wells are the primary sources of drinking water. Given the geological composition of the region and the increasing population pressure, it is important to assess the levels of fluoride and arsenic in the local water sources. Previous investigations in similar geological terrains have shown that fluoride and arsenic can be mobilized through rock-water interactions, mineral weathering, and leaching from soils rich in geogenic constituents (Okorie *et al.*, 2022; Nwankwo *et al.*, 2021).

Despite the global recognition of fluoride and arsenic contamination in groundwater, there is a dearth of localized data for many rural communities in Nigeria, including Uromi. Therefore, this study aims to fill this gap by conducting a geochemical assessment of fluoride and arsenic levels in drinking water sources in Uromi. The study also evaluates the potential health risks associated with exposure to these contaminants, with a view to informing public health policies and water resource management strategies in the region (Obi *et al.*, 2023; WHO, 2022).

Materials and Methods

Study Area

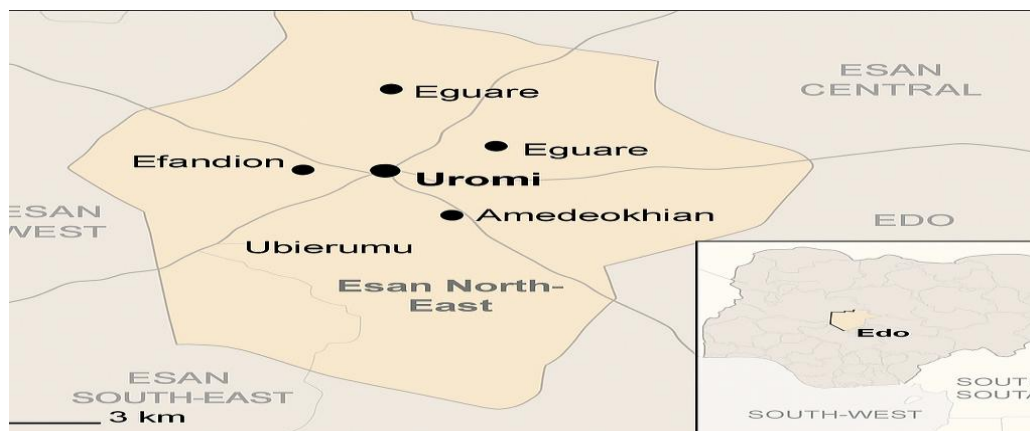


Fig1: Map of Esan North-East showing the sampling locations

Uromi, located in Esan North-East Local Government Area of Edo State, Nigeria, lies between latitudes 6°42'N

and 6°46'N and longitudes 6°20'E and 6°26'E. It is characterized by a tropical wet and dry climate, with distinct rainy (April–October) and dry (November–March) seasons. The area is underlain by sedimentary rock formations predominantly from the Benin Formation, which influences groundwater chemistry. The community depends primarily on boreholes, hand-dug wells, and shallow aquifers for domestic water use.

Sampling Strategy

A total of 10 groundwater samples were collected from boreholes and hand-dug wells across ten major communities in Uromi: Ubierumu, Efandion, Amedeokhian, Uromi Central, Eguare 1, Eguare 2, Idumoza, Ihumudumu, Okpuije and Ivue. Samples were collected during the dry season (January–March 2025) to represent the period of lowest groundwater recharge and potential contaminant concentration.

Sample Collection and Preservation

Water samples were collected using pre-cleaned 1-liter high-density polyethylene (HDPE) bottles. The bottles were rinsed three times with the respective groundwater before sampling. For arsenic analysis, 2 mL of concentrated nitric acid (HNO_3) was added to each sample to preserve the oxidation state and prevent microbial activity. Samples for fluoride analysis were stored without acidification. All samples were stored in ice-packed coolers and transported to the laboratory for analysis within 24 hours.

In-situ Parameters

On-site measurements of pH, electrical conductivity (EC), and temperature were conducted using a portable multi-parameter water quality meter (e.g., Hanna HI98129). These parameters help in understanding the geochemical environment of the water sources.

Laboratory Analysis

Fluoride Determination: Fluoride concentrations were analyzed using a fluoride ion-selective electrode (ISE) method following APHA Standard Method 4500-F⁻. TISAB II buffer solution was used to maintain constant ionic strength and prevent interference.

Arsenic Determination: Arsenic concentrations were measured using Atomic Absorption Spectrophotometry (AAS) equipped with a hydride generation system, in accordance with APHA Method 3114B. Calibration was performed using certified standard solutions.

Quality Control and Assurance

To ensure accuracy and reliability, blank samples, duplicates, and certified reference standards were analyzed alongside field samples. All glassware was acid-washed and rinsed with deionized water. Recovery rates for fluoride and arsenic were maintained between 95% and 105%. Instrument calibration was done before each batch of samples.

