



Ecological silence in Ibadan drainages: Degradation, fish extinction and restoration pathways

Ogundeji Obadara Emmanuel¹, Ogbuagu Samuel Ifeanyi¹, Chindo Jimkuta¹, Kargbo Esther Edith², Yusuff Babatunde Raji³

¹ Wuxi Fisheries College (Freshwater Fisheries Research Centre), Nanjing Agricultural University, Jiangsu Province, People's Republic of China

² Department of Aquaculture and Fisheries Management, Njala University, Njala Campus, Moyamba District, Kori Chiefdom, Sierra Leone

³ Department of Physics, University of Ilorin, Kwara State, Nigeria

Abstract

Ibadan's Ona-Ogbere-Ogunpa drainage network has been established to be an ecologically collapsed, pollution-dominated urban conveyance system, despite its potential to sustain artisanal fisheries and floodplain livelihoods. Multiple lines of evidence from chronic organic loading, severe hypoxia, persistent heavy-metal contamination, physical channel simplification, and episodic biocide use indicate that this ecological degradation has driven beyond declines to localized extinction of historically native fish assemblages within the urban reaches of the basin system. Contemporary surveys repeatedly report toxic conditions and absent ichthyofauna, while nearby, less-degraded waters both within and outside the same Ogun basin retain diverse fish communities, underscoring that current environmental thresholds in Ibadan's streams are incompatible with recolonization. Situated within the broader context of urban stream syndrome and freshwater biodiversity erosion in rapidly urbanizing regions, this review assembles hydrological, chemical, biological, and governance evidence to diagnose drivers of functional ecological collapse in the Ona-Ogbere-Ogunpa system. It further synthesizes regional records to infer lost species and trophic guilds, and draws on international experience, especially urban-river restoration, sponge-city concepts, and nature-based infrastructure, all being Chinese models, to outline a context-appropriate pathway that couples pollution prevention, sediment and habitat rehabilitation, waste-to-energy solutions, and institutional accountability. The review also highlights an urgent need for dedicated ichthyofaunal surveys along the Ona, Ogbere, and Ogunpa channels to establish current species baselines and provide benchmarks for assessing local extinction and future recovery. Ultimately, it argues that the recovery of Ibadan's rivers must be evaluated not by cosmetic improvements in water appearance alone but by measurable restoration of trophic complexity and the verified return of native fish species as indicators of renewed socio-ecological function.

Keywords: Fish extinction, metal contamination, degradation, toxic fishing, Ibadan drainages, ecological silence, water pollution, Ona River, Ogbere River, Ogunpa channel, ecological silence

Introduction

Ibadan's historical development is inseparable from its hydrological landscape. Early settlement patterns followed river valleys, and waterways such as the Ona River and its tributaries sustained domestic water supply, floodplain agriculture, and artisanal fisheries well into the mid-twentieth century (Ajayi and Salawu, n.d; Lloyd, 1967; Mabogunje, 1968^[54, 55]; Michael, n.d; Olaniyi, 2015). Rivers were not merely drainage conduits; they were socio-ecological assets embedded in everyday life. Yet this relationship has undergone a dramatic inversion. Rapid population growth, industrial expansion, and unregulated urbanization have progressively transformed these same rivers into polluted channels marked by severe ecological dysfunction. This trajectory mirrors the globally recognized "urban stream syndrome," characterized by altered hydrology, elevated nutrient and contaminant loads, simplified habitats, and biotic impoverishment (Walsh *et al.*, 2005; Cao *et al.*, 2024)^[24, 82]. In such systems, the cumulative pressures of wastewater discharge, impervious surface runoff, and channel engineering shift rivers from dynamic ecosystems to degraded conveyance infrastructure. Ibadan's waterways now exemplify this paradox: a city born of rivers that has rendered its rivers ecologically silent.

The Ona-Ogbere-Ogunpa drainage network constitutes the principal urban outflow of Ibadan's central basin,

hydraulically linking densely populated neighborhoods, industrial corridors, and downstream rural waters (Msheila and Ode, 2013)^[62]. Ecologically, it represents a coupled human - natural system in which urban activity directly determines aquatic health. Interestingly, historical accounts (Atanda, 2007; Alabi, 2021)^[7, 10], drawing from oral histories and archival records (Adedeji and Bigon, 2024)^[5], infer that these streams once supported fish assemblages (Ezemonye and Ogbomida, 2010)^[36]. These streams were probably functional ecosystems, supporting diverse species across trophic guilds: benthic invertivores, detritivores, grazers, and predators.

However, contemporary ecological surveys of these streams consistently fail to recover ichthyofauna. Instead, findings point to persistent toxic loading, hypoxic conditions, and habitat collapse (Adekanmbi and Falodun, 2015; Dele-Alimi *et al.*, 2023)^[8, 28]. The absence of formerly common native species strongly indicates extirpation (localized extinction), which is a process distinct from temporary decline and suggestive of sustained environmental thresholds incompatible with recolonization. The degradation of the Ona-Ogbere-Ogunpa system is therefore not episodic; it is structural and cumulative.

This review has three interlinked objectives. First, it synthesizes hydrological, chemical, biological, and governance evidence to diagnose the extent and drivers of

ecological degradation in the Ona-Ogbere-Ogunpa drainage network, with particular emphasis on native fish populations. Second, it compiles historical and regional ichthyological information to infer and document the local extinction of multiple native fish species from Ibadan’s urban streams. Third, it integrates lessons from international urban-river restoration, especially recent experience from China, outlining a context-appropriate framework for ecological and institutional rehabilitation of Ibadan’s drainage system.

The importance of this review is twofold. Scientifically, it provides the first basin-scale synthesis explicitly linking documented heavy-metal contamination, chronic organic pollution, and channel engineering in the Ona-Ogbere-Ogunpa system to document and inferred localized extinction of native fish species. And practically, it offers a structured evidence base to support policy reform, targeted restoration investments, and community-level action aimed at transforming Ibadan’s rivers from hazardous drains back into functional socio-ecological assets.

This review was developed through a structured but narrative synthesis of interdisciplinary literature and contextual sources. Peer-reviewed articles, technical reports, theses, and government documents were identified using

Google Scholar, Web of Science, and Scopus with combinations of geographic and thematic keywords such as “Ibadan”, “Ona River”, “Ogbere River/Stream”, “Ogunpa Channel”, “urban drainage”, “water quality”, “heavy metals”, “fish”, “biodiversity”, and “restoration”, focusing primarily on publications from 1980 to 2025. Inclusion criteria required that sources provide primary data or detailed analyses on surface-water quality, sediment contamination, aquatic biota, public health impacts linked to Ibadan’s waters, or urban-river restoration frameworks relevant to rapidly urbanizing contexts. Foundational conceptual works on urban stream syndrome, freshwater ichthyofauna loss, and governance innovations were included to provide theoretical framing. Media reports and institutional bulletins were consulted to document major pollution incidents, flood events, and public-health emergencies, while regional ichthyological checklists for the Ogun basin and related systems were used to infer historical species pools for Ibadan’s urban streams. The synthesis is complemented by the author’s long-term local observations along streams within the Ogbere drainage, which are used illustratively to corroborate trajectories inferred from published evidence.

