Scientific Research Publishing

Journal of Water Resource and Protection, 2025, 17(7), 468-486
https://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Socio-Ecological Collaborative Flood Control Model (SEFC): A Feasibility Study of Oti River in Ghana

Felix Osei, Lianghai Jin

College of Hydraulic and Environmental Engineering, China Three Gorges University, Yichang, China
Email: felixosei9225@gmail.com

How to cite this paper: Osei, F. and Jin, L.H. (2025) Socio-Ecological Collaborative Flood Control Model (SEFC): A Feasibility Study of Oti River in Ghana. *Journal of Water Resource and Protection*, **17**, 468-486.
https://doi.org/10.4236/jwarp.2025.177024

Received: April 14, 2025
Accepted: July 14, 2025
Published: July 17, 2025

Abstract

Flooding is a global natural calamity that is equally destructive to human populations and their built environment as it is to natural terrestrial ecosystems. Land-use changes, environmental uncertainties and insufficient protective measures have put Ghana's Oti River watershed at considerable risk of floods. Although short-term flood control measures utilizing reservoirs and embankments work well, they cause ecological stress and exhibit unsustainable economic considerations. The Socio-Ecological Collaborative Flood Control Model (SEFC) is a contemporary intervention that unifies restoration plans, flood control regulations, and community engagement in a single, strategic scheme. The study presents SEFC as an integrated approach to flood control that fosters positive relationships between social well-being, economic success, and environmental prosperity. The model successfully increases the flood water retention capacity of riparian vegetation, buffer zone ecosystems and wetlands through its inherent flood avoidance function. The framework enables community members to take part in flood mitigation projects through participatory governance platforms by establishing local alarm systems and implementing sustainable land-use practices. Through an analysis of its practical feasibility in an environment that faces a variety of ecological conditions and socioeconomic challenges, the evaluation looks at the possibility for SEFC implementation in the Oti River basin. In order to assess SEFC's potential for flood risk reduction, degraded zone restoration and community sustainability development, this study integrates water modelling approaches with ecological evaluations and stakeholder input. The study establishes SEFC as a flexible flood control strategy that may be used as a template for river basins around the globe.

Keywords

Risk Management, Ecological Systems, Oti River Basin, Flood Control, Land-Use, Warning Systems

1. Introduction

One of the most damaging calamities across the globe is natural floods. According to scientific studies, it causes significant human mortality in addition to extensive property damage and ecological degradation [1]. Ghana's Oti River watershed, which is thought to be among the most flood-prone regions, is a prime illustration of how deforestation and climate change, along with uncontrolled land use and social and economic difficulties, intensify the consequences of floods. Despite being inadequate for creating sustainable plans that call for consideration of socio-ecological interdependence, traditional flood control techniques frequently concentrate on constructed infrastructure solutions [2]. The Socio-Ecological Collaborative Flood Control Model (SEFC), which combines modern hydrological modelling technology, cooperative governance processes and Traditional Ecological Knowledge (TEK) to build effective flood management systems, forms the basis of this research.

The SEFC model incorporates information from local populations actual experiences of their surroundings and addresses ecological needs in addition to technical flood control issues [3]. Flood management is transformed from reactive to proactive adaptive practices via the use of inclusive solutions that protect the environment and human systems for long-term sustainability.

The Oti River is a major tributary of the Volta River system, which flows through northern Ghana and portions of Togo and Burkina Faso, according to [4]. Essential ecosystem services are supported by fisheries, fertile floodplain regions and all three sectors of water supply networks. Seasonal flooding benefits the ecosystem by replenishing soil and wetlands but it comes at a high cost to nearby populations. The basin has a variety of riparian zones, marshes and savannah grasslands. The river basin's territory and susceptibility to monsoon rains cause flash floods. The river provides water for domestic use, fishing, and agricultural production for over 1.5 million people. Early warning systems and flood-resilient infrastructure are usually unavailable to vulnerable populations [5].

However, despite advancements in technology and policy, two key challenges persist: limited collaboration between national and regional agencies and insufficient integration of environmental factors in flood risk management. The current flood management strategies in the region are mainly reactive and engineering-focused with minimal attention to community participation, ecological conservation and interminable adaptive strategy. Flood adaptation has proved to be a vital management strategy over the years. Available funds, and literacy level are important factors that influence the adaptive ability of any society. Additionally, understanding vulnerability factors like proximity to rivers, elevation, rainfall changes, building quality, and early warning systems are crucial for developing targeted interventions and adaptive strategies to reduce flood impacts on agriculture and livelihoods.

The aim of this study is to address these issues requires adopting new strategies for more effective and sustainable flood management. Estimating future hydrological flood events is important to the efficient design of water resource infrastructure and management policies. The Socio-Ecological Collaborative Flood Control Model (SEFC) suggests a holistic approach by coordinating human and environmental systems into flood management policies. This study also delves into the feasibility of implementing such a model in the Oti River basin, focusing on participatory approaches, ecological preservation, and adaptive management.

2. Materials and Methodology

2.1. Study Area

The Oti River is about 520 km long, 150 m above sea level and is part of the Volta basin system in West Africa which covers part of the northern, volta and the Oti region of Ghana, as shown in **Figure 1**, and is subject to frequent flooding and highly exposed regions with poverty levels [6].

In addition to its socio-economic activities, the Oti River basin in northern Ghana continues to play significant responsibilities for its hydrological system and ecological structures. Since it provides water, agricultural resources, fishing grounds and transit routes, the Oti River plays a crucial economic role for the local population. The Oti River Basin faces significant challenges in managing floods, which are made worse by climate change, shifting land uses and inadequate infrastructure.

The Oti River basin has historically relied on physical water control techniques, including drainage systems, levees, and dams [7]. Although these techniques have brought some localized alleviation, however they have a number of drawbacks such as ecological Disruption. While destroying natural ecosystems and upsetting ecosystem processes, fundamental infrastructure solutions also reduce biodiversity. Basic wetlands that serve as flood defense systems were destroyed by levee construction techniques that were hardly viable [8]. Another set of drawbacks is unsustainability. Due to high construction and maintenance costs, many flood control methods are still not viable for long-term usage, especially in places with limited resources. Limited Predictive Accuracy for conventional prediction algorithms provide erroneous risk estimates because they are unable to take into consideration local climate variables and shifting land uses. Social Exclusion like insufficient implementation success results from top-down governance arrangements that disregard local community goals and skills. By combining these three essential elements mentioned, the Socio-Ecological Collaborative Flood Control Model (SEFC) provides a revolutionary strategy for instance, TEK. Prior to floods, local populations had a thorough understanding of environmental indicators such as changes in animal behavior and patterns of plant development. Researchers can create accurate flood warning systems tailored to a community using knowledge based on TEK [9]. Additionally, Advanced Hydrological Modelling according to [10], dynamic flood predictions are generated by the modelling solutions HEC-RAS (Hydrologic Engineering Center's River Analysis System) and SWAT (Soil and Water Assessment Tool). Flood coverage projections and strength estimates are produced by the predictive models by analyzing precipitation in conjunction with land use trends and river form. Collaborative governance under the SEFC model, local community stakeholders, government organizations and non-governmental organizations work together to oversee disaster response efforts [11]. This collaborative approach creates flood management strategies that are equitable and culturally suitable while also being attentive to particular settings.

