FUDMA Journal of Engineering and Technology

ISSN: 3092-9385

https://fjet.fudutsinma.edu.ng/index.php/fjet/

Volume 2, Issue 2, 2026, 571-580

Ecological and Public Health Implications of Dumpsite Leachate: Bio-Monitoring of Aquatic Organisms and Community Perceptions in Offa Garage Axis, Ilorin, Nigeria

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Abstract

Dumpsite leachate poses significant ecological and public health concerns in many developing urban centers due to its potential to contaminate groundwater and surrounding aquatic ecosystems. This study assessed the ecological and public health implications of dumpsite leachate in the Offa Garage axis, Ilorin, Nigeria, using biomonitoring of aquatic organisms and community perception assessment. Groundwater samples were collected from locations situated at distances of <100 m, 100–200 m, and >200 m (control) from the dumpsite. Ecological impacts were evaluated using macroinvertebrate assemblages and algal toxicity bioassays involving Pseudokirchneriella subcapitata and Chlamydomonas reinhardtii, while residents' exposure pathways, environmental perceptions, and health concerns were assessed through structured interviews. Macroinvertebrate diversity increased with distance from the dumpsite, with Simpson's Diversity Index rising from 0.188 at <100 m to 0.7015 at >200 m, while the Hilsenhoff Biotic Index decreased from 8.50 to 4.89, indicating improved ecological condition away from the contamination source. Algal toxicity bioassays showed reduced chlorophyll A, chlorophyll B, and carotenoid concentrations under acute exposure conditions, particularly in samples collected closest to the dumpsite, suggesting contaminant-induced physiological stress and reduced primary productivity. Survey findings revealed that 86.7% of respondents used well water for domestic activities, whereas 73.3% did not believe that the dumpsite affected groundwater quality despite observable changes in water characteristics and environmental conditions. The study demonstrated that dumpsite proximity adversely affected ecological integrity and may increase public health vulnerability through continued groundwater exposure and limited risk awareness. It was concluded that biomonitoring provided valuable evidence of ecological stress associated with leachate contamination and complemented conventional environmental assessment approaches. Continuous groundwater monitoring, improved waste management practices, and enhanced community environmental awareness programme were recommended to mitigate potential ecological and public health risks.

Keywords: *Groundwater contamination, Dumpsite leachate, Biomonitoring, Macroinvertebrates, Algal toxicity.*

1.0 Introduction

Rapid urbanization, population growth, and increasing rates of solid waste generation have become major environmental challenges in many developing countries. In Nigeria, inadequate waste management practices and the widespread use of open dumpsites have contributed significantly to environmental degradation and groundwater contamination. Open dumpsites generate leachate through the decomposition of waste materials and the percolation of rainwater through refuse deposits. These leachates often contain dissolved organic matter, nutrients, heavy metals, pathogenic microorganisms, and other toxic substances capable of migrating through soil layers into groundwater systems. Since groundwater serves as a major source of potable water for many Nigerian communities, its contamination presents significant environmental and public health concerns [1].

Similar concerns have been reported in several Nigerian cities where uncontrolled waste disposal practices have resulted in the migration of leachate into surrounding groundwater systems, leading to deterioration of water quality and increased risks to human health. Studies conducted around dumpsites in southwestern Nigeria have documented elevated concentrations of physicochemical pollutants, heavy metals, and microbial contaminants in groundwater sources located close to waste disposal facilities [2], [3]. The environmental impacts of open dumpsites are often exacerbated by inadequate engineering controls, poor leachate collection systems, and increasing urban population pressures.

Groundwater contamination resulting from dumpsite leachate has been reported in several parts of Nigeria and other developing countries. Previous studies have shown that leachate migration can increase the concentrations of physicochemical pollutants, heavy metals, and microbial contaminants in nearby wells and boreholes, thereby reducing water quality and posing risks to human health [1]. The extent of contamination is influenced by factors such as waste composition, rainfall characteristics, hydrogeological conditions, soil permeability, groundwater flow direction, and the proximity of water sources to disposal sites. Consequently, communities that depend on untreated groundwater sources located near dumpsites may be vulnerable to long-term exposure to hazardous contaminants.

Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026

The public health implications of contaminated groundwater are substantial. Exposure to water containing elevated concentrations of heavy metals and pathogenic microorganisms has been associated with gastrointestinal diseases, kidney dysfunction, neurological disorders, developmental abnormalities, and other chronic health effects [4]. Recent investigations have further demonstrated that groundwater contaminated by dumpsite leachates may contain heavy metals and pathogenic microorganisms at concentrations capable of posing both non-carcinogenic and carcinogenic health risks to exposed populations. Elevated levels of lead, chromium, cadmium, and microbial contaminants have been reported in groundwater sources located near dumpsites in Nigeria, emphasizing the need for proper continuous monitoring and risk assessment [4], [5]. In many developing countries, inadequate water treatment practices and limited public awareness further increase the vulnerability of populations residing near waste disposal facilities. Therefore, continuous assessment of groundwater quality around dumpsites is essential for protecting public health and ensuring sustainable water resource management.