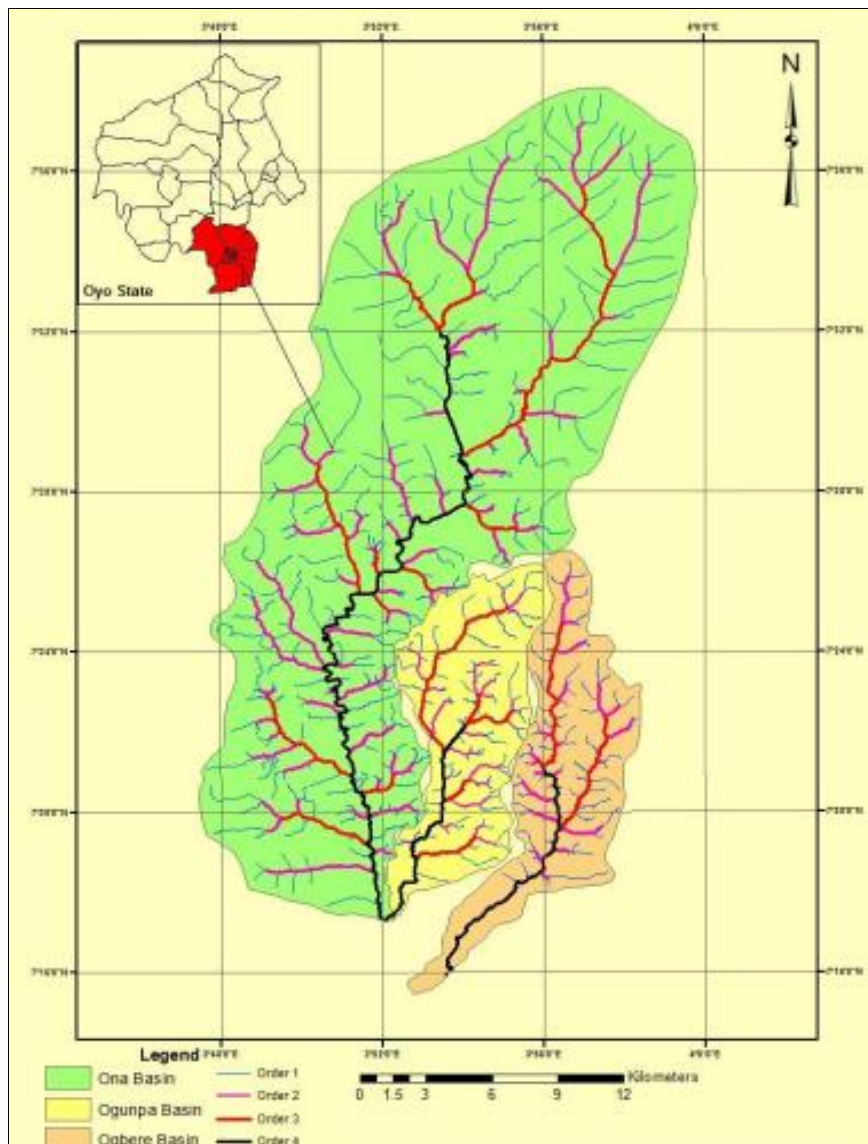


Fig 1: Ona-Ogbere-Ogunpa drainage network. Source: Mshelia and Ode, 2013 [62].

Drivers of Localized Fish Extinction

The disappearance of native fish species from the Ona-Ogbere-Ogunpa system reflects interacting stressors rather than a single causative factor. Chronic pollution, toxic metal loading, physical habitat alteration, and episodic poisoning events operate synergistically, reinforcing ecological collapse.

1. Chronic Organic Pollution and Eutrophication

Uncontrolled wastewater discharge remains the dominant driver of ecological degradation. Continuous inflows of organically rich effluents, from abattoirs, domestic sewage, markets, and small-scale industries, elevate biochemical oxygen demand (BOD) and depress dissolved oxygen (DO) concentrations to levels lethal for most fish species (Adekanmbi and Falodun, 2015) [18]. Under such conditions, microbial decomposition intensifies oxygen depletion, while ammonia and hydrogen sulfide accumulate in bottom waters and sediments. These compounds exert direct toxic effects and inhibit recolonization even when episodic flushing occurs (Dele-Alimi *et al.*, 2023) [28]. The resulting water-quality state corresponds to Class V pollution under the WHO classification, effectively unsuitable for sustaining aquatic life. In ecological terms, the system has crossed from stress to collapse.

2. Heavy Metals and Industrial Effluents

In addition to organic pollution, persistent trace metals significantly compound ecological stress. Elevated

concentrations of lead (Pb), cadmium (Cd), chromium (Cr), and zinc (Zn) have been reported in sediments, exceeding Nigerian and WHO sediment quality guidelines (Adeyemo, 2007; Akinyemi *et al.*, 2014) [10, 13], as against an earlier report within limits (Mombeshora *et al.*, 1981) [60]. These metals bioaccumulate in aquatic organisms, induce histopathological damage in gills and liver tissues, impair reproductive capacity, and reduce juvenile survival. Unlike organic pollutants that may fluctuate seasonally, metals persist in sediments, creating long-term contamination reservoirs. Informal battery recycling, textile dyeing operations, and mechanic workshops along the Ogbere and Ogunpa corridors, and some parts of the Ona stream, constitute major anthropogenic sources (Alfred, 2022; Premium Times, 2021) [18, 75].

Ona River

Recent assessment of Ona River bank soils and bed sediments identified elevated concentrations of Fe, Mn, Zn, Cu, Pb, and Cd. Enrichment and pollution indices indicate moderate to strong contamination, alongside non-negligible non-carcinogenic risk to nearby residents (Adeyemo, 2007; Ganiyu, 2024 [10, 37]; Akande, 2025; Akinyemi *et al.*, 2014) [13]. Source apportionment attributes Pb and Cd primarily to anthropogenic inputs from industrial and residential activities along the river corridor (Olanrewaju *et al.*, 2017) [66]. These findings confirm that sediment contamination is not incidental but structurally embedded in the system.



Fig 2: Ona River Channelization (IUFMP, 2024) [37]

Ogbere Drainage

In the Ogbere River, speciation analysis of eight metals revealed Mn, Fe, and Zn as dominant elements, with Pb, Cr, Ni, and Cd present in both dissolved and particulate phases at ecologically concerning concentrations (Adeyemo, 2007; Achi 1 *et al.*, 2021; Achi 2 *et al.*, 2021) [1, 10].

Notably, the partitioning of metals into colloidal and particulate fractions enhances their potential bioavailability to fish and benthic fauna, where such fauna persists. Thus, even in the absence of acute toxicity events, chronic sublethal exposure likely undermines long-term population viability.



Fig 3: Ogbere Stream (Oduola, n.d.)

Regional and Global Context

Meta-analysis of global urban rivers demonstrates consistent associations between Pb, Cd, and Cr contamination and traffic emissions, informal industry, and mixed urban runoff. Concentrations in many developing-country cities exceed ecological guideline values (Iyiola *et al.*, 2023^[44]; Zhou *et al.*, 2020).

