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An Investigation of Nwangene River Pollution in Onitsha, Anambra State, Southeastern Nigeria: Causes, Effects, and Preventive and Remedial Approaches

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***Abstract* - This study investigated the pollution of the Nwangene River, Onitsha, Southeastern Nigeria, through detailed fieldwork, literature review, and interactions with nearby residents. The objective was to identify the causes of pollution, assess its impacts on both humans and the environment, and propose preventive and remediation measures. The major causes of Nwangene River pollution were identified as poor solid waste management infrastructure, ignorance, urban runoff, industrial effluents, erosion, encroachment, and urban development. Waste characterization revealed that plastics accounted for the largest share in both quantity and nuisance value (80%), followed by metal cans (20%). Within the plastic waste category, sachet water packs ranked highest (30%) in both quantity and nuisance value. Furthermore, although organic wastes and industrial effluents are less recognizable, their significant nuisance values were evident in the dark coloration and foul odor of the river. Findings indicated that Nwangene River pollution has led to severe environmental and human impacts, including heavy metal and organic contamination, disruption of microbial communities, mosquito breeding, flooding, biodiversity loss, land and groundwater pollution, surface water degradation, and adverse health, aesthetic, and economic consequences. The results underscore the urgent need for effective pollution prevention and eco-friendly remediation strategies in the study area. Recommended preventive measures include strict regulation of industrial waste, establishment of sustainable waste management systems, promotion of alternative waste utilization, public awareness campaigns, installation of pollutant traps, reforestation, erosion control, community participation, and periodic monitoring. A hybrid remediation approach-combining dredging, microbial bioremediation, phytoremediation, floating treatment wetlands, and natural attenuation-was also suggested to restore the Nwangene River as a vital resource for Onitsha residents.**
***Keywords:* Nwangene River, Water Pollution, Waste Management, Remediation Strategies, Environmental Impacts**

I. INTRODUCTION

A. Study Background

Onitsha metropolis lies within the Nakweze-Idemili drainage area, covering about 300 km² between coordinates 6°45′00″N and 6°62′00″E, as shown in Fig. 2. Onitsha, located in Anambra State, is one of Nigeria's largest commercial cities, renowned for its bustling markets and vibrant economic activities. However, alongside its economic prosperity, Onitsha faces significant environmental challenges, particularly pollution. Rapid urbanization, industrial growth, and population expansion have resulted in increased waste generation [1]. This growth has outpaced the development of adequate waste management infrastructure, leading to substantial waste accumulation. A common practice in Onitsha is the indiscriminate disposal of waste in open spaces, roadsides, drainage systems, and rivers. Markets, residential fronts, and major streets often contain heaps of uncollected waste [2], [3]. This not only makes the city unsightly but also poses health risks. Addressing unmanaged waste in Onitsha requires collective efforts from individuals, families, communities, and the government, each with a distinct role in managing waste [4].

The rapid population growth in Onitsha over the last three decades has increased the quantity of waste generated per capita from human activities. Unfortunately, both urban and suburban areas still struggle to adopt and enforce proper domestic, industrial, and fecal waste management practices. This contributes to the indiscriminate disposal of waste, facilitating the introduction of harmful pathogens [5], heavy metals, and organic pollutants into drinking water sources. Wastes originate from various sources-industrial, commercial, and domestic-and are classified into biodegradable and non-biodegradable categories. Biodegradable wastes include green waste, food, paper, and textiles, while non-biodegradable wastes consist of plastics, metals, glass, wood, and bone. Their degradation times vary depending on material type and environmental conditions. Municipal solid waste management, therefore, remains a critical public health concern. This highlights the importance of proper, systematic, and environmentally safe waste disposal to prevent adverse impacts on human health [3].

B. The Studied Area

The study area is the Nwangene River, located at Fegge in Onitsha South Local Government Area, Anambra State, Nigeria. The river lies east of the River Niger (Fig. 2) and drains through Enu-Onitsha, Odoakpu, Woliwo, and Fegge, before emptying into the River Niger (Fig. 2). At Fegge, with coordinates 06°08′29″N and 06°46′39″E, the Nwangene

River has been converted into a large dumpsite, rendering the water stagnant, dark in color, and producing a severe foul odor (Fig. 4).

II. GEOLOGY AND HYDROGEOLOGY OF ONITSHA

Onitsha is situated in the Anambra Basin, which lies within the Benue Trough. The basin is primarily composed of clastic sediments that form several distinct lithostratigraphic units, ranging from the Upper Campanian to Recent.

The thickness of these lithostratigraphic units is approximately 2500 m [6]. They comprise the Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, Ameki Formation, Nanka Sands, Ogwashi-Asaba Formation, Benin Formation, and the Alluvial Plain Sands. The Cameroon Highlands serve as the major source of sediments into the Anambra Basin.

