World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

Check for updates

Disappeared Streams: Causes, Implications and Mitigations: A case study of Akwa Ibom State, Nigeria

Emmanuel Anietie Essien [1, *], Aniefiokmkpong Okokon Okon [1], Enenwan Precious Udoinyang [1], Godwin Asukwo Ebong [2], Imaobong Daniel Ekwere [2], Sandra Gogo Okere [3] and Anthony William Akpan [1]

[1] *Department of Animal and Environmental Biology, Faculty of Biological Science, University of Uyo, Akwa Ibom State, Nigeria.*
[2] *Department of Chemistry, Faculty of Physical Science, University of Uyo, Akwa Ibom State, Nigeria.*
[3] *Department of Environmental Health Science, School of Health Technology, Federal University of Technology, Owerri, Imo State, Nigeria.*

World Journal of Advanced Research and Reviews, 2025, 27(01), 599-619

Publication history: Received on 12 May 2025; revised on 28 June 2025; accepted on 30 June 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.1.2390

Abstract

Streams are vital components of ecosystems, supporting the survival of plants, animals, and humans. This study utilized an extensive review of literature from both online and offline sources to understand the causes and consequences of stream shrinkage and disappearance. Findings from international and local contexts, including Akwa Ibom State, revealed that both natural and human-induced factors contribute to this decline. Natural causes include climate change, erosion-induced siltation, changes in rainfall patterns, and prolonged droughts. Human activities such as urbanization, industrial expansion, poor waste disposal, pollution, over-irrigation, and dam construction further exacerbate stream depletion. The disappearance of streams has broad implications. Ecologically, it results in biodiversity loss, riparian zone degradation, and destruction of aquatic habitats. Economically, it raises production costs for agriculture and fisheries. Socially, it leads to community displacement, increased resource conflicts, reduced water supply, and loss of cultural and recreational benefits, along with heightened flood risk. To combat these issues, the review highlights the importance of mitigation strategies including reforestation, establishment of riparian buffer zones, effective pollution control, sustainable legal frameworks, and community participation. Successful global and local initiatives such as the Ganga Action Plan (India), Elwha River dam removal (USA), and sustainable water policies in the Hadjie Naguru Wetlands (Nigeria) underscore the effectiveness of integrated water management. The study emphasizes the urgent need for collaborative efforts from governments, NGOs, researchers, and communities. It recommends integrating these strategies with stakeholder involvement and encourages geographers to map vanished and existing streams using GIS for future reference.

Keywords: Streams Losses; Causes; Implication; Corrective Measures

1. Introduction

Stream is a long watercourse that flows down a slope along a bed between banks. It originates from a 'source' and culminates to a sea or lake at its 'mouth'. Along its length, it may be joined by other streams called 'tributaries' (NC DWQ, 2003). A stream is a continuous flow of water within a natural channel. Streams play a crucial role in shaping landscapes, supporting biodiversity, and serving human needs (Gordon *et al*., 2013). A stream, defined as anybody of flowing water confined within a channel regardless of size, flows downhill through local topographic lows, carrying water across the earth's surface; its flow is controlled by three main inputs: surface runoff from precipitation or meltwater, daylighted subterranean water, and surfaced groundwater such as spring water (NC DWQ, 2003; US EPA, 2013).

* Corresponding author: Essien, E. A

Streams have historically been essential for human settlement, agriculture, and industry. They provide freshwater for drinking, irrigation, and hydroelectric power generation (Poff *et al*., 1997). However, various factors such as habitat degradation, urbanization and deforestation, road expansion, pollution, exotic species, habitat fragmentation, and climate change threaten stream health, water quality and waterway construction, have accelerated biodiversity loss in stream ecosystems (Reid *et al*., 2019; Akpabio *et al.,* 2024). Additionally, the construction of dams, water diversions for irrigation and industrial purposes can alter the natural flow regimes, converting perennial streams into intermittent ones (Döll and Schmied, 2012).

Only 2.5% of water on the Earth is fresh water, and water demand already exceeds supply in many parts of the world (IPCC, 2022). Virtually all humans require fresh water (Chartres and Varma, 2010). According to Vörösmarty *et al.,* 2010), streams cover about 0.8% of the Earth's surface, but deliver many critical goods and services to human beings. The world's available water supply from streams is also distributed unevenly around the globe due to the facts that some streams are disappearing (Udoidiong, 1999; Dudgeon *et al*., 2005). Streams defend against floods, remove contaminants, and recycle nutrients that are potentially dangerous as well as provide food and habitat for many aquatic flora and fauna. Such streams also play a vital role in preserving our drinking water quality and supply, ensuring a steady flow of water to surface waters and helping to restore deep aquifers, prevent erosion, recharge groundwater, reduce pollution and protect wildlife habitat, (US EPA, 2013).

Streams are classified based on their flow characteristics and the duration for which they carry water. The three primary types of streams are perennial which flows continuously all year, ephemeral streams flow only during and immediately after precipitation (MDEP, 2009; Leopold *et al*., 2019) and the intermittent (or seasonal) streams fill up a portion of land quickly during rains and flow for only part of the year (NC DWQ, 2003).

Disappearing streams, also known as sinking streams or losing streams, are unique hydrological features where surface water flow vanishes into the ground, typically through sinkholes or fractures in limestone bedrock (Ford and Williams, 2013). These streams play a crucial role in karst landscapes, where underground drainage systems dominate over surface water channels (White, 2019). Unlike typical surface streams that flow continuously to larger bodies of water, disappearing streams contribute to groundwater recharge, feeding underground rivers and aquifers (Kresic and Stevanovic, 2010). Some authors referred disappearing streams as streams that reduce in width and breadth as it flows along river course. There are streams that decrease in size over time. There are popularly described as disappearing streams (Paul, 2021). Dry streambeds are defined as the channels of temporary streams during the dry phase that can be exposed during periods of drought (Paul, 2021).

These streams are prevalent worldwide, particularly in arid and semi-arid regions, and their occurrence is increasing due to both natural and anthropogenic factors (Datry *et al*., 2014). The occurrence of disappearing streams is closely associated with geological formations, particularly karst topographies, which are characterized by soluble rock formations such as limestone and dolomite (Palmer, 2024).

Aquatic ecosystems are disrupted, leading to loss of biodiversity as species dependent on consistent water flow struggle to survive in altered habitats (Moyle, 2013). Terrestrial ecosystems adjacent to these streams are also affected due to changes in soil moisture and vegetation patterns. Moreover, the loss of perennial streams can impact human communities by reducing water availability for domestic and agricultural use, thereby affecting livelihoods and food security (Brooks *et al*., 2013).

2. Case studies

2.1. International Cases

Goldbaum (2015) reported on disappearing lakes and stream and referred them as ‘’disappearing stream’’ because of their reduction in depth, breadth and width.

In Colorado, the headwaters for much of the United States, is one of the fastest growing states in terms of both population and land development. These land use changes are impacting jurisdictional streams, and thus require compensatory stream mitigation via environmental restoration. In this article, we first characterize current demand and supply for stream mitigation for the entire state of Colorado. Second, we assess future demand by forecasting and mapping the lengths of streams that will likely be impacted by specific development and land use changes. Third, based on our interviews with experts, stakeholders, resource managers, and regulators, we provide insight on how regulatory climate, challenges, and water resource developments may influence demand for stream mitigation. From geospatial analyses of permit data, we found that there is currently demand for compensatory stream mitigation in 13 of the 89

HUC-8 watersheds across Colorado. Permanent riverine impacts from 2012–2017 requiring compensatory mitigation totalled 38,292 linear feet (LF). The supply of stream mitigation credits falls well short of this demand. There has only been one approved stream mitigation bank in Colorado, supplying only 2539 LF credits. Based on our analyses of future growth and development in Colorado, there will be relatively high demand for stream mitigation credits in the next 5–10 years. While most of these impacts will be around the Denver metropolitan area, we identified some new areas of the state that will experience high demand for stream mitigation. Given regulatory agencies stated preference for mitigation banks, the high demand for stream mitigation credits, and the short supply of stream credits, there should be an active market for stream mitigation banks in Colorado. However, there are some key obstacles preventing this market from moving forward, with permanent water rights' acquisitions at the top of the list. Ensuring stream mitigation compliance is essential for restoring and maintaining the chemical, physical, and biological integrity of stream systems in Colorado and beyond (Julian *et al.,* 2015).