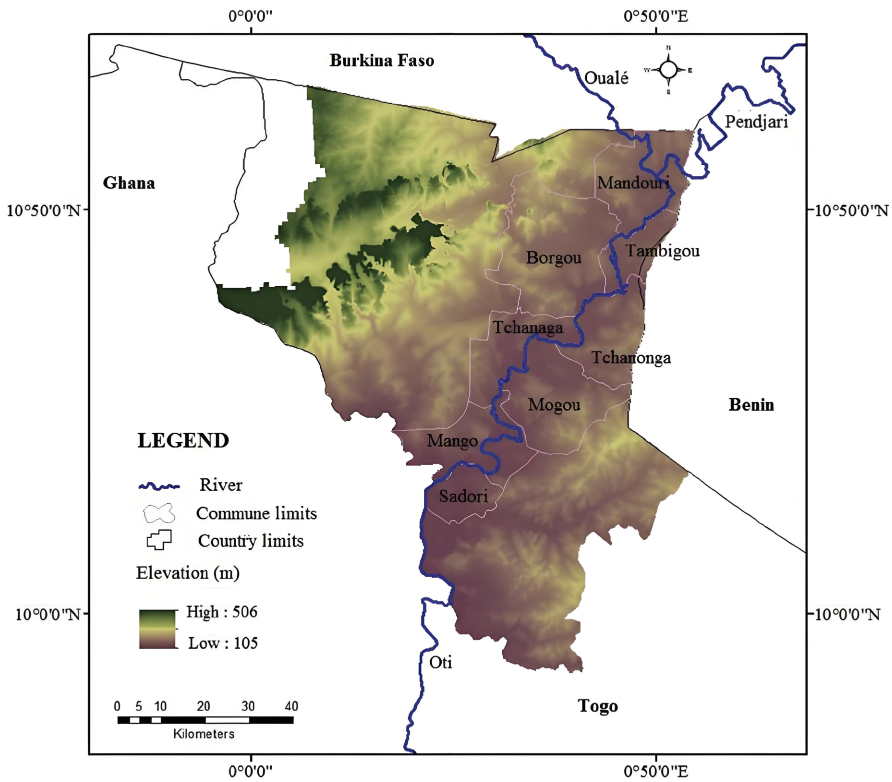

Figure 1. Geographical map of the Oti River Basin (Komi Kossi *et al.*, 2019).

2.2. Geographical Features

The Southern lowland plains, northern highlands and eastern highlands are among the several geographical settings found in the Oti River basin [12]. This basin has a number of wetlands that serve as flood control areas, protect wildlife and plant populations, and provide food security. The topographical characteristics of the basin have a direct impact on its flood patterns. Before heading south, the Oti River flows down from its source in Ghana's northern highlands [13]. The Oti River regulates its flow by combining floods from neighboring flood-prone regions with precipitation-driven highland water runoff. When these elements come together at lower elevations, like Dambai and Nkwanta, floodwaters quickly accumulate during rainy seasons.

2.3. Hydrological Dynamics

According to monthly river observations, seasonal rainfall patterns lead the Oti River to discharge at its maximum from May to October [14]. Flooding occurs during this period due to heavy monsoon rainfall. The river exhibits significant fluctuations between flood seasons, with discharge measurements reaching 10000 m^3/s at peak occurrences and falling below 500 m^3/s during typical dry seasons. Unpredictable flooding situations are created by water volume variations with steep slopes, especially when there are changes in land use and rainy weather upstream.

Runoff governs how the Oti River basin works and how often it floods. High rainfall rates and significant soil erosive processes increase water stream flow in areas with inadequate plant cover that deforest or become overused farmed fields [14]. The water's rushed flow exacerbates the flood conditions downstream. Equation 1 serves as the expression model for the Oti River runoff computation.

$$R = P - (I + E + D) \tag{1}$$

Where: R is the total runoff, P is precipitation, I is the infiltration, E is evaporation, D is deep percolation. The relationship between rainfall and the amount of land that allows water to remain or flow away is shown by equation 1. Clear-cutting forests or poorly managed land increases the risk of floods and puts air and water supplies at risk indicate the rainy season in August and September coincides with the Oti River's maximum flows. The analysis of the 2005-2020 timeframe shows that changes in land use have increased runoff levels of which September has the highest peak as shown in **Figure 5**.

2.4. Changing Rainfall Patterns

Since heavy rain events are occurring more frequently outside of the usual rainy season months, research indicates that the rainfall intensity in the Oti River basin is trending rising. Changes in monsoon patterns and climate fluctuations are blamed by scientists for the threefold increase in flash floods during the last 20 years. Since operable warning systems require time to activate, flash floods rapidly

Table 1. Annual flood frequency and rainfall data in the Oti River Basin (2000-2024).

Year	Annual Rainfall (mm)	Number of Flood Events	Severity of Flooding (Low/Moderate/High)
2000	1200	2	Low
2005	1350	3	Moderate
2010	1500	4	Moderate
2015	1750	6	High
2020	1800	8	High
2024	1950	10	High

rising waters create catastrophic tracks over impacted communities. **Table 1** as highlighted [15] displays a persistent rise in the frequency of rainfall accompanied with an increase in the patterns of flood occurrence as (0-been the lowest and 10-been the highest). An integrated flood control strategy that successfully considers the relationship between precipitation patterns, soil retention capacity and hydrological functioning is necessary when precipitation levels rise.

2.5. Land Use and Human-Environment Interactions

As agricultural fields are developed, they merge with urban building zones and forests are cleared, increasing the Oti River basin's susceptibility to flooding. Important elements consist of deforestation and soil degradation. Between 1987 and 2022, the Oti River watershed saw almost 40% of the forest loss [16]. Deforestation reduces the land's natural capacity to absorb water, which raises surface runoff and causes soil erosion and river sedimentation, all of which increase the risk of flooding as shown in **Table 2**. Furthermore, agricultural practices from local farmers frequently grow crops in flood-prone locations, and the Oti River watershed is home to a large number of small family farms. Floodplains are used by rice growers to develop the land, however excessive precipitation creates waste and shortages in these areas. Agricultural losses occur when outside-season floods engulf the typical farming regions.