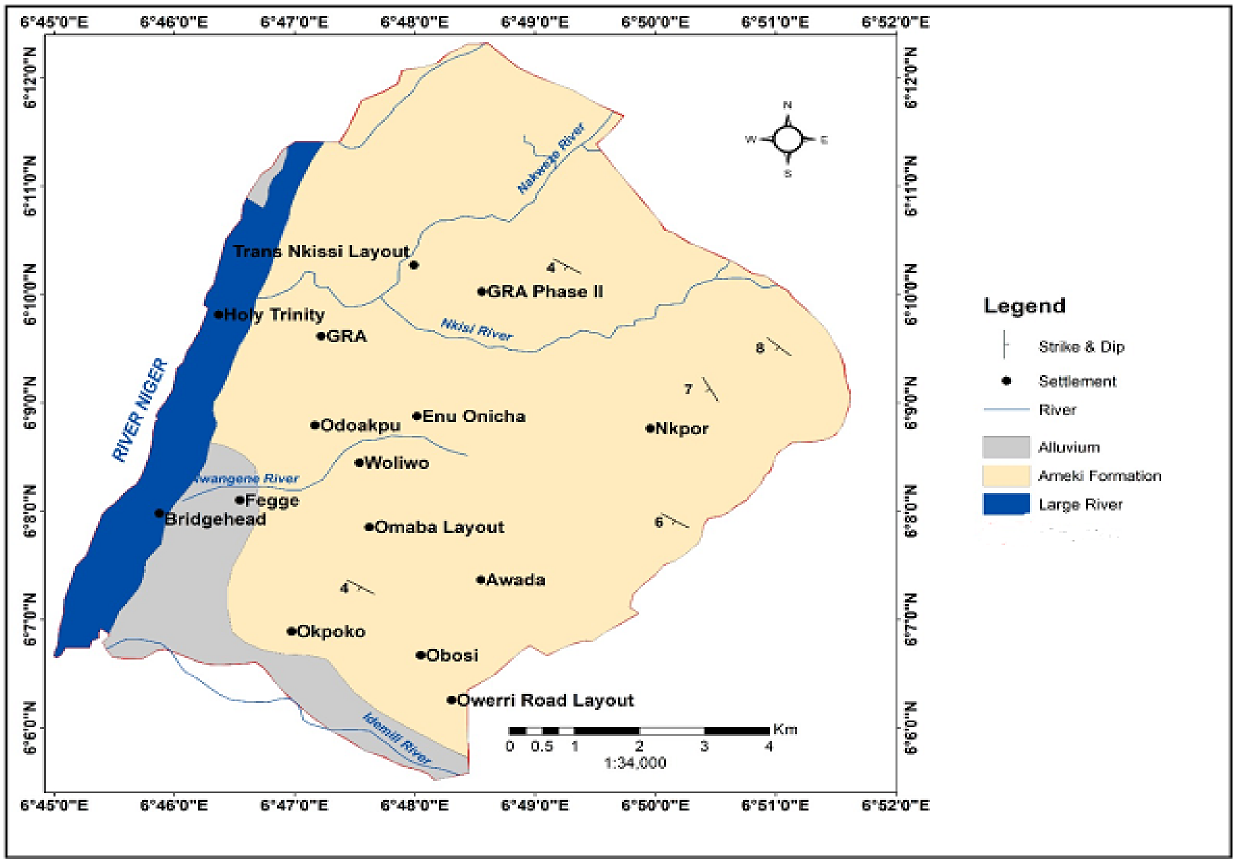

Fig. 1 Geology map of Onitsha

However, the Onitsha area is situated on the Ameki Group and is bordered to the west by the River Niger, with its edge containing alluvial deposits (Figure 1). The Ameki Group consists of the Nanka and Nsugbe Formations. The Nanka Formation, estimated at 305 m thick, largely comprises sands with minor calcareous clay/mud and heterolithic layers [7]-[9]. The Nsugbe Formation consists mainly of sands with several conglomerate bands, with an estimated thickness of approximately 100 m [8]. The Nsugbe Formation is separated from the Nanka Formation and considered its lateral equivalent due to differences in lithological succession, textural characteristics, and its degree of induration, which is unknown in the Nanka Formation. It also covers a substantial area of over 1000 km² [8].

Hydrogeological studies have shown that Onitsha and its surrounding areas source their groundwater from the middle aquifer (40-90 m), which is part of the Ameki Group [10]. The main aquifer types in Onitsha include unconfined aquifers in shallow sandy deposits, often recharged by rainfall, and semi-confined to confined aquifers located at deeper levels.