Disappeared streams were identified in the Portland, Oregon metropolitan area using historical topographic maps for four time periods, and related them to the history of urban development. The historical maps were used to identify streams visible in older maps but not shown in a more recent version. From 1852 to 1895, 15% of streams disappeared, but the majority of streams disappeared between 1896 and 1953 (65%). This trend continued mainly in suburban areas after 1954 with 12% of streams being removed from 1954 to 1989 and 8% from 1990 to 2017. Stream disappearance can be linked to residential development and prior conversion of land for agriculture depending on the area and time period. Mapping disappeared streams can help urbans partial planners identify where stream day lighting or restoration could be targeted (Post *et al.,* 2022).

The majority (65%) of identified stream length loss occurred between the years 1896–1953. Many houses built on these disappeared streams were likely constructed many years after the stream was removed (Post *et al.,* 2022). Just like a stream in Ibeno where a family house is currently residing (Field Source, 2024). - A possible explanation is that the stream was first removed for agriculture, and the same land was later developed into housing (Han *et al*., 2020; Julian *et al*., 2015).

The highest density of disappeared streams occurred in areas where the average house was constructed between 1954 and 1989. However, further development period (1990-2017) has a low density of disappeared streams. This low density of disappeared streams is likely attributed to either newstorm water management practices that minimize the alteration of existing streams or stream restoration efforts that result in daylighting covered streams (Fahy and Chang, 2019)

There are many potential benefits of day lighting urban streams since they provide multiple ecosystem services (Yeakley *et al.,* 2016). Streams in urban environments reduce nutrient pollution (Beaulieu *et al.*, 2015), support wildlife and biodiversity in and around the streams (Meyer *et al.,* 2007), and offer aesthetic value to residents and visitors (Kenney *et al.,* 2012).

A major study of 900 rivers published in the American Meteorological Society's (AMS) Journal of Climate in 2009 concluded that flows into the oceans have decreased significantly over the last 50 years, with that trend predicted to continue (Garcia, 2008).

Striving for an integrated semi-natural stream-floodplain system as restoration target would optimally serve biodiversity and the provisioning of ecosystem services. This pursuit is currently limited by multiple pressures and constraints that come with, amongst others, a high human population density and intensive land-use. To be able to weigh the ecological and societal needs in lowland-stream watersheds, we analysed the developments in lowland-stream restoration in relation to the actual and potential state of ecosystems services these systems provide. To reach an ecological-societal balance in stream restoration, five steps were posed, which included: (i) Choose a clear and realistic restoration target, (ii) Map and quantify environmental stressors at local to watershed scale, (iii) Map and quantify biological indicators at local to regional scale, (iv) List potential restoration measures to remove or mitigate stressors, and (v) Build scenarios, composed of combinations of measures fitting the societal context of the watershed. The most promising scenarios make use of watershed processes and involve establishing a transverse landscape zonation, from the streams' riparian zone to the uplands. Such landscape transition poses a challenge for policy makers and implies a strong societal change. Therefore, a framework is provided with building blocks that help to find a suitable balance in practice (Verdonschot and Verdonschot, 2023).

There is inconsistent evidence that stream restoration projects lead to recovery of ecosystem attributes, especially stream biota. While some assessments have documented desired changes in fish community metrics in the first years following restoration, longer-term studies have not always corroborated these findings. In this study, we used data and monitoring reports submitted to federal regulators by stream mitigation consultants to examine whether in-stream restoration activities led to changes in fish community attributes at 23 compensatory mitigation projects representing 53 sampling sites in Georgia, United States over 7 years of post-restoration monitoring. Modeling results indicated that abundance and species richness of fishes generally increased in the first years after restoration before decreasing to baseline levels by the seventh year. This pattern was consistent for models considering sensitive fish taxa, as well as at sites across a range of agricultural and forested land cover percentages. However, the effect of restoration on species richness was dampened in larger streams and at more urbanized locations. A community trajectory analysis supported the findings that fish community change was transitory at most sites. Remote estimation of canopy cover change at restoration sites suggested that the hump-shaped response may be driven by increased light availability during the immediate-post restoration period, followed by subsequent re-shading of stream channels by riparian plantings. Our analysis indicates that reach-level manipulation of streams should not be expected to induce long-term changes in fish communities, and that publicly available monitoring reports may be leveraged to address questions of stream restoration efficacy (Stowe *et al.,* 2023). Lettenmaier *et al.* (1999) and Paul (2021) reported that changes in precipitation have a stronger influence on runoff. Park et. al. (2011) assessed the future of climate change impacts on water quantity and quality for a mountainous dam watershed in South Korea using SWAT. The impacts of projected future climate change scenarios on evapotranspiration, groundwater recharge, and streamflow were increases of +23.1%, +28.1%, and +39.8%, respectively.

Disappeared streams have been mapped in in conjunction with sewage lines in Pittsburgh, Pennsylvania (Hopkins and Bain, 2018). Hence, Streamflow was positively related to precipitation but negatively related to temperature, with the annual percentage departure of streamflow greater than the annual percentage departure of temperature. Thus, streamflow was more sensitive to temperature changes when precipitation increased (Paul, 2021) **-** It usually increased with temperature as precipitation decreased, and decreased with temperature as precipitation increased.

Paul (2021) reported that 22% of the total rivers are disappearing in the study area, with additional 38% shrinking at an alarming rate. Chen *et. al.* (2011) conducted a study of the hydrological impacts of climate change for a Canadian Watershed. Results from the study demonstrate that climate change has contributed to the increase of shrinking and disappearance of streams in the watershed by 46%.

2.2. Local Cases (Akwa Ibom State, Nigeria)

It was necessary to ascertain the extent of stream disappearance in the middle Enyong basin in Akwa Ibom State, Nigeria basin. A study was based on the collection of data for morphometric analysis as well as adopting quantitative analysis to determine depth and width of streams in 2016 and then qualitative method of PRA and oral testimony to get depth and width of streams in 1966. Drainage density dropped by –3.7% signifying that percentage drop of drainage density is low. The percentage change in morphometric parameters of the basin between 1966 and 2016 showed that change had occurred in the basin with less impact factor. Stream number dropped by -10.94%, that is, from 64 to 57 between 1966 and 2016. That meant 7 streams had disappeared. Direct proportion showed that about 14 streams will be disappearing in one hundred years to come. ANOVA was used to test the significant difference in the extent of stream disappearance between 1966 and 2016. The test of hypothesis one showed that there was no significant variation in the extent of stream disappearance between 1966 and 2016 in the basin. Testing hypothesis two showed that there was significant difference in disappearance of various streams in the basin. It has been recommended that proactive measures such as dredging of streams be considered at this early stage of disappearance because it will be cost effective than mature stage (Udofia and Udofia, 2018).

Table 1 Villages and streams of Ibom sub-basin of Enyong Creek sampled (Udofia and Udofia, 2018)

Parameters	As at 1966	As at 2016	% Change
Stream number (Nu)	64	57	-10.94
Stream length (Lu)	113.81	109.75	-3.57
Stream frequency (Fs)	0.46	0.41	–10.87

Table 2 Villages, their streams and variations in Depth and Width between 1966 and 2016 of Ibom sub-basin of Enyong Creek sampled (Udofia and Udofia, 2018)

Villages	Streams	L.G.A.	1966		2016	
			Depth	Width	Depth	Width
Nk wot Ikot Imo	Ibom	Ikono	40	37	17	30
Nk wot Ikot Esen	Urua Uko	Ikono	1.9	3	0.6	2
UkpomIbakachi	Otime	Ikono	3.8	3.8	1.6	3
Aba ItiatUkwok	Okon	Ini	5	5.3	2	4.1
Ikot Iduot Ukwok	Afia	Ini	3	3.9	0.7	3.6
Ikot Ekpe	Adiaha Eka	Ibiono Ibom	0.9	1.4	0.3	1.3

2.3. In a space of 50 years, 7 streams have been lost

Based on the above tabulated results from Udofia and Udofia (2018) conducted a morphometric analysis of disappearing streams and its implications for water resources utilization and management in middle Enyong Basin and showed the disappearance of 5 streams in the Ibom sub-basin,

It was a small excavated portion that erupts water alongside rain water and gathered water from its environs and stores it there which the community uses for their domestic activity. For a few years now, the water level has gone extremely low. However, the water from the ground would provide water enough to swim in, water clothes and farming activities. In fact, currently it serves as a fortified portion for plantation of vegetables and palm trees. - Ete Ikpe Isung Mmakara (Field Source, 2024).