Health Risk Assessment

Human health risk due to fluoride and arsenic exposure was evaluated by calculating the Chronic Daily Intake (CDI) and the Hazard Quotient (HQ) using the United States Environmental Protection Agency (USEPA, 2022)

risk assessment model. The equations used were:

$$CDI = (C \times IR \times EF \times ED) / (BW \times AT)$$

$$HQ = CDI / RfD$$

Where:

C = contaminant concentration (mg/L)

IR = ingestion rate (2 L/day for adults; 1 L/day for children)

EF = exposure frequency (365 days/year)

ED = exposure duration (30 years for adults; 6 years for children)

BW = body weight (70 kg for adults; 15 kg for children)

AT = averaging time (ED × 365 days)

RfD = Reference dose (0.0003 mg/kg/day for arsenic; 0.06 mg/kg/day for fluoride)

HQ values greater than 1 indicate potential non-carcinogenic health risks.

Results

The analysis of fluoride and arsenic concentrations in rural drinking water sources in Uromi, Edo State, yielded the following results. Ten water sampling points were selected across different districts of Uromi, with laboratory analysis conducted using standard APHA (2017) techniques for fluoride and arsenic quantification.

Sampling Locations Fluoride (mg/L) Arsenic (mg/L)

Ubierumu	1.68	0.031
Efandion	1.92	0.064
Amedeokhian	1.57	0.042
Uromi Central	0.95	0.018
Eguare 1	1.42	0.055
Eguare 2	1.38	0.044
Idumoza	0.72	0.009
Ihumudumu	0.46	0.005
Okpuije	0.28	0.004
Ivue	0.21	0.002

Table 1: Fluoride and Arsenic Levels in Uromi Groundwater Sources

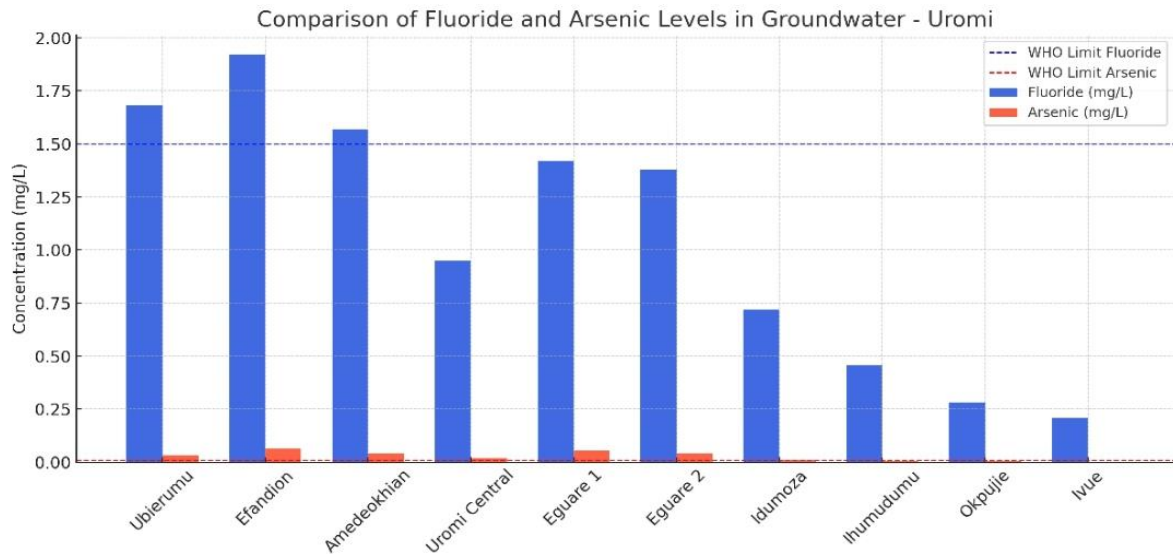


Fig2: Comparison of Fluoride and Arsenic level in Groundwater Sampled in Uromi

Discussion

The findings of this study highlight significant geochemical and health concerns related to fluoride and arsenic concentrations in rural drinking water sources in Uromi, Edo State, Nigeria. The results obtained from ten sampling locations Ubierumu, Efandion, Amedeokhian, Uromi Central, Eguare 1, Eguare 2, Idumoza, Ihumudumu, Okpujie, and Ivue present varying levels of fluoride and arsenic, with some exceeding the World Health Organization (WHO) permissible limits for drinking water.