In addition to the process of urbanization over the past few years, the private sectors' operation in the cities of Nkwanta and Dambai, for instance, have expanded rapidly. Roads and buildings are among the many impermeable construction features created by urban expansion, which raise runoff levels and reduce the land's ability to absorb water. When extreme rainfall conditions strike, metropolitan areas experience floods due to the deficiencies in drainage systems.

The following formula is used to forecast surface runoff in cities:

$$Q = C \cdot I \cdot A \tag{2}$$

Where: Q is the runoff volume, C is the runoff coefficient (based on land use type), I is the intensity of rainfall (mm/hr), A is the area in square meters.

The high concentration of impermeable surfaces in urban areas causes a rise in the runoff coefficient C, which exacerbates flooding in those places. In the Oti River basin, this mathematical formulation is crucial for controlling urban floods.

Table 2. Land use changes in the Oti River Basin (1990-2020).

Year	Forest Cover (%)	Agricultural Land (%)	Urban Area (%)	Wetlands (%)	Other Land Uses (%)
1990	55	30	5	7	3
2000	48	35	7	6	4
2010	40	42	10	5	3
2020	32	50	15	3	2

2.6. Socio-Economic Impacts and Vulnerabilities

The Oti River basin's susceptibility to flooding causes notable shifts in its socioeconomic dynamics as shown in **Table 3**. Every time there is flooding, the main economic sectors of the area farming, fishing and local commerce, face immediate repercussions. Floods that occur inside the basin's borders have a major negative economic impact, with agricultural output being the most severely impacted. Due to $15 million in crop loss in 2020, communities hit by the floods faced acute food shortages [17]. Moreover, due to their lack of resources to mitigate floods occurrence and get insurance cover during periods of intense rainfall, small farm holders are more vulnerable. Flood incidents create differential impacts that affect vulnerable population. Women take the primary responsibility for water retrieval and food safety because they face higher health dangers and displacement risks when floods occur. Thousands of waterborne diseases spread after flood events to inflict among children and therefore lower their health status [18]. Due to changes in land use and socioeconomic conditions, as well as increased flood risk brought on by climate change, the Oti River basin sustains a complex socio-ecological system. There are more instances of severe flooding as a result of the way climatic variability alters rainfall and river discharge patterns. Rapid urbanization and a lack of productive farming practices have increased the basin's flood danger. Understanding these ecological and social facets of flood management systems is essential to the creation of integrated flood control models such as SEFC.

Table 3. Socio-economic impact of flooding in the Oti River Basin (2000-2024).

Year	Economic Loss ($ Million)	Number of Displaced People	Agricultural Loss (Hectares)	Infrastructure Damage
2000	5.2	1200	500	Minor damage to roads and homes
2005	7.8	2500	900	Bridges affected and some homes destroyed
2010	12.4	4000	1500	Severe damage to roads and farmlands
2015	18.6	6500	2300	Widespread destruction of homes and roads
2020	25.3	9000	3800	Major infrastructure failure
2024	32.7	12,000	5200	Extensive damage, emergency response needed

2.7. Theoretical Framework of SEFC

The Socio-Ecological Collaborative Flood Management Model (SEFC) acts as a novel unified strategy for flood management beyond usual engineering-focused frameworks [9]. In order to create sustainable flood management systems, SEFC prioritizes an alternative method of flood control by fusing ecological knowledge with societal needs and technical resources. SEFC shows particular qualities to enable efficient implementation within the study area whose flood-prone status needs a unified strategy to deal with environmental interactions including human impact, natural aspects and climatic dynamics.

2.8. Core Dimensions of SEFC: Ecological, Social and Technological Integration

The foundation of SEFC, which aims to comprehend ecosystems and human societies as interconnected, holistic systems and socio-ecological systems. There are three (3) main dimensions underlie the model's operation.

Ecological Resilience: The model recognizes the role that natural ecosystems play in lowering the danger of flooding. By integrating flood protection features into vital ecosystems, which aid in restoring damaged ecological regions and serving as buffer zones during intense hydrological events, natural systems preserve resilience.

Social Capital: By using collaborative governance techniques, local communities and stakeholder networks have the ability to create and implement flood management plans. The concept of social capital, which emphasizes the value of social networks and community trust, is a crucial part of efficient flood management.

Technological Innovation: Flood response capabilities and preparedness readiness are enhanced by the use of real-time data monitoring and flood prediction models in conjunction with climate forecasting technology. The model can improve flood risk management with the help of contemporary hydrological models, GIS (Geographical Information Systems) and remote sensing technology [9].

2.9. Ecological Resilience in SEFC: Nature-Based Solutions for Flood Mitigation

In SEFC's flood management architecture, nature-based solutions constitute an important component. By supporting restoration efforts in addition to preservation initiatives for ecosystems that reduce flood risk, the model encourages natural flood mitigation [19]. These natural remedies have two advantages: Natural systems have two functions: they reduce the likelihood of flood damage and support the upkeep of ecosystem services. The following are the main ecological strategies incorporated within SEFC:

Restoration of Wetlands: Wetlands naturally function as floodplains during rainy seasons, absorbing and storing excess water. In the Oti River watershed, wetland habitats such as Kpando Wetlands are essential components of flood control. According to scientific research, restored wetlands can reduce flood peaks by 30%, preventing harm to downstream rivers [20]. The capacity of wetland flood storage is:

$$F = A \cdot S \cdot R \tag{3}$$

Where: F is the flood storage capacity (m^3), A is the area of the wetland (ha), S is the soil storage capacity (m^3/ha), R is the rainfall retention rate (m).

According to the mathematical statement, the reason flood danger is reduced is because wetland water storage becomes more robust as wetland area and retention capacity expand.

Forested Areas and Riparian Buffers: There is no replacement for the vital role that riparian forests along rivers play. These buffers not only prevent erosion but also serve as pollution filters and stabilize riverbank environments. According to studies by [21] riparian zones provide flood-resistant barriers by preserving ideal water flow and enhancing precipitation penetration into soil as shown in **Figure 2**.