Figure 1 A stream named Idim Afia in Iwuo-Achang in Ibeno, Akwa Ibom State (A) where a family house is currently situated (B) currently undergoing road construction (Field Source, 2024)

Abubakar *et al.* (2013) defined drought as the protracted absence, deficient or poor distribution of precipitation. It is as an extended period – a season, a year, or several years – of deficient rainfall relative to the long-term average rainfall for a region. It is the inability of rainfall to meet the Evapo-transpiration demands of crops resulting in general water stress and crop failures. Rainfall in the Nigerian Sudano –Sahelian region is characterized by considerable fluctuations and periods of diminishing annual totals especially in recent years. Drought or dry spells at the beginning or end of the season had a constant reoccurrence decimal since the beginning of the 20th century. The underlying cause of most droughts can be related to changing weather patterns such as low rainfall, reduced cloud cover and greater evaporation rates which are exacerbated by human activities such as deforestation, bush burning, overgrazing and poor cropping methods, which reduce water retention of the soil. The impacts of drought are mass starvation, famine and cessation of economic activity especially in areas where agriculture is the main stay of the economy. It was reported that drought is the major cause of forced human migration and environmental refugees, deadly conflicts over the use of dwindling natural resources, food insecurity and starvation, destruction of critical habitats and loss of biological diversity, socio-economic instability, poverty and climatic variability through reduced carbon sequestration potential. The impact of drought could be reduced through irrigation, use of drought tolerant and early and extra early maturing varieties, reduction of postharvest crop losses, increased fisheries and micro-livestock production and strategic grain storage.

Figure 2 Different sites of Gekko stream in EkambaNsukara Offot, Uyo Akwa Ibom State, where most of the space have been largely used as farm lands (Field Source, 2024). A- showing a shrank stream, B - showing refuse dumb along the stream path, C - artificial water collection and D - farmers fetching water

Figure 3 Different sites of angles of Ete Ikpe Isung Mmakara in Ukanafun LGA, Akwa Ibom State is currently a rich portion for palm trees and palm wine (Field Source, 2024); A, B and C water pathway collected to a reservoir; D - the Reservoir

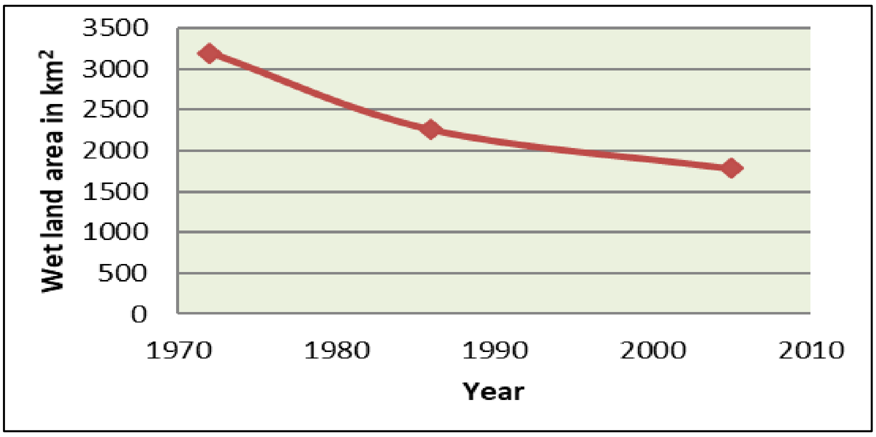

Figure 4 Trend of wetlands shrinkage in Hadejia-Nguru Wetlands (Yobe State, Nigeria) between 1972 and 2005 (The SMEC Group, 2019)

Table 3 Villages and streams of Ibom sub-basin of Enyong Creek sampled (Udofia and Udofia, 2018)

Parameters	As of 1966	As at 2016	% Change
Stream number (Nu)	64	57	-10.94
Stream length (Lu)	113.81	109.75	-3.57
Stream frequency (Fs)	0.46	0.41	–10.87

Table 4 Villages and streams of Ibom sub-basin of Enyong Creek sampled (Udofia and Udofia, 2018)

Villages	Streams	L.G.A.	1966		2016	
			Depth	Width	Depth	Width
Nkwot Ikot Imo	Ibom	Ikono	40	37	17	30
Aba Itiat Ukwok	Okon	Ini	5	5.3	2	4.1
Ikot Iduot Ukwok	Afia	Ini	3	3.9	0.7	3.6
Nkwot Ikot Esen	Urua Uko	Ikono	1.9	3	0.6	2
Ikot Ekpe	Adiaha Eka	Ibiono Ibom	0.9	1.4	0.3	1.3
UkpomI bakachi	Otime	Ikono	3.8	3.8	1.6	3

Figure 5 Different sizes of disappearing stream in Nduetong Oku, Uyo, Akwa Ibom State (Field Data, 2025)

3. Causes of disappearing streams

3.1. Human made causes

3.1.1. Installation of dam

Azad et at., (2020) reported 47% respondents (male- 52% and female- 42%) responded in favour of the installation of dam for drying up of the Bhairab River; 24% (male- 24%% and female- 25%) gave a negative opinion and rest 29% (male- 24% and female- 33%) had no opinion in terms of installation of dam as the cause for river dry. Misra (2010) worked on River Yamuna and identified one of the most polluted rivers of India. The barrages formed on the river were playing a major role in escalating the river pollution. Normally no water was allowed to flow downstream of the Himalayan segment (Tejewala barrage) especially in the summer and winter seasons. Freshwater input to estuaries might be greatly altered by the river-barrages and prevent saltwater intrusion. Moreover, a new type of salt plug formation in the multi-channel Pasur River Estuary (PRE) was discovered to cause by decreasing river discharges resulting from an upstream barrage (Shaha and Cho, 2016). That means the installation of dam might cause river dry.

Figure 6 Hydraulic components of the floodwater spreading system in India; A- diversion dam, B - conveyance channel, C - spreader/conveyor spreader channel and D - water gateway (Glendenning and Vervoort, 2011)

3.2. Establishment of bridge

Figure 7 An overhead bridge on astream body from Obot Idim, Nsit Ibom L.G.A. area, Akwa Ibom State (Field Data, 2024)

A study reported 78% respondents (male 86% and female 71%) supported the establishment of bridge for drying river, 11% (male 10% and female 12%) denied and rest 11% (male 4% and female 17%) didn't give any opinion regarding bridge as the cause of drying up of river. Sengupta (2006) studied on heavy metals at Nizamuddin bridge in the Yamuna River and found the presence of Cadmium, Nickel, Iron, Zinc and Chromium at Nizamuddin bridge, whereas the maximum concentration of Aldrin of 213.41 µg/L, Dieldrin of 50.85 µg/L and Endosulfan of 4591.08 µg/L at Nizamuddin bridge (Azad *et at.,* 2020). Islam *et al.* (2017) assessed on the environmental impact of Lebukhali bridge construction project over the river of Paira, Bangladesh and found that there were no significantly sensitive ecological, physicochemical, socio-cultural impacts in the area. The environmental impact value was estimated +2 (Positive two), which showed the acceptance of this project. That means establishment of bridge might perform river dry.

- **Excessive irrigation in agricultural land:** According to (Azad *et at.,* 2020), 64% participators (male -81% and female 50%) supported, whereas, denied participants were 29% (male 14% and female 42%) as well as 7 % (male 5% and female 8%) didn't give any opinion in terms of excessive irrigation in agricultural land for drying up of river. Many perennial watercourses converted into temporary flow due to the effects of water extraction for human use or as a result of changes in land use (Steward *et al.,* 2012). Besides, the TajMahal situated on the bank of Yamuna River had been reduced to a pale and stinking drain due to its irregular available water treatment facilities. During dry weather, the flow of Yamuna River consisted almost entirely of polluted effluents which resulted in the death of thousands of fishes over the TajMahal area along the water body (Verma, 2002). River dry might be executed due to excessive irrigation in agricultural land.
- **Streams Feeding Lake Chad:** Okpara *et al.,* (2015) reported over-extraction of water for agriculture and desertification as a threat in the Northeastern Nigeria (Borno and Yobe States). Streams feeding into Lake Chad, such as the Yedseram and Ngadda Rivers, have disappeared or drastically reduced in flow. This has exacerbated the shrinkage of Lake Chad, reducing water availability for millions of people across four countries. Farmers and herders in Nigeria's Northeastern region face significant livelihood challenges, driving migration and conflicts.

