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REVIEW PAPER

Attenuating the volume of storm runoff flow through sustainable practices: A potential solution for flood-prone areas

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ABSTRACT

Floods in urban areas remain a critical threat to human life, health, and economic stability. This study focused on Nigeria's urban flooding, which has become a yearly occurrence. Recently, floods have been deepened by the climate change situation, urban planning lapses, and overwhelmed drainage infrastructures. Other factors intensifying urban flooding in Nigeria include rapid urbanization, choking off the natural spaces and vegetation with impervious surfaces, and accelerating stormwater runoff. The Nigerian government has implemented various flood risk management strategies, including the National Disaster Response Plan and flood control measures such as flood warning, preparedness, and responses. However, studies from the literature confirmed the insufficient understanding of flood events, such as the driving variables and uncertainties about watershed characteristics and climatic variability that impede flood risk management and prediction skills. Therefore, more proactive, sustainable strategies to handle floods are desperately needed in light of the numerous recent climate and flooding-related calamities ravaging the low-lying regions. Similarly, there is a paucity of empirical research on sustainable solutions for attenuating the volume of runoff that is seemingly resulting in flooding. This review fills this gap in the literature. More so, aligning with the United Nations' 2030 Agenda for Sustainable Development, the Sustainable Development Goals. Sustainable flood risk solutions touch on several SDGs, targeting all sustainable practices, resilient infrastructure, water management, sustainable cities and communities, and the sustainable use of terrestrial ecosystems. This review equally focuses on harnessing the potential embedded in the sustainable practices that can fit into other purposes.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
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INTRODUCTION

Floods usually occur when a significant amount of water overflows into normally dry ground. This natural disaster is often triggered by extreme weather conditions such as heavy rainfall, resulting in accelerated storm runoff. Others include rising global temperatures, melting glaciers, and the thermal expansion of oceans, which all contribute to rising sea levels and subsequent flooding of coastal areas (Ujene *et al.,* 2020, Aderogba *et al.,* 2014; Ekpoh, 2015; Udoh, 2015). Evan, (2017) explained that flooding is one of the most frequent disasters, accounting for a significant proportion of natural disasters. It equally poses significant threats to plants, animals, humans, buildings, and infrastructure, with severe environmental impacts. The flooding menace has risen to become a global concern, generating hazards, disrupting lives, leading to property loss, and even causing ecosystem species as well as influencing the overall quality of the environment (Abubakar *et al.,* 2020). Due to its widespread and destructive nature, flooding has remained a critical factor used in assessing the environmental quality of residential neighborhoods, alongside other hazards like droughts, desertification, soil erosion, and tsunamis (Daniel & Udo, 2019). The potential consequence of flooding has been recognized as an annual destructive and damaging occurrence, prompting numerous international efforts to mitigate its impact (Bamidele *et al.,* 2019). The World Bank Group (2016) highlighted that flooding is among the most frequent and damaging natural disasters worldwide, severely impacting livelihoods. Bamidele *et al.,* (2019) pointed out that developing countries are particularly vulnerable due to inadequate environmental management and weak institutional frameworks that have resulted in unplanned building constructions in flood-prone areas and insufficient funding for the provision of essential infrastructure, like adequate drainage systems. (Komolafe, 2015; Nkwunonwo, 2016; Yesufu, 2016; Sule, 2016; Adetuji and Oleyele, 2018; Nwilo *et al.,* 2022). In developing countries, including Nigeria, floods are becoming a persistent environmental challenge, with studies indicating their frequent occurrence is associated with negative potential impact on livelihoods, social values, and economic activities (Abubakar *et al.,* 2020). Several scientists from literature have surveyed flood cases in different communities in Nigeria, evaluating their impact on man's health, environment, and means of survival, indicating their intensity varies in severity with mitigation strategies (Umar and Gray, 2023). The reality is that all six geopolitical regions in Nigeria have been greatly affected by this flood menace. For instance, Onugba *et al.,* (2021) examined the impact of flooding on public health in flood-prone areas using basically the flood event of 2022 as a case study. Mitigation measures as suggested by the study include nature-based solutions such as retaining water with the use of natural elements in the form of wetlands, soil, marshes, and forests as a mechanism to capture water runoff for conservation. Ogunribido & Ogunribido, (2024) investigated the causes of the 2022 flood in 14 states in Nigeria, which affected all the geographical regions in Nigeria. The focus of the study was on environmental and socio-economic implications. Curbing measures focused on policy and strategies such as preparedness, flood forecasting, and accurate warning. Cirella and Iyalomhe (2018) assessed locations at risk of flood and prone to disaster, and suggested policy programmes to alleviate this hazard. Dalil *et al.,* (2015) evaluated the effect of flood calamities on human health in Ajegunle community, a highly crowded high residential zone in the Lagos state (South-west) region. Water-related diseases resulting from flooding were studied. Otomofa *et al.,* (2015) appraised the socio-economic impact of flooding affecting a community in Isoko South LGA of Delta state (South-south region). The activities mostly affected by flooding in the community include water quality, agricultural activities, education, and transportation. Obiwulu *et al.,* (2023) examined the impact of flooding on socioeconomic activities in the South-east region. The investigation revealed a huge potential impact of socioeconomic activities on the communities. Ezebube *et al.,* (2023) investigated contributory factors of continual flooding in the Onitsha (South-east) region. Flood events in this region have specifically resulted in land use and land cover changes and depletion with result showing an increase in built-up area, drastically reducing the natural vegetation, therefore, indicating more flooding cases. Chinwedu *et al.,* (2017) examined the effect of deteriorating climate conditions on the livelihoods of six villages along the Kaduna River basin (North-east) region. The study discovered that women were disproportionately affected due to their responsibility for running the home. The situation of flood occurrences and frequency seems to be increasing despite all the efforts the Nigerian government has made. There is a need to consider other remedial options that have been successfully implemented in developed countries. Therefore, this study focused on lowering runoff volume through sustainable practices. The objectives anticipate aligning with the United Nations' 2030 Agenda for Sustainable Development SDGs, on sustainable flood risk solutions to ensure sustainable cities and communities

