United Nations University
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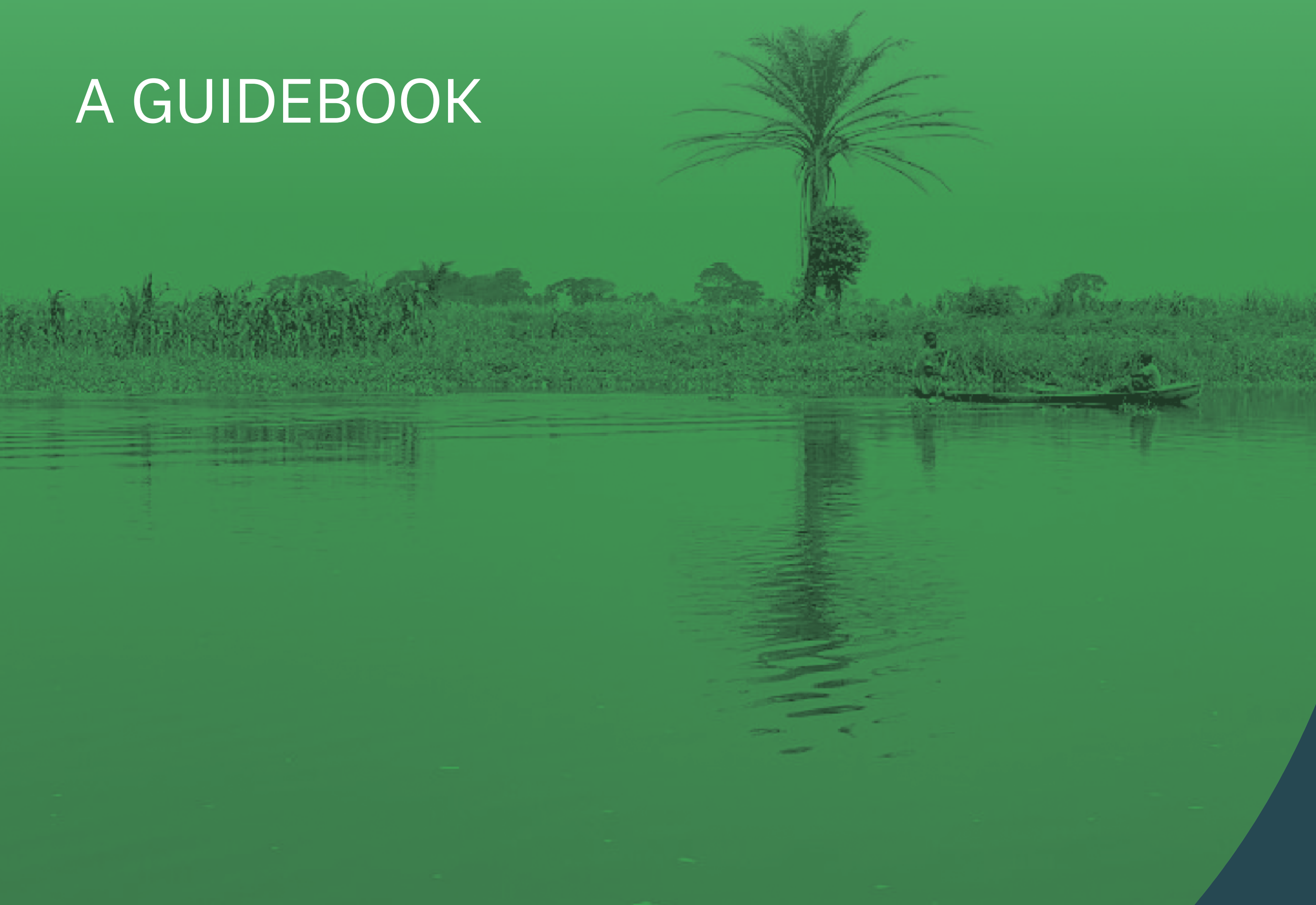
Planning and evaluating ecosystem-based flood risk reduction measures in West Africa

A GUIDEBOOK



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Planning and evaluating ecosystem-based flood risk reduction measures in West Africa

A GUIDEBOOK

Authors
Sally Janzen, Jana Balzer, Fabian Merk, Jonas Hansohm, Yvonne Walz

Reviewers
Andrea Ortiz-Vargas, Andreas Fink, Emmanuel Nketiah Ahenkorah, Fabian Rackelmann, Fabrice Renaud, Karen Sudmeier-Rieux, Raymond Djangma, Udo Nehren

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West African Science Service Centre on Climate Change and Adapted Land Use

Federal Ministry of Education and Research

Executive summary

With climate change exacerbating flood risks in West Africa, "Ecosystem-based Disaster Risk Reduction" (Eco-DRR) is increasingly recognized as part of the solution to address this challenge. This guidebook outlines the strategic planning and evaluation of Eco-DRR measures to support tailoring them to local needs and conditions, strategically locating the intervention for increased risk reduction benefits and comprehensively evaluating their effectiveness. It guides the successful implementation of Eco-DRR, with practical steps on 'how to' plan and locate and evaluate the interventions.