III. RELIEF AND DRAINAGE

Topographically, Onitsha consists of hilly and lowland (undulating) terrain. The elevation of the study area ranges from 32 m above sea level in the eastern coastal region near the River Niger to approximately 100 m above sea level in the central part extending toward the eastern extremity. The Anambra, Nkisi, and Idemili Rivers drain the area, eventually emptying into the River Niger [10]. The drainage system is influenced by the region's topography, geology, and urbanization. The River Niger is the primary drainage feature in Onitsha, flowing southwards and forming a significant natural boundary, while the smaller streams and tributaries exhibit a dendritic drainage pattern (Fig 2).

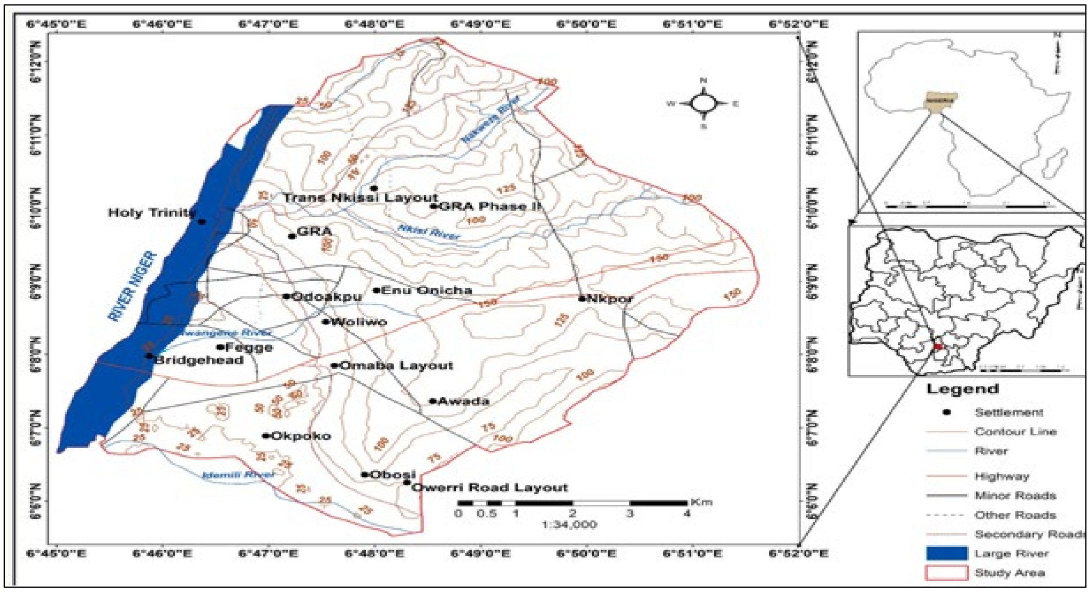

Fig. 2 Location, Topography and Drainage of Onitsha, showing Nwangene River (Fegge)

IV. STATEMENT OF THE PROBLEM

Considering the significance of maintaining good water quality, the monitoring of pollutants has become essential. The Nwangene River area, into which various types of sewage and chemical effluents flow, is one of the most polluted regions in Onitsha. Additionally, the city's largest garbage landfills are emptied into this river [11].

The river has suffered severe degradation due to improper disposal of municipal waste, including plastics, metals, organic matter, paper, and industrial effluents. The continuous dumping of waste in the Nwangene River poses a serious public health issue, threatening both humans and the environment. This study therefore investigates Nwangene River pollution, focusing on its causes, impacts, preventive measures, and remediation approaches.

V. AIM AND OBJECTIVES OF THE STUDY

This study aims to assess the causes and impacts of pollution in the Nwangene River and to propose possible preventive and remediation measures.

The specific objectives of this study are as follows:

1. To investigate the causes of Nwangene River pollution.
2. To characterize the types of waste.
3. To examine the effects on both humans and the environment.
4. To suggest possible pollution prevention measures.
5. To recommend appropriate remediation approaches.

VI. METHODOLOGY

The successive activities that will be carried out in order to achieve the listed objectives are as shown in figure 1.

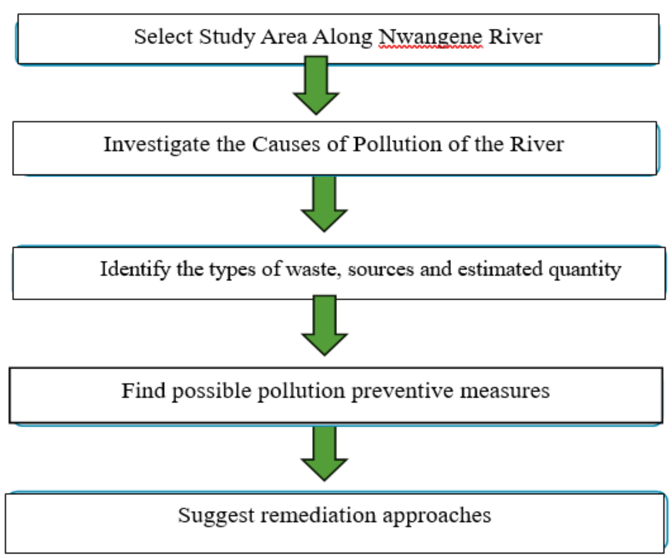

Fig. 3 Workflow

VII. FIELD INVESTIGATION

The field investigation covered the identification of the causes of pollution in the Nwangene River, with particular attention to the types of waste, their sources, and estimated quantities. It also included an assessment of both human and environmental impacts of the river pollution, as well as the identification of possible preventive measures and remediation approaches.