Prevalence of flood incidents in Nigeria

Flooding has remained a frequent natural disaster that occurs in Nigeria each year. The devastating effects of floods occurring season after season are being felt in many parts of Nigeria. This incident is expected to increase with much emphasis on the climate change situation. Flood events are not evenly distributed; some areas experience more frequent and severe floods than others (Oladokuni & Proverbs, 2016, Hirbayashe, 2013). The Northern area of Nigeria is noted to have experienced more flood incidents with associated implications than other regions (Umar & Gray, 2023). From 2011 to 2023, Nigeria's highest frequency of flooding showed that the North-west geographic zones had the highest record of more than 31 occurrences. North-central records 20 instances, and North-east had 19 instances (NBS, 2018, Umar & Gray, 2023). However, other regions in Nigeria are not left out of the flood menace. Agbonkhese *et al.,* (2014) pointed out that almost all the cities in the South-west region, including inland regions, have been greatly ravaged by flood cases. In the year 2011, the Nigerian national newspapers on August 29th, conveyed flood event cases that hit Ibadan after a five-hour intense downpour, with severe consequences on the environment, infrastructures, and loss of lives. The coastal region, such as Lagos, has the same history of flooded streets and homes, especially when there is heavy downpour, usually from June to September (Agbonkhese *et al.,* 2014; Oladokuni & Proverbs, 2016). Similarly, other states, which include Kogi, Benue, Niger, Plateau, Taraba, and parts of Kaduna in North-east, were among the inland states that suffered the most. The main causes are the overflow of the Niger and Benue Rivers, extended rainfall, and the discharge of surplus water from Cameroon's Lagdo Dam Oladokuni & Proverbs, 2016). Coastal areas, river basins, and low-lying plains face higher flood risks (Umar & Gray, 2023). The Niger and Benue Rivers, for instance, are prone to seasonal flooding, exacerbated by heavy rainfall and dam releases (Ogunribido & Ogunribido, 2024). Coastal areas, particularly in the Niger Delta, face the dual threat of riverine flooding and rising sea levels, which contribute to more frequent and severe flooding events. However, the South-east region is noted to have fewer flood cases similar to the South-south zones (Umar & Gray, 2023). The first peak flood cases in the past years were recorded in 2012 in the country, with about 18 heavy occurrences; similarly, 2014 and 2016 flood incidences had fewer incidences (Ogunribido & Ogunribido, 2024). The next severe flood event was recorded in 2015 and 2017, having 17 occurrences respectively. 2018 and 2019, with 12 incidents each. Another peak flood incident was recorded in the year 2022. This was regarded as the worst ever in recent decades, with higher fatalities affecting almost all the states (Ogunribido & Ogunribido, 2024). This affected mostly the South-South region, such as Cross River, Delta, Bayelsa, and Rivers states. Anambra and Ebonyi states in the South-East, the Federal Capital Territory in North-Central, and Jigawa, Adamawa, and Yobe States. However, Bayelsa state was described as the worst-hit state with very high instances. There are quite a few severe instances of flooding in the years 2023 and 2024 affecting mostly the coastal regions, among others (Ogunribido & Ogunribido, 2024, Ishaya *et al.,* 2009).

Flash flood events

Contributing factors to the flooding scenario in some regions are the release of water from various Dams and other water bodies, which is usually known as a flash flood event. For instance, the Lagdo Dam in Cameroon was noted to have released continuous water on September 13, 2024, after heavy rainfall, which caused the River Benue and its tributaries to overflow, devastating villages in the North-eastern states of Kogi and Benue state (Ezenwajiobi, 2024). The Nigerian government had originally planned to build a second dam, the Dasin Hausa Dam in Adamawa State, to manage these overflows from Lagdo Dam, but the project was never completed. Similarly, the water discharge from the Oyan Dam in the 2012 flood event worsened the situation of

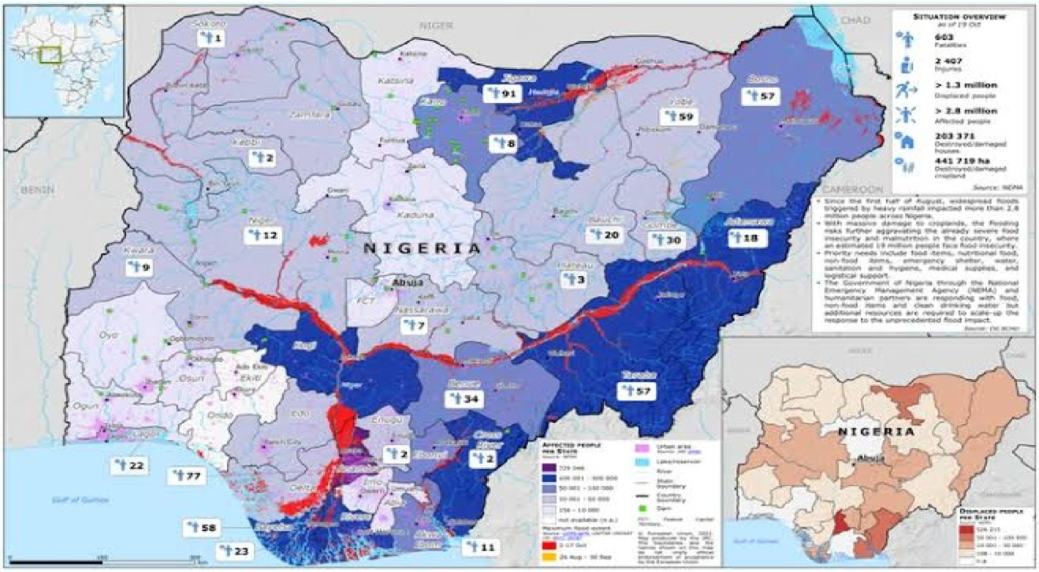

Fig. 1: Map Showing Vulnerable Areas in Nigeria (Ogunribido & Ogunribido, 2024).

the Ogun River, causing approximately 1000 people in the Lagos and Ogun States region of Nigeria to be displaced (Ezenwajiobi, 2024). Flash flood is expected to persist, especially with settlements close to Dam locations, major rivers, and the riverine areas (Ogunribido & Ogunribido, 2024).

