Approaches to Provision of Flood and Climate-Resilient Civil Infrastructure in Africa: Evoking the Integrated Technological, Policy and Community Model to Work

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Abstract

Civil infrastructure in Africa remains vulnerable to floods and climate-related extreme weather events. This has caused severe socio-economic losses that threaten the region's ability to meet its targets for the Sustainable Development Agenda. Traditionally based silo-approach proved to be insufficient, as they focused on engineering solutions to address the continent's climate, socio-economic and governance challenges. The inadequate integration of new and sustainable technologies in urban planning, design

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and maintenance is one of the gaps behind this vulnerability. This study argues that resilience can only be achieved through a multi-prolonged approach that brings technological innovations, institutional frameworks and community-driven adaptation strategies. The adoption of innovations that are context-specific, such as nature-based solutions, climate-smart infrastructure, GIS-based flooding models, IoT-based early warning systems, and adaptive design principles, may help Africa to adjust. The research draws from three case studies from Kenya, South Africa and Senegal to illustrate how the adoption of modern technologies can accelerate when combined with inclusive and participatory approaches. Key barriers like financing gaps, weak institutional coordination, and limited technical expertise are identified in this. The article concludes that integrated approaches will help Africa to realise that infrastructural solutions are technically sound, socially inclusive, economically viable and ecologically sustainable.

***Keywords**:* emerging technologies, community-based adaptation, sustainable development, Africa, institutional texture, design

INTRODUCTION

As climate change intensifies, the hydro-climatic conditions in sub-Saharan Africa make it prone to floods. Flooding is the leading environmental disaster globally and a critical challenge being faced by countries since the year 2000 (Wakuma *et al.*, 2009; Okaka and Odhiambo, 2018). Floods pose serious socio-economic challenges annually, with flooding affecting 20 000 lives and affecting 20 million people across the globe. On a global scale, floods have frequently affected over 2.8 billion, causing 200 000 deaths over the past decades. Worse floods hit the western African region in countries like Burkina Faso, Ghana, Senegal, and Niger in 2007, affecting 600 000 people (Aliye *et al.*, 2023). In Sub-Saharan Africa (SSA), the occurrence of floods is not a new phenomenon. In Lagos, floods have been recurring annually since 1947 (Atufu and Holt, 2018). Recently, Cyclone Idai, which originated from the Indian Ocean, resulted in floods that caused unforeseen circumstances never seen before in Zimbabwe and Mozambique.

Rapid urbanisation in SSA, the rate of movement of people from the countryside to urban areas looking for better opportunities, is a significant driver of flooding. The growth of the population in Africa is 2.6% and this is expected to double by the year 2050 (Pate *et al.*, 2022). This has resulted in the proliferation of informal settlements in urban spaces in an unplanned manner. Low-income earners who cannot afford to buy houses in flood-free areas settle in these areas. Urbanisation and poor drainages exacerbated the crises. Cities like Accra in Ghana lost almost 50% of vegetation from 1986 to 2013, causing flooding (Ighile and Shirakawa, 2020). Some floods destroy communities, particularly in townships of South Africa (Haung *et al.*, 2016). In Cameroon, floods that occurred between 2024 to 2025 affected at least one million people with the destruction extending to schools, hospitals and farmlands (Mafire, 2025).

In South Africa, floods are now considered a new normal that needs planning at all levels of the government (*Mail and Guardian,* 20 August 2025). In East African countries, including Burundi, Kenya, Rwanda, Somalia, Ethiopia, and Tanzania, 637 000 people, in just one week, were displaced by flooding in 2024 (UN, 2024). Mali, Niger, the DRC and Nigeria experienced infrastructural damage due to floods that destroyed cropland, healthcare facilities and education facilities that catered for 10 million pupils (Africa Centre for Strategic Studies, 2024). The historic floods that hit Chad due to heavy rainfall in 2022 were the heaviest ever recorded in the country in three decades, showing that extreme weather events will be frequent. In South

Sudan, floods come with them Malaria which affected more than 50% of the people in its states (*ibid.*).

CONCEPTUAL FRAMEWORK

Developing flood- and climate-resilient civil infrastructure in Africa requires a systems approach that integrates technological innovation, adaptive policy frameworks, and inclusive community engagement. This approach views infrastructure as part of a complex socio-ecological system, where resilience emerges from the dynamic interplay between physical assets, institutional mechanisms, and human behaviour (Ambily *et al.*, 2022). Technological tools such as IoT-based flood sensors, machine learning for predictive modelling, and early warning systems enhance real-time responsiveness and risk anticipation (Wang *et al.*, 2024). However, their effectiveness depends on supportive policy environments that promote data sharing, incentivise green infrastructure, and embed climate risk into urban planning. Instruments like parametric insurance and climate-informed zoning regulations have shown promise in reducing vulnerability and accelerating recovery in flood-prone regions (World Economic Forum, 2024).

Equally vital is the role of communities as co-producers of resilience. Community-based adaptation (CBA), participatory planning, and local knowledge integration ensure that infrastructure solutions are contextually grounded and socially accepted (Climate Action Africa, 2023). Informal settlements, often located in high-risk zones, require tailored interventions that combine engineered solutions with nature-based approaches such as wetlands restoration and permeable surfaces (JG Afrika, 2023). The systems approach thus calls for inter-operability across domains; technologies must be designed with community input and policy alignment; policies must incentivise innovation and empower local actors; and communities must be equipped with tools and knowledge to adapt and respond. This integrated framework fosters transformative resilience, enabling African cities and regions to not only withstand climate shocks, but also evolve toward more equitable and sustainable futures (Climate Cosmos, 2025).