- **Use of chemicals, pesticides, industrial effluents etc.:** Results from questionnaire interview, 64% respondents (male- 71% and female- 58%) gave positive opinion in favour of using of chemicals, pesticides, industrial effluents for drying up of the Bhairab River; 31% (male- 24% and female- 38%) gave negative opinion and rest 5% (male- 5% and female- 4%) had no opinion. The Karnafuli River received huge number of untreated effluents from various industries. So, the environment of the River Karnafuli was getting polluted. The Yamuna had been reduced to a small stream due to drainage of industrial effluents, sewage, dirt and other toxic substances (Misra, 2010). The exceeded level of bioaccumulation of some heavy metals (Ahmed *et al*., 2012) was found in a freshwater fish Ayre (Hamilton, 1822) collected from Rajfulbaria of Dhaleshwari river due to solid residue from the iron ore processing at the headwaters of the Doce River basin (Pires *et al*., 2003). Also, Essien *et al.,* (2025) reported heavy metals in fish collected from Oron River, Akwa Ibo State Nigeria. These might decrease the water flow of river. River dry might be performed due to use of chemicals, pesticides, industrial effluents etc.
- **Irresponsible management of fishing:** Azad *et at.,* (2012) reported 73% respondents (male- 71% and female- 75%) gave positive opinion in favor of using of chemicals, pesticides, industrial effluents for drying river; 9% (male- 5% and female- 12%) gave negative opinion and other 18% (male- 24% and female- 13%) had no opinion in terms of irresponsible management of fishing as the cause for drying up of the river. The lack of proper drainage systems, adequate sanitation facilities and waste management facilities increased the vulnerability of those communities during hazards (Alam*et al.,* 2016). Human disturbances such as the irrigation and storage of water in reservoirs did not play a decisive role, they accelerated the degradation (Steward *et al*., 2012). Moreover, other irresponsible management of fishing such as excessive fishing from rivers, catching brood fish and fry, reducing the biodiversity of rivers might lead to the drying of the Bhairab River. River dry might be performed due to irresponsible management of fishing.

3.2.1. Urbanization

Urbanization in Lagos has significantly altered the natural landscape, leading to the disappearance of urban streams and the intensification of urban heat island (UHI) effects. Bassett *et al*. (2020) argue that as these streams are lost due to land reclamation, pollution, and infrastructural development, the ability of natural water bodies to regulate temperature through evaporative cooling is diminished. Water bodies typically absorb and store heat during the day and release it slowly at night, moderating temperature fluctuations (Oke*et al*., 2017). However, the removal of streams has reduced this natural cooling mechanism, leading to increased surface temperatures, especially in densely populated areas.

Studies have shown that urban areas without sufficient green and blue spaces experience temperature rises of up to 5°C higher than surrounding rural regions due to the UHI effect (Akbari *et al*., 2016). The disappearance of urban streams in Lagos has exacerbated this problem, leading to prolonged heat waves and discomfort for residents, particularly those in low-income areas where access to cooling systems is limited (Adegun and Adedeji, 2021). This highlights the urgent need for sustainable urban planning that integrates stream conservation into climate adaptation strategies.

The loss of urban streams in Lagos has also contributed to a sharp rise in energy consumption for cooling systems. Bassett *et al*. (2020) report that areas experiencing significant stream disappearance have witnessed an increase in the use of air conditioning and other cooling technologies, placing additional strain on Lagos' already overburdened energy grid. The increased demand for electricity has resulted in higher costs for both households and businesses, exacerbating economic disparities between different socio-economic groups (Nwokoro and Okusipe, 2020).

Furthermore, excessive reliance on air conditioning has contributed to higher greenhouse gas emissions, further aggravating climate change challenges in Lagos (Ajayi *et al*., 2019). The lack of natural cooling from urban streams means that residents must rely on artificial means to maintain comfortable indoor temperatures, leading to a vicious cycle of increased energy consumption and environmental degradation. As a result, experts advocate for the restoration and preservation of urban water bodies as a cost-effective and environmentally sustainable solution to mitigate heat stress and reduce energy demands in Lagos (Ogunjobi and Adeyemi, 2022).

3.3. Natural causes

- **Climate change:** A study revealed 65% respondents (male- 76% and female- 54%) supported the climate change for drying river, 24% (male- 14% and female- 33%) refused and the rest 11% (male- 10% and female- 13%) had no opinion in respect of climate change as the cause for drying up of the Bhairab River. Many perennial watercourses turned into temporary flow regimes due to the effects of climate (Steward *et al*., 2012). The Global Climate Risk Index (CRI) identified Bangladesh as being among the top ten most vulnerable countries and ranked fifth in terms of death toll, losses and number of extreme events in the ten years between

1993–2012 (Kreft and Eckstein, 2014). In recent years, the magnitude and recurrence of climate-induced disasters such as floods, cyclones, droughts, river erosion, salt-water intrusion and its biological effects had increased significantly (Roy, 2011). The hydrological cycle of the basin of the Yellow River had changed greatly due to climate change impact (Liu and Zheng, 2002).

- **Siltation:** The present study investigated that 62% respondents (male- 62% and female- 62%) responded in favor of the siltation for drying up of the Bhairab River; 25% (male- 29% and female- 21%) gave negative opinion and rest 13% (male- 9% and female- 17%) had no opinion in terms of siltation as the cause for river dry. Kreft and Eckstein (2014) found mean concentrations of suspended solids in the UK Yorkshire Rivers varying between approximately 1 and 100 mg l-1. River dry might be executed due to siltation.
- **Rainfall pattern:** Datry *et al.,* (2011) reported that 60% respondents (male- 57% and female- 63%) supported the rainfall pattern for drying up of the river, 16% (male- 29% and female- 4%) denied and other 24% (male- 14% and female- 33%) had no opinion in terms of rainfall pattern as the cause for river dry. A temporary riverbed could be dried for much of the time and might only be aquatic for a brief period after a flood or a period of heavy rainfall (Datry*et al*., 2011). River dry might be caused due to rainfall pattern.
- **Temperature:** Steward *et al.,* (2012) reported 67% participants (male- 67% and female- 67%) responded in favor of the temperature for drying up of the Bhairab River, 18% (male- 9% and female- 25%) gave a negative opinion and rest 15% (male- 24% and female- 8%) had no opinion in terms of temperature as the cause for river dry. Steward *et al*. (2012) found that extreme temperatures were subjected to flow disturbances that deposited and scoured bed sediments in dry riverbeds as well as could also be exposed to intense solar radiation. Sumon (2013) found that temperature regulated the metabolic activity of fishes and other aquatic organisms and most of the rivers were supersaturated with CO_2, CH_4 and N_2O during the study period (Qu *et al*., 2017). River dry could be performed due to temperature.
- **Drought:** During the present study, 80% respondents (male- 86% and female- 75%) supported drought for drying up of Bhairab River, 13% (male- 5% and female- 21%) disavowed and remaining 7% (male- 9% and female- 4%) had no opinion in terms of drought as the cause for river dry. Dry riverbeds were defined as the channels of temporary rivers during the dry phase that could be exposed during periods of drought (Kassas and Imam, 1954; Steward *et al*., 2012). Scientists also anticipated that the drought occurrence would be worsened as a result of climate change and sea-level rise (Dodman and Satterthwaite, 2008). Hence, the drought might be the result of other natural causes related to river dry. So ultimately drought could also cause river dry.

4. Implications and Mitigations

4.1. Implications of disappearing streams

4.1.1. Loss of Biodiversity

- **Impact on Aquatic Ecosystems:** Streams are habitats for diverse aquatic species, including fish, amphibians, and macroinvertebrates. The drying up of streams eliminates these habitats, leading to species extinction and reduced biodiversity. In the Appalachian region, the drying of small streams due to mountaintop mining has caused a significant decline in salamander populations. These species, which rely on clean, cool streams, have faced habitat loss and fragmentation (Muncy *et al.,* 2014).
- **Riparian Zone Degradation:** Riparian zones—ecosystems adjacent to streams—depend on water availability. Stream disappearance leads to the degradation of these zones, affecting plant and animal species that rely on this habitat. In Colorado River Delta: The loss of flow in the Colorado River has devastated the delta's riparian zones, resulting in the disappearance of wetlands and species like the Southwestern willow flycatcher (Hinojosa-Huerta *et al.,* 2013).