Conventional groundwater quality assessment typically relies on physicochemical and microbiological analyses. Parameters such as pH, electrical conductivity, total dissolved solids, dissolved oxygen, nutrients, heavy metals, and microbial counts are commonly employed to determine the extent of contamination. Although these approaches provide valuable information regarding water quality status, they may not adequately capture the cumulative ecological impacts of pollutants on biological communities. Chemical measurements often provide only a snapshot of environmental conditions and may not fully reflect the long-term effects of contamination on ecosystem integrity.

To address this limitation, biological monitoring has gained increasing attention as a complementary tool for environmental assessment. Biomonitoring involves the use of living organisms to evaluate environmental quality and detect ecological changes resulting from pollution. Biological communities integrate the effects of multiple stressors over time and therefore provide a more comprehensive indication of ecosystem health than physicochemical measurements alone [6]. Biological monitoring has become an important component of environmental assessment because organisms integrate the effects of multiple pollutants over time and respond to changes that may not be immediately detected through chemical analyses. As a result, biomonitoring has become an increasingly recommended method for evaluating ecological health in freshwater ecosystems exposed to human-induced disturbances [7]. Bioindicator organisms such as algae, aquatic insects, macroinvertebrates, molluscs, and fish have been widely used to assess pollution levels in aquatic environments [6].

Among biological indicators, aquatic macroinvertebrates are particularly valuable because of their relatively long-life cycles, limited mobility, and varying tolerance to environmental stressors. Changes in their abundance, diversity, and community composition often reflect alterations in water quality and habitat conditions. Pollution-sensitive organisms generally decline in contaminated environments, while pollution-tolerant taxa become dominant. Consequently, macroinvertebrate-based biomonitoring has become an important tool for assessing ecological health and identifying pollution impacts in aquatic ecosystems [8], [9]. Furthermore, the relationship between physicochemical variables and macroinvertebrate assemblages has been widely recognized, making these macroinvertebrates reliable indicators of environmental disturbance [10]. Several studies in Nigerian freshwater systems have demonstrated that organic pollution and habitat degradation are associated with reductions in macroinvertebrate diversity and increased dominance of pollution-tolerant taxa, whereas less disturbed environments support greater abundance of sensitive groups such as Ephemeroptera and Odonata [11], [12].

In addition to ecological assessment, understanding community perceptions is important for evaluating the broader implications of environmental pollution. Residents living near dumpsites often experience environmental nuisances such as offensive odors, insect infestations, poor aesthetic conditions, and concerns regarding water quality. Community awareness and perception of these risks can influence water-use behavior, public health practices, and support for environmental management initiatives. Integrating community perception studies with scientific assessments provides a more holistic understanding of the impacts of dumpsite leachate contamination and facilitates the development of effective intervention strategies. Community perception studies have shown that residents living near dumpsites frequently recognize visible environmental nuisances such as odors, smoke, insects, and aesthetic degradation, while awareness of groundwater contamination pathways and associated health risks often remains limited. This mismatch between measured environmental conditions and public perception can hinder or limit the adoption of appropriate environmental and health-protective practices [13], [14].

Despite increasing concern regarding groundwater contamination from dumpsites, relatively few studies in Nigeria have integrated physicochemical assessment, ecological biomonitoring, and community perception analysis within a single framework. Furthermore, limited information exists regarding the ecological and public health implications of dumpsite leachate contamination in the Offa Garage axis of Ilorin, Kwara State, Nigeria. This knowledge gap restricts the availability of scientific evidence needed to support effective groundwater protection and waste management policies.

Therefore, this study investigates the ecological and public health implications of dumpsite leachate contamination in the Offa Garage axis of Ilorin, Nigeria, through the assessment of groundwater quality, biomonitoring of aquatic organisms, and evaluation of community perceptions regarding environmental and health risks. The findings are expected to provide useful information for environmental management, groundwater resource protection, and sustainable waste management planning.

2.0 Materials and Methods

2.1 The Study Area

The spatial distribution of the river sampling points around the dumpsite is shown in Figure 1. The sampling locations were classified into three distance-based proximity zones: less than 100 m, 100–200 m, and greater than 200 m. The location situated at a distance greater than 200 m from the dumpsite was designated as the control site for comparison. Sampling points located within 100 m of the dumpsite represented the high-exposure zone, while those located beyond 200 m were considered to have relatively lower anthropogenic influence and were used as the control.