LITERATURE REVIEW

Early warning systems help to maintain preparedness and response in flood-risk areas. Internet of Things (IoT) based smart sensors can be used to monitor water levels, rainfall and environmental parameters in real time whilst transmitting data directly to cloud platforms and smartphones. Countries like Indonesia have used the IoT to measure water characteristics and transmit real-time data to smartphones in time, allowing fast and wide coverage (Yuliandoko *et al.*, 2018). The integration of IoT and Artificial Intelligence (AI) or Machine Learning (ML) in flood-risk areas helps to accelerate the accuracy of flood prediction (Ashwini *et al.*, 2024). AI/ML technologies. like random forest and the support vector machine (SVM), have dominated flood susceptibility and early warning studies, together with IoT and cloud computing. Al-Rawas *et al.* (2024) indicate that predictions using AI-driven systems can achieve 90% accuracy, though challenges like variable selection, internet connectivity and data consistency persist. In addition, improved efficiency and reduced latency have been reported in systems that combine IoT with edge computing for on-device neural network predictions (Samikwa *et al.*, 2020). The integration of forecasting models with community-based warning dissemination increased preparedness and reduced lead time and risks in Nepal (Smith *et al.*, 2017).

The identification of flood-prone areas has been made easier recently with the use of Geographic Information Systems (GIS) and remote sensing (RS) (Farhadi and Najafzadeh, 2021). Moreover, these tools are used in modelling flood dynamics and supporting sustainable risk reduction strategies. The combination of GIS and RS with models like the Hydrologic Engineering Centre's River Analysis System (HEC-RAS) and the Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS) has informed the simulation of the extent and depth of floods, thereby improving accuracy (Peker *et al.*, 2024). Farhadi and Najafzadeh (2021) highlight the production of high-resolution flood risk maps that have improved urban planning and disaster preparedness in the country. Modern technologies like Sentinel-1 SAR and Landsat imagery have been successfully used for flood mapping in cloudy conditions (Ali *et al.*, 2021). Abdelkarim *et al.* (2019) posit that the integration of these technologies with GIS has helped to improve flood monitoring and management. In the Global South, the use of indigenous knowledge systems (IKS) is integrated with RS datasets (Tedla *et al.*, 2021). This has produced more trusted and actionable maps for flood preparedness and land-use planning.

The principles of climate-smart agriculture also extend to the construction industry. The improvement of water absorption and reduction of runoff through soil stabilisation, permeable surfaces and bio-based composites in agriculture helps to lower the risks of floods (Bhanuwanti *et al.*, 2024). Musonda *et al.* (2023) recommend the use of locally available low-carbon materials in combination with digital construction management, for readiness to flood risks. The use of embedded fibre-optic sensors, scour detection systems, and AI-driven predictive maintenance can help to prevent structural failures in flood-prone infrastructure like bridges. Buka-Vaivade *et al.* (2025) document that such integrated approaches extend the lifespan of infrastructure even under extreme flood events. Literature highlights the importance of hybrid systems that integrate green infrastructure like green roofs and wetlands with flood-resistant materials to enhance resilience and dense coastal cities (Aziz *et al.*, 2024).

Nature-based solutions are recognised as effective sustainable methods for flood risk reduction. They also deliver benefits to the society, ecosystem and biodiversity. When wetlands are restored, they act as natural water storage systems, whilst helping to reduce peak flood flows and improving the quality of water (Van Coppenolle *et al.*, 2018). Management of storm waters through green roofs, rain gardens, and permeable pavements helps to delay runoffs and reduces the load on the drainage systems (Liao *et al.*, 2017; Liu and Zhang, 2025). The solutions are more effective in dense urban areas where spaces are limited. The integrated use of engineering structures like floodwalls with restored riparian buffers has also proved to be an effective solution in improving flood protection (Fenner *et al.*, 2019). The use of NbS projects has also proved to be successful when cross-sector collaboration, long-term monitoring and community engagement are in use, as they help to increase awareness and acceptance by the pubic (Perosa *et al.*, 2021). Wetlands restoration and green infrastructure provide measurable reductions in flood risk, while delivering biodiversity and climate adaptation benefits (O'Donnell *et al.*, 2019).

The integration of resilience into national infrastructure policies is an important issue for ensuring critical systems that can adapt and withstand the impacts of climate change. The inclusion of resilience principles in national policy frameworks ensures that planning for infrastructure at different levels takes care of risk reduction, adaptive capacity, and sustainability. To succeed in mainstreaming resilience, cross-sectorial coordination should be implemented. In addition to this, strong regulatory frameworks, and institutional mechanisms that connect infrastructural development to the objectives of climate adaptation should be put in place. It has been proven in different countries that that integration of resilience metrics within project appraisal and investment decisions will improve the capacity to anticipate risks and reduce long-term costs.

Climate adaptation financing mechanisms remain a key challenge in the field of floods. Some projects, like investment in land reclamation, are very important as they can generate finance that can be used to offset adaptation costs. Although its advantageous, the distribution of the benefits in this case remains a serious challenge (Bisaro *et al.*, 2019). In the agricultural sector, cooperative risk-sharing agreements and diversification of livelihoods can help with financial resilience. Amandaria *et al.* (2025) contend that the first step should be formalising the mechanisms and gaining access to credits. At the national level, laws are shifting from reactive to proactive risk reduction. However, the integration of climate change projections, NbS and cross-sectoral coordination still has some gaps (Mehryar and Surminski, 2020). In some cases, where Protect, Accommodate, Retreat, Avoid (PARA) were used, there was proof that effective flood resilience policies need the integration of engineering, zoning, and land-use planning, whilst considering equity (Doberstein *et al.*, 2018). Meng *et al.* (2020) postulate that innovations such as green-blue corridors and buffer zones are effective when they are strongly supported by institutional capacity, inclusivity and climate policy.

Local governance bodies with resources and authority, like village protection committees, are significant in mobilising stakeholders for preparedness, early warning systems, and community adaptation (Imperiale and Vanclay, 2020). Cross-country comparisons reveal that public-private partnerships, funding for green infrastructure, and participatory planning processes can significantly enhance both financial and institutional resilience (Fekete, 2019). The African Union's (AU) Programme of Action for the Implementation of the Sendai Framework in Africa sets continent-wide priorities for disaster risk reduction, emphasising financing mechanisms, infrastructure standards, and regional early warning systems (Manyena, 2016). The AU Agenda 2063 includes climate resilience as a core goal, calling for harmonised policies and continental funding mechanisms to address climate-induced floods and droughts (Uchiyama *et al.*, 2021).