4.1.2. Reduced Water Availability for Human Use

- **Agricultural Impacts:** Disappearing streams reduce water available for irrigation, threatening food security in regions dependent on stream-fed agriculture. In Pakistan, the drying of smaller streams feeding the Indus River has led to reduced irrigation capacity, affecting crops like wheat and rice. Farmers have been forced to adopt expensive alternatives, increasing production costs (Geographical, 2022).
- **Drinking Water Scarcity:** Streams often serve as sources of drinking water. Their disappearance forces communities to rely on overburdened or contaminated alternatives. Disappearing Streams in Sub-Saharan Africa: In regions of the Sahel, the loss of streams due to desertification has exacerbated water scarcity, forcing communities to travel long distances for water. This has increased health risks and reduced time for productive activities (Geographical, 2022).

- **Increased Vulnerability to Flooding:** Streams play a critical role in channelling water during storms. Their disappearance can lead to reduced drainage capacity, increasing the risk of flooding in surrounding areas. The urban Streams in Jakarta, Indonesia Jakarta has lost numerous streams due to urbanization. This has significantly worsened the city's flooding problem during monsoon seasons, displacing thousands of residents annually (Rimba and Yastika, 2020).
- **Cultural and Recreational Loss:** Streams hold cultural and recreational significance, serving as sites for religious practices, tourism, and leisure activities. Their disappearance diminishes these opportunities, impacting community identity and economic activities. Ganga Tributaries in India were smaller streams feeding the Ganges River have dried up due to pollution and overuse. This has affected religious practices, such as river rituals, and reduced tourism in regions once known for their pristine water bodies (Geographical, 2022).
- **Loss of Ecosystem Services:** Streams provide vital ecosystem services, such as nutrient cycling, carbon sequestration, and groundwater recharge. Their disappearance disrupts these functions, leading to cascading environmental impacts. Streams in the Murray-Darling Basin, Australia overextraction of water from streams in the Murray-Darling Basin has led to a loss of ecosystem services. The drying of wetlands has reduced fish populations, impacting both the environment and local fisheries (Williams, 2017).
- Plotnikov *et al*., (2023) attributed dried up streams to sea salinization. This refers to the process of increased salinity in a body of water, such as a sea or an ocean. Their submission was that there was limited input of freshwater into the sea that would have caused titration, thus maintaining salt level in the sea within the acceptable range for organism survival. In addition, evaporation without in-flow of salt water added to salt increase. Other causes include evaporation; high evaporation rates can lead to increased salt concentration in seawater, especially in warmer climates, river diversion can reduce freshwater inflow, leading to a higher concentration of salts, agricultural runoff and industrial discharges can introduce salts into aquatic ecosystems, prolonged dry periods can reduce freshwater input and increase salinity (Nasreen, 2022).

4.1.3. Social and Economic Impacts

- **Displacement of Communities:** Communities dependent on streams for water, food, and livelihoods often face displacement when these streams disappear.
- In Lake Chad Basin Communities, the disappearance of streams feeding Lake Chad has forced millions to migrate in search of water and arable land. This has led to conflicts over resources and a rise in climate refugees (Kamta *et al.,* 2021).
- **Economic Losses:** Industries such as fishing, tourism, and hydropower generation suffer significantly when streams disappear.
- The Mekong Delta's fisheries have been adversely affected by reduced stream flows due to upstream dam construction. This has resulted in economic losses for millions of people who depend on fishing for their livelihoods (Yoshida *et al*., 2020).
- **Ecological Implications:** The drying up of the Osun River's tributaries, due to pollution from mining activities and deforestation, has led to significant habitat loss. Species dependent on these streams, including amphibians and freshwater fishes, are at risk of extinction. Additionally, the Osun Sacred Grove, a UNESCO World Heritage Site, faces threats due to reduced water levels (Eludoyin, 2024).

4.2. Mitigations

Stream restoration improves hydrology by reducing peak flow and sediment delivery (Ahilan et al., 2018) and increasing property values (Netusil*et al.,* 2019). Effective restoration requires understanding when and where streams disappeared and the impact of land development on stream loss, which threatens water resources and socio-economic stability. In the Middle Enyong Basin, seven streams have vanished between 1966 and 2016, indicating early-stage disappearance. Streams support both aquatic and terrestrial ecosystems, providing essential ecological services. Neglecting stream loss may lead to ecological imbalance and environmental degradation. Early intervention, such as dredging, is recommended to prevent further decline and reduce long-term costs. Modern stream restoration focuses on improving hydrogeomorphic and ecological conditions to resemble those of healthier streams (Qu et al., 2017). Restoration projects aligned with the Clean Water Act (CWA) measure water quality, discharge patterns, and biological health to restore chemical, physical, and biological functions (Roy, 2011). Proactive measures at the early stages of stream disappearance are essential for maintaining ecosystem balance and securing water resources.

4.2.1. Restoration of Riparian Vegetation

Replanting trees and vegetation along streambanks stabilize soils, reduces sedimentation, and improves water quality, enhancing stream longevity. Efforts to restore riparian zones along the Rhine River have involved planting native vegetation and removing invasive species. This has improved water retention and streamflow stability (Liu *et al.,* 2023).

Restoring forests along watersheds helps improve water retention, reduces erosion, and enhances stream recharge. Riparian buffer zones can stabilize streambanks and regulate water flow. In Osun State, reforestation projects have improved streamflow in areas where streams dried up due to deforestation for farming and logging. The initiative involved planting native tree species along riverbanks (Eludoyin, 2024).

4.2.2. Sustainable Water Management Practices

- **Regulated Water Abstraction:** Implementing water-use quotas and monitoring groundwater extraction can prevent overuse, preserving streams fed by aquifers. The Australian government introduced the Murray-Darling Basin Plan to regulate water use and maintain environmental flows in streams. The plan has mitigated the effects of over-extraction, sustaining stream ecosystems (Samnakay*et al.,* 2024).

4.2.3. Pollution Control Measures

- **Reduction of Industrial Effluents:** Enforcing stricter pollution regulations ensures cleaner streams, preventing ecological degradation. The Indian government launched the Ganga Action Plan to reduce industrial and sewage pollution in the Ganges and its tributaries. Improved water quality has helped restore some previously degraded streams (Chaudhary and Walker, 2018).

4.2.4. Rainwater Harvesting and Groundwater Recharge

Promoting rainwater harvesting (RWH) in regions with declining groundwater helps recharge aquifers and support stream flow. In Rajasthan, India, watershed programs have used check dams and percolation tanks to sustain seasonal streams (Chaudhary and Walker, 2018). A survey of 200 households in Gayama, Akate, Sidi, and Sabongari found that over half rely on drought-prone sources like shallow wells and natural water bodies, while only 3% harvest rainwater. Taraba and Gombe states, with annual rainfall of 1,064 mm and 915 mm respectively, have an estimated RWH potential of 63.35 m^3 and 54.47 m^3 per household. Installed RWH systems and recharge wells have replenished groundwater, benefiting farming communities. Gayama could meet its water needs through RWH, while the other villages would require additional sources. Improved RWH mechanisms and greater community involvement could enhance water security and support stream flow (Ishaku *et al*., 2011).

4.2.5. Streamflow Restoration Programs

Restoring natural flow regimes by removing outdated dams or maintaining minimum flow levels sustains stream ecosystems. A case study in Elwha River Dam Removal, USA- The removal of two dams on the Elwha River in Washington State restored the natural flow, reviving fish populations and riparian habitats (NOAA Fisheries, 2024).

4.2.6. Sustainable Water Management Policies

Implementing regulations to control water abstraction, encourage efficient irrigation practices, and reduce overextraction of groundwater can help mitigate stream disappearance. A case study Hadejia-Nguru Wetlands in Yobe-Borno facility. The use of water regulations in the Hadejia-Nguru Wetlands have helped restore some streams affected by upstream dam construction and excessive irrigation. Farmers adopted water-saving irrigation techniques, reducing pressure on water sources (The SMEC Group, 2019).

4.2.7. Community-Based Conservation Programs

Engaging local communities in conservation promotes sustainable water use and stream protection. A study in Gashaka-Gumti National Park, Taraba State, showed that community participation improved stream flow into the Benue River, benefiting biodiversity and ecosystem health (Madaki et al., 2024). Community-led initiatives enhance water security, addressing global water scarcity and quality issues (Funds for NGOs, 2024). Expected outcomes include improved water access, stronger partnerships, and enhanced community capacity. The project aligns with the Sustainable Development Goals (SDGs) and serves as a model for sustainable water management in other communities.