Runoff-inducing flooding

Flooding has emerged as a significant global threat, and Nigeria is particularly vulnerable to its devastating impacts. Most studies of literature have attributed increasing frequency and intensity of floods in Nigeria to a combination of factors ranging from geographical structures and land terrain, poor urban planning, climate change impact, rapid urbanization, uncontrolled deforestation, and lack of proper attention to environmental problems (Ornguze *et al.,* 2022; Brian 2021; Oladokun & Proverbs, 2016; Dalil *et al.,*2015, Abaje, *et al.,* 2015; Hirabayashi, 2021, IPCC, 2014). Emerging discoveries that expand on our knowledge of recent causes of floods include groundwater extractions, increased plastic pollution resulting in drain blockages, and the microclimatic impact of land use change. However, as these factors remain valid for flooding occurrences, stormwater runoff's implications on flooding should not be overlooked. In this study, Rainfall runoff (storm water runoff) will be discussed as another major inducing cause of flooding affecting the urban areas in Nigeria. Storm runoff is the excessive overflow from previous and impervious surfaces, such as roofs, driveways, pavements, sidewalks, and road infrastructure typical features of urban regions (Nagare & Supekar, 2024) The rapid growth of cities with a high concentration of impervious surfaces featuring variety of land coverings, including parking lots, buildings and roadways (Stransky *et al.,* 2010, Hirabayashi, 2021). These land coverings have a major impact on the urban hydrological cycle, noticeable in the reduction of natural methods of infiltration and evaporation with a significant increase in the volume of storm runoff (Bobbi *et al.,* 2014). Roxane *et al.,* (2024) pointed out that the permeable nature of Earth's surface in a natural system allows rainwater to seep in and replenish the groundwater table. However, the present-day experiences of water leakages from urban slopes and impervious surfaces are typically the cause of flooding and the notable rise in river water levels (Bobbi *et al.,* 2014; Roxane *et al.,* 2024; Stransky *et al.,* 2010). Managing stormwater in recent times should be given utmost consideration, especially in the midst of mounting population growth and the climate change situation, resulting in adverse consequences of the new hydrological circumstances of precipitation (Lina *et al.,* 2024, Nagare & Supekar, 2024). By 2050, it is projected

Fig. 2: Associated threat of flooding

that about 9 billion people will be on the planet, which would significantly alter the organization of urban regions. This would exacerbate the effects of rainfall and, in conjunction with anticipated storm runoff and flooding (Jusi *et al.,* 2020). The necessity to safeguard public health, well-being, and safety, as well as to shield property from flood dangers, will require attenuating and discharging stormwater from developments (Kristiina. 2020). Similarly, the obligation to protect nature's surroundings and the desire to offer the best strategies for managing runoff will be more needed. Stormwater attenuation has been observed to have negatively affected flood risk. However, the design flow chosen, the position of the development within a catchment, and the broader catchment characteristics are factors considered (Thomas *et al.,* 2024). Different methods of sustainable storm attenuation exist in developed nations ranging from Low Impact Development (LID). practiced in the United States of America (USA). The method focused on preserving natural areas and lowering impervious cover through site design (Bobbi *et al.,* 2014). Ciu *et al.,* (2021) pointed out that bioretention methods (Low Impact Development techniques) were demonstrated with proven results that delayed and decreased peak flows, allowing the system to retain a larger runoff volume. Chan *et al.,* (2018) investigated the usage of a treatment train under Best Management Practice (BMP) for stormwater concerns, flooding, and runoff quality control in Kualas Damansara, Selangor, Malaysia. The techniques included a detention pond and a constructed channel ecological swale. The result proved that the long-term solution to stormwater problems, such as floods and runoff volume control, was the treatment train, an improved technology for capturing stormwater runoff.

Associated flood risk in Nigeria

Every year, the rainy season in Nigeria, starting from June, records an erratic degree of flooding. Varying havoc and damage have followed the annual flood incidence all over the country. From the report, the states most affected in 2022 are Adamawa, Borno, and Yobe states in the North-east region, the North central region includes Nasarawa state, Bauchi, Taraba, Benue, and Kogi. Others include Bayelsa state from South-south, Anambra from South-east, and Jigawa in the North-west (Ekpoh, 2015; Udoh, 2015 Evan, 2017; Abubakar, 2020). In recent years, floods have resulted in a considerable loss of lives and property, significant agricultural losses,

Table 1: Summary of associated flood risk in Nigeria (NEMA, 2022; IOM, 2022)

States	Number of Affected Persons	Number of displaced persons	Number of houses with partial damage	Number of houses totally damaged
Anambra	675,953	526,015	5,511	2,755
Kogi	206,562	200	-	-
Yobe	160,000	42,700	8,641	8,885
Adamawa	135,552	14,439	2,136	15,156
Benue	83,016	32,633	358	34
Borno	50,242	30,516	9,477	10,201
Jigawa	150,438	61,942	1,564	3,849
Bauchi	25,122	2,738	3,136	2,059
Nasarawa	34,827	22,040	381	1,689
Taraba	147,755	6,089	1,343	16,082
Bayelsa	38,442	-	25	34
Total	1,702,909	739,322	32,372	60,754

with an estimated 110,000 hectares of farmland ruined, resulting in food scarcity and price increase (Nkwunonwo *et al.,* 2016). Socioeconomic impacts are noticeable in exacerbating poverty and inequality in Nigeria. Vulnerable communities, particularly those in low-lying regions, are disproportionately affected. Fig. 2 exposed other associated flood threats in Nigeria. Moreover, reports from NEMA) National Emergency Management Agency and (DTM) Displacement Tracking Matrix (DTM) flood flash reports from September 2022 state that 1,664,467 people across all the regions were affected. Moreover, shelters covering 60,720 were destroyed, while 33,542 shelters were nearly destroyed. Moreover, more than 600 individuals, including children, have died across the country (NEMA, 2022; IOM, 2022). Table 1 reveals an overview of the states in Nigeria affected by flooding.