The guidebook makes the following key recommendations:

Flood risk assessments:
Use a flood risk assessment as the basis for any Eco-DRR placement and evaluation. Such assessment can be conducted in different ways, depending on your time and resources.

Context-specific Eco-DRR selection:
Choose Eco-DRR measures based on specific local needs and conditions.

Strategic locations:
Identify locations for Eco-DRR measures that maximize their impact on reducing overall flood risk. This involves understanding the specificities of each area and finding a compromise between several aspects that come into play.

Comprehensive evaluation:
Assess the effects of Eco-DRR on all three components of flood risk to finally combine them to evaluate overall risk reduction benefits of an Eco-DRR measure.

Stakeholder involvement:
Actively involve local stakeholders in the selection, locating and evaluation of Eco-DRR. This engagement is crucial for gaining local insight, enhancing buy-in and ensuring the sustainability of the measure.

Multi-disciplinary team:
Considering the interdisciplinary nature of the task, involve hydrologists, geoscientists, ecologists, meteorologists, planners, risk scientists, sociologists, etc. to benefit from the different expertises and perspectives for an enhanced outcome.

Heavy rain in Togo and Benin causes the Mono River to overflow affecting thousands of people living close to the river. The water level is monitored by the community.

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1. Introduction

Flood incidences have been increasing in West Africa (Nka et al., 2015). Exacerbated by climate change, flood risk needs to be addressed. Ecosystem-based disaster risk reduction measures (Eco-DRR) are increasingly recognized as cost-effective contributors in reducing flood risk (Nehren et al., 2019). Yet, strategic planning and comprehensive evaluation of a measure's effectiveness is key for effective use. This guide provides practical steps for planning and evaluating Eco-DRR in West Africa. By supporting the strategic location and assessment of these measures, this publication guides the successful implementation of Eco-DRR, increasing the resilience of West African communities.

Targeted primarily at local, regional and national disaster risk reduction teams, spatial planners, NGOs and other stakeholders involved in flood risk management in West Africa, this guide offers straightforward guidelines for implementing effective Eco-DRR measures.

Around the Mono River, located at the border of Togo and Benin, the impacts and effects of floods are felt by the communities living along the river in both countries.

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The guide is organized as follows:

Chapter 2
Understanding and assessing flood risk

Explains the concept of flood risk and informs on different approaches to assess flood risk.

Chapter 3
Ecosystem-based flood risk reduction

Explores how ecosystems can reduce flood risk, by showing the importance of understanding ecosystem functions and services for most effective use.

Chapter 4
Strategically locating ecosystem-based flood risk reduction measures

Discusses selecting and locating ecosystem-based measures for flood risk reduction based on the understanding of risk drivers, ecosystem functions, service provision, climate variability, land use and feasibility.

Chapter 5
Evaluation of ecosystem-based flood risk reduction measures

Details how to evaluate the impact of an Eco-DRR measure on all components of flood risk and how to conduct a comprehensive assessment.

Chapter 6
Example of locating and evaluating ecosystem-based flood risk reduction measure

Illustrates chapters 4 and 5 using the examples of agroforestry for flood risk reduction in a rural context.

Conclusion and Recommendations

Summarizes key messages and provides practical advice for planning and evaluating Eco-DRR measures.

Annex: A catalogue of Eco-DRR measures effective for flood risk reduction in West Africa.

2. Understanding and assessing flood risk

By the end of this chapter you will know about:

- Flood risk and its main components
- Different approaches to assess the components of flood risk

The chapter is divided into two sub-chapters. **2.1.** defines the three components of flood risk, namely hazard, exposure and vulnerability and illustrates what they mean for flood risk assessments, while **2.2** summarizes relevant approaches to assess components of flood risk and directs to relevant tools and data sources.

2.1. Key components of flood risk

Below are two pictures from West Africa – one rural (Figure 1) and one urban (Figure 2)-, that could represent your area of assessment, to understand the components of flood risk and how to capture them in an assessment.

The submerged area is an observation of the **flood hazard**[1]**.** The flood hazard in both pictures is **characterized by the extent (flooded area), duration and depth of the water**. The inland flood hazard can emerge directly from heavy rainfall (pluvial flooding) or from overflow of a riverbed (fluvial flooding).

Exposure[2] **to floods describes** all elements of concern of a socioecological system in the flood´s area of impact. It varies from setting to setting and looks very different in the rural and urban examples above. To understand and assess it, consider the following: **Who is exposed and what are the key exposed assets that could be affected by water** in your setting? What elements should be considered to understand exposure? Is it the crops, as in the example of the rural setting, or is it rather the critical infrastructure, such as roads or the electricity grid in the urban context?

1 IPCC (2023) defines hazard as: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

2 IPCC (2023) defines exposure as: The presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected.

Figure 1 - Rural flood in the context of West Africa. Source: WFP

Figure 2 - Urban flood in the context of West Africa. Source: AFP / John Wessel

Finally, what remains to be understood is the **vulnerability**[3] to the flood: **how susceptible are these exposed elements to be adversely affected by the flood?** Examine and decide whether your assets are sensitive to flood or not.