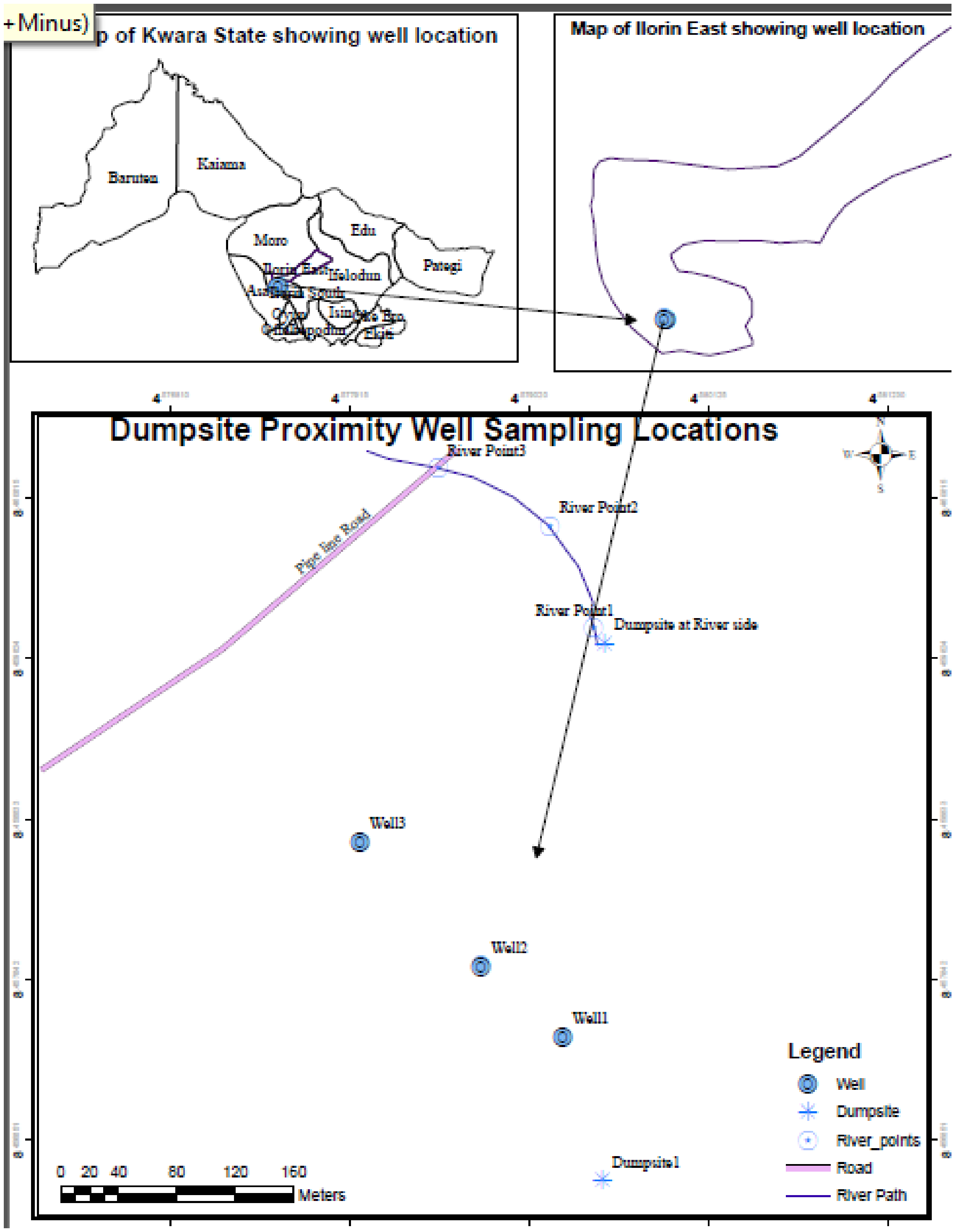

Figure 1: Spatial distribution of river sampling locations and distance-based sampling zones around the Offa Garage dumpsite, Ilorin, Nigeria (adapted from [15]).

Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026

2.2 Bio-monitoring and Ecological Assessment

Bio-monitoring was carried out to evaluate the ecological stress associated with dumpsite leachate contamination using macroinvertebrate assemblages and algal toxicity bioassays. Macroinvertebrate samples were collected using a 500-μm mesh kick-net in accordance with the United States Environmental Protection Agency (USEPA) Rapid Bioassessment Protocols for streams and wedeable rivers [16]. Sampling was conducted in riffle and slow-flowing sections of rivers located at distances of less than 100 m, 100–200 m, and greater than 200 m (control) from the dumpsite.

After collection, the specimens were preserved in 70% ethanol and identified to the family level with the aid of standard taxonomic identification guides [17], [18]. Community structure, species diversity, and pollution tolerance were evaluated using Simpson's Diversity Index (SDI) [19] and the Hilsenhoff Biotic Index (HBI) [20].

Algal toxicity bioassays were conducted using freshwater green algae, namely *Pseudokirchneriella subcapitata* and *Chlamydomonas reinhardtii*, which were cultured under controlled laboratory conditions. Acute and chronic toxicity tests were performed following the Organisation for Economic Co-operation and Development (OECD) Test Guideline 201 for freshwater algal and cyanobacterial growth inhibition tests [21]. For the acute toxicity test, algal cultures were exposed to serially diluted groundwater samples for 96 h, whereas chronic exposure was maintained for a period of 7–14 days. Growth inhibition, biomass production, chlorophyll content, and cell density were monitored spectrophotometrically. Toxicity endpoints, including the median effective concentration (EC_{50}) and the No Observed Effect Concentration (NOEC), were determined and used to assess the ecological risks associated with dumpsite leachate contamination [21], [22].