Flood risk management

Advances in flood behavior and prediction have been informed by recent floods, with technologies like remote sensing, GIS, and flood modeling enhancing the accuracy of forecasts and the efficiency of early warning systems. These tools have strengthened disaster response efforts and guided better planning and risk management strategies (Oke *et al.,* 2023, Oladokun *et al.,* 2016). The need for improved policies and response mechanisms has been underscored by recent flood events, emphasizing the importance of timely and coordinated responses, resilient infrastructure, and the integration of scientific knowledge into flood management strategies (Oladokun *et al.,* 2016). These insights have influenced both national and international efforts to improve flood preparedness and resilience (Oke *et al.,* 2023, Kundzewicz, 2014). Flood hazards and human response through adaptation, flood control, and protective measures. Adaptation involves actions taken to reduce or mitigate the impact of flood risks. Flood control focuses on modifying land use within a river basin to lower the likelihood of flooding (Ebhuoma *et al.,* 2021). Protective measures involve constructing physical barriers like river channelization, embankments, dykes, levees, flood diversion channels, and reservoirs to store floodwaters (Ward, 2015). Table 2 shows studies from several authors on suggested flood risk control in Nigeria. Flood problems have persisted despite all the effort put in place and various government policies to reduce the impact of flooding. Strategies suggested for flood control are still mostly found on an abstract basis. Nigeria is experiencing its worst seasonal flooding in recent years, impacting more communities, destroying homes, businesses, and vital public infrastructure like roads, bridges, and utilities (Nkwunonwo *et al.,* 2024). The worst of it all is loss of lives, loss of environmental quality, and habitat displacement. This destruction leads to business interruptions, loss of income, and increased expenses for repairs and reconstruction (Adesola *et al.,* 2024). Fig. 3 revealed the recent flood havoc in the Nigerian environment. The growing concern is that this flooding will exacerbate the country's already severe food insecurity and malnutrition crisis. At present, over 19 million people in Nigeria are suffering from extreme food insecurity, with more than 440,000 hectares of cropland partially or

Table 2: Suggested flood risk management

Study Focus	Suggestions	Sources	
The study focused on curative and management strategies of flood in Nigeria	• Flood plain management Utilizing storm water run-off water for inter-basin reuse.	(1)	Agbonkhese et al., 2014
	• Construction of embankments in flood prone area to capture runoff. (1)	(2)	Oladokuni & Proverbs, 2016
The study analyzed flood risk management and opportunities	• embracing of sustainable integrated FRM system such as blue system and green infrastructures. (2)	(3)	Ologunorisa, 2009
The study focused on approaches for extenuation of flood related risk in Niger Delta, region	• Flood reduction Schemes. Achievable through land-to-channel runoff phase and deforestation practices. (3)	(4)	Oluchi, et al., 2017
The study examined effective flood management system in Anambra state.	• The authors suggested that dams should be constructed across river channels as well as wing dykes and afforestation practices. (4)	(5)	Bridge & Oguno, 2023
The study investigated flood risk and coping strategies in one of the low-lying regions in Nigeria	• The effective strategy recommended apart from policy suggestions was to develop water drainage channels to ease surface run-offs (5)	(6)	Brian, 2021
The study examined flood risk impact and management practices in Nigeria	• Ecological based solution such as vegetated banks to reduce runoff off, The use of porous paving material to allow infiltration of runoff and adoption of green roof technology to capture runoff at source. (6)	(7)	Adelekan, 2014
The study evaluated flood risk management by public and private agents in Lagos coastal region.	• Management approaches suggested are more of structural and policy base with reverence to flood preparedness, the need for improved meteorological forecasts was recommended. (7)	(8)	Bridge & Oguno, 2023
Flood risk, management and coping strategies in Cross river state was examined in this study.	• Traditional drainage canals were the major method used to control flood risk while most residents depend on flood prediction by government agencies. (8)	(9)	Ezezue et al., 2017
The study examined suitable flood management in six communities in Anambra state (South-east) regions	• The recommended strategies include construction of artificial levees, wing dams, diversion spillways, and afforestation practices. (9)	(10)	Adefisoye, 2017
A study of flood management in Ekiti state (South- west) region.	• Suggested solution from this study is the involvement of citizen" s participation and involvement in local communities to participate in flood management. (10)	(11)	Nwosu, 2014
Nigeria's flood management prospects were the focus of this study.	• Disaster management such as systematically observing and analysing disasters in order to enhance preparedness, mitigation, prevention, emergency response, and recovery procedures. (11)	(12)	Echendu, 2023
The study investigated efficiency of local methods for managing flood risks in Port Harcourt (South -south) region.	• The study suggested eco-system restoration such as building urban forest to reduce storm water runoff within the local community. (12)	(13)	Nkwunonwo et al., 2024
The study examined the management of flood using ecosystem-based approach in Ogun state (South- south) region	• The study offers a fresh perspective on how to strengthen community resilience, integrate environmental services into local FRM, and adapt traditional practices and resources for flood risk reduction. (13)	(14)	Mafimisebi, 2024
Issues and strategies for flood management was the focus of the study	• According to this study, a complete approach should be used to build urban infrastructure, enable more entrepreneurs to create and provide FRM solutions, and include FRM ideas and practices into the nation's educational programs. (14)	(15)	Adesola et al., 2024
The study examined the public health impact of the 2022 flooding event in Nigeria	• Nature-based solution was recommended, such as understanding the role of wetlands, soil, marshes, and forests for the storage effect. (15)		

completely destroyed (Anabaraonye *et al.,* 2022). The Food and Agriculture Organization predicts that cereal production will likely be 3.4% lower than the previous year due to the floods, high production costs, and ongoing insecurity problem (Anabaraonye *et al.,* 2022). The advancements in technology that allow for monitoring and predicting floods, improving early warning systems, and enabling more effective disaster response seem to be more abstract and less practical solutions. Seeking a better solution and a way out remains the only option. This review harnessed divers' sustainable solutions and natural local methods to tackle runoff-induced floods in affected regions in Nigeria. This is critically needed given the climate-changing impact and urbanization circumstances (Daniele & Vivian, 2020).