For example, if an agricultural land were to be flooded, flood-sensitive crops such as ground nuts or corn would be damaged by floods, while rice can withstand floods better and would experience less damage. In urban settings, the building material would define the (physical) vulnerability of a house: one made of bricks is more likely to withstand a flood compared to one made of mud and clay. People can also be more or less affected by floods depending on their susceptibility. For example, economic conditions may impede or allow populations to recover from incurred flood impacts. Physical conditions may hamper or facilitate evacuation during a flood event and their (lack of) coping or adaptive capacity, e.g. whether there are flood protection measures in place, will also determine the outcome.

Taken together, the three components form flood risk, as illustrated in Figure 3.

Figure 3 - Risk propeller showing risk being composed of hazard, exposure and vulnerability. Adapted from IPCC, 2014

3 IPCC (2023) defines vulnerability as: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

2.2. Approaches to assess flood risk

After having understood all components of flood risk, evaluate flood risk by individually assessing each flood risk component and bringing them together to calculate flood risk.

Flood hazard - The goal of the flood hazard assessment is to have a map with information on **WHERE** the hazard may occur or did occur, **HOW SEVERELY** this hazard materializes (flood depth, extent, velocity) and **HOW LONG** it lasts. To measure the flood hazard in a spatially-explicit manner, use any of the following approaches, depending on time and resources:

- Using either or both hydrological and hydrodynamic modelling to simulate water flow and flood spread based on flood return periods and extreme precipitation statistics.
- Flood masks from previous flood events: use maps from previous floods showing the extent of water and affected areas.
- High-water marks: look for physical signs of maximum water levels in your area of assessment to understand areas previously affected by floods and the severity of the floods.
- Previous flood assessment or logbooks: inform yourself on whether past floods have been documented.

Tools for flood hazard modelling

Hydrological models, such as Soil & Water Assessment Tool (SWAT), and hydrodynamic models, such as HEC-RAS, can serve as tools for the spatial visualisation of flood areas, with the latter computing the spatial extents of the flood hazard. Ideally, use a combination of both (feed discharges from the hydrological into the hydrodynamic model) to trade-off oversimplification and intensive computing power.

To validate the models, consider information for the temporal flood genesis and the hazard extent, as follows:

For the temporal evaluation: measure streamflow or water tables from gauging stations. If no discharge data is available, design the flood hazard according to return levels of precipitation.

For spatial reference: compare satellite-based flood masks (e.g., from the SENTINEL mission) to the simulated flood extents. Using gauging station data and spatial flood masks, the reliability of the flood hazard computation can be increased.

Flood exposure - Having identified key assets that may be at risk, such as people, hospitals, roads, etc., map assets out in a spatially-explicit manner to assess where these assets overlap with the flood hazard. Only where there is an overlap, key assets are exposed and the scale of exposure can be quantified. More and larger assets underwater mean higher exposure of assets that could be damaged or suffering harm.

Methods to gauge exposure include:

- Indicator-based assessment: quantify exposed assets within relevant administrative units through the use of indicators.
- Satellite images: look at which assets were affected during a previous flood.
- Damage functions: quantify the monetary damage to extract exposed assets.
- Field visits: inspect first-hand what assets have been affected by the flood.
- Local, regional or national records: gather information on what assets have been flooded in past flood events, for example from Post Disaster Needs Assessments.

Vulnerability to floods – After understanding which characteristics play into the vulnerability of your system, quantify these characteristics to assess them. Use an indicator-based approach for the vulnerability assessment, turning drivers of vulnerability, like "poverty", into indicators, for example, "share of population below national poverty line [%]". Make sure to understand the relationship between each indicator and vulnerability, for instance, the higher the share of population below national poverty line, the higher the level of vulnerability vs. the higher the share of protected areas, the lower the ecosystem vulnerability. For methodology, see the Handbook for Practitioners on Risk Assessment in West Africa and Climate Risk Sourcebook.

Data sources for exposure and vulnerability assessments

Data on locating assets for exposure assessments

In addition to consulting sector-relevant local,regional,national records and plans, see the following platforms for data:

- OpenStreetMap – a map of the world with open-content license.
- Humdata – humanitarian data provided by UN OCHA.
- Worldpop – spatial demographic data for health and development application.

Data for characterizing susceptibility or coping/adaptive capacities

In addition to consulting the census or similar local/regional/national records, as well as contacting local/regional/national relevant institutions for data, check out the following international platforms and datasets:

- Humdata – humanitarian data.
- USAID DHS Program - demographic and health survey.
- Afripop – population distribution in Africa.

Flood risk - Combining the three components – hazard, exposure and vulnerability – allows you to define the overall flood risk. This aggregation provides an overview of hotspots of flood risk, where interventions are needed. However, this aggregation is not suitable to understand underlying drivers of risk, meaning it also needs products at the level of the risk components. The risk assessment is conducted spatially and is typically based on indicators. Consult available guides and resources for detailed analysis (see additional resources below).

The understanding of flood risk and what drives the key components of flood risk is essential for designing targeted Eco-DRR measures and evaluating their effectiveness in comprehensively reducing flood risk (See Janzen et al. 2024 for tailoring your risk assessment to enable for Eco-DRR evaluation).