2.3 Survey Design and Data Collection

A field-based observational study design integrating environmental biomonitoring and community assessment was adopted. Semi-structured face-to-face interviews were conducted with twelve adult residents residing within the vicinity of the dumpsite to obtain information on groundwater usage, perceived water quality, exposure pathways, and health-related concerns.

Respondents were selected using a distance-based stratified purposive sampling technique across three proximity zones: less than 100 m, 100–200 m, and greater than 200 m from the dumpsite. Only residents who had lived within the study area for a minimum period of one year were included in the survey. Interviews were conducted in either English or Yoruba language, and responses were documented through note-taking. Ethical considerations were observed throughout the study. Verbal informed consent was obtained from all participants prior to the interviews. Participation was voluntary, and the anonymity and confidentiality of respondents were maintained throughout the study.

2.4 Statistical Analysis

The ecological, toxicity, and survey data generated during the study were analyzed using descriptive and inferential statistical techniques. Physicochemical and toxicity parameters were expressed as mean ± standard deviation, while interview responses were summarized using frequencies and percentages.

Differences among sampling zones were evaluated using one-way Analysis of Variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$. Biodiversity indices, including Simpson's Diversity Index and the Hilsenhoff Biotic Index, were calculated and interpreted to assess ecological stress and pollution tolerance. Comparative analyses across the distance-based sampling zones were performed to establish relationships between dumpsite proximity, groundwater contamination, ecological responses, and community perceptions.

3.0 Results and Discussion

3.1 Macroinvertebrate Diversity and Biotic Indices

Macroinvertebrate assemblages exhibited clear spatial variations across the sampling distances, indicating ecological responses to the influence of dumpsite leachate. Simpson's Diversity Index increased progressively from 0.188 at locations situated less than 100 m from the dumpsite to 0.7015 at locations situated beyond 200 m (Table 1). The lowest diversity value was recorded at the site closest to the dumpsite, whereas the highest value was observed at the control site. This trend indicated reduced biodiversity in areas exposed to greater contamination and progressive ecological improvement with increasing distance from the dumpsite.

The taxonomic composition of macroinvertebrates also varied across the sampling zones. The assemblage at the site located within 100 m of the dumpsite was dominated by pollution-tolerant taxa, particularly Annelida, while the control site supported a more diverse community comprising Ephemeroptera, Odonata, Bivalvia, Coleoptera, and Annelida. The occurrence of Ephemeroptera and Odonata at greater distances from the dumpsite suggested improved environmental conditions because these taxa are generally more sensitive to pollution than annelid species. The observed pattern indicated that ecological stress was greatest near the dumpsite and decreased with increasing distance from the contamination source.

Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026

Table 1: Simpson's Index of Macroinvertebrates Across Sampling Distances

Distance	Dominant Taxa	Simpson's Index
<100 m	Annelida, Coleoptera	0.188
100–200 m	Ephemeroptera, Coleoptera, Annelida	0.550
>200 m	Ephemeroptera, Coleoptera, Annelida, Bivalvia, Odonata	0.7015

A similar trend was observed for the Hilsenhoff Biotic Index (HBI). The HBI value decreased from 8.50 at the site located within 100 m of the dumpsite to 4.89 at the control site (Table 2). The highest HBI value was recorded in the zone closest to the dumpsite, indicating severe organic pollution and poor ecological condition, while the lowest value recorded at the control site suggested relatively better water quality and habitat condition. The progressive decline in HBI values along the distance gradient indicated a reduction in pollution pressure and a corresponding improvement in ecological integrity.

The observed decline in biodiversity and increase in pollution-tolerant taxa near the dumpsite may be attributed to the discharge and migration of leachate containing organic matter, nutrients, microorganisms, and other contaminants into the aquatic environment. Such contamination can alter habitat quality, reduce dissolved oxygen availability, and create environmental conditions that favor tolerant organisms while excluding sensitive species. Consequently, macroinvertebrate community composition appeared to respond directly to the contamination gradient associated with dumpsite proximity.

Table 2: Hilsenhoff Biotic Index (HBI) of Macroinvertebrates Across Sampling Distances

Distance from Dumpsite	Dominant Taxa Observed	Mean HBI
<100 m	Annelida, Coleoptera	8.50
100–200 m	Ephemeroptera, Coleoptera, Annelida	6.95
>200 m (Control)	Ephemeroptera, Coleoptera, Annelida, Bivalvia, Odonata	4.89

The findings of this study were consistent with the observations of [9], who reported that macroinvertebrate assemblages respond sensitively to environmental disturbances and can serve as reliable indicators of ecological condition in African aquatic ecosystems. Similar patterns of reduced biodiversity and increased dominance of pollution-tolerant taxa in contaminated environments have also been reported by [23], who identified and reported observed organic pollution caused significant changes in the structure of macroinvertebrate communities in Nigerian freshwater systems. The progressive increase in diversity with increasing distance from the dumpsite further supports the use of macroinvertebrate-based indices as effective tools for assessing ecological impacts of anthropogenic pollution.