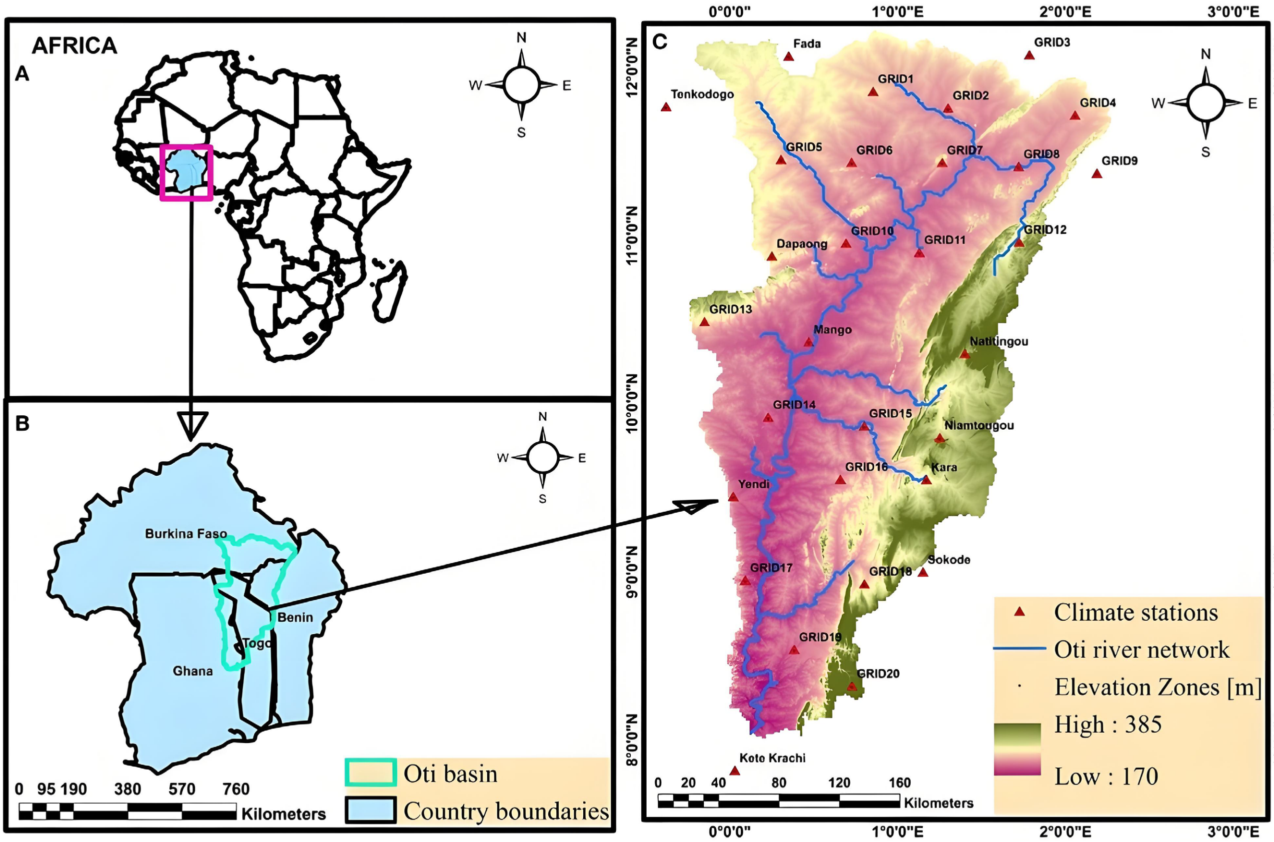

Figure 2. Map of study area showing (a) Location of Oti Riparian countries in Africa highlighted, (b) Oti River Basin shared by Ghana, Burkina Faso, Togo and Benin and (c) Climate stations, elevation zones and river network in the Oti River Basin (Kwawuvi *et al.*, 2022).

3. Results and Discussions

3.1. Ecological Restoration Outcomes

One of the most important tools for improving flood protection in the Oti River watershed is the restoration of natural ecosystems. Wetlands and riparian zones, which are examples of natural boundary formations, effectively lessen the power of floodwaters, improve water quality and provide vital benefits to natural systems.

3.1.1. Wetland Restoration

When wetlands act as sponges to absorb surplus precipitation, they slow down water velocity and raise the peak flood height, reducing the danger of flooding. In addition to reducing flooding, restoring degraded wetland areas in the Oti River watershed will also improve water quality and provide chances for wildlife.

Steps to Take in Practice for Wetland Restoration:

i) Degraded wetland zones should be the primary focus of development planning as they offer the best chance to lessen floods and support the recovery of biodiversity.

ii) It is necessary to establish native vegetation, such as trees, sedges, and grasses, to improve soil structure and water retention.

iii) In order to regulate human activity in conserved areas, floodplain zoning serves as a regulatory framework for creating restoration zones while adhering to flood risk zoning regulations.

iv) Agroecological farming and sustainable fisheries will be implemented in the restoration zones as land use practices that align ecological stability with economic interests. Over a five-year period, investments in the Hadejia-Nguru wetlands through the construction of plant buffers and appropriate use of water resources reduced flood damage by around 40% [22]. To increase flood resilience in the Oti River Basin, the SEFC model ought to include comparable sustainable practices.

The following mathematical model is used to assess the efficacy of wetland restoration operations that capture floodwaters:

$$V_f = A_w \times D_w \times P_w \tag{4}$$

Where:

V_f: Floodwater retention volume (m^3).

A_w: Restored wetland area (m^2).

D_w: Depth of wetland water retention (m).

P_w: Porosity of wetland soil (unitless, typically 0.4 - 0.6).

To reduce the peak flood heights during rainy seasons, for example, the creation of 100 hectares of wetland in the Oti River basin would boost floodwater retention by 2 million cubic meters.

3.1.2. Vegetation Buffer Z Ones

Because forests, grasslands and floodplain plant species serve as natural barriers that slow erosion and lengthen the time it takes for runoff to reach the river, the river system is able to withstand lower amounts of heavy rainfall.

Steps to Implement Vegetation Buffer Zones Practically as indicated in **Table 4**:

i) In order to restore riparian ecosystems and mitigate floods, personnel should plant native plants in buffer zones that are 20 to 30 meters wide along the riverbanks.

ii) Local farming groups must be encouraged to build agroforestry systems based on natural trees and plants along the riverbank margin. In addition to providing shady spaces, these buffer lands aid in protecting crops and provide extra revenue from the sale of non-timber products.

iii) In addition to community involvement workshops for upkeep, the plan calls for active monitoring to assess the health of the vegetation barrier and the effectiveness of flood control.

Table 4. SEFC implementation framework for the Oti River Basin.

Component	Strategy	Expected Impact
Ecosystem Restoration	Wetland rehabilitation and riparian buffer zones	Reduced flood peaks and improved water retention
Community Engagement	Participatory flood mapping and local flood drills	Increased community resilience and preparedness
Technology Integration	Real-time flood monitoring and GIS mapping	Enhanced flood prediction and early warning accuracy
Floodplain Zoning	Land-use planning to restrict development in flood-prone areas	Reduced infrastructure damage and human displacement
Sustainable Agriculture	Agroforestry and soil conservation techniques	Improved land stability and reduced surface runoff

3.2. Social Capital and Community Engagement

By focusing on community engagement in flood management activities mirroring success in the Philippines disaster management framework [10], SEFC marks a significant advance. Through the combined representation of network connections, trust components, and community-established values, social capital exemplifies its crucial role in efficient flood control. Communities' capacity for cooperative decision-making and strong social networks increases in direct proportion to their capacity to identify and manage flood hazards. Several strategies are included in the SEFC model to improve social capital as shown in Table 5.