Resources and tools for risk assessments:

- Risk Assessment in West Africa: A Handbook for Practitioners (Part 1 and Part 2)
- Climate Risk Sourcebook: guidelines on comprehensive Climate Risk Assessment
- The INFORM Risk Index: a global indicator-based disaster risk assessment tool
- KalypsoIndicatorRisk: an open-access software that facilitates the computation of the risk assessment and allows for quick comparison of scenarios. Please consult (CLIMAFRI 2022) for user guide and self-paced training material.

Around the Mono River, located at the border of Togo and Benin, the impacts and effects of floods are felt by the communities living along the river in both countries.

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3. Ecosystem-based flood risk reduction

By the end of this chapter you will know about:

- How ecosystems can reduce flood risk through providing benefits for all components of risk.
- How to differentiate between ecosystems' potential of retention and drainage and where to exploit these functions to help reduce the flood hazard more effectively.

Ecosystems like mangroves or wetlands can act as buffers to regulate floods (Nehren et al. 2023). They provide services that can reduce all components of disaster risk (Sudmeier-Rieux et al. 2021; Ruangpan et al. 2020). The approach of using ecosystems as part of an overall strategy to reduce disaster risks is known as ecosystem-based disaster risk reduction (Eco-DRR) (see Estrella & Saalismaa, 2013). It builds on using so-called "ecosystem services", which can be categorized into provisioning services, e.g. food, timber or water provision; regulating services, e.g. moderation of extreme events; habitat services, e.g. habitat for species; and cultural services, such as recreation (TEEB, 2013). The figures 4 and 5 illustrate ecosystem services provided by mangroves and wetlands for risk reduction.

While the focus of Eco-DRR is mainly on prevention before a disastrous event, such measures can also support other stages of the disaster risk management cycle. For instance, timber provision can support reconstruction after an event. Furthermore, Eco-DRR provides a range of co-benefits that improve societal well-being and make Eco-DRR actions contribute to multiple other goals, such as ensuring food security and conserving biodiversity.

Consult the following documents to better understand ecosystem services:

- Millennium Ecosystem Assessment (MEA) (2005)
- The Economics of Ecosystems and Biodiversity (TEEB) (2013)
- The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) Guidance on the diverse conceptualisation of multiple values of nature and its benefits (2016)

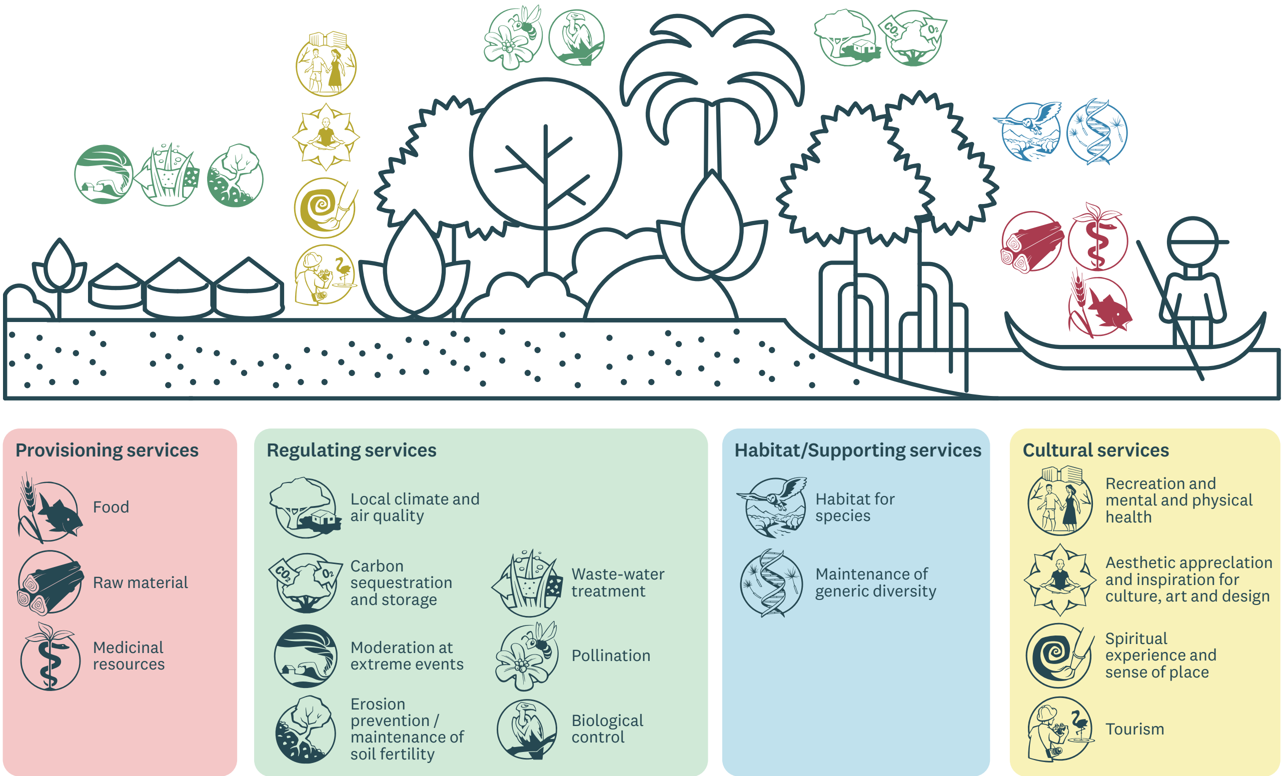

Figure 4 - Illustration of ecosystem services obtained from mangroves. Icons: TEEB