The biological evidence obtained from the macroinvertebrate assemblages was further supported by the microbiological results. Groundwater samples collected within 100 m of the dumpsite recorded higher microbial counts than samples obtained from more distant locations. In addition, *Escherichia coli* was detected only in wells located within 200 m of the dumpsite and was absent at the control site. This pattern suggested faecal contamination associated with leachate infiltration and indicated a greater public health risk for residents relying on groundwater sources located near the dumpsite. The absence of *E. coli* at the control site further suggested that contamination decreased with increasing distance from the waste disposal area.

Overall, the combined macroinvertebrate and microbiological evidence indicated that dumpsite leachate exerted measurable ecological and public health impacts on the surrounding environment. The reduction in biodiversity, elevated HBI values, increased dominance of pollution-tolerant taxa, and occurrence of faecal indicator organisms near the dumpsite collectively suggested environmental degradation associated with waste disposal activities.

3.2 Algal Toxicity Bioassay

The algal toxicity bioassay revealed distinct differences between acute and chronic exposure responses across the sampling locations. Chlorophyll A, chlorophyll B, and carotenoid concentrations were generally lower under acute exposure conditions than under chronic exposure conditions (Figures 2–4). The lowest pigment concentrations were observed in samples collected closest to the dumpsite, while progressively higher concentrations were recorded with increasing distance from the contamination source. The highest pigment concentrations were recorded at the control site located beyond 200 m from the dumpsite.

The reduction in chlorophyll A, chlorophyll B, and carotenoid concentrations during acute exposure suggested that contaminants present in the groundwater exerted immediate physiological stress on the algal cells. Exposure to leachate-associated pollutants may have disrupted photosynthetic processes, impaired pigment synthesis, and reduced cellular metabolic activity. Since chlorophyll pigments play a critical role in light absorption and energy transfer during photosynthesis, their reduction may indicate adverse effects on primary productivity and ecosystem functioning. Similar reductions in chlorophyll synthesis and algal growth under contaminant exposure have been reported by [24], who observed that toxic substances can interfere with photosynthetic activity and pigment production in freshwater algae.

In contrast, pigment concentrations were generally higher during chronic exposure than during acute exposure. This trend suggested that the algal species exhibited a degree of physiological adaptation or tolerance under prolonged exposure to lower contaminant concentrations. The increase in pigment levels observed under chronic exposure may have resulted from cellular acclimation mechanisms that enabled the algae to partially compensate for environmental stress. Nevertheless, pigment concentrations remained comparatively lower in samples obtained closer to the dumpsite, indicating that the effects of contamination persisted despite prolonged exposure.

The progressive increase in chlorophyll and carotenoid concentrations with increasing distance from the dumpsite further indicated a reduction in ecological stress along the contamination gradient. This pattern was consistent with the physicochemical, microbiological, and macroinvertebrate findings, which collectively demonstrated improved environmental quality at locations farther from the dumpsite. The higher pigment concentrations observed at the control site suggested more favourable conditions for algal growth and photosynthetic activity, whereas reduced pigment synthesis near the dumpsite reflected the adverse influence of leachate-derived contaminants.

The observed responses were consistent with previous studies that reported reductions in algal growth and photosynthetic pigment production following exposure to contaminated water containing elevated concentrations of nutrients, heavy metals, and organic pollutants. [21]-based algal toxicity assessments have similarly demonstrated that pollutants can inhibit chlorophyll synthesis and reduce algal productivity through oxidative stress and disruption of cellular metabolic processes. The increased pigment concentrations observed at greater distances from the dumpsite therefore suggested reduced contaminant pressure and improved ecological conditions.

Overall, the algal toxicity bioassay provided additional biological evidence of the ecological effects of dumpsite leachate contamination. The suppression of photosynthetic pigments under acute exposure and the gradual recovery of pigment concentrations with increasing distance from the dumpsite indicated that leachate contamination influenced primary producers within the aquatic ecosystem. These findings corroborated the macroinvertebrate and groundwater quality results and demonstrated that dumpsite leachate affected ecological stability and biological productivity within the study area.