Fig. 3: Recent flood cases with a) Adamawa state, b) Lagos state, c) Niger delta, d) Anambra state (Obianer, 2024; Olasunkanmi *et al.,* 2024)

Sustainability target for 2030, sustainable development goal agenda SDG

The word sustainability has persisted as a long-term goal that focuses on the ability of society to grow and develop without exhausting or depleting the natural resources required for future generations to live. United Nations Commission (Brundtland Report, 1987) (Kulman & Farrington, 2010, Echendu, 2020). Sustainable development is defined as the process of "meeting the needs of the present without compromising the ability of future generations to meet their own needs (UN, 2016). This significant report lays out the fundamental characteristics and consensus surrounding the idea of sustainable development for all countries. The concept of sustainability is based on the idea that Earth's natural resources are limited; therefore, supporting sustainable practices helps preserve a balance between the environment, economy, and equity (Maria, 2020). However, aligning with the United Nations Sustainable Development Goals SDGs target for 2030 will require a proactive step towards achieving sustainable development and a better future for everyone. Attaining this goal will involve tackling many problems that humanity faces to guarantee economic growth, human well-being, and environmental preservation for both developed and developing nations by 2030 (Parry, 2018). Problems like flooding are creating consequential damage both to human life and the environment. The disparities in influence are explained by the fact that nations around the world have varying degrees of development with distinct difficulties (Echendu, 2020). Sustainable flood risk solutions touch on Agenda 11 of SDGs, a target that will be discussed under the subheading below.

SDG 11 (Sustainable cities and communities)

SDG 11 agenda aim at making cities and human settlements livable and to guarantee that human settlements are in the best possible condition for living, while having the least detrimental effect on other communities or environmental impact on natural elements (UNDP., 2016). Its primary goal is to meet the needs of the community's most vulnerable and impoverished individuals and to protect human settlements' security and integrity in the face of present climate change risks. (Wahab, 2017; UNDP. 2016). However, insight and knowledge about nature-based solutions for urban resilience with a greater focus on equality in city design for populations at risk should be included. Flooding poses a serious risk to accomplishing SDG 11, while communities that are vulnerable to flooding are not viable and livable, which usually results in fear of future cities and communities (Echendu, 2020). The urban poor in Nigeria are particularly susceptible because they lack most of the social protection and the capacity to recover from the effects of flooding (Oke *et al.*, 2023). Urban flooding is noted to have been caused by several variables, including climate change, fast urbanization, poor urban planning, deforestation, and a lack of concern for environmental problems. Inadequate solid waste management and poor water and wastewater infrastructure maintenance (Koop & van Leeuwen, 2017). Given Nigeria's rapid urbanization and population growth, more attention must be devoted to settlements and communities susceptible to flooding, which is presently the most frequent and severe environmental issue it faces, to create sustainable cities and communities (Echendu, 2020; Security, 2013). Sustainable practices in developed countries that have yielded positive results in attenuating runoff flow volume should be incorporated to reduce the impact of flooding in human settlements as an attainment of the SDGs 2030 agenda.

Incorporating sustainable solutions in flood-prone regions

Recent studies in the literature have begun to pay more attention to the issue of sustainable management of water resources in relation to flooding and stormwater attenuation (Lapointe *et al.*, 2022). Flood risk management touches on several SDGs, including those about climate change, water management, resilient infrastructure, sustainable cities and communities, and the sustainable use of terrestrial ecosystems. Sustainability in flood control practices emphasizes proper and robust flood risk management (Owen, 2022). Sustainable flood risk management depends on the growth of information regarding the risk and likelihood of flood events, which will guide successful and resilient flood risk management techniques and enable the development of appropriate and effective policies and decision-making (Shah *et al.*, 2018). To incorporate a variety of flood risk perceptions into the decision-making process, sustainable flood risk solutions will necessitate broad community and stakeholder engagement. This will ensure proper adaptation and a full variety of flood risk perceptions in the decision-making process, especially from grassroots (Almoradie *et al.*, 2020). Fig. 4 revealed sustainable solutions to be applied in floodplain regions in Nigeria.

Sustainable drainage system (SUDS)

Sustainable drainage system is a widely accepted concept essential for runoff flow reduction, leading to sustainable and natural flood control with agreeable principles, especially for urban areas (Miklas, 2015). It is needed at this critical time to support the weakness of conventional drainage system functions because of the implications of urbanization and climate change (Qianqian, 2014). The impact of climate change has been broadly recognized as a