The Southern African Development Committee (SADC) Climate Change Strategy and Action Plan promotes member state coordination on adaptation finance, integrated water resource management, and cross-border flood early warning networks (Agbehadji *et al.*, 2023). SADC protocols, such as the Protocol on Shared Watercourses, provide legal backing for cooperative flood management and investment in resilient infrastructure, although implementation is uneven due to national capacity gaps (Salami *et al.*, 2017). Regional bodies help pool resources and negotiate climate finance at global fora, increasing bargaining power and reducing transaction costs for member states (Phibbs *et al.*, 2016). Joint research initiatives under AU and SADC frameworks also improve knowledge transfer and standard-setting for flood-resilient building codes and risk mapping (Munpa *et al.*, 2022).

Community-centred approaches are vital for creating flood- and climate-resilient civil infrastructure in Africa because they integrate local knowledge, foster inclusion, and build shared responsibility. Participatory planning and mapping, as seen in Ghana, help communities articulate vulnerabilities and adaptive strategies that reflect their unique socio-environmental contexts, while addressing socio-spatial inequities that often leave marginalised groups more exposed to flood risks (Ibrahim *et al.*, 2024). Integrating local knowledge, as demonstrated in community science and citizen engagement projects, not only improves infrastructure monitoring, but also increases community ownership and trust in resilience measures

(Hendricks *et al.*, 2022). Social equity and inclusion are further strengthened when resilience strategies explicitly address the needs of vulnerable groups, such as women and farmers, and prioritise recognitional equity in policy frameworks (Adebayo, 2024).

Capacity building is another pillar of community-centred resilience. Participatory action research in disaster resilience education has shown that co-learning between residents and researchers can enhance the technical and organisational skills needed to manage stormwater infrastructure and respond effectively to floods (Meyer *et al.*, 2018). Building this capacity supports the creation of local monitoring systems, such as smartphone-based infrastructure assessment tools, which empower communities to maintain and improve their own resilience over time. When communities possess both the knowledge and agency to act, they can mobilise resources, influence policy, and sustain resilience interventions beyond the scope of external aid. In Africa's diverse contexts, merging such bottom-up empowerment with coordinated policy and technological support creates a more sustainable pathway to climate- and flood-resilient civil infrastructure.

Building flood- and climate-resilient civil infrastructure in Africa requires the integration of technological innovation, coherent policy frameworks, and strong community engagement. However, several barriers hinder the adoption of these approaches. Economic and institutional constraints, such as limited access to finance, insecure land tenure, inadequate extension services, and fragmented institutional support, slow down the uptake of innovative solutions (Olabanji and Chitakira, 2025). Social and cultural factors, including gender inequalities, low awareness of climate risks, and community reluctance to relocate, further complicate resilience efforts (Dewa *et al.*, 2022), (Bryan *et al.*, 2017). Technical limitations, such as the lack of localised flood models, weak monitoring systems, and insufficient expertise to operate advanced tools like AI, GIS, and digital twin technologies, also pose significant challenges (Aziz *et al.*, 2024).

Governance and coordination issues are equally significant. Climate resilience initiatives often suffer from fragmented policies, where water, energy, agriculture, and infrastructure sectors operate in silos, reducing efficiency and creating policy conflicts (Mpandeli *et al.*, 2018). Weak institutional capacity, limited resources at the local government level, inconsistent enforcement of regulations, and unclear agency roles undermine the potential of integrated flood management frameworks (Grigg, 2024). Furthermore, a lack of participatory planning processes often means that resilience strategies fail to reflect community needs and local knowledge, limiting their effectiveness and sustainability (Adebayo, 2024).

Despite these challenges, there are clear opportunities for scaling and replication. Nature-based and green infrastructure solutions such as wetlands restoration, permeable pavements, and urban green spaces offer cost-effective, adaptable methods for enhancing resilience (Takin *et al.*, 2023). Policy integration through cross-sector frameworks, such as the water-energy-food nexus, can improve resource efficiency and harmonise climate adaptation measures (Mpandeli *et al.*, 2018). Technology-enabled early warning systems, leveraging AI-based flood modelling and mobile alerts, can significantly enhance preparedness (Aziz *et al.*, 2024), while empowering community-based committees and promoting gender-inclusive planning ensures local ownership and long-term sustainability (Dewa *et al.*, 2022). Together, these strategies highlight the potential for Africa to move toward an integrated, technology-driven, and community-centred model of climate and flood resilience.

METHODOLOGY

The methodology for this study adopts a qualitative research design, emphasising an in-depth desk review as the primary data collection method. The desk review involved a thorough analysis of secondary sources such as books, peer-reviewed journal articles, government reports, policy documents, and other relevant publications. These materials were chosen based on specific criteria: their relevance to the research topic, credibility, and recency. This selection ensured that the data reflected the most current and reliable information available on integrated technological, policy, and community approaches for flood and climate-resilient civil infrastructure in Africa. For data analysis, textual analysis is employed, a method that allows for the systematic examination of written content to extract meaningful insights. This approach facilitates the identification of recurring themes, patterns, and relationships within the data, helping to answer the research questions effectively. Textual analysis also enabled the researchers to explore the narratives and conceptual frameworks presented in the literature, offering a comprehensive understanding of how different African countries are implementing or struggling to implement integrated approaches to enhance the resilience of civil infrastructure against flooding and climate change impacts. The qualitative nature of this study, combined with the use of textual analysis, provides a flexible yet structured approach to investigate the research problem.

FINDINGS

Results in this study are presented in the form of case studies. Three African countries were selected based on their vulnerability to climate related risks. The research concentrated on countries from the sub-Saharan region, choosing one country from each of the West African, Southern African and East African regions for generalisability of results.