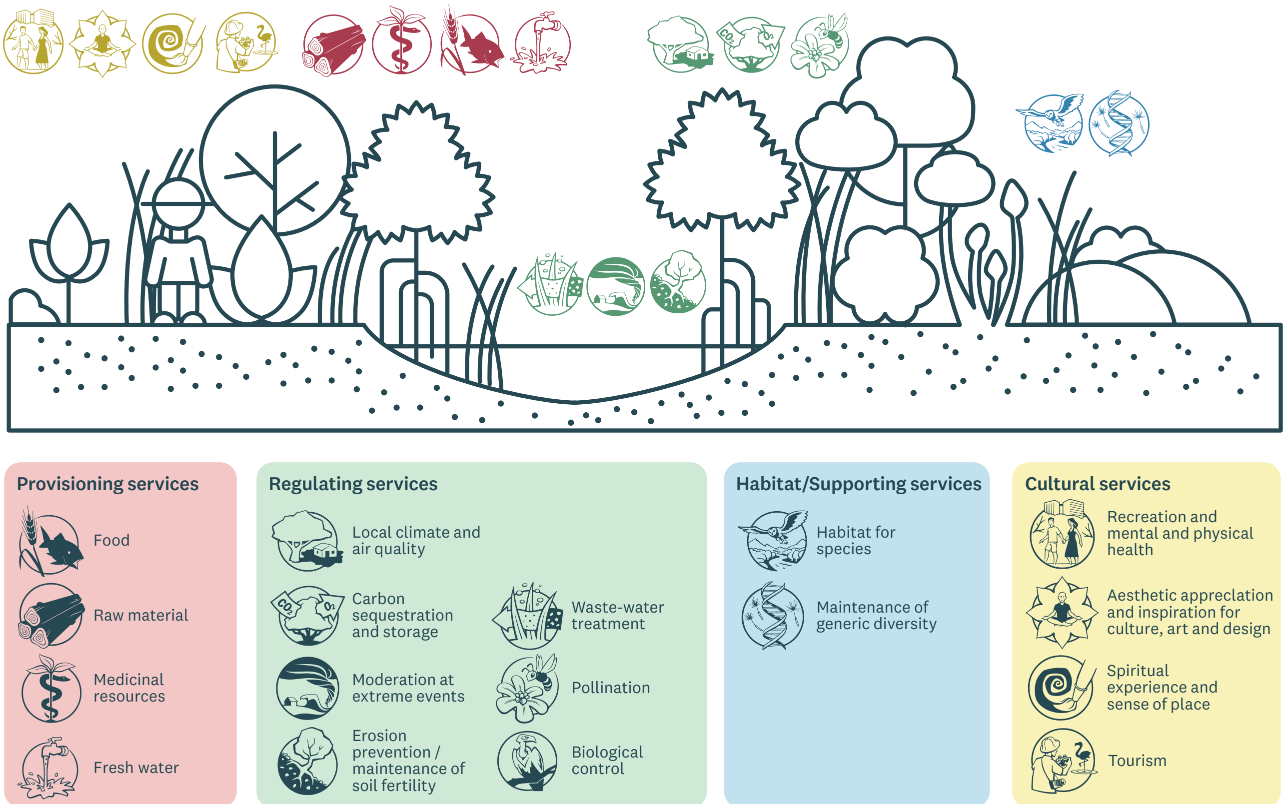

Figure 5 - Illustration of ecosystem services obtained from wetlands. Icons: TEEB.

Lake Aheme in Benin has been home and source of living for the communities for many years.

3.1. The concept of Eco-DRR

Ecosystems can regulate the flood hazard by reducing erosion and retaining or draining floodwaters. Forests, for example, help improve soil structure and stability, holding the soil in place and enhancing its resistance to erosion. Additionally, they can contribute to increased water retention, particularly in upstream areas where water volume is still low and there is potential to store water in the ground. This reduces the run-off and thereby the amount of water that flows into the river that could contribute to a flood. In areas where the run-off volume is too large for increased retention to be effective, floodwaters should be drained to ecosystems that can store water. Ecosystems can serve as overflow areas, collecting surplus stormwater and preventing other areas of interest from flooding.

This is why, for example, reforestation as an Eco-DRR measure is more effective in upper catchments, while wetlands are best utilized in flood-prone lower catchments, if space allows and along the river.

To select the right Eco-DRR measure, consider whether the catchment benefits more from a drainage or a retention (or both) and where in the catchment the Eco-DRR measure should be placed (see Figure 6 as illustration of retention or drainage separation in a catchment).

Often, a combination of drainage and retention measures is beneficial. Combining upstream retention with downstream drainage strategies can further enhance the risk reduction potential of Eco-DRR.