The Ona-Ogbere-Ogunpa contamination profile aligns closely with these global trends, situating Ibadan's experience within a broader pattern of metal-driven degradation in tropical urban streams. Local extinction is therefore not anomalous but emblematic of systemic pressures facing rapidly urbanizing regions.



Fig 4: Ogunpa channel (Sources: 1 by Modder-Oyefeso, 2024; 2 by Juju Films, 2018)^[46, 58]

Evidence from comparable systems underscores these mechanisms. A study of four urban rivers in Beijing found that artificial, channelized reaches exhibited higher temperatures, lower dissolved oxygen, elevated COD, ammonium, and sulfides, and significantly reduced fish diversity and biomass relative to natural sections (Chen S. *et al.*, 2025)^[25]. Concrete banks, simplified substrates, and vegetation loss shifted assemblages toward a few tolerant species, an outcome directly analogous to conditions observed along the concretized Ogunpa corridor.

Similarly, a longitudinal study of twelve urban headwater streams documented strong coupling between channel enlargement, bank instability, substrate simplification, and declines in native fish richness and evenness (Rieck and Sullivan, 2020)^[76]. Loss of riffle-pool sequences and riparian complexity reduced habitat niches for benthic invertivores and small-bodied native fishes, precisely the functional groups now absent in Ibadan's drainage network. Habitat simplification, therefore, acts synergistically with chemical stressors to preclude ecological recovery.

4. Deliberate Toxic Fishing Practices

Beyond chronic and structural stressors, episodic pulse disturbances have contributed to rapid local collapses. Reports document the use of harmful chemicals such as Gamalin-20 (lindane-based formulations) (Omotosho, 1987)^[71] and detergent mixtures to capture fish in stagnant pools. Such practices cause immediate mass mortality, contaminate sediments, and disrupt microbial communities essential for nitrification and organic matter processing. Even isolated events can eliminate remnant populations and further diminish the probability of natural recolonization in already stressed reaches.

3. Habitat Alteration and Channelization

Physical modification of river channels has further amplified ecological decline. Channelization of the Ogunpa stream eliminated critical refugia for spawning and juvenile development (IUFMP, 2014)^[59]. Concrete embankments suppress macrophyte growth, reduce benthic complexity, and eliminate the microhabitats necessary for feeding and predator avoidance (Wang and Huang, 2021; Wang Z *et al.*, 2021)^[83, 84]. Siltation in the Ogbere River compounds these impacts, producing shallow, slow-moving reaches that favor anaerobic decomposition and exclude oxygen-demanding taxa.

In combination, chronic pollution, toxic metal loading, habitat simplification, and chemical fishing create a reinforcing cycle of ecological exclusion, culminating in the effective silencing of native fish assemblages.

Evidence of Species Loss

Comparative analysis of historical records, recent ecological surveys, and local observations indicates a pronounced contraction in fish diversity and abundance within the Ona-Ogbere-Ogunpa drainage network. Early ichthyological reports (Omotosho, 1987^[71]; Atanda, 2007) and regional checklists documented assemblages typical of southwestern Nigerian rivers in the Ogun basin (Adedeji and Bigon, 2024; Ezemonye and Ogbomida, 2010^[5, 36]; Alabi, 2021). In contrast, contemporary studies of the Ona-Ogbere-Ogunpa system consistently report unhealthy water quality and only limited ichthyofaunal presence, implying simplified assemblages and the disappearance of more sensitive taxa (Sunday *et al.*, 2025; Adegbola *et al.*, 2021^[7, 80]; Adewale *et al.*, 2022).

A recent comprehensive survey of the Eleyele Reservoir (2019-2023)^[44], a dam along the Ona river, recorded nine families, 13 genera, and 15 species (Ayoade *et al.*, 2024)^[23]. These include *Hemichromis fasciatus*, *Coptodon zillii*, *Coptodon guineensis*, *Chromidotilapia guentheri*, *Oreochromis niloticus*, *Sarotherodon melanotheron*, *Sarotherodon galilaeus*, *Polypterus senegalus*, *Hepsetus odoe*, *Schilbe mystus*, *Clarias gariepinus*, *Lates niloticus*, *Parachanna obscura*, *Gymnarchus niloticus*, and Mormyridae spp. This diversity, though, contrasts sharply with studies in segments of Ona-Ogbere-Ogunpa, where only two or four species, primarily pollution-tolerant taxa such as *Hepsetus odoe*, *Oreochromis niloticus*, *Sarotherodon melanotheron*, and *Clarias gariepinus*, have

been reported, often with documented heavy-metal bioaccumulation (Adegbola *et al.*, 2021^[7]; Adewale *et al.*, 2022), it aligns in that they are dominated by opportunists and pollution-tolerant species. Another study (Sunday *et al.*, 2025)^[80] reported nine species from six families (*Hepsetus akawo*, *Gymnarchus niloticus*, *Oreochromis niloticus*, *Hemichromis bimaculatus*, *Sarotherodon melanotheron*, *Sarotherodon galilaeus*, *Clarias gariepinus*, *Polypterus senegalus senegalus*, and *Parachanna obscura*), again dominated by tolerant and opportunistic forms.

Comparative evidence from nearby, less-polluted systems underscores the severity of biotic contraction in Ibadan's urban reaches. In the Asejire Reservoir, 13 species across 10 families (Kareem *et al.*, 2024)^[50], 18 species from 12 families (Omoike, 2021)^[70], and 16 species from 10 families (Ipinmoroti and Iyiola, 2022)^[41] have been documented. The Oni River (Adetola and Olute, 2012; Wuraola and Adetola, 2011)^[11, 88] and other parts of the Ogun River (Adeosun *et al.*, 2025)^[9] support 28 species across 16 families, while the Jebba HEP dam harbours 83 species belonging to 42 genera (Oladipo *et al.*, 2021)^[65]. These assemblages demonstrate that southwestern Nigerian rivers retain high biodiversity potential where pollution and habitat degradation are less severe. Notably, there is no recent published record of fish presence in the Ogbere River, and only a single study has reported fish from the concretized Ogunpa channel (Etim and Adie, 2012)^[35], underscoring how depauperate and under-documented these urban reaches have become.

Based on repeated documentation of diverse fish assemblages in hydrologically connected systems such as the Oni River (another tributary of the Ogun River), geographically proximate waters such as the Asejire Reservoir, and broader regional faunal inventories (Omoike, 2021; Adebambo, 2020; Iyiola *et al.*, 2023; Ipinmoroti and Iyiola, 2022; Oladipo *et al.*, 2021; Adetola and Olute, 2012)^[3, 11, 41, 44, 65, 70], historically native species must once have occurred in Ibadan's urban streams. Their consistent absence, or extreme rarity, in recent surveys of degraded reaches of the Ona-Ogbere-Ogunpa network (Ayoade and Adoh, 2022; Adekanmbi and Falodun, 2015; Dele-Alimi *et al.*, 2023; Ayoade and Olusegun, 2012)^[8, 21, 22, 28] supports the inference of localized extirpation or functional extinction within the most polluted segments.