Case 1: Kenya

The implementation of real-time flood monitoring systems based on IoT technology in Kenyan flood-prone areas like River Tana and Turkana County helped to improve disaster preparedness. The systems are integrated with ultrasonic sensors, predictive analytics and Short Message Services (SMS) alerts. The International Water Management Institute (IWMI) in the country is working with different stakeholders in Tukana County to establish an innovative flood detection and prediction system, which can be used to deliver accurate early warning information to surrounding communities (IWMI, 2025). The county faces climate-related challenges like droughts, dry spells and erratic rainfall patterns. Due to intensifying climate change, rising temperatures and extreme weather events have been prevalent, disrupting people's livelihoods and their welfare.

In trying to respond to these challenges, the IWMI supported the County Government of Turkana to launch a climate information system. This was meant to strengthen community resilience through access to information, integration of IKS and promoting climate resilient practices in decision making. The region lacks ground-based data, which makes this innovation a milestone to the county. Machine learning and earth observation data were used to test a flood detection and forecasting model. A specific amount of rainfall received is used as a predictor in conjunction with a regression model on daily rainfall data from the Climate Hazards Group InfraRed Precipitation with Station data. Through this process, it is now possible to identify flood-prone areas using images from remote sensing. The designed model was piloted whilst working together with local people to gather insights from communities in the flood-prone areas. The model produced promising results, particularly in areas near the Turkwel River.

Traditional flood monitoring and forecasting methods are failing to offer real-time data for disaster response in urbanising flood-prone areas like the River Tana in Kenya. In such areas, it is difficult to forecast floods due to their rapid onset (Pradhan *et al.*, 2019). The need for more reliable and accurate flood monitoring was identified in this region to provide real-time data for predictive modelling and effective communication (Kamau, 2024). Challenges posed by traditional flood monitoring systems reduced flood resilience and preparedness, making it difficult to save lives and infrastructure. The integration of emerging flood monitoring systems revolutionises prediction, monitoring, and early warning systems. The machine learning model was trained using historical data for the prediction of future flood events. Reed *et al.* (2022) highlight that the effectiveness of these tools is based on training using comprehensive datasets. Continuous upgrades are done with new evolving data to adjust with time.

The model demonstrated 85% accuracy in predicting flood events, showing that it is reliable and flexible. The system relies on wireless communication protocols like SMS and Long-Range Wide Area Network (LoRaWAN) to transmit real-time alerts. These are important, particularly in areas with limited internet connectivity, transmitting data over long distances with low power use (MDPI, 2023). Early warning mechanisms are regularly and automatically generated. Its advantage is that it adjusts based on the new data that is fed into it. The residents in the flood-prone areas were now satisfied that they were receiving early flood warnings due to the system. Jung (2023) emphasises the importance of accessing information in flood-prone areas.

CASE 2: MOZAMBIQUE

In Mozambique, climate adaptation and resilience is happening through the lens of nature-based solutions, GIS integrated hydrological modelling and community driven disaster reduction risk management. As one of the climate vulnerable countries in Africa, Mozambique has a 2770-km coastline that is vulnerable to cyclones and rise in sea levels. Over 70% of the workforce in the country depend on rain-fed agriculture which is threatened by repeated extreme weather events like Cyclone Dineo of 2017 and Cyclones Kenneth and Idai of 2019. The country lost over $3 billion in damages and over a million lives were affected and these promise to become more intense in future. Cyclone Idai killed 600 people and left 1.85 million in need, 33 000 homes were destroyed completely in Mozambique alone. The country experienced an El-Nino related drought in 2016, the worst in 35 years. Many farmers list crops and livestock, which caused tremendous results to the country's food security decreasing food availability by 15 %.

The government is putting people at the centre of climate adaptation through devolution and inclusive process for planning and different levels from district level. Local adaptation methods include early warning systems that enhance capacity to respond to climatic changes. In addition, the country is making use of more available land in an effective way, with priorities to protect floodplain and other areas that are threatened by floods.

The country has also been implementing initiatives to protect biodiversity and counter soil degradation. In implementing these efforts, the government is working towards the transformation of hydro-meteorological services project for Mozambique, an initiative connected to the World Bank (2013-2019). This was to strengthen hydrological and meteorological information services so that they deliver timely and reliable climate information to local communities. A plethora of initiatives for implementation of climate adaptation have been taken in association with national and international partners.

GIZ (2012- 2020) designed a climate change related project known as Adapting to Climate Change. This was meant to improve climate change adaptation with much emphasis on water resources in Rio Busi are. In addition, the country designed the Mozambique Coastal City Adaptation Project in partnership with the USAID (2014-2019). Two most vulnerable cities along the coastline were considered for improvement of the municipal planning processes and adaptation to climate change. Lastly, another initiative was the Cities and Climate Change - Pilot Programme for Climate Resilience of Mozambique in association with the World Bank (2012-2019). This was meant to strengthen municipal capacity for sustainable urban infrastructure provision and environmental management which enhances resiliency to climate related risks.

The country is also embracing nature-based solutions for restoration of ecosystems and protection of communities. In the Limpopo estuary, community led reforestation efforts have been implemented for over 100 hectares of land since the year 2007. This has seen immense benefits that include reduced saltwater intrusion, improved flood protection, and new forms of livelihoods like mangrove honey and tilapia farming (Nature-based Solutions, n.d.). The nature-based solutions projects also extend to Beira with the support of the World bank. In this case, green infrastructure provision to manage flooding has been dominant and lessons from these initiatives have been scaled to Quelimane and Nacala (World Bank, 2020).

GIS and hydrological modelling was also integrated in Mozambique. The country applied advanced models for mapping flood risks and guide planning, a good example being the Chókwè City flood risk mapping. GIS and HEC-RAS were used to simulate flood scenarios and identify areas that are more vulnerable to floods. The use of Digital Elevation Models (DEMs) helped to locate 25% flood exposures (Laice *et al.*, 2025).

In Motola City, hydrological modelling was used to predict flood risks for 2000, 2020 and 2040. GIS data was integrated with precipitation and urbanisation trends to produce hazard maps (Sellick, 2020). TOPMODEL simulations, using satellite data, was used in Limpopo River basin modelling. This was based on predicting floods and early warning system for both Chókwè and Xai-Xai (Januário, *et al.*, 2022).