VIII. RESULTS AND DISCUSSION

An investigation of Nwangene River pollution in the Fegge area was conducted through detailed field studies, observations, literature review, and interactions with nearby residents. The causes of pollution were identified, including the types of waste, their sources, and estimated quantities. The environmental impacts of the pollutants were also examined, along with possible preventive measures and appropriate remediation approaches.

A. Causes of Pollution

1. *Lack of Proper Solid Waste Management Infrastructure:* Human activities in various settings, such as homes, markets, offices, hospitals, schools, farms, hotels, restaurants, social gatherings, and tourist areas, contribute significantly to the generation of large quantities of municipal solid waste. Cities across Nigeria are at risk of environmental and public health impacts due to improper solid waste management. Municipal solid waste in urban areas is a mixture of residential, commercial, institutional, industrial, and tourist wastes [12]. The lack of proper waste management infrastructure, such as adequate waste collection bins, functional landfill sites, and efficient waste transportation systems in Onitsha, has led to indiscriminate dumping of refuse along streets and within drainages. These wastes are eventually carried into the river, mostly through runoff, while some are dumped directly into the river by passersby and nearby residents.
2. *Ignorance:* Onitsha is primarily populated by people who are more business-oriented than environmentally conscious. Many residents are unaware that whatever is introduced into the environment has consequences, either positive or negative. There is a need for residents to recognize that dumping waste into Nwangene River has widespread environmental impacts, threatening both human and animal health.
3. *Urban Runoff:* Urbanization has increased the prevalence of impermeable surfaces (e.g., roads and buildings), altering the natural drainage and leading to higher surface runoff. Onitsha, being a highly urbanized area, generates significant amounts of solid and liquid waste. During rainfall, untreated runoff carrying plastics, sewage, and other pollutants flows into Nwangene River. The city's topography facilitates the transportation of improperly disposed municipal solid waste by runoff into nearby rivers [12], including the Nwangene River.
4. *Industrial Effluents:* Factories and workshops in Onitsha, including chemical, plastic, textile industries, and breweries, often discharge their wastes either directly into water bodies or into drainage systems that eventually empty into nearby rivers. Many of these wastes are inadequately treated or not treated at all. Nwangene River is significantly impacted by this pollution. The concentration of industries near the River Niger and Nwangene River contributes substantially to the degradation of these water bodies. None of the industries has implemented effluent treatment programs, nor is there significant governmental pressure to enforce such measures [13].
5. *Erosion:* Onitsha experiences significant erosion, particularly during heavy rainfall. The eroded soil, often containing urban debris, ends up in the river, causing sedimentation and pollution. Nwangene River has increasingly become stagnant due to heavy sediment and waste loads (Figure 4). Its length is progressively shortened by rapid sedimentation (Figure 2).
6. *Encroachment and Urban Development:* The expansion of settlements and construction activities around the river has intensified pollution levels (Figures 5a and 5b).

Fig. 4 Heavily polluted Nwangene River (Fegge)

Fig. 5 a and b Buildings and heaps of waste-containing soils along the water way


Fig. 6 Wastes in Nwangene River (Fegge)

IX. WASTE CHARACTERIZATION

A. Types of Waste, Sources, and Estimated Quantity

The types of waste dumped into the Nwangene River include plastic bottles, plastic food packs, sachet water packs, polythene bags, organic waste, paper, metal cans, and industrial effluents. The degradable wastes are primarily organic matter and paper, while the non-degradable wastes consist mainly of plastics and metal cans.