In many degraded urban rivers, fish assemblages become dominated by a narrow suite of pollution-tolerant, generalist species (Dudgeon, 2024)^[33], producing biological homogenization and reduced ecological resilience. This is noted in Ona-Ogbere-Ogunpa with the consistency of families such as cichlids (e.g. *Oreochromis niloticus*, *Sarotherodon melanotheron*), clariid catfishes (e.g. *Clarias gariepinus*), and snakeheads (e.g. *Parachanna obscura*). In southwestern Nigeria, additional relatively tolerant species that commonly persist in disturbed waters include *Tilapia guineensis*, *Tilapia zillii* (or *Coptodon zillii*), *Hemichromis fasciatus*, *Hemichromis bimaculatus*, *Schilbe mystus*, and *Chrysichthys nigrodigitatus*. The near-absence or very limited records of several of these typically resilient taxa in polluted urban reaches of the Ona-Ogbere-Ogunpa network is therefore ecologically significant: it implies that environmental conditions have deteriorated beyond thresholds that even tolerant species can withstand, reinforcing the argument for localized extinction and functional collapse.

Regional Biodiversity Context

Freshwater ecosystems in West Africa are globally recognized as hotspots of threatened and data-deficient fish taxa, with urbanization, pollution, and hydrological modification among the principal drivers of decline (Dudgeon, 2019; Darwall *et al.*, 2018)^[27, 32]. Within this broader regional crisis, the Ona-Ogbere-Ogunpa system appears to function as a localized extinction hotspot. The disappearance or extreme reduction of even relatively pollution-tolerant species represents more than a numerical loss of taxa. Diverse assemblages perform critical ecological roles, from grazers that regulate periphyton and algal growth, to benthic feeders that facilitate sediment bioturbation and nutrient cycling, to predatory taxa that structure trophic interactions. The loss or weakening of any of these trophic links signals the collapse of functional guilds essential for trophic balance and ecosystem regulation. Similar patterns have been documented in heavily urbanized African rivers where a few tolerant generalists replace diverse native assemblages, resulting in diminished ecosystem resilience and pronounced biotic homogenization (Dudgeon, 2019)^[32]. Thus, species loss and assemblage simplification in Ibadan waters are not isolated anomalies; they mirror continental-scale processes of freshwater biodiversity erosion.

Broader Ecological Consequences

The extinction of native fishes from the Ona-Ogbere-Ogunpa drainage system extends beyond taxonomic loss. It reflects systemic ecological simplification with cascading consequences for nutrient cycling, ecosystem services, and urban resilience.

1. Trophic Simplification and Functional Collapse

The absence of predatory, omnivorous, and detritivorous fishes compresses the trophic structure of the system. Current ecological assessments indicate dominance by microbial communities, oligochaetes, and other pollution-tolerant invertebrates in organically enriched sediments (Adekanmbi and Falodun, 2015)^[8]. In intact systems, fish-mediated predation, grazing, and sediment disturbance enhance nutrient redistribution and prevent excessive accumulation of organic matter. Their absence fosters a decomposition-dominated regime characterized by persistent hypoxia and internal nutrient loading. This trophic simplification reduces the river's natural self-purification capacity, effectively locking it into a degraded ecological state. Recovery becomes increasingly difficult as feedback loops reinforce anoxic conditions and biotic exclusion.

2. Loss of Ecological and Socioeconomic Services

Localized fish extinction also entails loss of tangible ecosystem services. Historically, peri-urban communities engaged in small-scale seasonal fishing (Aladeojebi, 2016^[16]; Alabi, 2021) and hunting. These activities provided supplementary protein and local livelihoods. The inability to record harvestable fish populations in the Ibadan streams represents both ecological and cultural loss.

Beyond provisioning services, fish contribute to regulating services such as controlling mosquito larvae and aquatic insect populations, nutrient export through biomass movement, and maintaining water clarity through trophic interactions. Their near absence increases reliance on artificial control measures and reduces ecological buffering capacity against environmental stressors.

3. Toxic Fishing Practices and Chemical Pulse Disturbances

Illegal use of organochlorine-based chemicals, including Gammalin 20 (lindane formulations) and DDT, for fish harvesting has been widely reported in Nigerian inland waters (Alagoa and Derefaka, 2002; Sogbesan and Kwaji, 2018) ^[17, 79]. Experimental studies demonstrate that exposure to lindane induces severe behavioral stress, respiratory impairment, and pronounced histopathological damage in *Clarias gariepinus*, even at sublethal concentrations (Oribhabor, 2016; Oluah *et al.*, 2005; Amabye and Semere, 2016; Ezemonye and Ogbomida, 2010) ^[19, 36, 69, 72]. When applied within confined or slow-moving reaches of the Ona-Ogbere-Ogunpa system, such chemicals can eliminate entire local cohorts within hours. Moreover, residues persist in sediments, disrupting nitrifying bacterial communities essential for ammonia oxidation and overall water quality regulation (Oribhabor, 2016) ^[72].

These episodic poisoning events interact with chronic pollution and habitat degradation to increase what ecologist's term "extinction debt" - the delayed but inevitable loss of species following sustained environmental stress. Even if pollutant inputs were reduced today, recolonization would be constrained by degraded habitat structure, contaminated sediments, and the absence of nearby source populations. The result is not merely degraded water quality but a structurally impaired ecosystem with diminished recovery potential.

Global Pathways to Urban River Recovery: Governance, Ecological Engineering, and System Resilience

The ecological decline of the Ona-Ogbere-Ogunpa drainage network is severe but not unprecedented. Across rapidly urbanizing regions, degraded rivers have been restored through coordinated pollution control, ecological engineering, and institutional reform. The global literature emphasizes that recovery requires moving from reactive cleanup toward systemic watershed governance and resilience-based design (Walsh *et al.*, 2005; Zhang *et al.*, 2026) ^[82, 91].

1. From Urban Stream Syndrome to Urban Water Resilience

Urban stream degradation follows predictable patterns: hydrological alteration, nutrient enrichment, toxic loading, and biodiversity loss (Walsh *et al.*, 2005) ^[82]. Similar patterns have been documented in China's rapidly urbanizing basins, where freshwater biodiversity has sharply declined under compounded anthropogenic stress (Cao *et al.*, 2024; Dudgeon, 2024) ^[24, 33]. Yet large-scale policy interventions demonstrate that recovery is possible when governance mechanisms align with ecological restoration technologies.

China's national campaign targeting "black and odorous" urban waters integrated wastewater interception, sediment remediation, ecological bank restoration, and strict accountability frameworks (MOHURD, 2014; MEE, 2020). Ecological restoration technologies applied in urban rivers, including riparian re-vegetation, in-stream habitat enhancement, and wetland reconstruction, have demonstrably improved biodiversity indices and ecosystem functioning (Li *et al.*, 2022; Zhang *et al.*, 2022) ^[90].

Critically, recent empirical work from the Minjiang River Basin shows that ecological restoration can enhance

ecosystem stability when interventions are spatially coordinated and monitored through adaptive management (Du *et al.*, 2025). These findings underscore that restoration is not merely aesthetic improvement but a measurable shift in ecological resilience.