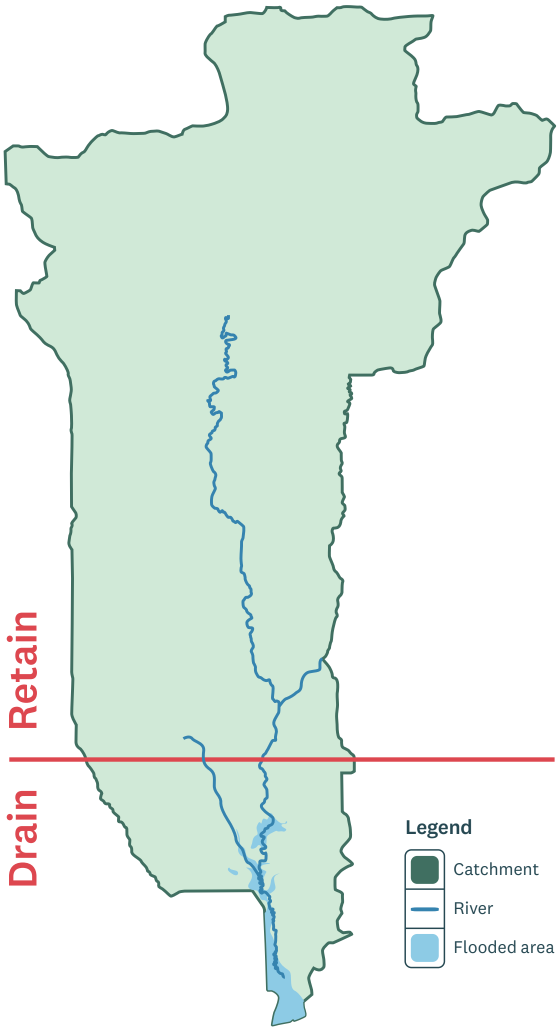

Figure 6 - Illustration of drainage and retention areas based on flood hazard. Source: UNU-EHS, after Björnsen Beratende Ingenieure GmbH, 2022

For a compilation of Eco-DRR measures based on their location in the watershed, see the WWF Flood Green Guide (2016) and the annex for examples of West African Eco-DRR measures.

An Eco-DRR measure can additionally have a barrier function and reduce exposure. For instance, the creation of riparian buffers reduces exposure. However, as hazard reduction is generally focused on in the river flood context, this guidebook focuses on hazard-reducing measures.

3.2. The regulation of flood hazard through ecosystems

Having understood the different functions and services provided by nature, take ecosystems relevant to your context and consider:

- **How does the ecosystem affect hydrological processes?** Does it retain rainwater, e.g. by intercepting rainwater; does it increase ground porosity and soil water storage capacities, letting more water infiltrate? Does it serve to drain by altering the flood water path?

- **What do people obtain from the ecosystem?** Is it a source of food? Is it inspiration?

- **How do people use the ecosystem?** For their livelihoods, for recreation, for spiritual activities or to relax?

As a final step, map out **WHERE** these services are obtained. For methodology, see:

- Burkhard and Maes, 2017 for mapping ecosystem services

- Brown and Fagerholm, 2015 for participatory ecosystem service mapping

- Campagne and Roche, 2018 to link land cover to ecosystem services

It is important to note that the benefits of Eco-DRR measures are not immediate. There is a time lag between the implementation and when impacts are felt (Purwanto et al., 2024). Furthermore, measures may result in so-called “disservices”, where Eco-DRR provides unwanted services (Friess et al., 2020). For example, agroforestry may result in increased shade and insect presence, which may affect crop yield (Kloos and Renaud, 2016).

Heavy rain in Togo and Benin caused the Mono River to overflow in 2019, affecting thousands of people living close to the river.

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4. Strategically locating Eco-DRR measures

By the end of this chapter you will know about:

- How to select and strategically locate an Eco-DRR measure

4.1. Selection of Eco-DRR measures

To effectively deploy Eco-DRR measures for flood risk reduction, it is crucial to understand the local context and available options. This can be approached through literature and surveys but also roundtable discussions with relevant stakeholders. Involve the local communities and stakeholders to integrate their knowledge and ensure the selected Eco-DRR measure(s) addresses their needs. This also creates buy-in and ownership of the people who will be living with and maintaining the implemented measures.

Figure 7 - Involvement of stakeholders for the selection and location of Eco-DDR measures. © Yvonne Walz / UNU-EHS.

4.2. Suitability and prioritization of location for Eco-DRR measures

Choosing the right location for Eco-DRR measures involves various factors (see Figure 8), often requiring a compromise between them. Define the potential locations for the selected measure, while considering regulatory frameworks and land suitability. Identify the best location between the potential locations, considering a number of additional aspects explained hereafter. Should the location be given already, the steps can be taken in reverse order to identify which measures are best placed in the given spot.