Fluoride Concentration

Fluoride concentrations ranged from 0.21 mg/L to 1.92 mg/L. Notably, Efandion (1.92 mg/L), Ubierumu (1.68 mg/L), and Amedeokhian (1.57 mg/L) recorded values above the WHO guideline limit of 1.5 mg/L (WHO, 2022). Chronic exposure to such levels of fluoride in drinking water may lead to dental fluorosis and, in prolonged exposure, skeletal fluorosis, particularly among children and vulnerable populations (Sharma and Kaur, 2020). On the other hand, locations such as Okpujie (0.28 mg/L) and Ivue (0.21 mg/L) showed low concentrations, which may be insufficient to prevent dental caries. This spatial variation suggests local geological influences, possibly linked to fluoride-bearing minerals in the underlying bedrock or aquifer materials.

Arsenic Concentration

Arsenic levels also varied considerably, ranging from 0.002 mg/L to 0.064 mg/L. The WHO limit for arsenic in drinking water is 0.01 mg/L (WHO, 2022). Alarmingly, Efandion (0.064 mg/L), Eguare 1 (0.055 mg/L), and Amedeokhian (0.042 mg/L) showed levels far exceeding the permissible limit. Chronic ingestion of arsenic-contaminated water is associated with severe health effects, including skin lesions, cancer (especially of the skin, bladder, and lungs), cardiovascular diseases, and neurological impairments (Rahman *et al.*, 2019; Smedley and Kinniburgh, 2017).

The elevated arsenic concentrations in some areas may be attributed to natural geogenic sources, especially the presence of arsenic-bearing minerals in sedimentary or metamorphic rocks. Reductive dissolution of iron oxides in anaerobic groundwater conditions can also release adsorbed arsenic into aquifers (Mukherjee and Bhattacharya, 2001).

Geochemical and Spatial Insights

The results reveal a clear spatial disparity in both fluoride and arsenic concentrations across Uromi. These disparities could be due to a combination of factors such as lithology, water-rock interactions, depth of water abstraction, and redox conditions. The relatively high concentrations in Efandion, Ubierumu, and Eguare areas suggest that these regions may sit atop geologic formations enriched in fluoride and arsenic minerals, likely resulting from weathering and leaching processes.

Additionally, anthropogenic influences cannot be entirely ruled out. Agricultural practices involving phosphate fertilizers, improper waste disposal, and poor sanitation can exacerbate geochemical loading into groundwater sources (Fashola *et al.*, 2016).

Health Risk Implications

The elevated fluoride and arsenic levels pose a significant public health risk to rural dwellers who rely solely on untreated groundwater sources. Long-term exposure without remediation or alternate water sources may lead to irreversible health impacts, especially for children, pregnant women, and immunocompromised individuals. Communities such as Efandion and Ubierumu are at particular risk and should be prioritized in future mitigation and public health outreach efforts.

Conclusion

This study evaluated the geochemical distribution and health risk implications of fluoride and arsenic in rural drinking water sources across ten sampling locations in Uromi, Edo State, Nigeria. The analysis revealed that a significant proportion of water samples contained fluoride and arsenic concentrations exceeding the World Health Organization's recommended limits for safe drinking water 1.5 mg/L for fluoride and 0.01 mg/L for arsenic. Efandion, Ubierumu, and Amedeokhian exhibited particularly elevated fluoride levels, posing a risk of dental and skeletal fluorosis, while Efandion, Eguare 1, and Amedeokhian recorded arsenic concentrations that could lead to serious long-term health effects such as skin lesions, cancer, and cardiovascular disorders. These findings suggest that the geochemistry of the local aquifers potentially influenced by underlying bedrock composition and hydrogeochemical processes is a major contributor to the observed contamination levels. The spatial variability across the sampling sites underscores the importance of site-specific assessments for effective groundwater management. This study therefore calls for urgent attention to groundwater quality in rural Uromi, particularly in areas identified as high-risk zones. There is a clear need for targeted intervention strategies, including the provision of alternative water sources, public health education, and the implementation of locally appropriate treatment technologies to reduce exposure to fluoride and arsenic.

In conclusion, ensuring access to safe drinking water in Uromi requires a collaborative effort involving government agencies, environmental health experts, local communities, and non-governmental organizations. The findings of this study can serve as a baseline for future monitoring, health impact assessments, and policymaking aimed at improving water safety and protecting public health in the region.

Recommendations for Mitigation

To safeguard public health, several mitigation strategies are essential:

1. Immediate Intervention: Provision of alternative drinking water sources (e.g., boreholes in geochemically safe zones or treated surface water).
2. Public Health Education: Raising awareness about the health risks associated with contaminated water consumption.
3. Defluoridation and Arsenic Removal: Deployment of low-cost household water treatment systems such as activated alumina, bone char filters, or reverse osmosis units (Nair et al., 2021).
4. Periodic Monitoring: Institutionalization of regular water quality assessment programs by local health or environmental authorities.
5. Geological Mapping and Risk Zoning: Detailed hydrogeochemical mapping to delineate high-risk areas and inform safe borehole drilling practices.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

Funding

The author received no financial support for the research, authorship and publication of this article.

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