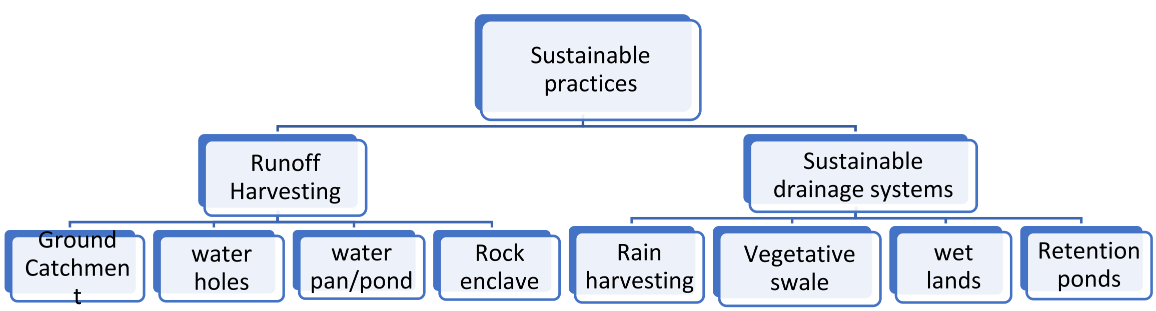

Fig. 4: Sustainable practices for flood control

universal issue affecting the global natural features, resulting in intense rainfall, accelerated urban water runoff, and flooding (Willems *et al.,* 2012). This situation has posed an enormous challenge to the available conventional drainage system, which was not designed for such storm runoff capacity. Ebele & Emodi, (2016) confirmed that the major cause of flooding remains in effectively addressing the root causes resulting from extreme weather events and heavy downpours, which have overwhelmed the existing drainage and runoff management systems, leading to devastating floods in various parts of the country. Sustainable Drainage Systems are envisioned to control surface storm runoff at a closer distance to where it falls, thereby encouraging a natural draining method at a closer spot (Ward, 2020, Daniele & Vivian, 2020). This will provide the chances of flood mitigation and a combination of water management functions. SUDS is of prodigious global importance, maintaining a beneficial tool for improvement of urban environment spaces, functioning to reduce the impact of flooding and forming a new management approach for sustainable cities (Rodriguez-Rojas *et al.,* 2017). Many developed countries, most particularly in Italy, the United Kingdom, the United States, and Asia countries have implemented the use of sustainable drainage systems to reduce runoff flow, advert the impact of flooding, and mitigate the climate change situation within the environment (Boluwatife, 2021). SUDS, purpose focuses on natural processes and methods that lower the catchment flow point and lessen runoff peak discharge. For instance, Coventry University conducted research on flood reduction using different kinds of SUDS methods, which include detention basin, green roof, decanting paved surface, and vegetated swales, used as an experimental study to control flood. However, the four adopted methods displayed positive responses in the reduction of runoff flow. However, swale recorded an effective reduction of storm water flow than others (Yiyang, 2024, Qiao *et al.,* 2018). This study authenticates the capacity of SUDS in reducing flood events and associated risk. Source control methods can be introduced in areas that are most vulnerable in Nigeria. This method includes detention basins, retention ponds, vegetative swales, and wetlands. It required identifying the low terrain areas that can accommodate the runoff flow, thereby preventing the peak accelerated drift to communities and settlement. Fig. 5 displayed a few examples of the recommended method for applicability in the Nigerian environment.

Rain runoff harvesting (RWH)

Several studies from the literature have proven that flooded areas in urban catchment can be condensed up to 100% with the employment of rainfall harvesting techniques, even with a small amount of rainfall. However, nearly a 35% reduction of flooded areas can be achieved with severe rainfall events (Gabriele & Lorena, 2019, Paolo *et al.,* 2020). RWH is another sustainable method that performs a double function. It captures water from the source, reduces runoff flow, controls flooding, and supplies water for re-use purposes (Paolo *et al.,* 2020). It is usually done at a small scale in a few rural communities in Nigeria based on household capacity. However, household collection of rainwater looks insignificant to solve these flood-related problems using rain harvesting because of the recent rainfall intensity caused by climate change. Government input is needed to develop a larger rain harvesting hub, especially in various affected communities. In developed countries, rain harvesting techniques with the adoption of open surface catchment methods were successfully implemented along with small-scale irrigation projects for the riparian state in Africa. This was executed to support agricultural production (Mati, 2012). Campisano and Modica, (2017) explored the effectiveness of an RWH system installed to reduce peak flow during storm runoff events in Sicily, a small city in Southern Italy. The results disclosed that, dependent on the capacity of the tank and rainfall intensity and features, the installed RWH tank efficiently reduced the peak flow of rainfall in a multitude of storm events. Similarly, Teston et al. (2018) evaluated the outcome of RWH using several scenarios on flood reduction in Curitiba city (Southern Brazil), the outcome indicated a reduction of runoff peak flow. Rainwater harvesting (RWH) is the process of collecting rainfall runoff either through the roofs, ground surface, or rock catchment. Storage of rainwater is usually achieved using tanks, rocks in the catchment area, and reclaimed dams (Paolo *et al.,* 2020). Rainwater harvesting serves many purposes, ranging from domestic water use, industrial processes, and irrigation functions (Gabriele & Lorena, 2019). The goal of this study's

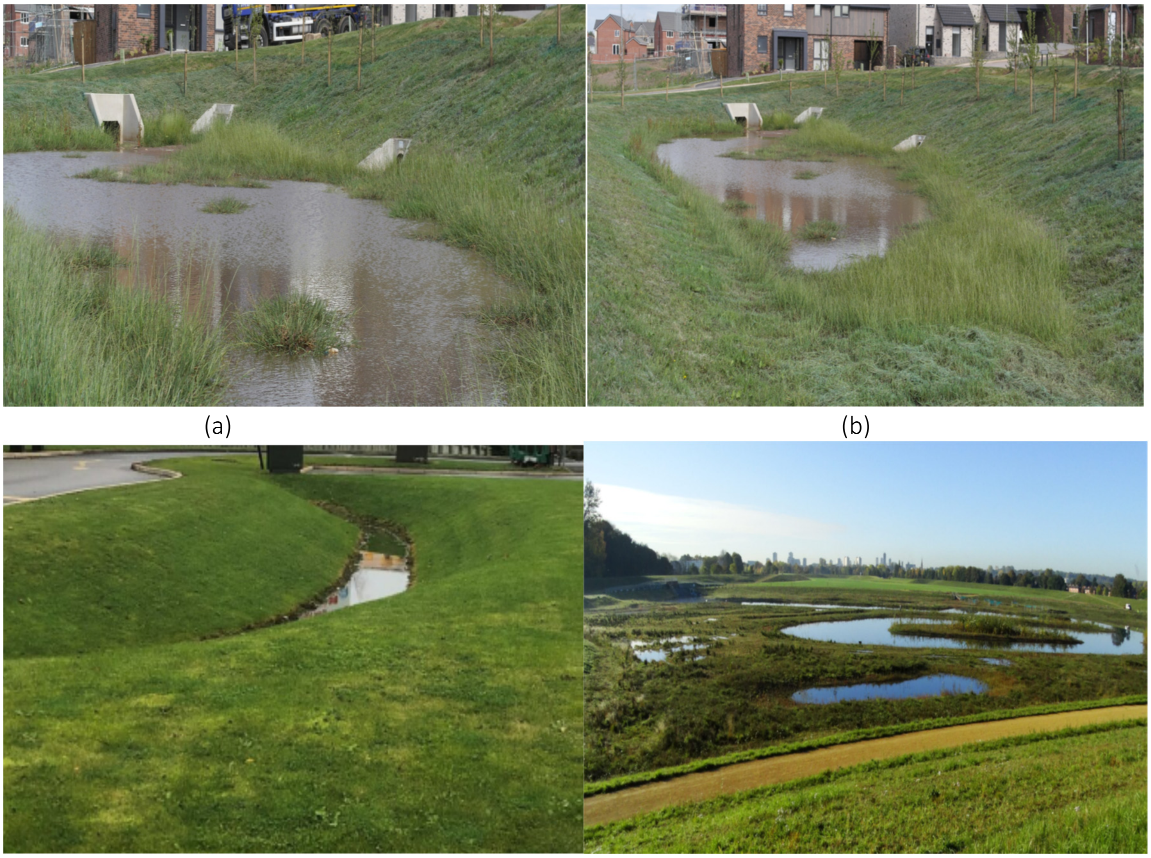

Fig. 5: SUDs practices showing SUDs practices. (Flood hub, 2021)

approach is to collect rainwater runoff from a collection point to lower peak flow, which typically causes environmental flooding. To lower the volume of runoff flow, the procedure may entail directing the roofs of every structure to a point where rainwater. However, it will involve some financial implications, which will prove a better result in the long run. Its potential as an option for water supply can also be harnessed for other purposes. Fig. 6 reveals the types of rain runoff harvesting methods practiced in developed countries. This is also explained using the following subheadings.