2. Constructed Wetlands and Nature-Based Infrastructure

Constructed wetlands have emerged globally as cost-effective systems for nutrient removal, heavy metal attenuation, and microbial load reduction in urban wastewater (Kadlec and Wallace, 2009 ^[49]; Wu *et al.*, 2015). Their sustainability depends on appropriate hydraulic loading rates, vegetation selection, and long-term maintenance (Wu *et al.*, 2015).

The "Sponge City" framework extends this logic by promoting infiltration-based green infrastructure that mimics natural hydrological processes (MOHURD, 2014). Sponge City design reduces surface runoff, enhances groundwater recharge, and improves pollutant interception before contaminants reach river channels (Ahmed *et al.*, 2024; Wang J. *et al.*, 2021) ^[12, 83]. Public communication has also highlighted its flood mitigation benefits in climate-vulnerable cities (Ruwitch, 2023) ^[77].

Given that Ibadan's drainage system is tightly coupled with flood dynamics, which have historically necessitated large-scale engineering responses (IUFMP, 2014), adopting sponge-based watershed retrofits could simultaneously address pollution, flood risk, and ecological degradation. Risk-dynamic modeling approaches further demonstrate that integrated flood and pollution management reduces systemic urban vulnerability (Zhao *et al.*, 2022) ^[93].

3. Governance Reform and Accountability Mechanisms

Technological solutions alone are insufficient without institutional accountability. China's River Chief System assigns named officials measurable responsibility for water quality outcomes and ecological indicators, significantly strengthening watershed governance (Wang, 2019; Wang B. *et al.*, 2021) ^[83]. Institutional analysis indicates that such systems improve cross-sector coordination and enforcement capacity (Wang B. *et al.*, 2021) ^[83].

Emerging eco-compensation mechanisms further incentivize upstream pollution control through inter-jurisdictional financial transfers (Cao and Chen, 2025; Xu *et al.*, 2025; Zhao *et al.*, 2025) ^[25, 92]. These mechanisms internalize environmental externalities and align economic incentives with ecological outcomes.

For Ibadan, where diffuse sources, including informal industry and unregulated waste discharge, contribute to contamination (Adedeji *et al.*, 2017; Odeleye and Idowu, 2015; Alabi *et al.*, 2024; Salaudeen *et al.*, 2018; Egbinola and Amanambu, 2014; Alfred, 2022 ^[6, 14, 18, 34, 63, 78]; Adetunji and Adetokun, 2011), governance reform must accompany infrastructural investments. Restoration must therefore be embedded in enforceable institutional frameworks rather than episodic environmental campaigns.

A Restoration Pathway for the Ona-Ogbere-Ogunpa Drainage Network

Restoration of Ibadan's urban drainage system requires an integrated socio-ecological strategy rooted in watershed thinking, pollution prevention, and community engagement.

Building on the global experiences and concepts outlined in Section 5, this section proposes a context-specific restoration pathway for the Ona-Ogbere-Ogunpa drainage network

1. Integrated Urban Water and Resource Nexus Approach

Water degradation in Ibadan intersects with food systems, energy use, climate vulnerability, and public health. Nexus-based approaches demonstrate that water productivity and environmental sustainability improve when water, food, and energy systems are co-managed rather than managed in isolation (Adebiyi *et al.*, 2021)^[4].

Organic waste streams from markets and abattoirs, currently the major contributors to elevated BOD and microbial contamination (Adekanmbi and Falodun, 2015; Dele-Alimi *et al.*, 2023)^[8, 28], could be redirected toward biogas production. China's extensive experience with livestock and agricultural waste-to-biogas systems illustrates how organic waste treatment can reduce pollution while generating renewable energy (Jiang *et al.*, 2011; Deng *et al.*, 2017; Wang Y. *et al.*, 2021; Du *et al.*, 2023^[29, 31, 45, 83]; Li *et al.*, 2016). Adapting decentralized anaerobic digestion systems in Ibadan would reduce organic loading into rivers, lower pathogen concentrations, produce usable biogas for peri-urban households, and convert digestate into safer agricultural inputs. Such circular-economy approaches align ecological restoration with economic productivity.

2. Pollution Source Control and Sediment Management

Heavy metal contamination in Ibadan's rivers has been documented for decades (Mombeshora *et al.*, 1981^[60]; Mombeshora *et al.*, 1983; Osibanjo *et al.*, 2011; Olayinka *et al.*, 2017)^[6, 61, 73] and remains evident in contemporary studies of Southwestern Nigerian rivers (Akinyemi *et al.*, 2014; Dele-Alimi *et al.*, 2023)^[13, 28]. Persistent sediment-bound metals require targeted remediation strategies, including dredging of hotspots or in-situ stabilization where feasible.

Surface runoff pollution control through sponge-based infiltration systems could significantly reduce diffuse contaminant transport (Ahmed *et al.*, 2024)^[12]. Satellite-based monitoring platforms, such as those accessible via the Copernicus Data Space Ecosystem (CDSE), offer additional capacity for tracking land-use change and watershed disturbance.

3. Public Health Integration

Water degradation in Ibadan has repeatedly manifested in public health crises, including documented cholera outbreaks (Vanguard, 2022; The Guardian, 2022)^[74] and reports linking river contamination to dysentery and sanitation failures (Ibitoye, 2025)^[40]. Groundwater vulnerability in shallow wells has also been established in Ibadan (Alabi *et al.*, 2024; Adedeji *et al.*, 2017; Odeleye and Idowu, 2015^[6, 14, 63]; Adetunji and Odetokun, 2011; Salaudeen *et al.*, 2018; Egbinola and Amanambu, 2014)^[34, 78].

Restoration, therefore, is not solely an ecological priority but a public health imperative. Improved river water quality reduces pathogen reservoirs, lowers disease transmission risk, and strengthens urban resilience against climate-amplified flood contamination events.

4. Institutional Accountability and Co-Management

A localized adaptation of the River Chief model (Wang, 2019) could formalize accountability within Oyo State's environmental governance framework. Clear performance benchmarks like dissolved oxygen thresholds, heavy metal reduction targets, and verified return of sensitive fish species should guide monitoring. Eco-compensation principles (Cao and Chen, 2025; Xu *et al.*, 2025)^[25] could further incentivize upstream pollution reduction within the broader Ogun basin. Community-based stewardship programs would complement formal governance. Historical evidence suggests Ibadan's rivers once supported livelihoods (Mabogunje, 1968; Mombeshora *et al.*, 1981)^[55, 60]. Revitalizing this social connection is essential for long-term compliance and cultural reintegration of rivers into urban life.

5. Baseline Ichthyofaunal Assessment and Long-Term Monitoring

A critical precondition for effective restoration of the Ona-Ogbere-Ogunpa drainage network is the establishment of robust baseline data on fish assemblages in each major stream segment (Huntsman *et al.*, 2022; Huntsman *et al.*, 2024)^[38, 39]. Despite scattered reports of fish presence in parts of the network, there is no coordinated, reach-by-reach inventory that systematically documents species composition, abundance, and functional traits across gradients of pollution and habitat modification (Theis *et al.*, 2024; Huntsman *et al.*, 2022; Huntsman *et al.*, 2024)^[38, 39, 81]. Targeted ichthyofaunal surveys by using standardized sampling protocols, replicated across seasons and along longitudinal transects of the Ona, Ogbere, and Ogunpa channels are therefore urgently needed to (i) confirm which native and non-native species persist (Huntsman *et al.*, 2022; Theis *et al.*, 2024)^[38, 81], (ii) identify potential source populations for natural recolonization (Lawson *et al.*, 2024)^[51], and (iii) define realistic biological endpoints for restoration interventions (Huntsman *et al.*, 2022)^[38]. Coupling these surveys with long-term monitoring frameworks and, where feasible, functional and genetic assessments would provide the empirical foundation for evaluating extinction risk, tracking recovery trajectories, and adapting management actions over time (Huntsman *et al.*, 2022)^[38].