CASE 3: SENEGAL

Mangrove estuaries, measuring 185 000 hectares, in the regions of Casamance and Sine Saloum in Senegal are disappearing at a rapid rate. The Natur'ELLES Project in Sine Saloum and Casamance Deltas focuses on the restoration of the mangrove ecosystems whilst empowering women in an economic sense through farming and fisheries. This is done through inclusive governance and capacity building. Over 85 000 people will benefit from the initiative in 113 villages. The mangrove forest provides several environmental services that strengthen resilience and adaptation to local communities. The Soloum Delta generates services and benefits worth 1.5 billion Euros, along with labour income of three billion Euros generated over 10 years (International Institute for Sustainable Development, n.d.). Activities, usually conducted by women, such as collection, processing, and sale of oysters, are prioritised, being recognised as the key sectors of sustainable development by the World Bank and the Senegalese government.

The ecosystem has been degraded by anthropogenic-related activities like global warming, extreme weather events, coastal erosion, fishing and deforestation related to farming. A lot of animal and plant-based biodiversity has been significantly degraded. Senegal has lost approximately 25% of the mangroves between 1980 and 2010 due to drought, wood harvesting and development of infrastructure, which interfered with the flow of water. The availability of resources and livelihoods opportunities have also been affected particularly for women. To address these challenges in empowering women, whilst enhancing climate change adaptation, an initiative called the Natur'ELLES project, spanning 2023 to 2026, was implemented. It is expected that the initiative will increase fishery resources, deal with food insecurity and mitigate climate change-related challenges. The project is being implemented in four marine protected areas and five indigenous and community-based protected areas.

The coastal fisheries initiative in the country serves to safeguard dependent communities in Siné Saloum Delta. The initiative invests in mangrove degraded plantations for them to be productive again, to save water or replenish it, stop coastal erosion and protect people's livelihoods. Mangroove soils act as carbon sinks, stopping it from entering the atmosphere. In addition, the mangrove stabilises soil, hence the need to reforest them so that the soil is not be eroded. The forests mobilise carbon and release it back to the atmosphere. They act as the nursery grounds for fisheries, barriers against storms and a source of wood for building, heating and cooking. As a fishing country, Senegal is facing challenges in terms of planning and management of the mangrove.

DISCUSSION

The case studies highlight how technological innovation is reshaping flood monitoring and climate adaptation in Africa, aligning with literature that emphasises the role of IoT, AI, and GIS tools. In Kenya, IoT-based flood monitoring systems, integrated with machine learning models, demonstrated 85% accuracy with flood prediction that supported preparedness in Turkwel River. Yuliandoko *et al.* (2018) found similar results using IoT based smart sensors in monitoring water levels, rainfall and environmental parameters in real time whilst transmitting data directly to cloud platforms and smartphones.

Likewise, the use of predictive models in Turkana County mirrors the assertion that “the integration of IoT and Artificial Intelligence (AI) or Machine Learning (ML) in flood risk areas helps to accelerate the accuracy of flood prediction” (Ashwini *et al.*, 2024). Mozambique’s use of GIS and hydrological models to map flood risks echoes literature that “the identification of flood-prone areas has been made easier recently with the use of Geographic Information Systems (GIS) and remote sensing (RS)” (Farhadi and Najafzadeh, 2021). Together, these examples illustrate how African countries are applying emerging technologies in ways that strengthen disaster preparedness and resilience.

In parallel, community-centred approaches play a central role in climate adaptation strategies across the three countries, echoing the literature on inclusion and equity. In Kenya, local communities were engaged in piloting predictive flood models, ensuring that interventions were informed by local insights. Mozambique has emphasised devolution and inclusive planning processes at the district level, while Senegal’s N*atur’ELLES* project empowers women in mangrove restoration and fisheries. This aligns with the recognition that “community-centred approaches are vital for creating flood- and climate-resilient civil infrastructure in Africa because they integrate local knowledge, foster inclusion, and build shared responsibility” (Ibrahim *et al.*, 2024). Moreover, Senegal’s focus on women resonates with evidence that “social equity and inclusion are further strengthened when resilience strategies explicitly address the needs of vulnerable groups, such as women and farmers, and prioritise recognitional equity in policy frameworks” (Adebayo, 2024). These parallels demonstrate that resilience is not only technological, but also deeply social, depending on knowledge-sharing and equity.

Nature-based solutions are another shared theme across the cases. In Mozambique, mangrove reforestation and the use of green infrastructure in Beira reduced saltwater intrusion and improved food security, while in Senegal, large-scale mangrove restoration was tied to livelihoods, biodiversity, and storm protection. These approaches correspond directly to literature that "nature-based solutions are recognised as effective sustainable methods for flood risk reduction. They also deliver benefits to the society, ecosystem and biodiversity" (Van Coppenolle *et al.*, 2018). Further, the case of wetlands restoration in Senegal affirms that "wetlands restoration and green infrastructure provide measurable reductions in flood risk, while delivering biodiversity and climate adaptation benefits" *(*O'Donnell *et al.,* 2019: 20). This alignment shows that African countries are increasingly embedding NbS into adaptation frameworks, reinforcing resilience while securing co-benefits for communities and ecosystems.

Finally, the findings highlight the importance of multi-level governance and policy integration in scaling resilience measures. Mozambique's Hydro-Meteorological Services Project and Senegal's partnerships with the World Bank echo literature that "the integration of resilience into national infrastructure policies is an important issue for ensuring critical systems that can adapt and withstand the impacts of climate change." Similarly, continental frameworks such as the AU Agenda 2063 and SADC protocols resonate with the observation that "regional bodies help pool resources and negotiate climate finance at global forums, increasing bargaining power and reducing transaction costs for member states*" (*Phibbs *et al., 2016).*

However, challenges remain, as highlighted by capacity gaps, fragmented policies, and financing barriers. This reflects the broader finding that "climate adaptation financing mechanisms remain a key challenge in the field of floods" *(Bisaro* et al.*, 2019).*

Overall, aligning national initiatives with regional strategies and global financing opportunities is crucial to overcoming institutional and economic barriers, while sustaining long-term resilience.