Ground catchment

Any kind of ground surface that provides surface runoff for water collection is referred to as a “ground catchment.” The surface can include roads, housing compounds, pasture plains, woodlands, rocky areas, and other open land surfaces, both paved and unpaved. In terms of variations in the intake and outflow of water and other variables, naturally occurring catchments are typical examples of an open system (Ariwadun, 2020, Xinyao *et al.,* 2022). For micro ground catchments, the sizes could range from a few square meters to vast land areas and entire watersheds used for massive storage devices like dams. In locations without suitable roofing, runoff can be collected using small or micro-scale ground catchments, while greater runoff flows can be collected in larger catchments and stored for reuse for either irrigation or large-scale water sources (Xinyao *et al.,* 2022). Stefanus, (2012) stated that the catchment size significantly affects the relationship between rainfall and runoff and, in turn, the applicability of calculation techniques. For instance, the relationship between rainfall intensity and soil infiltration rate is crucial in small catchments, whereas in big catchments, the amount of rainfall in proportion to the ground's capacity to store water is more significant (Brown *et al.,* 2005). Ground catchments often have the advantage of collecting water from a broader area when compared to roof harvesting (Mati, 2012). This will be helpful, especially in flood-prone areas in Nigeria.

Water holes

Water holes are minor excavated ponds used to collect small amounts of water, mostly for domestic use in rural areas, livestock purposes, and occasionally for modest garden irrigation (Mati, 2012). They are extremely adjustable both spatially and temporally. They are frequently part of larger wetlands, such as a waterhole within a riverine wetland. In regions with a high-water table or where the soils are self-sealing, it is unlikely that you will experience seepage issues. waterholes are typically dug by hand in most cases (Hayward & Hayward, 2012). A residential compound's water hole is typically situated in the lower portion to take advantage of natural drainage and the potential for minimal earthwork. It is ideal for the catchment surface to be impervious. If at all feasible, the catchment area could be artificially prepared through soil conditioning or concrete pavement (Paolo et al., 2020). Developed countries such as Queensland in Australia developed waterholes for diverse purposes, among which is retaining storm flow and reducing runoff (Zivee et al., 2020). The purpose here is engineered towards the reduction of runoff flow in flood-prone areas.

Rock enclave catchment

This is a ground catchment arrangement where a large rocky surface is utilized as a surface runoff source (Mati, 2012). The runoff is channeled to a storage tank or reclaimed facility. This should be considered in regions where the rock surface is dominant for capturing storm runoff and reducing the impact on communities. Rock catchments work well in places where there are large, irregular rock outcrops (Nissen-Petersen, 2006). This method of runoff catchment is noted with several distinctive features and gravity flow supplies. It is also regarded as a cost-effective method of rainwater runoff catchment system (Ogen, 2015). They exhibit high runoff coefficients because of the impervious surface nature of the rock, which speeds up the acceleration of water flow even with a limited amount of rain (Nissen-Petersen, 2006). The water derived from the rock catchment can be reused for other purposes that suit the nature of the water. Constructing a rock

Fig. 6: Rain harvesting methods (Mati, 2012).

Fig. 7: showing types of water pan/ pond with a) local water pan, b) retention ponds (Mati, 2012)

catchment can be done by community members as a form of participation towards reducing the impact of floods in the built environment.

Water pan/ponds

Excavated pans/ponds are small reservoirs that range in depth from one to three meters, typically dug off-stream with compacted banks surrounding them (Mati, 2012). The distinction is that ponds are built in areas with a high-water table or some groundwater contribution, whereas pans get all of their water from surface runoff (Chalov et al., 2016). Both pans and ponds are built to catch and hold runoff water from a variety of surfaces, including roadways, hillsides, rocky regions, and open rangeland. Pans and ponds are typically constructed near communities in industrialized nations, on grazing grounds as opposed to farmlands. When compared to surface or subsurface tanks, one benefit of pans and ponds is their ability to store a comparatively large volume of rainwater. Pans do not get groundwater contribution; they are entirely dependent on surface runoff (Chalov *et al.,* 2016). Storm runoff can be reduced into ponds in flood-prone areas to lower the runoff flow. Both retention and detention ponds exist in sustainable drainage, functioning as pools filled with water that fluctuate in response to runoff and rainfall. They prevent erosion and flooding by collecting water and releasing it gradually (Lisetskii & Buryak, 2023). Retention ponds type of SUDs, are primarily used to enhance the quality of urban runoff and reduce peak stormwater runoff rates by temporarily retaining water after heavy storm. They can be made by building embankments, excavating a new depression, or utilizing an already-existing natural depression (Zabolotnia *et al.,* 2022). Fig. 7 shows the water pan and retention pond adopted in developed countries.

Required green infrastructure practices

Green infrastructure, according to the World Bank Group, aims at managing the effects of rainy weather while providing social, economic, and environmental advantages by utilizing natural processes (UFCOP, 2016, Maria, 2020). Apart from the earlier-mentioned green practices for immediate solutions, other green infrastructures can also be integrated as a long-term provisional solution. These practices include the following

Green/ Blue roof

Green roofs are flat or gradually sloping roofs with vegetation and a planting medium on top of the roof material. They help to retain runoff from the roof, thereby lowering peak flow at ground level (Kristiina. 2020). It is typically a filtering crust, drainage coating, waterproof membrane, thermal padding, and vapor control layer (Parry, 2018). It works to control climate change impact with a lot more advantages, such as lowering building temperature, cooling and heating requirements, enhancing air quality, prolonging roof membrane life, lessening the heat island effect, and using less water by reusing collected rainwater (Skjeldruma & Tore, 2017). Blue roof is also known as a non-vegetative type. They are designed to be retained on the surface or in specially premeditated trays. These surfaces or trays gradually release the water using a flow-restriction device surrounding the roof drains. Green and blue roofs both lower the volume of stormwater runoff and peak floods; they also remove pollutants by absorbing and filtering them (Mohammed *et al.,* 2020; Parry, 2018).