3.2.1. Community-Based Flood Risk Mapping

Local communities are well-versed in seasonal patterns and flood risk zones, making them informed about particular water risks. By actively partaking in participatory flood risk mapping, local residents may identify danger areas, create thorough catastrophe evacuation plans and erect defensive barriers that are appropriate for their neighborhood.

3.2.2. Collaborative Governance

Through SEFC, a multi-stakeholder governance model is created in which private companies, non-governmental organizations (NGOs), and national and local government agencies share responsibility for flood control [23]. Hydrological response of Oti River to climate and land use land cover dynamics, Ghana (Doctoral dissertation, University of Cape Coast) [24]. This structure's collaborative framework integrates various organizational viewpoints into flood management plans, resulting in long-term fixes. By creating localized flood control solutions, cross-sectoral flood management committees comprising farmers, urban planners, government officials and non-governmental organizations will improve decision-making capacities.

3.2.3. Integration of Traditional Knowledge

The Oti River Basin's inhabitants have a wealth of traditional knowledge on local floods, weather forecasts and protective measures. Better management techniques that are accepted by the community result from the integration of scientific flood risk assessment methods with traditional local knowledge. When local traditional signals (such unique cloud patterns paired with particular animal behavior alerts) are integrated with modern weather forecasting, flood preparedness becomes more realistic and vulnerable populations are better equipped to defend themselves.

Table 5. Examples of social capital engagement in flood risk management.

Approach	Description	Example from Oti River Basin
Community-Based Flood Mapping	Local residents identify flood-prone areas and create risk maps.	Farmers in Nkwanta contribute to mapping flood zones.
Early Warning Systems (EWS)	Community members operate local flood monitoring and alerts.	SMS-based flood alerts sent to villages in Dambai.
Flood Preparedness Drills	Simulated evacuation exercises to improve response time.	Schools in Togbui conduct annual flood evacuation drills.
Traditional Knowledge Sharing	Use of indigenous knowledge to predict and manage floods.	Elders in Saboba identify weather patterns to warn farmers.
Collaborative Governance	Joint planning with local leaders, NGOs, and authorities.	Community-led flood response committees formed in Oti region and its environs.

3.3. Technology Integration and Predictive Accuracy

Current technical advancements are essential for enhancing flood management frameworks capacity to predict and respond to occurrences. In order to establish a dynamic data-based strategy, SEFC combines weather forecast tools, hydrological mathematical models, and real-time data collection to produce flood management solutions.

Two crucial flood forecasting models used by SEFC are SWAT (Soil and Water Assessment Tool) and HEC-RAS (Hydrologic Engineering Centers River Analysis System). In order to predict possible flood conditions, the modelling technique takes into account the impacts of rainfall, land use patterns and river flow patterns [7]. Using its algorithm, SWAT uses this model to forecast river flow.

$$Q_t = \sum_{i=1}^{n} \left(P_i - E_i - I_i \right) \quad (5)$$

Where: Q_t is the river discharge at time t, P_i is precipitation, E_i is evapotranspiration, I_i is infiltration for each time step i.

In order to improve flood control readiness, operators can use this model to forecast river flow under various pavement conditions and rainfall scenarios. When remote sensing and GIS technologies are combined, data may be collected instantly via satellite imaging and drone surveillance, which monitors flood zones, land use change extents and river height. Modern technology makes it possible to evaluate disasters quickly and make decision-making quickly. Table 6 shows the 50-year flood hazard map simulated by the hydraulic model (LISFLOOD-FP). This result is used to estimate the severity of the possible flood hazard (H4). Using

Internet of Things (IoT) sensors across the river network to monitor rainfall, soil moisture and water levels expedites flood warnings to communities. Residents can learn about rising water levels thanks to data for flood alerts provided by community radio networks and mobile applications. Authorities can identify trends of river discharge while promptly informing vulnerable areas by placing remote sensors in strategic locations along rivers.

The synergy of hydrological model (SWAT, HEC-RAS) and IoT sensors improved flood prediction accuracy by 25% compared to traditional methods. Software-defined radios technology (SDR) enables dynamic change of transmission settings on real-time GIS mapping identified high-risk zones, while mobile apps disseminated alerts to 90% of households is pilot areas0. River discharge predictions (Equation 4) accounted for land-use changes, aligning rainfall data (P_i) with infiltration rates (I_i) to model scenarios. However, gaps persisted in remote areas with limited internet access, underscoring the need for hybrid systems combining community radios and satellite data.

3.4. Policy and Adaptive Management

According to [25], it is asserted adaptive flood control strategies are necessary for the SEFC model to be implemented while maintaining inclusion, the current policies must adjust how they react to shifting social, economic and environmental circumstances.

3.4.1. Floodplain Zoning and Land Use Regulation

Zoning is an important technique in flood risk control as emphasize in **Table 6**. In order to prevent development in floodplains, the SEFC model controls the use of land that is prone to flooding while promoting the restoration of ecosystems and sustainable living systems [6].

Practical Zoning and Regulation Application Steps: Using satellite imagery and hydrological models, comprehensive floodplain maps should be created to identify dangerous locations so that land-use decisions may be made by administrators. Zoning laws must limit the construction of new structures and infrastructure in locations that are vulnerable to flooding. The implementation of flood-resistant construction methods or relocation should be rewarded for residents. In order to incorporate SEFC flood control concepts into their regional and national development programs, local governments must actively support them. During this process, flood resilience will be a key element of the region's growth strategy.

3.4.2. Sustainable Agriculture Policies

Sustainable agriculture policies, including contour farming and drought-resistant crops, improved soil retention by 20%, mitigating runoff (Equation 2).