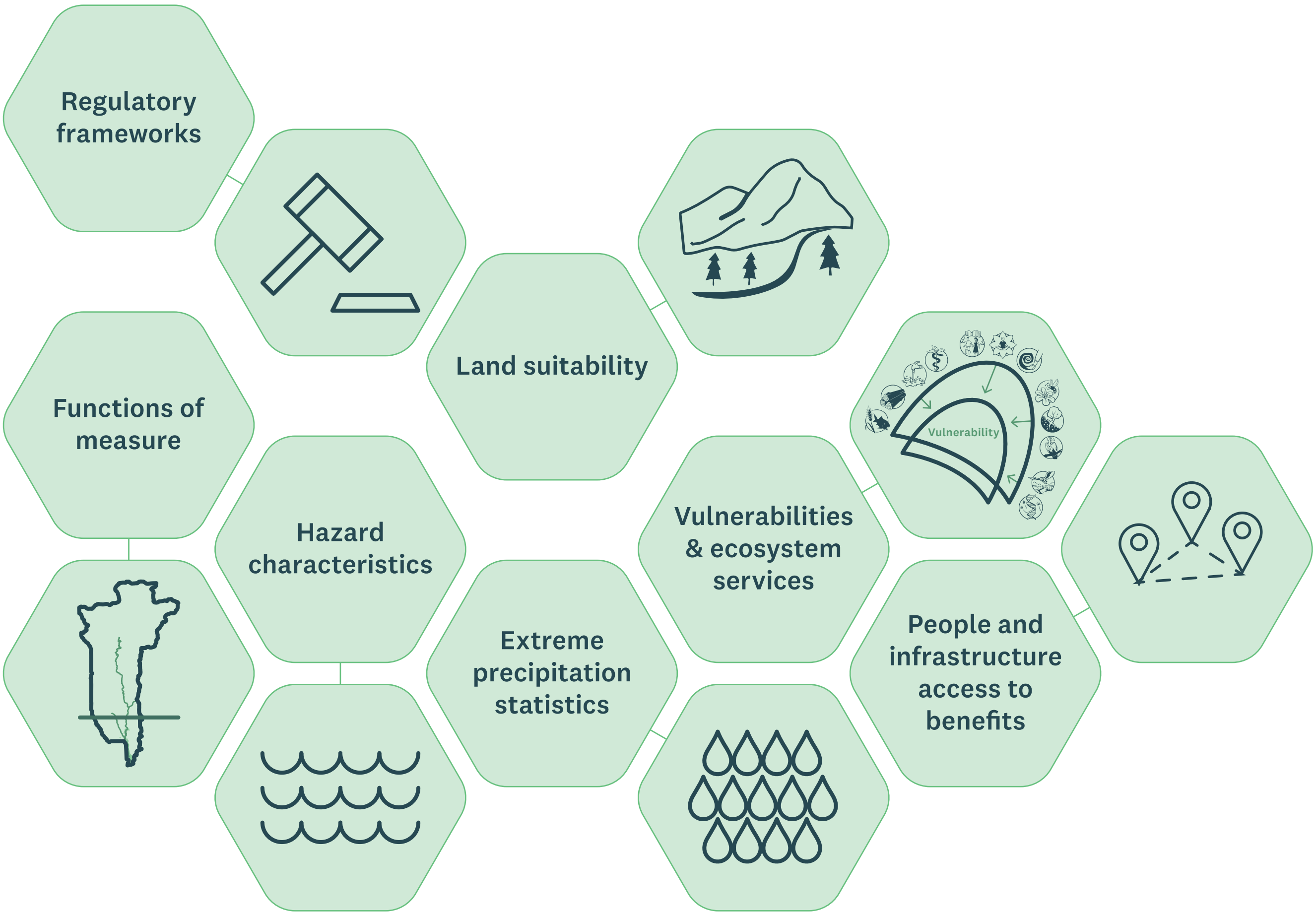


Figure 8 – Trade-offs to consider in the strategic Eco-DRR location.

Regulatory frameworks

Land use planning and regulations restrict how land can be used. Just like there may be frameworks that hinder a certain land use development, there may be financial incentives to guide and encourage other land use forms. It is, therefore, important to be aware of local land use planning and regulatory frameworks to work in line with land tenure.

Land suitability

Eco-DRR measures, depending on their type and functionality, can be related to different environments. Therefore, factors such as topography, soil type and space must be considered in the placement of Eco-DRR measures. For example, wetlands can thrive in topographic sinks where water accumulates, while measures that can increase the resilience of food systems (e.g. agroforestry) should be linked to agricultural land.

Functions of measure

There are multiple functions of the ecosystem in flood risk management – whether it addresses the hazard by draining or retaining water, the exposure by creating retention areas or buffer zones or the vulnerability by providing ecosystem services like food or fresh water.

Extreme precipitation statistics

Meteorological data and models on where and how often extreme precipitation occurs (or will occur in the future) can inform the strategic location of measures. For instance, if heavy rains frequently affect the lower catchment, placing flood mitigation measures in the upper catchment may not be effective.

Hazard characteristics

Inland floods can be pluvial (rainfall intensity exceeds the land's capacity to retain water) or fluvial (high-water levels in river channels exceed bank heights) with very different hydrodynamic characteristics. Understanding how the flood hazard is generated in your area will allow you to know whether to consider the entire catchment area in the case of fluvial floods or to focus on pluvial floods, which generally appear in areas where a combination of high precipitation and a hilly topography leads to the accumulation of stormwater in low-laying areas.