4.2.8. Integrated River Basin Management (IRBM)

Integrated River Basin Management (IRBM) ensures sustainable water resource management by considering the entire river basin and balancing ecological needs with human demands (GWP, 2020). Scientific assessments of water quality help develop targeted strategies to address specific challenges. Setting measurable water quality targets enables progress tracking and accountability. Public and stakeholder involvement enhances planning and fosters community support (UNESCO, 2019; WMO, 2021). The Benue River Basin Development Authority (BRBDA) applied IRBM through water allocation reforms and stakeholder engagement, successfully revitalizing tributaries affected by drought and overuse. This highlights the importance of comprehensive oversight and local participation in sustainable water governance (WMO, 2021).

4.2.9. Legal and Policy Frameworks

Integrated Water Resources Management (IWRM) in Malaysia focuses on sustainable river basin management through enforceable legal frameworks. These frameworks regulate water usage, conservation, and pollution control, ensuring accountability and promoting sustainable water management practices (Yusofa and Saadb, 2022). The strategy balances environmental sustainability, economic development, and societal needs by managing rivers, streams, groundwater, and ecosystems efficiently. It aims to conserve resources for future generations while reducing conflicts among stakeholders, including farmers, industries, communities, and environmental groups.

Palmer and Hondula (2024) analyzed 434 stream mitigation projects from 117 surface mining permits in Appalachia. Most mitigation focused on perennial streams, while impacts were mainly on ephemeral and intermittent streams. Regulatory oversight was weak, with visual assessments being the most common evaluation method. After five years of monitoring, 97% of projects reported suboptimal or marginal habitat conditions. Less than a third of the projects provided biotic or chemical data, most of which showed impairment. Stream conductivity often exceeded federal water quality standards, and harmful selenium levels were reported in 7 of 11 projects providing data. The findings suggest that mitigation efforts for coal mining in Appalachia are failing to meet the Clean Water Act's goals of restoring stream ecosystems and functions.

5. Conclusion

The disappearance of streams has far-reaching implications; disrupting ecosystems, threatening livelihoods, hydrological stability, and cultural heritage. Addressing these impacts requires a combination of sustainable water management practices, conservation initiatives, and global cooperation. Immediate action is needed to mitigate the consequences and preserve the remaining streams. Implementing these mitigative measures in Nigeria requires a collaborative approach involving governments, NGOs, researchers, and local communities. With proper planning and execution, these strategies can help restore and preserve Nigeria's disappearing streams.

Recommendations

Based on the submitted literatures, it is recommended to incorporate the underscored mitigative measures in partner with all concerned stakeholders and geographers are advised to design maps on disappeared and still running streams using geographic information systems (GIS). This will be a baseline for following in future research.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Author's Contributions

- EAE: Conceptualization, Data curation and collection, Funding acquisition, Resources, Validation, Writing – review and editing
- AOO: Conceptualization, Data acquisition, Resources, Supervision, Validation, Writing – review and editing
- EPU: Supervision, Validation, Writing –original draft
- EGA: Validation, Writing – review and editing
- EID: Validation, Writing – review and editing
- AAW: Supervision, Validation, Writing – review and editing
- All authors read and approved the final manuscript.

Artificial Intelligence (AI)-Assisted Technology

NO artificial intelligence (AI)-assisted technologies (such as Large Language Models [LLMs], chatbots, or image creators) was used in the production of submitted work. Chatbots (such as ChatGPT) were NOT used. There is NO plagiarism in their paper, including in text and images.

References

[1] Adegun, O. B. and Adedeji, J. A. (2021). Urban heat island mitigation strategies for African cities: Challenges and opportunities. *Journal of Urban Climate*, 37, 100898. https://doi.org/10.1016/j.uclim.2021.100898

[2] Ahilan, S., Guan, M., Sleigh, A., Wright, N. and Chang, H. (2018). The influence of floodplain restoration on flow and sediment dynamics in an urban river. *Journal of Flood Risk Management*, 11(S2), S986–S1001.

[3] Ahmed, A. T. A., Mandal, S., Chowdhury, D. A., Tareq, A. R. M. and Rahman, M. M. (2012). Bioaccumulation of some heavy metals in Ayre fish (SPERATA AOR HAMILTON, 1822), sediment and water of Dhaleshwari river in dry season. *Bangladesh Journal of Zoology*, 40(1), 147-153. https://doi.org/10.3329/bjz.v40i1.12904

[4] Ajayi, O. O., Oladipo, A. A. and Akinyemi, F. O. (2019). Energy consumption and climate change: Impacts of urbanization on electricity demand in Lagos. *Renewable Energy and Environmental Sustainability*, 4(1), 45-58. https://doi.org/10.1051/rees/2019004

[5] Akbari, H., Kolokotsa, D. and Santamouris, M. (2016). The cooling effect of urban water bodies: A review of evidence-based studies. *Energy and Buildings,* 114, 119-132. https://doi.org/10.1016/j.enbuild.2015.06.031

[6] Akpabio, J. U., Okon, A. O., Ebong, G. A., Udoinyang, E. P., Essien, E. A., Josiah, I. U., and Akpan, A. W. (2024). Perturbation of road construction and inorganic sedimentation on the macroinvertebrate fauna in the midstream segment of Qua Iboe River, Nigeria. *Asian J Adv Res Rep*. 18(4):24-33. Article no. AJARR.113630. ISSN: 2582-3248.

[7] Alam, S. S., Alam, A. T. M. J., Rahman, M. F., Rahman, S. and Rahman, N. (2016). Building climate resilience to Noapara Town. A coastal urban centre of Bangladesh. Asian Cities Climate Resilience. Working Paper Series 32.

[8] Azad, K. N., Hasan, N. and Azad, K. N. (2020). Causes for drying up of Bhairab River in Bangladesh. *Journal of Fisheries, Livestock and Veterinary Science*, 01(01), 18-27. Crossref: https://doi.org/10.18801/jflvs.010120.03

[9] Bassett, R., Nwokolo, C. and Okafor, K. (2020). The disappearance of urban streams in Lagos: Implications for climate and energy consumption. *Environmental Research and Sustainability*, 15(2), 67-81. https://doi.org/10.1088/ers.2020.1502

[10] Bassett, R., Young, P. J., Blair, G., Samreen, F. and Simm, W. (2020). The Megacity Lagos and Three Decades of Urban Heat Island Growth. *Journal of Applied Meteorology and Climatology* 59(12). http://dx.doi.org/10.1175/JAMC-D-20-0059.1

[11] Beaulieu, J. J., Golden, H. E., Knightes, C. D., Mayer, P. M., Kaushal, S. S., Pennino, M. J., Arango, C. P., Balz, D. A., Elonen, C. M., Fritz, K. M. and Hill, B. H. (2015). Urban stream burial increases watershed-scale nitrate export. *PLoS One*, 10(7), e0132256.

[12] Brooks, K. N., Ffolliott, P. F., and Magner, J. A. (2013). Hydrology and the management of watersheds. Wiley-Blackwell.

[13] Chang, H., Eom, S., Yasuyo, M. and Bae, D. (2020). Land use change, extreme precipitation events and flood damage in South Korea: Aspatial approach. *Journal of ExtremeEvents,* 07(03:3), 2150001.

[14] Chartres, C. and Varma, S. (2011), "Out of Water: From Abundance to Scarcity and How to Solve the World's Water Problems", *Management of Environmental Quality*, 22(2). https://doi.org/10.1108/meq.2011.08322bae.002

[15] Chaudhary, M and Walker, T. R. (2018). River Ganga pollution: Causes and failed management plans-(correspondence on Dwivedi *et al.,* 2019) - Ganga water pollution: A potential health threat to inhabitants of Ganga basin. *EnvironmentInternational*, 126 (2019) 202–206

[16] Chen, J., Brissette, F. P., Poulin, A., and Leconte, R. (2011) Overall uncertainty study of the hydrological impacts of climate change for a Canadian watershed. *Water Resources. Res*., 47, W12509, https://doi.org/10.1029/2011WR010602.

[17] Datry, T., Arscott, D. and Sabater, S. (2011). Recent Perspectives on Temporary River Ecology. *Aquatic Science*, 73:453 – 57.

[18] Datry, T., Corti, R., Claret, C. and Philippe, M. (2011). Flow intermittence controls leaf litter breakdown in a French temporary alluvial river: the "drying memory". *Aquatic Sciences*, 73(4), 471–483. https://doi.org/10.1007/s00027-011-0193-8.

[19] Datry, T., Larned, S. T., and Tockner, K. (2014). Intermittent rivers: A challenge for freshwater ecology. *BioScience*, 64(3), 229–235.

[20] Dodman, D. and Satterthwaite, D. (2008). Institutional capacity, climate change adaptation and the urban poor. *IDS Bulletin*. 29(4), 67–74.