CONCLUSION AND RECOMMENDATIONS

This study establishes that achieving flood and climate-resilient civil infrastructure in Africa requires a holistic integration of technological innovation, institutional reform, and community engagement. The case studies of Kenya, Mozambique, and Senegal illustrate that the deployment of emerging technologies such as IoT-enabled monitoring systems, GIS-based modelling, and predictive analytics can substantially enhance early warning and disaster preparedness. Furthermore, the utilisation of nature-based solutions, including mangrove restoration and green infrastructure, demonstrates their dual role in safeguarding ecosystems while strengthening socio-economic resilience. Equally significant is the integration of community-driven strategies, which reinforce inclusivity, equity, and local ownership of resilience interventions. Despite these advances, substantial barriers persist. Financial constraints, fragmented institutional arrangements, and limited technical expertise continue to impede the scaling and sustainability of resilience initiatives. The findings emphasise that infrastructural resilience must extend beyond engineering responses to encompass governance innovation and inclusive participation.

The alignment of national policies with regional frameworks and global financing opportunities emerges as critical for bridging existing gaps. A transformative pathway for Africa lies in strengthening institutional capacities, embedding local knowledge, and fostering adaptive systems that are technologically sound, socially just, and ecologically sustainable. First, governments and development partners should expand investments in emerging technologies, particularly IoT, GIS, and

AI-based flood monitoring, to strengthen predictive capacities and facilitate evidence-based responses. Second, financing strategies must be diversified through climate funds, public–private partnerships, and cooperative risk-sharing mechanisms to reduce dependency on limited state resources. Third, policy frameworks should integrate resilience indicators into planning and development processes, ensuring cross-sectoral coordination between water, energy, agriculture, and infrastructure sectors.

Fourth, the scaling of nature-based solutions such as mangrove rehabilitation, wetland restoration, and permeable surface design should be prioritised given their cost-effectiveness and capacity to provide ecological co-benefits. Fifth, structured capacity-building initiatives are needed to equip local communities with technical, organisational, and decision-making skills, thereby reinforcing sustainability and long-term ownership. Sixth, resilience policies must institutionalise gender-responsive and socially inclusive approaches that recognise and empower women, youth, and other vulnerable groups as central actors in adaptation processes. Collectively, these recommendations provide a roadmap for fostering resilient infrastructure systems in Africa that are technologically advanced, institutionally coherent, and socially equitable.

REFERENCES

Abdelkarim, A. *et al.* (2019). Flood Hazard Assessment of the Urban Area of Tabuk City, Kingdom of Saudi Arabia by Integrating Spatial-based Hydrologic and Hydrodynamic *Modeling. Sensors, 19*(5), 1024. https://doi.org/10.3390/s19051024

Adebayo, W. G. (2024). Resilience in the Face of Ecological Challenges: Strategies for Integrating Environmental Considerations into Social Policy Planning in Africa. *Sustainable Development, 33*(1), 203-220. https://doi.org/10.1002/sd.3113

Africa Center for Strategic Studies (2024). Record Levels of Flooding in Africa Compounds Stress on Fragile Countries. https://africacenter.org/spotlight/record-levels-of-flooding-in-africa-compounds-stress-on-fragile-countries/

Agbehadji, I. E *et al.* (2023). Climate Risks Resilience Development: A Bibliometric Analysis of Climate-related Early Warning Systems in Southern Africa. *Climate, 12*(1), 3. https://doi.org/10.3390/cli12010003

Ali, S. *et al.* (2021). Flood Mitigation in the Transboundary Chenab River Basin: A Basin-Wise Approach from Flood Forecasting to Management. *Remote Sensing, 13*(19), 3916. https://doi.org/10.3390/rs13193916

Al-Rawas, G. *et al.* (2024). A Critical Review of Emerging Technologies for Flash Flood Prediction: Examining Artificial Intelligence, Machine Learning, Internet of Things, Cloud Computing, and Robotics Techniques. *Water, 16*(14), 2069. https://doi.org/10.3390/w16142069

Amandaria, R. *et al.* (2025). Sustainable Resilience in Flood-Prone Rice Farming: Adaptive Strategies and Risk-Sharing Around Tempe Lake, Indonesia. *Sustainability, 17*(6), 2456. https://doi.org/10.3390/su17062456

Ambily, A. *et al.* (2022). *Concepts and Methodologies for Ecological Flood Resilience Assessment*. SpringerLink. https://link.springer.com/rwe/10.1007/978-3-030-51812-7_343-1

Ashwini, A., Sangeetha, S. andand Sriram, S. (2024). IoT-based Smart Sensors, 202-223. igi global. https://doi.org/10.4018/979-8-3693-2280-2.ch010

Atufu, C. E. and Holt, C. P. (2018). Evaluating the Impacts of Flooding on the Residents of Lagos, Nigeria. *WIT Transactions on the Built Environment*, *184*, 81-90. https://doi.org/10.12495/FRARI180081

Aziz, F. *et al.* (2024). Coastal Urban Flood Risk Management: Challenges and Opportunities − A Systematic Review. *Journal of Hydrology, 645*, 132271. https://doi.org/10.1016/j.jhydrol.2024.132271

Bhanuwanti, B. *et al.* (2024). Climate Smart Agriculture: Innovating Sustainable Practices for a Changing Climate. *Journal of Scientific Research and Reports, 30*(11), 568-576. https://doi.org/10.9734/jsrr/2024/v30i112585

Bisaro, A. *et al.* (2019). Leveraging Public Adaptation Finance through Urban Land Reclamation: Cases from Germany, the Netherlands and the Maldives. *Climatic Change, 160*(4), 671-689. https://doi.org/10.1007/s10584-019-02507-5

Bryan, E. *et al.* (2017). Making Climate Change Adaptation Programmes in Sub-Saharan Africa More Gender Responsive: Insights from Implementing Organizations on the Barriers and OLpportunities. *Climate and Development, 10*(5), 417-431. https://doi.org/10.1080/17565529.2017.1301870