TABLE I CLASSIFICATION OF NWANGENE RIVER WASTES

Type of Waste	Source	Estimated Quantity (%)
Plastic bottles	Commercial & Domestic	25
Plastic (food) packs	Commercial	10
Sachet water packs	Commercial &Domestic	30
Polythene bags	Commercial & Domestic	15
Organic wastes	Commercial & Domestic	Not recognized
Paper	Commercial &Domestic	Not recognized
Metal cans	Commercial & Domestic	20
Industrial Effluent	Industrial	Not recognized

TABLE II ESTIMATED QUANTITY OF RECOGNIZABLE WASTES

Type ff Waste	Estimated Quantity (In %)
Plastic bottles	25
Plastic (food) packs	10
Sachet water packs	30
Polythene bags	15
Metal cans	20

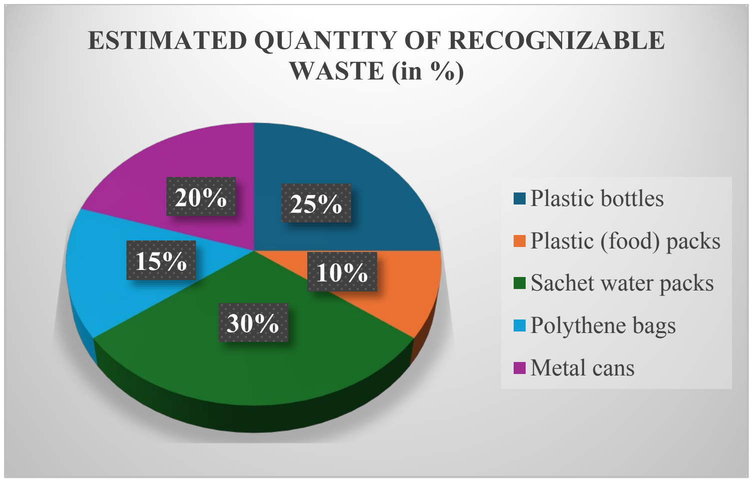

Fig. 7 Pie chart showing estimated quantity of recognizable wastes in Nwangene River

B. Estimated Recognizable Wastes Nuisance Values:

This refers to the significance of the recognizable wastes, arising from their capacity to cause inconvenience or annoyance. This is calculated using the estimated quantity of recognizable wastes as follows:
Estimated quantity of plastics (%):

Plastic bottles = 25
Plastic (food) packs = 10
Sachet water packs = 30
Polythene bags = 15
Total Quantity of Plastic Wastes = 80
Estimated quantity of metal cans = 20

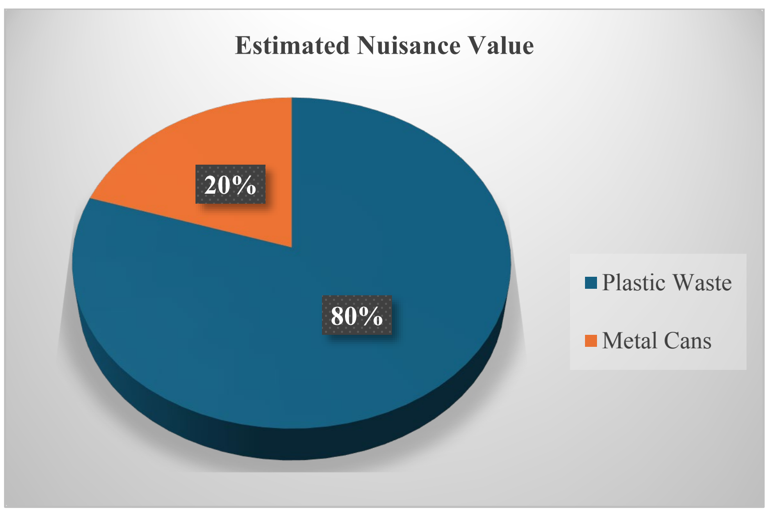

Fig. 8 Pie chart showing Estimated Nuisance Values of Recognizable wastes

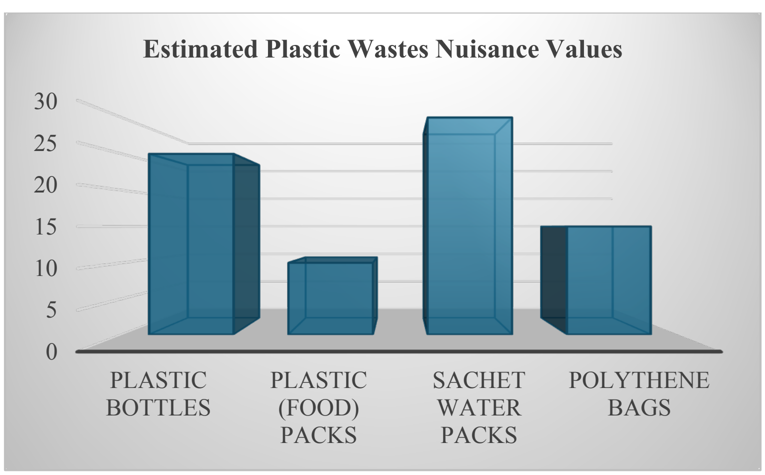

Fig. 9 Column chart showing estimated plastic waste nuisance values

The Nwangene River waste characterization revealed the following:

1. Plastic wastes constitute the highest recognizable wastes nuisance value (Figures 6&8) in Nwangene River.
2. Sachet water packs constitute the highest nuisance among the plastic wastes (Figures 6&9)
3. The decomposed organic wastes, in as much as were not recognized, also contribute to the dark coloration of the river (Figure 10)
4. The industrial effluent, also not recognized but contributes its nuisance value to the offensive odour that emanate from the river.