[21] Döll, P., and Schmied, H. M. (2012). How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. *Environmental Research Letters,* 7(1), 014037.

[22] Eludoyin, A. O. Ike, F., Onanuga, M. Y., Omosuyi, O. S. and Adewoyin, A. A. (2024). Gold Mining Activities and Impact on Osun River Basin in Southwestern Nigeria. Springer Nature Switzerland AG R. C. Brears (ed.), *The Palgrave Encyclopedia of Sustainable Resources and Ecosystem Resilience*, https://doi.org/10.1007/978-3-030-67776-3_51-1

[23] Essien, U. B., Essien, E. A., Okechukwu, B. N., Merenini, I. F., Yogesh, K.,Ensafy, M., Udotong, U. F. and Uzoma, O.(2025). "Heavy Metals Composition in Fish Species from Oron River Metropolis, Akwa Ibom State, Nigeria". *Journal of Materials Science Research and Reviews* 8 (1):223-33. https://doi.org/10.9734/jmsrr/2025/v8i1391.

[24] Fahy, B. and Chang, H. (2019). Effects of storm water Green infrastructure on water shed outflow: Does spatial distribution matter? *International Journal of Geospatial and Environmental Research*, 6(1), Article5.

[25] Ford, D. C. and Williams, P. W. (2013). Karst Hydrogeology and Geomorphology. John Wiley and Sons.

[26] Funds for NGOs (2024). Enhancing Water Security through Community-Led Conservation Initiatives. Accessed via https://www.fundsforngos.org/proposals/enhancing-water-security-through-community-led-conservation-initiatives/

[27] Garcia, D. (2008). The climate security divides: Bridging human and national security in Africa. *African Security Review,* 17(3), 1–17. http://doi.org/10.1080/10246029.2008.

[28] Geographical (2022). The Ganges: river of life, religion and pollution. Accessed via https://geographical.co.uk/culture/the-ganges-river-of-life-religion-and-pollution and https://geographical.co.uk/wp-content/uploads/8E7A9536.jpg

[29] Glendenning, C and Vervoort, R. W. (2011). Hydrological impacts of rainwater harvesting (RWH) in a case study catchment: The Arvari River, Rajasthan, India. *Agricultural Water Management*; 98(4):715-730

[30] Global Water Partnership (GWP). (2020). Integrated Water Resources Management in Practice: Better Water Management for Development. Routledge.

[31] Han, L., Xu, Y., Deng, X. and Li, Z. (2020). Stream loss in an urbanized and agricultural watershed in China. *Journal of Environmental Management*, 253, 109687

[32] Hinojosa-Huerta, O., Nagler, P. I., Nagler, P. I., Carrillo-Guererro, Y. K. and Glenn, E. (2013). Reprint of: Effects of drought on birds and riparian vegetation in the Colorado River Delta, Mexico. *Ecological Engineering* 51:275–281 DOI:10.1016/j.ecoleng.2012.12.082.

[33] Hopkins, K. G. and Bain, D. (2018). Research note: Mapping spatial patterns in sewerage, material, and proximity to surface waterways to infer sewer leakage hotspots. *Landscape and Urban Planning*, 170, 320–324.

[34] Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability (Contribution of WGII to the Sixth Assessment Report of the IPCC). Cambridge University Press.

[35] Ishaku, H. T., Majid. M R. and Johar, F. (2011). Rainwater Harvesting: An Alternative to Safe Water Supply in Nigerian Rural Communities. *Water Resource Management*. DOI 10.1007/s11269-011-9918-7

[36] Islam, M. S., Majumder, M. S. I., Hasan, I. and Yeasmin, T. (2017). Environmental impact assessment of Lebukhali bridge construction project over the river of Paira, Bangladesh. *Journal of Energy, Environmental and Chemical Engineering*, 2(1), 10-15. https://doi.org/10.11648/j.jeece.20170201.13

[37] Julian, J. P., Wilgruber, N. A., de Beurs, K. M., Mayer, P. M. and Jawarneh, R. N. (2015). Long-term impacts of land cover changes on stream channel loss. *Science of the Total Environment*, 537, 399–410.

[38] Kamta, F. N., Schilling, J. and Scheffran, J. (2021). Water Resources, Forced Migration and Tensions with Host Communities in the Nigerian Part of the Lake Chad Basin. *Resources*, 10, 27. https://doi.org/10.3390/resources10040027

[39] Kassas, M. and Imam, M. (1954). Habitat and plant communities in the Egyptian Desert: III. The wadi bed ecosystem. *Journal of Ecology*, 42(2), 424-441. https://doi.org/10.2307/2256869.

[40] Kenney, M. A., Wilcock, P. R., Hobbs, B. F., Flores, N. E. and Martínez, D. C. (2012). Urban stream restoration worth It?1 *Journal of the American Water Resources Association (JAWRA),* 43(1), 86–103.

[41] Kreft, S. and Eckstein, D. (2014). Global Climate Risk Index 2014. (Accessed 12/09/2017). Available at: http://germanwatch.org/en/download/8551 .pdf

[42] Kresic, N. and Stevanovic, Z. (2010). Groundwater Hydrology of Springs: Engineering, Theory, Management, and Sustainability. Butterworth-Heinemann.

[43] Leopold, L. B., Wolman, M. G., and Miller, J. P. (2019). Fluvial processes in geomorphology. Dover Publications.

[44] Lettenmaier, D. P., A. W. Wood, R. N. Palmer, E. F. Wood, and Stakhiv, E. Z. (1999). "Water Resources Implications of Global Warming: A U.S. Regional Perspective." *Clim. Change* 43: 537-79.

[45] Liu, C. and Zheng, H. (2002). Hydrological cycle changes in China's large river basin: The Yellow River drained dry. In climatic change: I*mplications for the hydrological cycle and for water management*. Pp. 209-224. Springer, Dordrecht.

[46] Liu, C., Qu, L., Clausen, J., Lei, T. and Yang, X. (2023). Impact of Riparian Buffer Zone Design on Surface Water Quality at the Watershed Scale, a Case Study in the Jinghe Watershed in China. *Water* 2023, 15, 2696. https://doi.org/10.3390/w15152696

[47] Madaki, K., Umaru, I. J., and Umaru3, K. I. (2024). Local Community Distribution and Participation in Biodiversity Conservation in National Parks: A case of GashakaGumti National Park safety. *International Journal of Humanities, Education, and Social Sciences*, 2(2):161-184. https://ejournal.yasin-alsys.org/index.php/IJHESS

[48] MDEP (Maine Department of Environmental Protection) (2009). A Citizen's Primer on Stream Ecology, Water Quality, Hydrology, and Fluvial Geomorphology-Volume II" Accessed via (https://www.maine.gov/dep/water/monitoring/rivers_and_streams/vrmp/stream-survey-manual/survmanv1_mainbody.pdf) (PDF). www.maine.gov.

[49] Meyer, J. L., Strayer, D. L., Wallace, J. B., Eggert, S. L., Helfman, G. S. and Leonard, N. E. (2007). The contribution of head water streams to biodiversity in river 8 G. C. POST et al. networks. *Journal of the American Water Resources Association (JAWRA)*, 43(1), 86–103.

[50] Misra, A. K. (2010). A River about to Die: Yamuna. *Journal of Water Resource and Protection,* 2, 489-500. http://www.SciRP.org/journal/jwarp

[51] Moyle, P. B. (2013). Novel aquatic ecosystems: The new reality for streams in California and other Mediterranean climate regions. *River Research and Applications*, 30(10), 1335–1344.

[52] Muncy, B. L., Price, S. J., Bonner, S., Barton, C. D. and Barton, C. D. (2014). Mountaintop removal mining reduces stream salamander occupancy and richness in Southeastern Kentucky (USA). *Biological Conservation* 180(418):115–121

[53] Nasreen, D. (2022) Ocean Salinity. *International Journal for Modern Trends in Science and Technology,* 8:296-302`. Available from: https://www.researchgate.net/publication/358140626_Ocean_Salinity accessed on Jan 2 2025.

[54] NC DWQ (North Carolina Division of Water Quality) (2003). Methodology for Identification of Intermittent and Perennial Streams and Their Origins. Accessed via (https://files.nc.gov/ncdeq/Water%20Quality/Surface%20Water%20Protection/401/Policies_Guides_Manuals/StreamID_v_4point11_Final_sept_01_2010.pdf

[55] Netusil, N., Jarrad, M. and Moeltner, K. (2019). Research note: The effect of stream restoration project attributes on property sale prices. *Landscape and Urban Planning*, 185, 158–162.