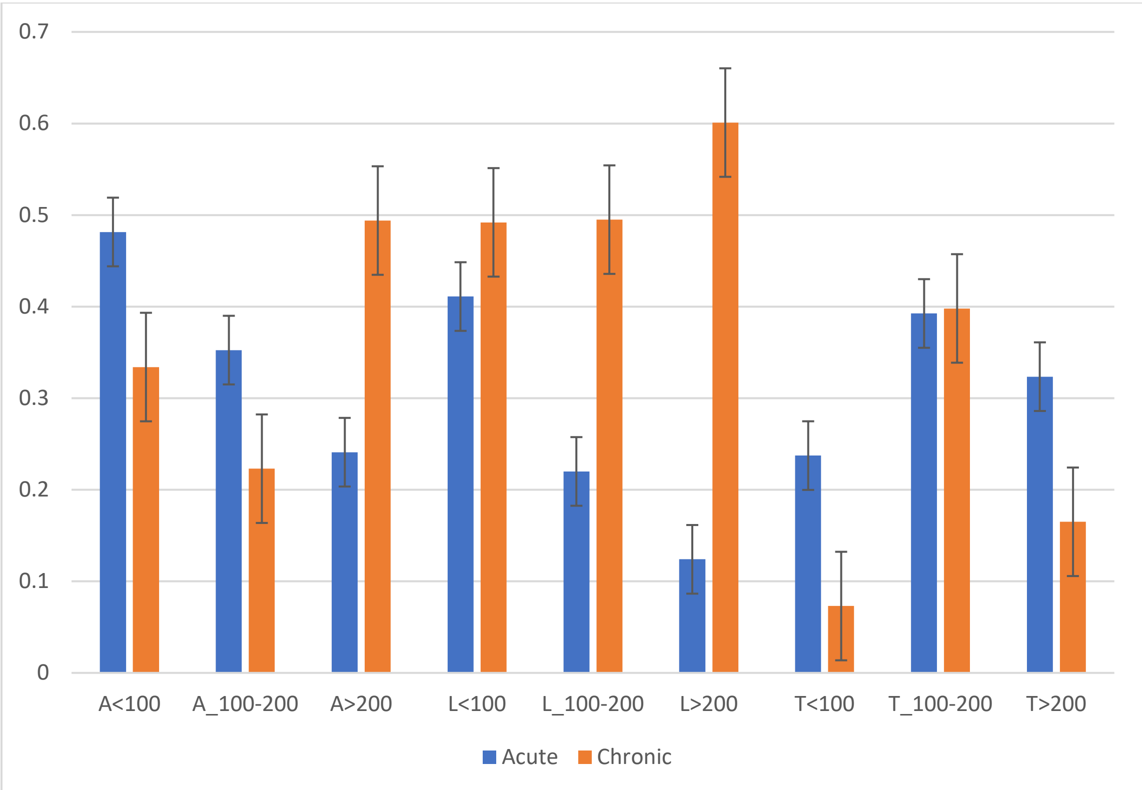

Figure 2: Chlorophyll A concentrations measured under both acute and chronic exposure conditions

Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026

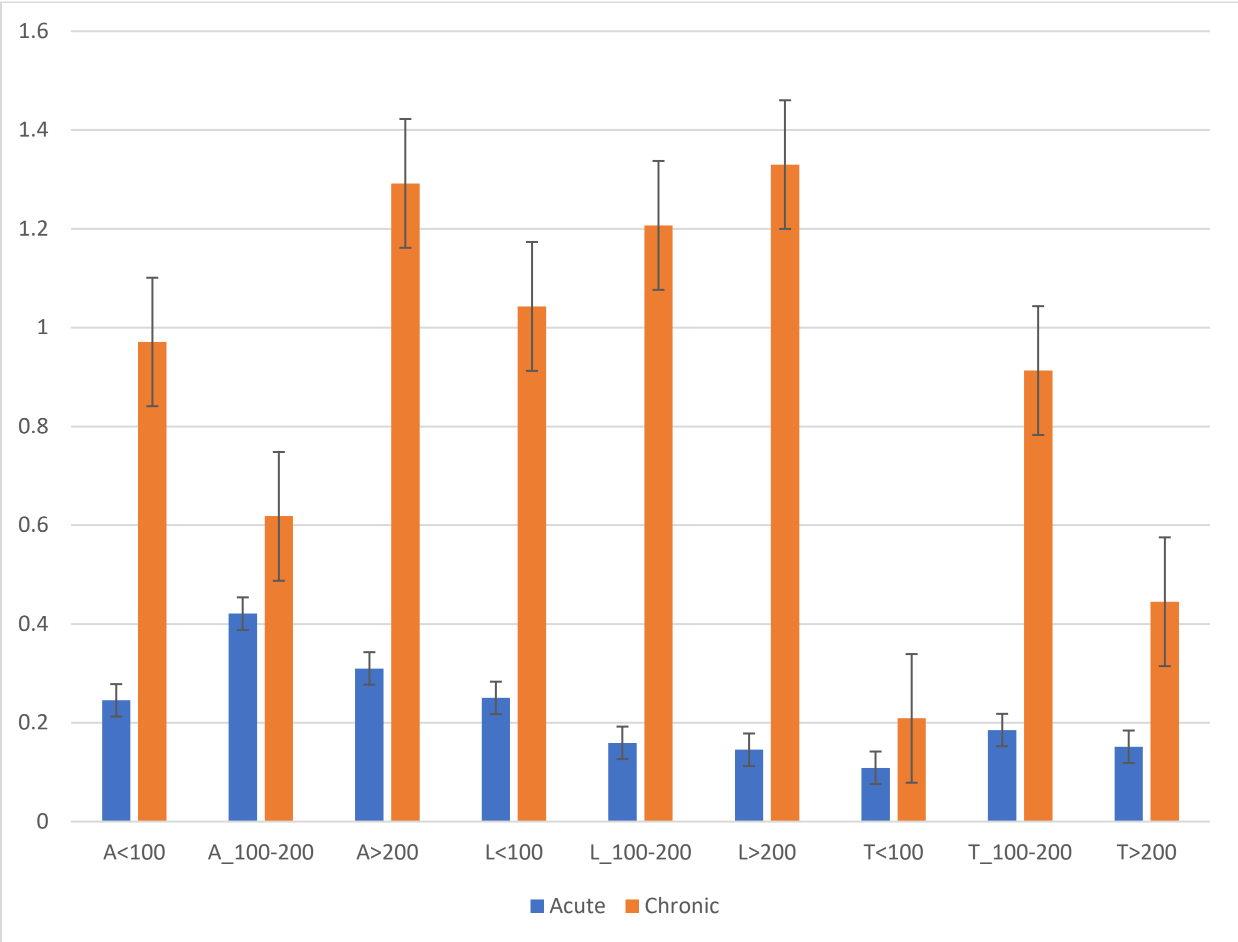

Figure 3: Chlorophyll B concentrations measured under both acute and chronic exposure conditions

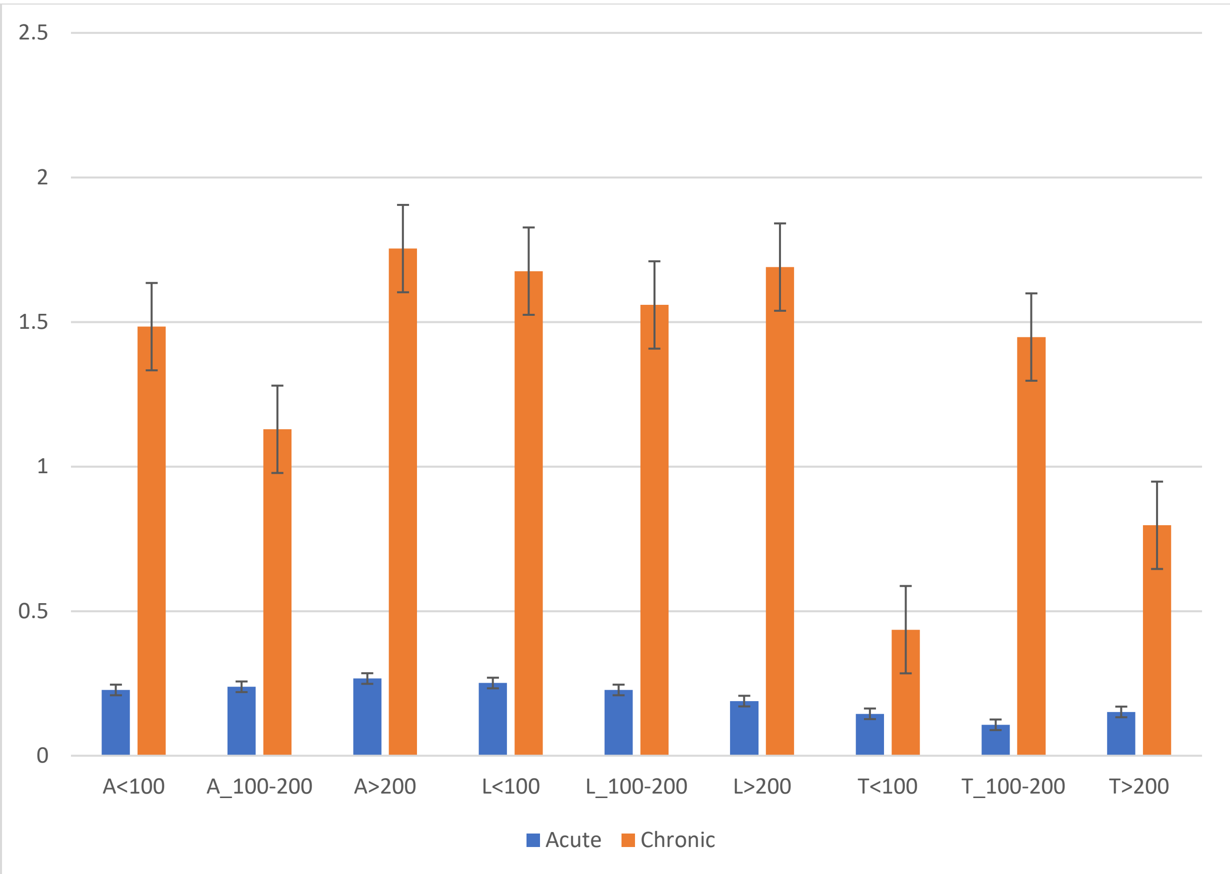

Figure 4: Carotenoid concentrations measured under both acute and chronic exposure conditions

Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026

3.3 Residents' Exposure, Perception and Health Concerns

The survey results revealed important relationships among groundwater use, environmental perception, and proximity to the dumpsite (Table 3). Most respondents had resided within the study area for more than six years, indicating prolonged potential exposure to environmental contaminants. Although sachet and bottled water constituted the primary source of drinking water for most residents, well water continued to be widely used for cooking, bathing, and washing. This finding suggested that indirect exposure pathways remained significant despite reduced reliance on groundwater for direct consumption.