Buka-Vaivade, K., Nicoletti, V. and Gara, F. (2025). Advancing Bridge Resilience: A Review of Monitoring Technologies for Flood-prone Infrastructure. *Open Research Europe, 5*, 26. https://doi.org/10.12688/openreseurope.19232.2

Climate Action Africa (2023). Enhancing Africa's Climate Resilience for a Future above the Floodwaters. https://climateaction.africa/africa-climate-flood-climate-change/

Climate Cosmos (2025). 20 New Approaches to Flood Prevention in Vulnerable Areas. https://climatecosmos.com/climate-science/20-new-approaches-to-flood-prevention-in-vulnerable-areas/

Dewa, O., Makoka, D. andand Ayo-Yusuf, O. A. (2022). Measuring Community Flood Resilience and Associated Factors in Rural Malawi. *Journal of Flood Risk Management, 16*(1). https://doi.org/10.1111/Jfr3.12874

Doberstein, B., Fitzgibbons, J., and Mitchell, C. (2018). Protect, Accommodate, Retreat or Avoid (PARA): Canadian Community Options for Flood Disaster Risk Reduction and Flood Resilience. *Natural Hazards, 98*(1), 31-50. https://doi.org/10.1007/s11069-018-3529-z

Farhadi, H. and Najafzadeh, M. (2021). Flood Risk Mapping by Remote Sensing Data and Random Forest Technique. *Water, 13*(21), 3115. https://doi.org/10.3390/w13213115

Fekete, A. (2019). Critical Infrastructure nd Flood Resilience: Cascading Effects beyond Water. *WIREs Water, 6*(5). https://doi.org/10.1002/wat2.1370

Fenner, R. *et al.* (2019). Achieving Urban Flood Resilience in an Uncertain Future. *Water, 11*(5), 1082. https://doi.org/10.3390/w11051082

Grigg, N. S. (2024). Two Decades of Integrated Flood Management: Status, Barriers, and Strategies. *Climate, 12*(5), 67. https://doi.org/10.3390/cli12050067

Haung, X. *et al.* (2016). Hydrogeochemical Signatures and Evolution of Groundwater Impacted by the Bayan Obo Tailing Pond in Northwest China. *Sci. Total Environ. 543*, 357-372. doi: 10.1016/j.scitotenv.2015.10.150

Hendricks, M. D., Meyer, M. A. and Wilson, S. M. (2022). Moving Up the Ladder in Rising Waters: Community Science in Infrastructure and Hazard Mitigation Planning as a Pathway to Community Control and Flood Disaster Resilience. Citizen Science: *Theory and Practice, 7*(1). https://doi.org/10.5334/cstp.462

Ibrahim, A.-S., Kuuire, V. and Kepe, T. (2024). On Mapping Urban Community Resilience: Land Use Vulnerability, Coping and Adaptive Strategies in Ghana. *Journal of Environmental Management, 370*, 122426. Https://Doi.Org/10.1016 /J.Jenvman.2024.122426

Ighile E, Shirakawa H. (2020). A Study on the Effects of Land or Change on Flooding Risks in Nigeria. *Geographia Technica,15*(1),19-101.

Imperiale, A. J. and Vanclay, F. (2020). Barriers to Enhancing Disaster Risk Reduction and Community Resilience: Evidence from the L'Aquila Disaster. *Politics and Governance, 8*(4), 232-243. https://doi.org/10.17645/pag.v8i4.3179

International Institute for Sustainable Development (n.d.). Wetlands and Mangroves in the Saloum Delta, Senegal. https://nbi.iisd.org/report/savi-saloum-delta-senegal/

Januário, T. E., Pereira Filho, A. J. and Salviano, M. F. (2022). Hydrometeorological Modeling of Limpopo River Basin in Mozambique with TOPMODEL and remote sensing. *Open Journal of Modern Hydrology*, *12*(2), 55-73.

JG Afrika (2023). *Building Climate-Resilient Water Systems in Africa*. https://www.jgafrika.com/news/building-climate-resilient-water-systems-africa/

Laice, F. A. *et al.* (2025). Modelling and Mapping of Hydrological Flood Risk Areas: A Case Study of Chókwè City, Mozambique. *International Journal of Environment and Climate Change*, *15*(5), 425-442.

Liao, K.-H., Deng, S. and Tan, P. Y. (2017). *Blue-Green Infrastructure: New Frontier for Sustainable Urban Stormwater Management,* 203-226). Singapore: Springer. https://doi.org/10.1007/978-981-10-4113-6_10

Mafire (2025). Flooding in Africa and Cameroon. https://rightforeducation.org/2025/08/18/flooding-in-africa-and-cameroon/

Manyena, B. (2016). After Sendai: Is Africa Bouncing Back or Bouncing Forward from Disasters? *International Journal of Disaster Risk Science, 7*(1), 41-53. https://doi.org/10.1007/s13753-016-0084-7

Mehryar, S. and Surminski, S. (2020). National Laws for Enhancing Flood Resilience in the Context of Climate Change: Potential and Shortcomings. *Climate Policy, 21*(2), 133-151. https://doi.org/10.1080/14693062.2020.1808439

Meng, M., Dabrowski, M. and Stead, D. (2020). Enhancing Flood Resilience and Climate Adaptation: The State of the Art and New Directions for Spatial Planning. *Sustainability, 12*(19), 7864. https://doi.org/10.3390/su12197864

Meyer, M. A. *et al.* (2018). Participatory Action Research: Tools for Disaster Resilience Education. *International Journal of Disaster Resilience in the Built Environment, 9*(4/5), 402-419. https://doi.org/10.1108/ijdrbe-02-2017-0015

Mpandeli, S. *et al.* (2018). Climate Change Adaptation through the Water-Energy-Food Nexus in Southern Africa. *International Journal of Environmental Research and Public Health, 15*(10), 2306. https://doi.org/10.3390/ijerph 15102306