Tree planting practices/afforestation

Studies from literature have constantly emphasized the need for tree planting given the current climate change situation ravaging the globe (Mercy Forest, 2014; Pataki *et al.,* 2021). By planting native trees or preserving existing ones, runoff can be slowed, captured, and stored in the canopy, and evapotranspiration can release water into the atmosphere (Pataki *et al.,* 2021). Additionally, the soil conditions created by tree roots encourage infiltration. Other benefits embedded in tree planting afforestation practices include, apart from reducing stormwater, temperature and noise reduction, absorption of carbon dioxide, accommodating urban wildlife habitat, providing shade for recreation and relaxation, promoting property values, and reduction in maintenance costs (Turner-Skoff & Cavender, 2019).

Tree box filter

Tree boxes, usually known as stormwater tree trenches, are usually joined by an underground trench, forming a row of trees within the soil featuring layers that help in storing and filtering stormwater runoff (Tobio *et al.,* 2014). They function effectively in parking lots and roadway spaces, with little room for stormwater management. The only disadvantage is the cost implication, especially for larger regions, because they work best for smaller sites or neighborhoods (Pataki *et al.,* 2021). Tree boxes are a particular kind of bioretention technique is They are engineered landscape techniques that use vegetation to filter or seep into stormwater runoff (Tobio *et al.,* 2014). These practices can be integrated into roadways and parking lots to attenuate storm runoff flow.

Potential Embedded in Sustainable Practices

Utilizing sustainable stormwater attenuation techniques is crucial to management and addressing several environmental issues, fostering resilience and sustainability in communities (Lina *et al.,* 2024). Studies from literature have identified lots of cost benefits and potential it engages, such as reduced flood danger, better water quality, more biodiversity, and higher amenity values, among others (Bobbi *et al.,* 2014). For instance, the method of restoring wetlands, extending stormwater retention, and retrofitting stormwater ponds enhances water quality while lowering flood risks and peak flows United States Environmental Protection Agency has harnessed these potentials, pointing out that the major goal of stormwater attenuation is to improve water quality and decrease runoff (EPA, 2024). In Nigeria, this process of stormwater management can fit in as another means of water supply, especially for remote areas where water scarcity exists. To increase water efficiency and lower the demand for domestic water use. Several factors should be taken into account, such as water conservation and water demand management. Reducing water loss and creating substitute water sources. All users, from primary residential use to water for irrigation, stock watering, recreation, and aquatic habitat maintenance, must meet certain water quality criteria. Actionable steps towards achieving these embedded potentials will require conducting a baseline evaluation, such as assessing flood history, flood-prone areas, and significant stormwater channels. However, information on rainfall patterns and runoff volume will be valuable. Collaboration and partnership with external professionals and experts should also be incorporated, while policy integration involving grassroots governance and stakeholders will be of great importance. Funding sources needed for effective, actionable steps could accommodate budgetary allocations from the national or local governments, the Ministry of Infrastructure and Environment, international aids and grants, social responsibilities from corporate organizations, while real estate and housing developers may also be required by regulations to provide drainage infrastructure while initiating development.

Economic and policy barriers

Sustainable stormwater attenuation has proven to have yielded many advantageous results, especially in the developed countries where such exist; however, there are also financial and policy obstacles that should not be disregarded, especially in Nigeria. Execution of sustainable infrastructure for conceivable runoff attenuation, such as rain gardens and detention basins, entails significant funding and investment; therefore, intending communities may witness limited financial support due to budget constraints. However, facilitating planned community involvement and private developers may oppose incorporating sustainable drainage systems (SuDS) due to perceived risks or lower immediate returns on investment. Similarly, policy hurdles and a lack of clear legislation that encourage or mandate sustainable stormwater management practices might be limited. Similarly, current zoning laws may not prioritize or allow for the incorporation of green infrastructure, especially in urban centers that have already experienced development.

CONCLUSION

This review assesses Nigeria's use of sustainable methods for stormwater runoff attenuation as a potential solution for flood impact reduction. The need arises due to the requirement for sustainable cities and settlements for everyone to meet SDG 11's target by 2030. Numerous SDGs, 2030 agenda, such as those related to climate change, water management, resilient infrastructure, sustainable cities and communities, and the sustainable use of terrestrial ecosystems, are touched upon by flood risk management. The review highlighted sustainable methods of attenuating storm runoff volume, with few practical examples practiced in developed countries. For instance, sustainable drainage systems and the source control methods, runoff harvesting/ rain harvesting hubs, runoff ground catchment/ water holes, rock enclaves, and water pans, among others. Government effort is urgently needed in practicality, not in abstract, towards achieving this target. However, in the broader framework of the SDGs' sustainability goal, improving our residential communities and environment remains essential; therefore, it demands a clarion call for all to participate, such as participation of stakeholders, including NGOs, the private sector, donors, politicians, religious organizations, philanthropists, institutional entities, and community participation. Moreover, Partnerships and collaborations in development also offer reliable and timely solutions for achieving the predetermined objectives. The terms partnership, collaboration, and other related terms like alliance, union, and networking. cooperation and work groups indicate a broad variety of interactions and arrangements. The difficulties of flooding and its related effects can be lessened by a concerted, persistent, and resolute effort by all parties, including government organizations.

AUTHOR CONTRIBUTIONS

G.U. Fayomi performed the literature review. E.K. Onyari supervised the work. S.R. Funsho conceptualized the work. F.J. Odekunle investigates and reviews the work.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely witnessed by the authors.

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ABBREVIATIONS (NOMENCLATURE)

BMP	Best Management Practices
DTM	Displacement Tracking Matrix
EPA	Environmental Protection Agency
FRM	Flood Risk Management
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LID	Low Impact Development
NBS	National Bureau of Statistics
NEMA	National Emergency Management Agency
NGOs	Non-Governmental Organizations
RWH	Rainwater Harvesting
SDGs	Sustainable Development Goals
SUDS	Sustainable Drainage System
UN	United Nations
UNDP	United Nations Development Programme

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