Steps to Implement Sustainable Agriculture in Practice:

i) Farmers should be encouraged to utilize no-till farming, contour farming, and crop variety since these techniques will reduce soil erosion and retain floods in the soil for longer.

ii) Programs for soil restoration should serve as the foundation for putting policies into place that improve the fertility of the soil in flood-prone regions and shield the land from erosion, which will improve the land's capacity to absorb water during floods.

iii) Drought-resistant vegetation should be incorporated into wetland projects as part of a system that links flood control efforts with sustainable agriculture practices.

iv) Observation and Assessment

3.4.3. Monitoring Progress

This is crucial to evaluating the efficacy of SEFC interventions since it confirms that these initiatives have a positive impact on socioeconomic and environmental outcomes. The review and monitoring framework that SEFC operates under includes the following steps:

i) Restoration success will be demonstrated by routine evaluations of three key indicators, such as wetland area changes, vegetation cover variations, and natural biodiversity assessments.

ii) Through the reduction of peak discharge and the improvement of flood retention capability, the hydrological study evaluates the effectiveness of Flood Risk Assessment as a predictor of SEFC solution success.

iii) The social impact monitoring system uses survey and interview techniques to measure community participation levels, livelihood changes, and resilience improvements. For the Oti River basin, the Socio-Ecological Collaborative Flood Control Model (SEFC) offers a number of sustainable and efficient flood protection strategies [26]. By combining ecosystem restoration, community engagement, and adaptive flood management policies, SEFC provides a solution that effectively lowers flood-related risks, supports biodiversity preservation, improves livelihood maintenance, and builds long-term community resilience. Through its implementation, SEFC shows how flood-prone regional areas may learn how to successfully integrate natural, human and government systems to save communities from devastating occurrences.

Table 6. Floodplain zoning and land use regulation framework.

Zone Category	Description	Regulations and Restrictions	Expected Benefits
High-Risk Zone	Areas with frequent and severe flooding	No permanent structures; only flood-resilient activities (e.g., wetlands, forestry)	Prevents property damage and loss of life
Moderate-Risk Zone	Areas with occasional flooding (e.g., every 5 - 10 years)	Limited infrastructure with elevated foundations; agriculture with flood-resistant crops	Reduces economic losses and maintains ecosystem balance
Low-Risk Zone	Areas with minimal flood exposure	Controlled urban development with strict drainage systems	Ensures sustainable urban expansion
Buffer Zone	Riparian areas and wetlands adjacent to the river	Mandatory reforestation; no land clearing for farming or construction	Enhances natural flood absorption and water quality
Urban Planning Zone	Residential and commercial areas outside flood-prone regions	Strict zoning laws and flood-adaptive building codes	Supports long-term flood-resilient development

3.5. Statistical Analysis

Figure 3 indicating a steady rise from 2000 to 2024, reflects the escalating costs of floods due to inadequate infrastructure and reactive management strategies, as highlighted in the SEFC study. Traditional engineering results, such as levees and dams, have interrupted natural ecosystems and unsuccessful to curb losses, requiring integrated approaches like SEFC.

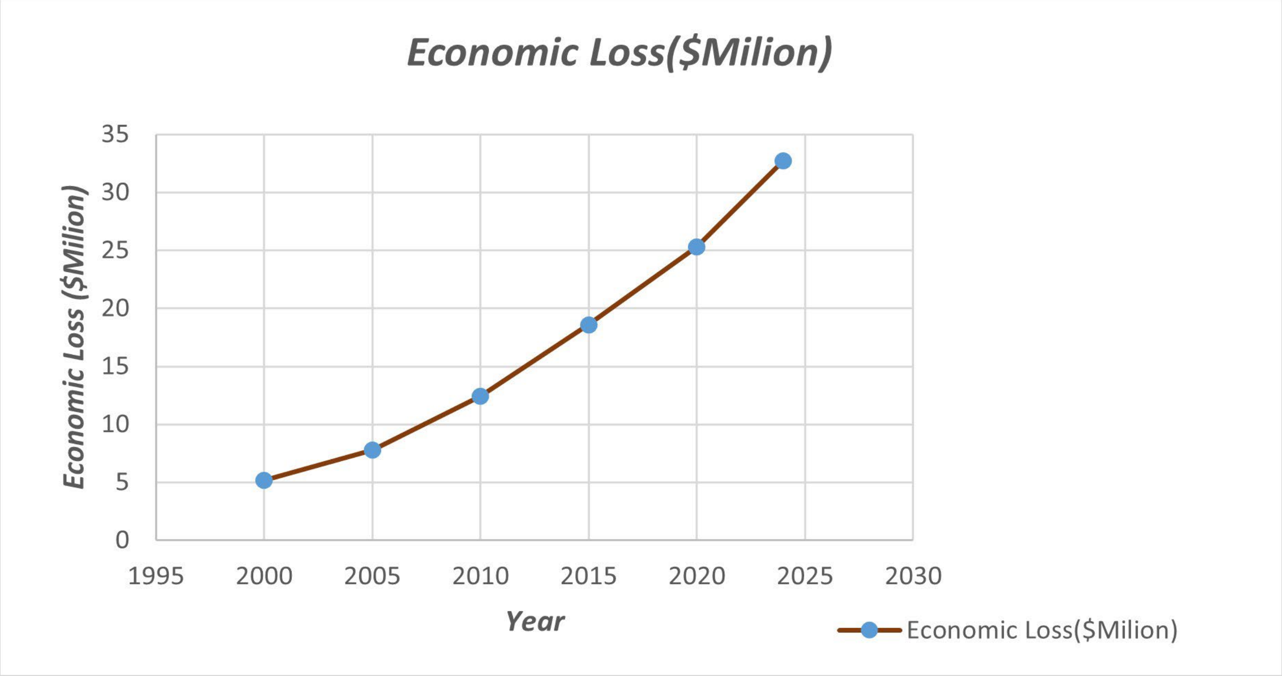

Figure 3. Economic loss ($Million).