Conclusion

This review evidently shows that the Ona-Ogbere-Ogunpa drainage network has crossed a critical ecological threshold: from a stressed but functioning river system to one characterized by sustained local extinction of native fish species and collapse of key trophic guilds. In contrast to other closely situated and regional rivers that still support diverse assemblages where pollution is less intense, Ibadan's urban streams now exhibit a combination of chronic organic and metal loading, severe hypoxia, habitat simplification, and recurrent chemical pulse disturbances that together preclude natural recolonization and lock the system into an ecologically silent state.

This localized extinction is not an anomaly but a stark expression of urban stream syndrome in a rapidly urbanizing tropical basin, mirroring global patterns in which degraded urban channels become biotic sinks rather than corridors for biodiversity. At the same time, international experience, especially large-scale restoration of "black and

odorous” urban rivers in China, demonstrates that even severely impaired systems can recover when pollution control, ecological engineering, and robust watershed governance are designed and implemented as an integrated whole.

Therefore, a strategic shift away from reactive desilting and episodic clean-up campaigns is necessary for Ibadan to achieve meaningful restoration. These basin-scale interventions should: (i.) drastically reduce organic and toxic inputs at the source, including through circular waste-to-energy schemes; (ii.) remediate contaminated sediments and restore hydraulic and habitat complexity; (iii.) use nature-based infrastructure and sponge-city style retrofits to reduce runoff and nonpoint pollution; and (iv.) integrate these measures into legally binding institutional arrangements with well-defined performance benchmarks for water quality, sediment toxicity, and biotic recovery. The presumed extinction of native fish species serves as a warning and a diagnostic tool in this regard, indicating the extent of systemic failure while also offering a specific, quantifiable endpoint for restoration. Realizing this benchmark will require not only pollution control and habitat rehabilitation but also systematic ichthyofaunal surveys of each major stream in the Ona-Ogbere-Ogunpa network to establish current species baselines, quantify local extinction, and rigorously track biological responses to restoration. The ultimate test of success will be the verified re-establishment of historically native fishes and associated trophic interactions, signaling that Ibadan’s rivers have been reclaimed as living socio-ecological infrastructure rather than sacrificed as permanent urban drains.

References

- Achi CG, Omoniyi AM, Coker AO, Sridhar MKC. Multivariate analysis of sediment quality in River Ogbere, Ibadan, South-West Nigeria. *H2Open Journal*,2021;4(1):1-11.
- Achi CG, Omoniyi AM, Coker AO. Distribution of selected toxic elements in water phases of River Ogbere, Ibadan, Nigeria. *Journal of Environmental Protection*,2021;12(7):429-437.
- Adebambo AAR. Fish species parasites: A review in Nigerian water bodies. *Journal of Research in Forestry, Wildlife and Environment*,2020;12(3):223-234.
- Adebiyi JA, Olabisi LS, Liu L, Jordan D. Water-food-energy-climate nexus and technology productivity: A Nigerian case study of organic leafy vegetable production. *Environment, Development and Sustainability*,2021;23(4):6128-6147.
- Adedeji JA, Bigon L. Cityscapes of hunting and fishing: Yoruba place-making and cultural heritage for a sustainable urban vision. *Sustainability*,2024;16(19):8494.
- Adedeji OH, Olayinka OO, Oladimeji O. Physicochemical and microbiological examination of hand-dug wells, boreholes and public water sources in selected areas of Ibadan, Nigeria. *Journal of Applied Sciences & Environmental Management*,2017;21(3):543-548.
- Adegbola IP, Aborisade BA, Adetutu A. Health risk assessment and heavy metal accumulation in fish species (*Clarias gariepinus* and *Sarotherodon melanotheron*) from industrially polluted Ogun and Eleyele Rivers, Nigeria. *Toxicology Reports*,2021;8(1):1445-1460.
- Adekanmbi AO, Falodun OI. Physicochemical, microbiological and heavy metal studies on water samples and bacteria obtained from Dandaru River in Ibadan, south-western Nigeria. *African Journal of Microbiology Research*,2015;9(20):1357-1365.
- Adeosun O, Adeosun F, Soyoye O. Fish species composition and distribution in fishing communities along Ogun River basin, southwest, Nigeria. *Journal of Agricultural Science and Environment*,2025;25(1):57-67.
- Adeyemo OK. Lead levels in rivers, sediments and fish ponds in the Ibadan metropolitan area, south-west Nigeria. *African Journal of Aquatic Science*,2007;32(2):153-157.
- Adetola JO, Olute BW. Fish composition of Oni River in Ogun Waterside Local Government Area, Ogun State. *The Nigerian Journal of Rural Extension and Development*,2012;6(1):50-55.
- Ahmed HG, Aziz SQ, Wu B, Ahmed MS, Jha K, Wang Z, *et al.* Application of Sponge City for controlling surface runoff pollution. *Asian Journal of Environment & Ecology*,2024;23(9):1-23.
- Akinyemi LP, Odunaike RK, Daniel DE, Alausa SK. Physico-chemical parameters and heavy metals concentrations in Eleyele River in Oyo State, south-west of Nigeria. *International Journal of Environmental Science and Toxicology Research*,2014;2(1):1-5.
- Alabi OS, Akintayo I, Odeyemi JS, Oloche JJ, Babalola CM, Nwimo C, *et al.* Suboptimal bacteriological quality of household water in municipal Ibadan, Nigeria. *American Journal of Tropical Medicine and Hygiene*,2024;110(2):346-354.
- Alabi WO. The urban-rural interface in Ibadan, 1900-1999 (Doctoral dissertation), 2021.
- Aladeojebi G. History of Yoruba land. Partridge Africa, 2016.
- Alagoa EJ, Derefaka AA. The land and people of Rivers State: Eastern Niger Delta. Onyoma Research Publications, 2002.
- Alfred O. Toxic chemicals pollute rivers, threaten lives, livelihood in Oyo communities. The Punch, 2022.
- Amabye TG, Semere T. Bioassay of lindane (Gamalin 20) to *Heterobranchus bidorsalis* juveniles. *Journal of Analytical & Bioanalytical Techniques*,2016;7(5):332.
- Ajayi OT, Salawu MB. Investigating fishers’ activities and management strategies of stakeholders of Eleyele Reservoir in Ibadan, Oyo State. n.d.
- Ayoade AA, Adoh DS. Environmental variables and benthic macroinvertebrates of Temidire Stream associated with an oil depot, Ibadan, southwest Nigeria. *The Zoologist*,2022;20(1):61-71.
- Ayoade AA, Olusegun AO. Impacts of effluents on the limnology of a tropical river, south-western Nigeria. *Journal of Applied Science & Environmental Management*,2012;16(2):201-207.
- Ayoade AA, Owolabi OM, Patience OT, Adeduntan OR, Kujooro P. Species diversity and catch per unit effort of fish in a perturbed tropical lake, Ibadan, Nigeria. *Academia Biology*,2024;2(1).
- Cao L, Shao W, Yi W, Zhang E. A review of conservation status of freshwater fish diversity in China. *Journal of Fish Biology*,2024;104(2):345-364.
- Cao Z, Chen X. Study of multi-stakeholder mechanism in inter-provincial river basin eco-compensation: Case