C. Environmental Impacts

Fig. 10 Poorly cited borehole close to the polluted Nwangene river channel

1. *Heavy Metals and Organic Pollution:* Globally, rivers and seas often serve as dumping grounds for various pollutants, ranging from chemical and organic wastes to heavy metals [14]. This is primarily because many industries and factories are situated close to riverbanks, including those along the River Niger and Nwangene River [13]. Heavy metal pollution is a consequence of growing industrialization worldwide. In Anambra State, untreated industrial effluents and other wastes are released into the environment due to insufficient monitoring and enforcement of environmental regulations [15]. This has resulted in numerous cases of aquatic ecosystem pollution. Cadmium, lead, mercury, arsenic, chromium, and copper are among the heavy metal pollutants commonly associated with waste disposal sites, while polycyclic aromatic hydrocarbons, pharmaceuticals, and phenols are organic pollutants often linked to waste dumps. Nwangene River is not exempt from these forms of contamination.
2. *Effect on Microbial Communities:* As organic matter decomposes, it releases nutrients such as nitrogen and phosphorus that support microbial proliferation. Different types of organic matter promote diverse microbial communities, as various microbes specialize in breaking down specific compounds. The abundance of organic matter stimulates microbial activity, accelerating decomposition and enhancing nutrient cycling. However, overloading organic matter in Nwangene River can lead to oxygen depletion (eutrophication), which reduces aerobic microbial populations while promoting anaerobic microbes. Moreover, heavy metals and organic pollutants from municipal waste act as environmental stressors due to their toxic nature. These stressors can stimulate the development and spread of resistance genes within microorganisms, including pathogens. Several studies have demonstrated that heavy metals and organic pollutants are among the environmental stressors responsible for the emergence of resistance genes in microbial communities [16], [17].
3. *Breeding Ground for Mosquitoes:* The stagnant nature of Nwangene River during the dry season, combined with high waste loads, creates favorable conditions for mosquito breeding. According to the United States Environmental Protection Agency (EPA), mosquitoes require water to complete their life cycle. They commonly breed in areas such as containers, tree holes, ground depressions, street gutters, abandoned ponds, swamps, and waste dumps [18]. Accumulated water in discarded plastics provides an ideal breeding habitat for Aedes aegypti, the mosquito species responsible for transmitting several viral diseases [18]. Thus, plastic waste significantly increases malaria and other mosquito-borne disease transmission near the Nwangene River.
4. *Flooding:* Large volumes of waste and sediment, along with construction activities along the riverbanks, have progressively reduced the river's length and width (Figures 4, 5a, and 5b). This has diminished the river's natural capacity to accommodate excess water. Consequently, heavy rainfall during the wet season (April-October) often overwhelms the river channel, leading to urban flooding.
5. *Loss of Biodiversity:* Pollution has caused a marked decline in aquatic biodiversity within the river, including fish and other aquatic organisms. The increasing waste load, coupled with sedimentation and urban

encroachment (Figures 4 and 5b), has resulted in the loss of aquatic habitats. Excess nutrients from decomposing organic matter may also trigger algal blooms, which suffocate aquatic plants and reduce biodiversity. Oxygen depletion (eutrophication) further exacerbates this issue by reducing aerobic microbial populations while favoring anaerobic microbes.

6. *Land and Groundwater Contamination:* Onitsha is highly susceptible to pollution due to its abundant surface water, shallow groundwater, and permeable soils, with limited presence of the Imo Shale Formation [13]. Given the area's geologic and hydrogeologic characteristics (shallow to intermediate unconfined aquifers) and poor waste disposal practices, contamination of groundwater by organic and heavy metals pollutants is almost inevitable [19].For over 30 years, Onitsha's growing population has increased the demand for water [20], [21]. To meet this demand, households rely on shallow hand-dug wells and boreholes that tap into prolific aquifer systems.

7. However, many of these wells and boreholes are poorly sited, being located near refuse dumps and polluted drainage systems (Figure 10) [10], [13]. Industrial and wastewater discharges, along with diffuse pollution sources, introduce nitrogen, heavy metals, pharmaceuticals, microbial pathogens, and volatile organic compounds into groundwater through leaching [22]. These pollutants often have long half-lives, posing long-term risks to aquifers and making remediation difficult. Studies in Onitsha revealed that concentrations of heavy metals-lead, zinc, cadmium, chromium, copper, mercury, and arsenic-were higher in boreholes near municipal solid waste dumpsites compared to a control borehole located away from waste sites [12].