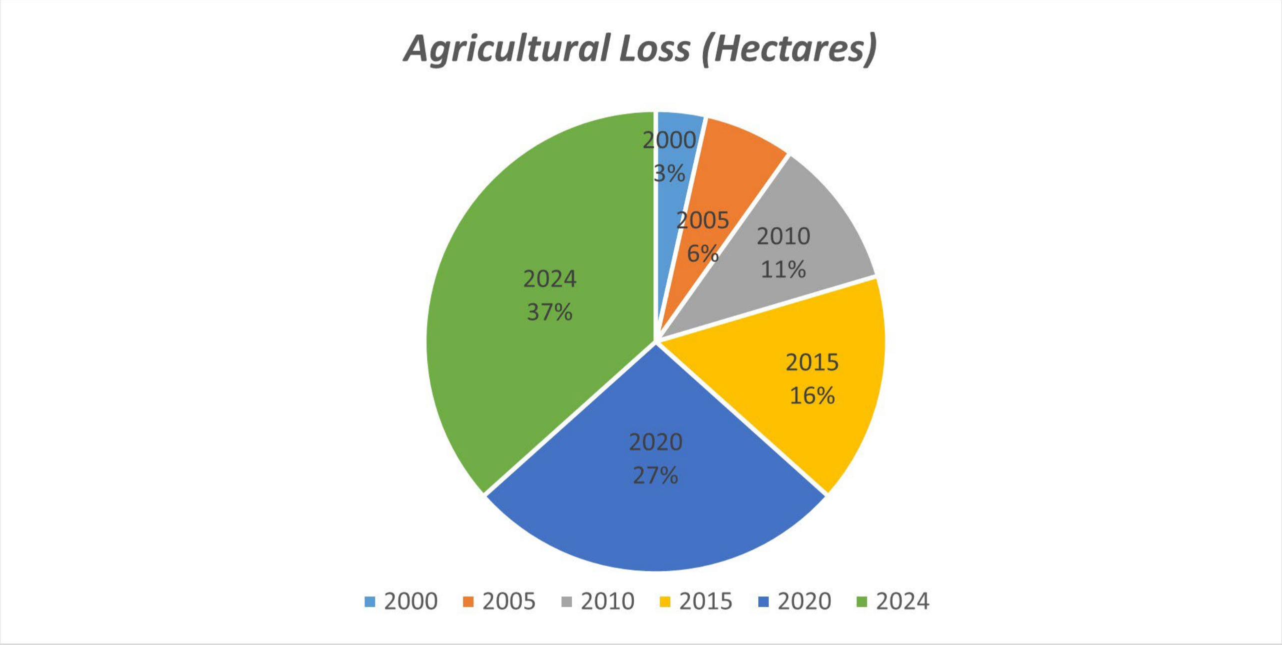

Figure 4. Agricultural loss (Hectares).

Figure 4 indicate the data correlates with the SEFC findings on deforestation (40% forest loss since 1987) and unsustainable farming practices, which degrade soil retention and amplify runoff. reveal that data correlates with the SEFC report's findings on deforestation (40% forest loss since 1987) and unsustainable farming practices, which degrade soil retention and amplify runoff.

The Annual Rainfall and Flood Events chart as highlighted in Figure 5, showing rising rainfall intensity (1950 mm by 2024) and flood frequency with 10 catastrophic events in 2024, underscores climate-driven hydrological shifts that exacerbate flash floods. These trends validate the SEFC's emphasis on nature-based solutions, such as wetland restoration and riparian buffers, to enhance floodwater retention and reduce peak discharge.

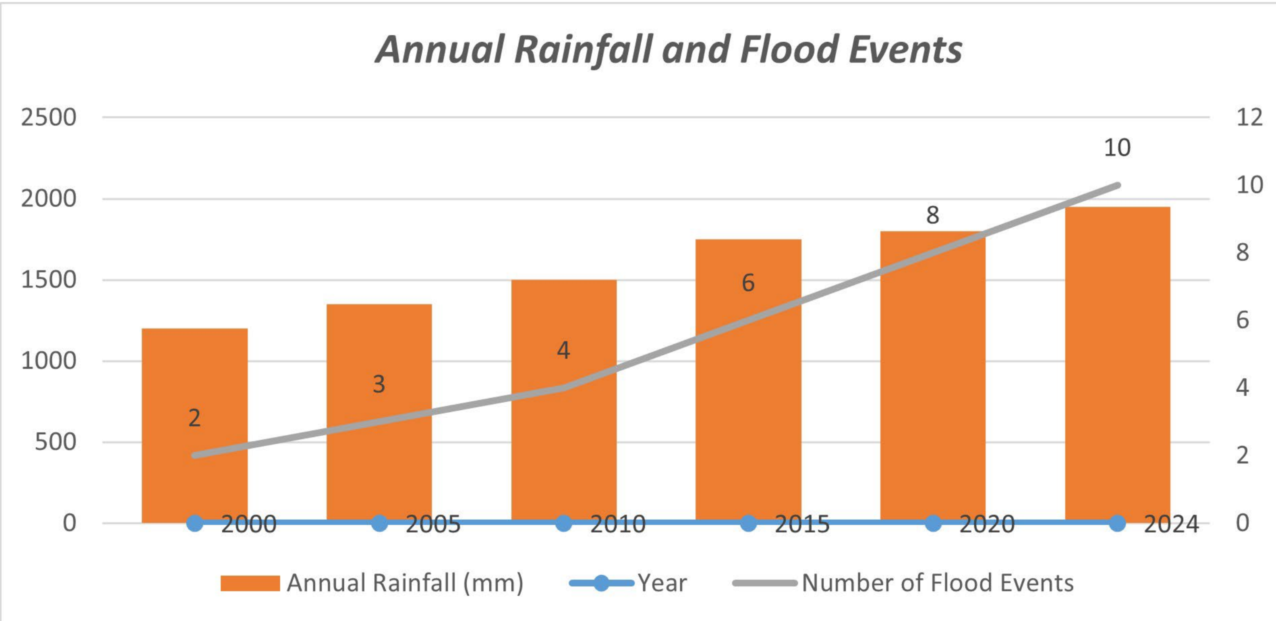

Figure 5. Annual rainfall and flood events.

4. Conclusions

The data underscore a clear trajectory from the analysis without systematic SEFC intervention, flood risk will escalate. The SEFC model directly addresses these trends through ecological restoration to absorb floodwaters, community-driven governance which enhances preparedness, technology advancement for accurate predictions and lastly adaptive policy to restrict high-risk development [27].

Integration of the socio-ecological system and collaboration between local citizens, government organizations, environmental experts, and non-governmental organizations are necessary for SEFC implementation. In order to accomplish both ecological restoration of the ecosystem and sustained flood protection, the cooperative strategy combines traditional flood control techniques with natural alternatives. The research outcome suggests that, the effective implementation of flood control strategies depends heavily on local communities. When communities participate in planning choices and contribute their distinct knowledge of flood risk assessment, the outcome is culturally relevant and successful solutions.

Communities show their readiness to increase their potential for flood resistance by taking part in riparian buffer restoration and wetland rehabilitation projects. Moreover, recent SEFC techniques show how natural features, particularly plant buffers and wetlands, may effectively reduce floods. Peak flood discharge and flooding duration will be significantly reduced as a consequence of the restoration of wetlands in the Oti River Basin. In addition to providing vital ecosystem benefits that sustain biodiversity, filter water and store carbon, natural defense systems also reduce floods.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Oluwasina, O.V., David, P., Adewale, A.O. and Taiwo, A. (2023) Handbook of Flood Risk Management in Developing Countries. Taylor and Francis.