- of the inland rivers of eastern China. *Sustainability*,2025;17(15):7057.
26. Chen S, Guo C, Wang X, Wu Y, Wang Y, Wang Y, *et al.* Channelization and flow depletion shift benthic macroinvertebrate and fish communities in urban rivers. *PLOS ONE*,2025;20(7):0328843.
 27. Darwall WRT, Smith KG, Allen DJ, Holland RA, Harrison IJ, Brooks EGE, *et al.* Freshwater Key Biodiversity Areas in Africa. *IUCN*,2018;1(1):1-86.
 28. Dele Alimi TO, Ogunlowo V, Akpabio CA, Awobode HO, Anumudu CI. Physicochemical characteristics and heavy metals levels in surface waters from Aba-Ila, Ibadan, Oyo State, Nigeria. *Journal of Applied Sciences and Environmental Management*,2023;27(8):1779-1784.
 29. Deng L, Liu Y, Zheng D, Wang L, Pu X, Song L, *et al.* Application and development of biogas technology for the treatment of waste in China. *Renewable and Sustainable Energy Reviews*,2017;70(1):845-851.
 30. Du H, Wang J, Wang J, Liu B, Mu J, Zhang X, *et al.* Does ecological restoration really improve ecosystem stability? An empirical test based on the Minjiang River Basin of China, 2025.
 31. Du W, Wang J, Feng Y, Duan W, Wang Z, Chen Y, *et al.* Biomass as residential energy in China: Current status and future perspectives. *Renewable and Sustainable Energy Reviews*,2023;186(1):113657.
 32. Dudgeon D. Multiple threats imperil freshwater biodiversity in the Anthropocene. *Current Biology*,2019;29(19):R960-R967.
 33. Dudgeon D. Prospects for conserving freshwater fish biodiversity in the Anthropocene: A view from southern China. *Integrative Conservation*,2024;3(4):294-311.
 34. Egbinola CN, Amanambu AC. Groundwater contamination in Ibadan, south-west Nigeria. *SpringerPlus*,2014;3(1):448.
 35. Etim EU, Adie GU. Assessment of qualities of surface water, sediments and aquatic fish from selected major rivers in south-western Nigeria. *Research Journal of Environmental and Earth Sciences*,2012;4(12):1045-1051.
 36. Ezemonye L, Ogbomida TE. Histopathological effects of Gammalin 20 on African catfish (*Clarias gariepinus*). *Applied and Environmental Soil Science*,2010;2010(1):138019.
 37. Ganiyu SA. Concentrations and health risk valuation of possibly toxic metals in soil and sediment in parts of Ona River, Ibadan, Nigeria. *Nigerian Journal of Theoretical and Environmental Physics*,2024;2(2):104-117.
 38. Huntsman BM, Mahardja B, Bashevkin SM. Relative bias in catch among long-term fish monitoring surveys within the San Francisco Estuary. *San Francisco Estuary and Watershed Science*,2022;20(1):1-17.
 39. Huntsman BM, Palenscar K, Russell K, Mills B, Jones C, Ota W, *et al.* Evaluation of extinction risk for stream fishes within an urban riverscape using population viability analysis. *Aquatic Conservation: Marine and Freshwater Ecosystems*,2024;34(6):4164.
 40. Ibitoye P. Living in stench: Ibadan residents face cholera, dysentery, others over open defecation fields at Kudeti River. *Nigerian Tribune*, 2025.
 41. Ipinmoroti MO, Iyiola AO. Diversity, distribution and abundance of fish species in Lake Asejire, Oyo State, Nigeria. *The Zoologist*,2022;21(1):49-56.
 42. IUFMP. Ibadan Urban Flood Management Project: Integrated Flood Management Plan for Ibadan City [Project report]. Oyo State Government, 2014.
 43. IUFMP. An Update on the Ona River Channelisation, Ibadan. *FeedbackOYSG*, 2024.
 44. Iyiola AO, Izah SC, Morya SS, Akinsorotan AM, Ogwu MC. Owalla Reservoir in south-western Nigeria: Assessment of fish distribution, biological diversity, and water quality index. *Indonesian Journal of Agricultural Research*,2023;6(2):106-125.
 45. Jiang X, Sommer SG, Christensen KV. A review of the biogas industry in China. *Energy Policy*,2011;39(10):6073-6081.
 46. Juju Films. Ogunpa River Canal, Bode, Ibadan, Oyo, Nigeria. *Flickr*, 2018.
 47. Li K, Liu R, Sun C. A review of methane production from agricultural residues in China. *Renewable and Sustainable Energy Reviews*,2016;54(1):857-865.
 48. Li P, Li D, Sun X, Chu Z, Xia T, Zheng B, *et al.* Application of ecological restoration technologies for the improvement of biodiversity and ecosystem in the river. *Water*,2022;14(9):1402.
 49. Kadlec RH, Wallace SD. *Treatment wetlands* (2nd Ed.). CRC Press, 2009.
 50. Kareem OK, Oluwale FV, Olatunde AO. Ecomorphology and heterogeneity of fish species in Asejire Dam, Oyo State, Nigeria. *Ife Journal of Agriculture*, 2024, 36(2).
 51. Lawson L, Edge CB, Fortin MJ, Jackson DA. Temporal change in urban fish biodiversity - Gains, losses, and drivers of change. *Ecology and Evolution*,2024;14(2):10845.
 52. Li K, Liu R, Sun C. A review of methane production from agricultural residues in China. *Renewable and Sustainable Energy Reviews*,2016;54:857-865.
 53. Li P, Li D, Sun X, Chu Z, Xia T, Zheng B, *et al.* Application of ecological restoration technologies for the improvement of biodiversity and ecosystem in the river. *Water*,2022;14(9):1402.
 54. Lloyd PC. *The city of Ibadan*. Cambridge University Press, 1967.
 55. Mabogunje AL. *Urbanization in Nigeria*. University of London Press, 1968.
 56. MEE. (Ministry of Ecology and Environment, People's Republic of China). *Bulletin on the progress of the special campaign for the treatment of black and odorous water bodies in cities*, 2020.
 57. Michael JS. A historical diagnosis into the impacts of Ijebu migrants on Ibadan since, 1960. [Unpublished manuscript]. n.d.
 58. Modder-Oyefeso RA. Murder of Ogunpa Forest Reserve: A monumental environmental crime. For "Save Our Green Spaces Group" and "The Ogunpa Forest Reserve Team." *EnviroNews Nigeria*, 2024.
 59. MOHURD. (Ministry of Housing and Urban-Rural Development, People's Republic of China). *Technical guide for Sponge City construction - Construction of low impact development rainwater system*, 2014.
 60. Mombeshora C, Ajayi SO, Osibanjo O. Pollution studies on Nigerian rivers: Toxic heavy metal status of surface waters in Ibadan city. *Environment International*,1981;5(1):49-53.
 61. Mombeshora C, Osibanjo O, Ajayi SO. Pollution studies on Nigerian rivers: The onset of lead pollution