   Chromium was identified as the greatest contributor to groundwater pollution, followed by arsenic, cadmium, mercury, copper, zinc, and lead. Other studies have also documented the presence of heavy metals and organic pollutants in both soil and groundwater, with some concentrations exceeding World Health Organization (WHO) maximum contaminant limits [23]-[27].

   Waste dumped in Nwangene River generates effluents containing both biological (including resistant pathogens) and chemical pollutants, which contaminate both land and groundwater [15]. These pollutants can promote the emergence and spread of antimicrobial resistance (AMR) within microbial communities [28]. Thus, groundwater resources, which serve as primary drinking water sources, may function as reservoirs for antimicrobial resistance development and transmission [29].

8. *Surface Water Degradation:* Nwangene River discharges into the River Niger, carrying pollutants that contribute to heavy metal and organic contamination in the Niger. Previous studies have attributed such contamination to runoff from agricultural, industrial, and domestic activities [30]. In addition to polluting boreholes along Creek Road and Abatete Street, Nwangene River has also contributed to pollution issues in the River Niger where it connects through the Otumoye Major Drain [11].

9. *Loss of Aesthetics:* The accumulation of plastic waste, metal cans, sachet water packs, and other solid wastes in Nwangene River creates an unsightly and unpleasant scene (Figures 4 and 6). Industrial effluents and decomposed organic matter further darken the water, diminishing its natural beauty. These pollutants also produce foul odors, making the river and surrounding areas unattractive and uninhabitable.

10. *Health and Economic Implications:* The stagnant nature of Nwangene River during the dry season, combined with high waste loads, facilitates mosquito breeding and increases malaria incidence. Flooding of the river also spreads waterborne diseases such as cholera and typhoid. Prolonged consumption of fish and seafood from the polluted river poses additional health risks [13]. Outbreaks of such diseases strain healthcare systems, requiring substantial resources for treatment, repair, expansion, and staffing. The dense population of Onitsha further amplifies the risk of disease spread, imposing significant healthcare costs on both government and society.

    Exposure to heavy metals and organic pollutants in groundwater induces stress responses in microorganisms, including pathogens [40]. This promotes genetic adaptations that enhance survival and resistance [31], [32]. Pollutants in lethal concentrations may cause microorganisms to resist antimicrobial agents (antibiotics, antivirals, and antifungals), a phenomenon known as AMR [32]. Antimicrobial resistance genes (ARGs), when ingested through contaminated water, can transfer resistance traits to previously susceptible pathogens in humans. Consequently, treatments that were once effective may become obsolete due to co-selection of antibiotics. Moreover, consumption of contaminated water further facilitates resistance development through stress-induced responses in pathogens [33].

    AMR is a critical global health concern. In 2019, an estimated 4.9 million deaths were linked to antibiotic-resistant bacteria. Sub-Saharan Africa recorded the highest mortality rates, with 27.3 deaths per 100,000 people, largely attributed to lower respiratory infections [35]. AMR undermines infectious disease control, increases morbidity and mortality, and places a heavy financial burden on healthcare systems [34], [36], [37].

D. Preventive Measures

The following measures must be implemented to prevent further pollution of the Nwangene River:

1. *Strict Regulation of Industrial Waste:* There is an urgent need for the enforcement of environmental laws to ensure that industries properly treat their effluents before discharging them into the river. The effectiveness of pollution control in the Nwangene River depends heavily on the strength and implementation of regulatory frameworks. Strengthening existing regulations and enforcement mechanisms is crucial for holding industries accountable and preventing harmful discharges. Regulatory improvements may include stricter monitoring, regular audits, and stringent penalties for non-compliance [38].
2. *Sustainable Waste Management System:* Sustainable waste management not only safeguards human health and the environment but also preserves the earth's limited resources for both present and future generations [12]. The Anambra State government should establish adequate and well-maintained waste management infrastructure, such as sufficient waste collection bins, functional landfill sites, and an efficient waste transportation and recycling system within the study area, to prevent waste dumping into the river. Establishing systems for proper plastic disposal simultaneously enhances public health by minimizing disease transmission and reduces local pollution.
3. *Alternative Uses of Non-Degradable Materials:* According to [4], plastic and aluminum cans, among other non-degradable materials, are not eco-friendly. Their degradation periods are relatively high, meaning they do not decay easily. Consequently, plastic and aluminum waste dominate Onitsha's environment, as most contemporary beverage and liquid containers are made of these materials. To address this environmental challenge, plastic and aluminum/metal containers can be repurposed in the production of sculptures and other creative applications.
4. *Public Awareness Campaigns:* Residents should be educated on the importance of adopting environmentally friendly attitudes, particularly regarding waste disposal practices [39]. They must be made aware that whatever is introduced into the environment often returns as a threat to human life and well-being, depending on the nature of the waste. Moreover, river pollution has widespread impacts due to extensive contaminant transport mechanisms.
5. *Pollutant Traps:* Pollutant traps are vital mechanisms designed to capture and filter pollutants before they enter the Nwangene River. These traps, strategically placed in stormwater drains (Figures 11a and 11b) and water channels (Figure 10), intercept debris, sediment, and other pollutants, thereby preventing them from reaching the river. Pollutant traps effectively reduce the inflow of solid wastes, sediments, and other contaminants, thus mitigating river pollution [38].