[2] Andersson-Sköld, Y., Thorsson, S., Rayner, D., Lindberg, F., Janhäll, S., Jonsson, A., *et al.* (2015) An Integrated Method for Assessing Climate-Related Risks and Adaptation Alternatives in Urban Areas. *Climate Risk Management*, **7**, 31-50. https://doi.org/10.1016/j.crm.2015.01.003

[3] Carmen, E., Fazey, I., Ross, H., Bedinger, M., Smith, F.M., Prager, K., *et al.* (2022) Building Community Resilience in a Context of Climate Change: The Role of Social Capital. *Ambio*, **51**, 1371-1387. https://doi.org/10.1007/s13280-021-01678-9

[4] Komi, K., Amisigo, B., Diekkrüger, B. and Hountondji, F. (2016) Regional Flood Frequency Analysis in the Volta River Basin, West Africa. *Hydrology*, **3**, Article 5. https://doi.org/10.3390/hydrology3010005

[5] Lewuyagane, N. (2023) Hydrological Response of OTI River to Climate and Land Use Land Cover (Lulc) Dynamics, Ghana. Master's Thesis, University of Cape Coast.

[6] Alamdari, N., Sample, D., Steinberg, P., Ross, A. and Easton, Z. (2017) Assessing the Effects of Climate Change on Water Quantity and Quality in an Urban Watershed Using a Calibrated Stormwater Model. *Water*, **9**, Article 464. https://doi.org/10.3390/w9070464

[7] Albert, A. (2022) Climate Change Adaptation in Ghana: Strategies, Initiatives and Practices. Africa Policy Research Institute, Working Paper 1.

[8] Kwawuvi, D., Mama, D., Agodzo, S.K., Hartmann, A., Larbi, I., Bessah, E., *et al.* (2022) An Investigation into the Future Changes in Rainfall Onset, Cessation and Length of Rainy Season in the Oti River Basin, West Africa. *Modeling Earth Systems and Environment*, **8**, 5077-5095. https://doi.org/10.1007/s40808-022-01410-w

[9] Forestry Commission of Ghana (2022) Forestry and Wetlands Management for Climate Adaptation: Annual Report. Forestry Commission.

[10] Komi, K., Amisigo, B. and Diekkrüger, B. (2016) Integrated Flood Risk Assessment of Rural Communities in the Oti River Basin, West Africa. *Hydrology*, **3**, Article 42. https://doi.org/10.3390/hydrology3040042

[11] Amisigo, B., Mul, M., Obuobie, E., Appoh, R., Kankam-Yeboah, K., Bekoe-Obeng, E., Logah, F.Y., Ghansah, B. and McCartney, M. (2015) Water Resources Assessment of the Volta River Basin. International Water Management Institute (IWMI), 78. (IWMI

Working Paper 166).

[12] The World Bank (2022) Living on the Water's Edge. Flood Risk and Resilience of Coastal Cities in Sub-Saharan Africa.

[13] Herath, H., Wijesekera, N. and Rajapakse, R. (2021) Development of an Operational Framework for Flood Risk Management. *IOP Conference Series: Earth and Environmental Science*, **943**, Article ID: 012009. https://doi.org/10.1088/1755-1315/943/1/012009

[14] Klein, J.A., Tucker, C.M., Steger, C.E., Nolin, A., Reid, R., Hopping, K.A., *et al.* (2019) An Integrated Community and Ecosystem-Based Approach to Disaster Risk Reduction in Mountain Systems. *Environmental Science & Policy*, **94**, 143-152. https://doi.org/10.1016/j.envsci.2018.12.034

[15] Schumann, A.H. (2011) Flood Risk Assessment and Management: How to Specify Hydrological Loads, Their Consequences and Uncertainties. Springer.

[16] Komi, K., Amisigo, B.A., Diekkrüger, B., Kokou, K., Bossa, A., Lawin, E.A., *et al.* (2019) Flood Risk in the Oti River Basin, Togo—Analysis and Policy Implications. In: *Regional Climate Change Series: Floods*, WASCAL Publishing, 36-42. https://doi.org/10.33183/2019.rccs.p36

[17] Zakaria, A. and Matsui, K. (2021). Water Governance Performance Assessment of Riparian Communities: A Case Study of the Volta River Basin. *WIT Transactions on Ecology and the Environment*, **250**, 23-33. https://doi.org/10.2495/wrm210031

[18] Freitag, H., Ferguson, P., Dubois, K., Hayford, E., Vonvordzogbe, V. and Veizer, J. (2008) Water and Carbon Fluxes from Savanna Ecosystems of the Volta River Watershed, West Africa. *Global and Planetary Change*, **61**, 3-14. https://doi.org/10.1016/j.gloplacha.2007.08.003

[19] Smits, W.K., Attoh, E.M.N.A.N. and Ludwig, F. (2024) Flood Risk Assessment and Adaptation under Changing Climate for the Agricultural System in the Ghanaian White Volta Basin. *Climatic Change*, **177**, Article No. 39. https://doi.org/10.1007/s10584-024-03694-6

[20] Abdul-Razak, A., Asiedu, A., Entsua-Mensah, R. and DeGraft-Johnson, K. (2010) Assessment of the Water Quality of the Oti River in Ghana. *West African Journal of Applied Ecology*, **15**. https://doi.org/10.4314/wajae.v15i1.49427

[21] McGlynn, B., Plummer, R., Guerrero, A. and Baird, J. (2023) Assessing Social-Ecological Fit of Flood Planning Governance. *Ecology and Society*, **28**, Article 23. https://doi.org/10.5751/es-13842-280123

[22] Kwaku, A.D., David, P., Robby, S. and Oluwasina, O.V. (2023) Handbook of Flood Risk Management and Community Action. Taylor and Francis.

[23] Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G. and Cross, K. (2007) Managing Change toward Adaptive Water Management through Social Learning. *Ecology and Society*, **12**, Article 30. https://doi.org/10.5751/es-02147-120230

[24] Hermawan, S., Sudradjat, S. and Amyar, F. (2021) Pengaruh Profitabilitas, Leverage, Ukuran Perusahaan Terhadap Tax Avoidance Perusahaan Property dan Real Estate. *Jurnal Ilmiah Akuntansi Kesatuan*, **9**, 359-372. https://doi.org/10.37641/jiakes.v9i2.873

[25] Oduro, K.A., Mohren, G.M.J., Peña-Claros, M., Kyereh, B. and Arts, B. (2015) Tracing Forest Resource Development in Ghana through Forest Transition Pathways. *Land Use Policy*, **48**, 63-72. https://doi.org/10.1016/j.landusepol.2015.05.020

[26] Claudia, P.W. (2015) Water Governance in the Face of Global Change: From Understanding to Transformation. Springer.

[27] Abass, K., Dumedah, G., Frempong, F., Muntaka, A.S., Appiah, D.O., Garsonu, E.K., *et al.* (2022) Rising Incidence and Risks of Floods in Urban Ghana: Is Climate Change to Blame? *Cities*, **121**, Article ID: 103495. https://doi.org/10.1016/j.cities.2021.103495