- of surface waters in Ibadan. *Environment International*,1983;9(2):81-84.
62. Mshelia ZH, Ode GO. Drainage morphometric analysis of Ogunpa, Ogbere and Ona basins in Ibadan, Oyo State, 2013.
 63. Odeleye FO, Idowu AO. Bacterial pathogens associated with hand-dug wells in Ibadan city, Nigeria. *African Journal of Microbiology Research*,2015;9(10):701-707.
 64. Oduola RO. Management and prevention of urban surface waters from pollution in Nigeria [Unpublished manuscript]. Ladoke Akintola University of Technology.
 65. Oladipo SO, Nneji LM, Iyiola OA, Nneji IC, Ayoola AO, Adelakun KM, *et al.* Patterns of ichthyofaunal diversity and distribution across Jebba hydro-electric power dam, Jebba, north-central Nigeria. *Brazilian Journal of Biology*,2021;81(2):258-267.
 66. Olanrewaju AN, Ajani EK, Kareem OK. Physico-chemical status of Eleyele Reservoir, Ibadan, Nigeria. *Journal of Aquaculture Research & Development*,2017;8(1):512.
 67. Olaniyi R. Economic history of Ibadan, 1830-1930. Institute of African Studies, 2015.
 68. Olayinka OO, Adedeji HO, Akinyemi AA, Oresanya OJ. Assessment of the pollution status of Eleyele Lake, Ibadan, Oyo State, Nigeria. *Journal of Health & Pollution*,2017;7(15):51-61.
 69. Oluah NS, Ezigbo JC, Anya NC. Effect of exposure to sublethal concentrations of Gammalin 20 and Actellic 25EC on the liver and serum lactate dehydrogenase activity in the fish *Clarias albopunctatus*. *Animal Research International*,2005;2(1):231-234.
 70. Omoike A. The trend in fish species diversity and abundance at Asejire Reservoir, south-western Nigeria. *Journal of Aquaculture & Fisheries*,2021;5(1):040.
 71. Omotosho JS. Fish: Their prize and pain (174th Inaugural Lecture). University of Ilorin, 1987.
 72. Oribhabor BJ. Impact of human activities on biodiversity in Nigerian aquatic ecosystems. *Science International*,2016;4(1):12-20.
 73. Osibanjo O, Daso AP, Gbadebo AM. The impact of industries on surface water quality of River Ona and River Alaro in Oluyole Industrial Estate, Ibadan, Nigeria. *African Journal of Biotechnology*,2011;10(4):696-702.
 74. The Guardian. Oyo records 11 cholera deaths, 50 suspected cases. *The Guardian*, 2022.
 75. Premium Times. Residents panic as “blood-like” water flows in Ibadan community. *Premium Times*, 2021.
 76. Rieck LO, Sullivan SMP. Coupled fish-hydrogeomorphic responses to urbanization in streams of Columbus, Ohio, USA. *PLOS ONE*,2020;15(6):0234303.
 77. Ruwitch J. Making cities “spongy” could help fight flooding — by steering the water underground. *NPR*, 2023.
 78. Salaudeen IA, Ogunbamowo P, Rasheed-Adeleke AA, Olaniyi AA. Assessment of heavy metals and microbial load of groundwater samples from Ibadan metropolis, Nigeria. *Pollution*,2018;4(3):429-438.
 79. Sogbesan OA, Kwaji BP. Sustainable artisanal fisheries practices in Nigeria. *Oceanography & Fisheries Open Access Journal*,2018;6(1):555677.
 80. Sunday JS, Sowunmi AA, Akomolafe IR, Jibiri NN. Evaluation of radiological risks from radionuclides in fish and sediment of Eleyele Reservoir, Ibadan, Nigeria. *Environmental Health Insights*,2025;19(1):11786302251347017.
 81. Theis S, Chreston A, Wallace A, Graham B, Coey B, Little D, *et al.* Nearshore fish community changes along the Toronto waterfront in accordance with management and restoration goals: Insights from two decades of monitoring. *PLOS ONE*,2024;19(2):0298333.
 82. Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP, *et al.* The urban stream syndrome: Current knowledge and the search for a cure. *Journal of the North American Benthological Society*,2005;24(3):706-723.
 83. Wang B, Wan J, Zhu Y. River chief system: An institutional analysis to address watershed governance in China. *Water Policy*,2021;23(6):1435-1444.
 84. Wang J, Huang J. Full-scale field study of using geofam to reduce earth pressures on buried concrete culverts. *Geotextiles and Geomembranes*,2021;49(5):1355-1367.
 85. Wang J, Xue F, Jing R, Lu Q, Huang Y, Sun X, *et al.* Regenerating Sponge City to Sponge Watershed through an innovative framework for urban water resilience. *Sustainability*,2021;13(10):5358.
 86. Wang Y, Zhang Y, Li J, Lin JG, Zhang N, Cao W. Biogas energy generated from livestock manure in China: Current situation and future trends. *Journal of Environmental Management*,2021;297(1):113324.
 87. Wu H, Zhang J, Ngo HH, Guo W, Hu Z, Liang S, *et al.* A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. *Bioresource Technology*,2015;175(1):594-601.
 88. Wuraola OB, Adetola JO. Assessment of fish biodiversity in Oni River, Ogun State, Nigeria. *International Journal of Agricultural Management and Development*,2011;1(4):107-113.
 89. Xu H, Li G, Chen B. Cross-basin horizontal eco-compensation policy and enterprise pollution emissions: Evidence from the Xin’an River Basin in China. *Chinese Public Administration Review*,2025;16(4):286-301.
 90. Zhang J, Ma J, Zhang Z, He B, Zhang Y, Su L, *et al.* Initial ecological restoration assessment of an urban river in the subtropical region in China. *Science of the Total Environment*,2022;838(1):156156.
 91. Zhang X, Huang S, Hu Y, Li G, Li W, Yang S, *et al.* Integrative approaches to river ecosystem assessment and restoration: A review of methodologies and strategies for coherent implementation. *Environmental Monitoring and Assessment*,2026;198(2):139.
 92. Zhao G, Tian S, Chen R, Cao Y, Chang J, Wang W, *et al.* Study on the ecosystem service value and inter-basin ecological compensation between provinces in China. *Water Policy*,2025;27(1):118-140.
 93. Zhao H, Li Z, Zhang J. Establishing a risk dynamic evolution model to predict and solve the problem of urban flood disaster. *Environmental Science and Pollution Research*,2022;29(35):53522-53539.
 94. Zhou Q, Yang N, Li Y, Ren B, Ding X, Bian H, *et al.* Total concentrations and sources of heavy metal pollution in global river and lake water bodies from 1972 to 2017. *Global Ecology and Conservation*,2020;22(1):00925.