Munpa, P. *et al.* (2022). Climatic and Hydrological Factors Affecting the Assessment of Flood Hazards and Resilience Using Modified UNDRR Indicators: Ayutthaya, Thailand. *Water, 14*(10), 1603. https://doi.org/10.3390/w14101603

Musonda, I. *et al.* (2023). Smart and Resilient Infrastructure for Emerging Economies: Perspectives on Building Better. crc. https://doi.org/10.1201/9781003435648

Nature-based Solution (n.d.). Flood Recovery nd Mangrove Reforestation in Mozambique. https://www.naturebased solutionsinitiative.org/news/flood-recovery-and-mangrove -reforestation-in-mozambique/

O'Donnell, E. *et al.* (2019). The Blue-Green Path to Urban Flood Resilience. *Blue-Green Systems, 2*(1), 28-45. https://doi.org/10.2166/bgs.2019.199

Okaka, F.O., Odhiambo B.D.O. Relationship between Flooding and Out Break of Infectious Diseasesin Kenya: A Review of the Literature. *J Environ Public Health.* 2018:5452938.doi: 10.1155/2018/5452938.

Olabanji, M. F. and Chitakira, M. (2025). The Adoption and Scaling of Climate-Smart Agriculture Innovation by Smallholder Farmers in South Africa: A Review of Institutional Mechanisms, Policy Frameworks and Market Dynamics. *World, 6*(2), 51. https://doi.org/10.3390/ world6020051

Pate, M. A. *et al.* (2022). A New Lancet Commission on the Future of Health and Economic Resiliency in Africa. *The Lancet*, *400*(10353), 641-643.

Peker, İ. B. *et al.* (2024). Integration of HEC-RAS and HEC-HMS with GIS in Flood Modeling and Flood Hazard Mapping. *Sustainability, 16*(3), 1226. https://doi.org/10.3390/su16031226

Perosa, F. *et al.* (2021). Integrated Valuation of Nature-based Solutions Using TESSA: Three Floodplain Restoration Studies in the Danube Catchment. *Sustainability, 13*(3), 1482. https://doi.org/10.3390/su13031482

Phibbs, S. *et al.* (2016). Synergising Public Health Concepts with the Sendai Framework for Disaster Risk Reduction: A Conceptual Glossary. *International Journal of Environmental Research and Public Health, 13*(12), 1241. https://doi.org/10.3390/ijerph13121241

Salami, R. O., Giggins, H. and Von Meding, J. K. (2017). Vulnerability of Human Settlements to Flood Risk in the Core Area of Ibadan Metropolis, Nigeria. *Jàmbá: Journal of Disaster Risk Studies, 9*(1). https://doi.org/10.4102/jamba.v9i1.371

Samikwa, E., Eriksson, J. and Voigt, T. (2020, November 1). Flood Prediction Using IoT and Artificial Neural Networks with Edge Computing. https://doi.org/10.1109/ithings-greencom-cpscom-smartdata-cybermatics50389.2020.00053

Sellick, T. (2020). Hydrological Modelling and Flood Risk in a Data Scarce Country: Matola, Mozambique. Student thesis series INES.

Smith, P. J., Brown, S. and Dugar, S. (2017). Community-based Early Warning Systems for Flood Risk Mitigation in Nepal. *Natural Hazards and Earth System Sciences, 17*(3), 423-437. https://doi.org/10.5194/nhess-17-423-2017

Takin, M., Ghosh, S. and Cilliers, E. J. (2023). Advancing Flood Resilience: The Nexus Between Flood Risk Management, Green Infrastructure, and Resilience. *Frontiers in Sustainable Cities, 5.* https://doi.org/10.3389/frsc.2023.1186885

Tedla, M. G., Cho, Y. and Jun, K. (2021). Flood Mapping from Dam Break Due to Peak Inflow: A Coupled Rainfall-Runoff and Hydraulic Models Approach. *Hydrology, 8*(2), 89. https://doi.org/10.3390/hydrology8020089

Uchiyama, C., Ismail, N. and Stevenson, L. A. (2021). Assessing Contribution to the Sendai Framework: Case Study of Climate Adaptation and Disaster Risk Reduction Projects Across Sectors in Asia-Pacific (2015-2020). *Progress in Disaster Science, 12,* 100195. https://doi.org/10.1016/j.pdisas.2021.100195

United Nations (2024). Unprecedented Flooding Displaces Hundreds of Thousands Across East Africa. https://news.un.org/en/story/2024/05/1149461

Van Coppenolle, R., Schwarz, C. and Temmerman, S. (2018). Contribution of Mangroves and Salt Marshes to Nature-based Mitigation of Coastal Flood Risks in Major Deltas of the World. *Estuaries and Coasts, 41*(6), 1699-1711. https://doi.org/10.1007/s12237-018-0394-7

Wakuma Abaya, S., Mandere, N. and Ewald, G. (2009). Floods and Health in Gambella Region, Ethiopia: A Qualitative Assessment of the Strengths and Weaknesses of Coping Mechanisms. *Global health action*, *2*(1), 2019.

Wang, Y., *et al*. (2024). Integrating Policy Instruments for Enhanced Urban Resilience: A Machine Learning and IoT-based Approach to Flood Mitigation. *Water, 16*(23), 3364. https://www.mdpi.com/2073-4441/16/23/3364

World Bank (2020). Upscaling Nature-Based Flood Protection in Mozambique's Cities: Knowledge Note. https://www.naturebasedsolutions.org/knowledge-hub/28-upscaling-nature-based-flood-protection-mozambiques-cities-knowledge-note

World Economic Forum. (2024). How Early Warning Systems and Parametric Insurance Can Build Climate Resilience in Africa. https://www.weforum.org/stories/2024/07/early-warning-systems-parametric-insurance-climate-resilience-africa/

Yuliandoko, H. *et al.* (2018). Design of Flood Warning System Based IoT and Water Characteristics. *Telkomnika (Telecommunication Computing Electronics and Control), 16*(5), 2101. https://doi.org/10.12928/telkomnika.v16i5.7636