A notable observation was the disparity between measured groundwater contamination and community awareness. While 40% of respondents reported observable changes in well water quality, including color changes, sediment accumulation, unpleasant odors, and reduced quality during the rainy season, approximately 73% did not believe that the dumpsite affected groundwater quality. This finding suggested limited awareness of groundwater contamination pathways and indicated that environmental risks associated with dumpsite activities may be underestimated within the community. Similar observations were reported by [13], who noted that residents living around waste disposal sites were often exposed to contaminated groundwater despite having limited awareness of the associated environmental and health risks.

The survey further indicated that reported health complaints, including eye irritation, skin irritation, gastrointestinal discomfort, and respiratory symptoms, were more common among residents living closer to the dumpsite. Although only a minority of respondents reported frequent illness, healthcare-seeking behavior was generally low, with most respondents indicating that medical attention was sought only occasionally. This pattern suggested that environmental health risks may have become normalized within the community or that awareness of potential exposure-related health effects remained limited. The findings corroborate previous studies which reported that contaminants originating from dumpsite leachates can pose significant public health risks through prolonged exposure to contaminated groundwater sources [25], [26].

The findings were consistent with previous studies that reported low public awareness of groundwater contamination despite evidence of environmental pollution around waste disposal sites. Similar observations have been reported in Nigerian communities where residents recognized visible environmental nuisances such as odor and air pollution but demonstrated limited understanding of the potential effects of leachate migration on groundwater quality and human health. The continued dependence and use of untreated groundwater for domestic activities has also been identified as an important exposure pathway in communities located near unmanaged dumpsites [26].

The perception data complemented the physicochemical, microbiological, macroinvertebrate, and algal toxicity findings obtained in this study. While scientific analyses indicated evidence of groundwater contamination and ecological stress associated with dumpsite leachate, community awareness of groundwater-related health risks remained comparatively low. This disconnect between measured environmental conditions and public perception highlights the need for improved environmental education, groundwater quality monitoring, and public health awareness programmes within communities located near waste disposal facilities.

Overall, the results demonstrated that residents within the Offa Garage axis experienced varying degrees of environmental exposure associated with dumpsite activities. The widespread domestic use of well water, limited water treatment practices, low awareness of groundwater contamination, and occurrence of self-reported health complaints collectively suggested potential public health concerns requiring further investigation and targeted intervention.

Table 3: Summary of residents' exposure pathways, environmental perceptions and self-reported health concerns associated with dumpsite proximity.

Variable	Category	Frequency (n=15)	Percentage (%)
Length of residence	≥ 6 years	10	66.7
Primary drinking water source	Sachet/Bottled water	9	60.0
Use of well water for cooking	Yes	13	86.7
Use of well water for bathing	Yes	13	86.7
Use of well water for washing	Yes	13	86.7
Water treatment before drinking	No	13	86.7
Observed changes in well water	Yes	6	40.0
Belief that dumpsite affects groundwater	Disagree	11	73.3
Perceived environmental risk	Yes	8	53.3
Air pollution reported	Yes	12	80.0
Bad odour reported	Yes	8	53.3
Insect infestation reported	Yes	7	46.7

Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026

Variable	Category	Frequency (n=15)	Percentage (%)
Frequent illness reported	Yes	3	20.0
Rare healthcare seeking	Yes	10	66.7
Willingness to relocate	Yes	6	40.0

Note: Detailed responses are available in supplementary records.

4.0 Conclusion

This study evaluated the ecological and public health implications of dumpsite leachate contamination in the Offa Garage axis, Ilorin, Nigeria, using biomonitoring techniques and community perception assessment. The findings revealed that proximity to the dumpsite adversely affected ecological condition, as indicated by reduced macroinvertebrate diversity, elevated Hilsenhoff Biotic Index values, increased dominance of pollution-tolerant taxa, and reduced algal pigment concentrations under acute exposure conditions, suggesting ecological stress and impaired aquatic ecosystem functioning. The survey further showed that residents remained regularly exposed to groundwater through domestic activities despite limited awareness of contamination risks, highlighting a disconnect between environmental conditions and community perception. The integration of biological indicators with community-based assessment provided a comprehensive evaluation of dumpsite impacts and demonstrated the effectiveness of biomonitoring in detecting ecological disturbances associated with leachate contamination. Overall, the study provides evidence that dumpsite leachate poses ecological and potential public health risks within the study area, underscoring the need for continuous groundwater monitoring, improved waste management practices, and enhanced environmental awareness programmes to protect ecosystem and human health.

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Received: 18/08/2026; Revised: 30/08/2026; Accepted: 31/08/2026; Published: 11/09/2026