E. Remediation Approaches for The Nwangene River: After the successful implementation of preventive measures, there remains a need to restore the polluted river to a safe and healthy state for both humans and aquatic organisms. Addressing the pollution of the Nwangene River requires a coordinated and sustained effort. A hybrid approach combining dredging, microbial bioremediation, phytoremediation, and floating treatment wetlands could prove most effective. The recommendations focus on eco-friendly remediation techniques to avoid secondary pollution and to ensure environmental sustainability. With proper action, the river can be restored as a vital resource for Onitsha residents. The recommended approaches include:

1. *Dredging:*
   Dredging the Nwangene River is an effective strategy for reducing sediment and waste loads, thereby improving the river's ecological health and functionality. This process involves the removal of accumulated sediments, debris, and waste from the riverbed. Over time, sediment and waste accumulation has reduced the river's depth, impeding water flow and resulting in flooding during the wet season. Dredging restores the river's carrying capacity and promotes healthier habitats for aquatic organisms, thereby supporting biodiversity. Removing waste such as plastics, metal cans, bones, organic debris, and other pollutants also improves water quality and prevents blockages.
   Mechanical dredging, which is suitable for areas with heavy solid pollution such as the Nwangene River, is recommended. This technique employs heavy equipment, such as excavators, to remove large volumes of sediment, waste, and debris from the river.
2. *Bioremediation:*
   Bioremediation refers to the use of biological agents-such as microorganisms, plants, or enzymes-to clean pollutants from a contaminated environment. These techniques aim to restore water quality and ecological balance. The approaches include:

A. Microbial Bioremediation

This involves introducing or stimulating microorganisms that degrade contaminants into less harmful compounds. Methods include:

1. *Bioaugmentation*: The introduction of specific strains of bacteria or fungi capable of degrading pollutants such as heavy metals and organic compounds.
2. *Biostimulation*: Enhancing the growth of indigenous microbial communities by adding nutrients (e.g., nitrogen and phosphorus) or oxygen to accelerate degradation.

B. Phytoremediation

The use of plants to absorb, stabilize, or degrade pollutants is particularly effective for heavy metals and organic compounds. Methods include:

1. *Phytoextraction*: Plants such as *Typha* or *Phragmites* absorb heavy metals (e.g., cadmium, lead, mercury) from the riverbed.

2. *Phytodegradation*: Certain plants produce enzymes that break down complex organic pollutants, such as polycyclic aromatic hydrocarbons and pesticides.
3. *Rhizofiltration*: Plant roots filter contaminants from the water, trapping them in their biomass.

B. Bioreactors

Bioreactors can be deployed for in-situ or ex-situ treatment of polluted water. A common type is:

1. *Floating Treatment Wetlands (FTWs)*: Man-made structures with plants that float on the water surface, supporting microbial communities to degrade pollutants. These are particularly effective for the removal of nutrients and organic pollutants.

C. Natural Attenuation

In some cases, allowing natural microbial and environmental processes to degrade pollutants is an option. However, this method requires extended time and careful monitoring to ensure effectiveness.

1. Additional Recommendation

Selecting microbial candidates with low antibiotic resistance for bioremediation is strongly advised to prevent the spread of antibiotic-resistant genes (ARGs) in the environment. While some authors consider resistance mechanisms advantageous for microbial resilience, the risks associated with ARGs in contaminated water are significant. In particular, horizontal gene transfer between ARGs and human pathogens poses a serious public health concern.

X. CONCLUSION

The issue of waste is closely linked to the growing human population and the accompanying domestic, commercial, agricultural, and industrial activities. If not properly managed, these wastes pose severe threats to both human health and ecosystem integrity. The pollution of the Nwangene River, caused by the continuous dumping of waste into the water body, has become a significant public health concern, threatening both humans and the environment. Urgent measures must be implemented to prevent further pollution and to restore the Nwangene River as a vital resource for Onitsha residents.

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Use of Artificial Intelligence (AI) - Assisted Technology for Manuscript Preparation
The authors confirm that no AI-assisted technologies were used in the preparation or writing of the manuscript, and no images were altered using AI.

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