[56] NOAA (National Oceanic and Atmospheric Administration) Fisheries (2024). The Elwha River Restoration: A Case Study in Adaptive Management for Salmon Recovery. Accessed via https://www.fisheries.noaa.gov/feature-story/elwha-river-restoration-case-study-adaptive-management-salmon-recovery

[57] Nwokoro, S. O. and Okusipe, O. M. (2020). Assessing urban infrastructure deficits and energy consumption patterns in Lagos State. *Journal of Sustainable Urban Development,* 10(3), 311-329. https://doi.org/10.1088/jsud.2020.10311

[58] Ogunjobi, K. O. and Adeyemi, B. T. (2022). Restoring urban water bodies as a climate adaptation strategy in Lagos. *Sustainable Cities and Society*, 80, 103784. https://doi.org/10.1016/j.scs.2022.103784

[59] Oke, T. R., Mills, G., Christen, A. and Voogt, J. A. (2017). Urban Climates. Cambridge University Press. https://doi.org/10.1017/9781139016476

[60] Okpara, U. T., Stringer, A. J. and Bila, M. D. (2015). "Conflicts about water in Lake Chad: Are environmental, vulnerability and security issues linked?" *Progress in Development Studies*, 15(4), 308-325.

[61] Palmer, M. A. and Hondula, K. L. (2024). Restoration As Mitigation: Analysis of Stream Mitigation for Coal Mining Impacts in Southern Appalachia. *Environmental Science and Technology*, 48, 10552–10560. dx.doi.org/10.1021/es503052f

[62] Park, J. Y., Park, M. J., Ahn, S. R., Park, G. A., Yi, V., Kim G. S., R. Srinivasan, and Kim S. J. (2011) "Climate change impacts on water quantity and quality for a mountainous dam watershed in South Korea using SWAT", *Transactions of the ASABE*, 54(5): 1725-1737.

[63] Paul, F. (2021). Climate Variability and Influent Streams in The Kwa Iboe River Basin of South-East Nigeria. *International Journal of Social Sciences*. 14(1):65-77.

[64] Plotnikov, I. S., Aladin, N. V., Zhakova, L. V., Mossin, J. and Høeg, J. T. (2023). Past, Present and Future of the Aral Sea -A Review of its Fauna and Flora before and during the Regression Crisis. *Zoological Studies*. 12;62:e19. doi: 10.6620/ZS.2023.62-19.

[65] Post, G. C., Chang, H. and Banis, D. (2022). The spatial relationship between patterns of disappeared streams and residential development in Portland, Oregon, USA. *Journal of Maps*, 18(2), 210–218. https://doi.org/10.1080/17445647.2022.2035264.

[66] Qu, B., Aho, K. S., Li, C., Kang, S., Sillanpää, M., Yan, F. and Raymond, P. A. (2017). Greenhouse gases emissions in rivers of the Tibetan Plateau. *Scientific Reports*, 7, 16573. http://sci-hub.tw/10.1038/s41598-017-16552-6.

[67] Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., Kidd, K. A., MacCormack, T. J., Olden, J. D., Ormerod, S. J., Smol, J. P., Taylor, W. W., Tockner, K., Vermaire, J. C., Dudgeon, D. and Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol. Rev*. 94, 849–873.

[68] Rimba, A. B. and Yastika, P. E. (2020). Indonesia: Threats to physical urban water problems. EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

[69] Roy, D. C. (2011). Vulnerability and population displacements due to climate-induced disasters in coastal Bangladesh. In Leighton, M., Shen, X. and Warner, K. (eds.). Climate change and migration: rethinking policies for adaptation and disaster risk reduction, Publication Series No. 15/2011, Germany: UNU-EHS. Pp. 24–33.

[70] Samnakay, N., J. Alexandra, C. A. Wyborn, and I. Bender. (2024). Climate adaptive water policy in Australia's Murray Darling basin: soft options or hard commitments? *Ecology and Society* 29(1):1. https://doi.org/10.5751/ES-14578-290101

[71] Sengupta, B. (2006). Water Quality Status of Yamuna River (1999-2005), Assessment and Development of River Basin Series: ADSORBS/41/2006-07, Central Pollution Control Board, Delhi. (Accesed on 20 November, 2017). Available at: http://www.cpcb.nic.in.

[72] Shaha, D. C. and Cho, Y. K. (2016). Salt plug formation caused by decreased river discharge in a multi-channel estuary. *Scientific Reports*, 6, 27176. https://doi.org/10.1038/srep27176.

[73] Sharda, V. N., Kurothe, R. S., Sena, D. R., Pande, V. C. and Tiwari, S. P. (2006). Estimation of Groundwater Recharge from Water Storage Structures in a Semi-Arid Climate of India. *Journal of Hydrology,* 329:224-243. DOI: 10.1016/j.jhydrol.2006.02.015.

[74] Steward, A. L., Schiller, D. V., Tockner, K., Marshall, J. C. and Bunn, S. E. (2012). When the river runs dry: human and ecological values of dry riverbeds. *Frontiers in Ecology and the Environment*, 10(4), 202–209.

[75] Sumon, K. A. (2013). Bioaccumulation of heavy metals in aquatic fauna collected from contaminated waters of the river Karnafuli in the south-east coast of Bangladesh. MS Thesis, Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh.

[76] The SMEC Group (2019). Preparation of Strategic Action Plan for the Development of Water Resources in the Komadugu Yobe Basin - Part 3: Strategic Environmental and Social Assessment.

[77] Udofia, E. S. and E. P. Udofia (2018) Disappearing Streams and Implication for Water Resources Utilization and Management in Middle Enyong Basin in Akwa Ibom State, Nigeria. *International Journal of Social Sciences, University of Uyo*. 12(2): 12-25.

[78] Udosen, C., Udoidiong, O., Etok, A. S. and Okoroji, M. U. (2021). Morphometric analysis of lower Enyong creek basin in South Eastern Nigeria; its implications for applied studies. *Global Journal of Pure and Applied Science*. DOI:10.4314/gjpas.v27i3.6

[79] UNESCO (United Nations Educational, Scientific and Cultural Organization) (2019). Water Quality Assessment: A Guide to Use of Biota, Sediments and Water in Environmental Monitoring. Cambridge University Press.

[80] US EPA (United States Environmental Protection Agency) (2013). "The importance of stream". Accessed via (https://archive.epa.gov/water/archive/web/html/streams.html). United States Environmental Protection Agency.

[81] Verma, P. (2002). The mystery of large-scale fish fatalities in the Yamuna near Agra and the conflicting official theories. *Down to Earth*. Vol. 12.

[82] Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Proussevitch, A. A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C., Liermann, C. R. and Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature* 467, 555–561 (2010).

[83] White, W. B. (2019). Geomorphology and Hydrology of Karst Terrains. Oxford University Press. pages

[84] Williams, J. (2017). Water reform in the Murray–Darling Basin: a challenge in complexity in balancing social, economic and environmental perspectives. *Journal and Proceedings of the Royal Society of New South Wales*, 150(1):68–92. ISSN 0035-9173/17/010068-25

[85] World Meteorological Organization (WMO). (2021). Integrated Water Resources Management: Guidelines for Basin-wide Planning and Implementation. WMO Publications.

[86] Yoshida, Y., Soo, L. H., Trung, B. H., Tran, H., Lall, M. K., Kakar, K. and Xuan, T. D. (2020). Impacts of Mainstream Hydropower Dams on Fisheries and Agriculture in Lower Mekong Basin. *Sustainability,* 12, 2408; doi:10.3390/su12062408.

[87] Yu, W., Yang, Y., Savitsky, A., Alford, D., Brown, C., Wescoat, J., Debowicz, D., Robinson, S. and World Bank (2013). The Indus Basin of Pakistan: The Impacts of Climate Risks on Water and Agriculture. International Bank for Reconstruction and Development / The World Bank 1818 H Street NW, Washington DC 20433.

[88] Yusofa, Z. and Saadb, N. A. (2022). Successful Approaches to Integrated Water Resources Management: A Mini Review. *Jurnal Kejuruteraan* 34 (2): 181-190 https://doi.org/10.17576/jkukm-2022-34(2)-01

[89] Zektser, S., Loáiciga, H. A. and Wolf, J. T. (2005). Environmental impacts of groundwater overdraft: Selected case studies in the southwestern United States. *Environmental Geology*, 47(3), 396–404.