Vulnerabilities and ecosystem services

Eco-DRR can reduce vulnerabilities by providing benefits such as food security, alternative income sources and enhanced well-being. Consider vulnerabilities and the potential of Eco-DRR to reduce them in the strategic Eco-DRR site.

Benefits to people and infrastructure

Eco-DRR measures should reach whom or what they aim to protect. Benefits should be accessible to people and close enough to safeguard critical infrastructure. Schemes like "payment for ecosystem service" (PES) can ensure that Eco-DRR benefits obtained downstream are also felt at the Eco-DRR implementation site. Access to benefits promotes local buy-in.

Additional resources:

- World Bank 2017 Implementing nature – based flood protection
- IUCN 2020 Global Standards for Nature-based Solutions
- World Bank 2024 Nature-based Solutions Opportunity Scan

Heavy rain in Togo and Benin caused the Mono River to overflow in 2019, affecting thousands of people living close to the river.

5. Comprehensive evaluation of ecosystem-based flood risk reduction measures

By the end of this chapter you will know about:

- A structured approach to comprehensively evaluate Eco-DRR measures
- Different methods and tools to use for assessing the impact of Eco-DRR on all components of flood risk

5.1. Comprehensive evaluation of the impacts of Eco-DRR on all components of risk

To assess the effectiveness of Eco-DRR measures in reducing flood risk, it is essential to understand their impact on all three components of risk: hazard, exposure and vulnerability (see Figure 9), bearing in mind there might be a time lag between implementation and effects. The process involves comparing the flood risk without and with Eco-DRR measure.

The following sub-sections look at how to evaluate the effect of an Eco-DRR measure on hazard (5.1.1), exposure (5.1.2) and vulnerability (5.1.3).

5.1.1. Evaluation of hazard reduction

Eco-DRR measures affect hydrological processes, generally reducing the flood hazard. To evaluate this, compare flood hazard "status quo" to flood hazard with Eco-DRR, as illustrated in Figure 10. Areas underwater in status quo, which are no longer underwater after an Eco-DRR measure has been implemented (highlighted in orange) represent the measure's hazard reduction benefit.

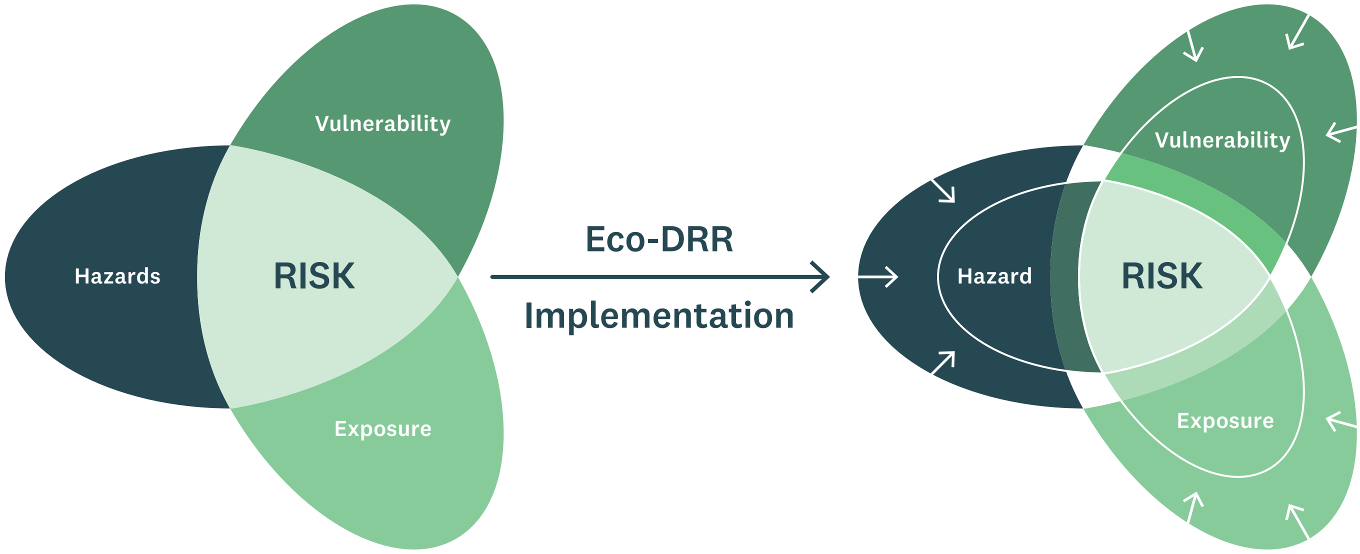


Figure 9 - Illustration of change in risk at the level of all three components as a result of Eco-DRR implementation. Based on Janzen et al., 2024

For the comparison of the flood hazard before and after:

- Use hydrological modelling, collaborate with a hydrologist to measure change. For the methodological approach to capture changes in hydrological processes such as surface run-off, infiltration, evapotranspiration and soil water as a result of Eco-DRR implementation, see Janzen et al. (2024);
- Measure the flood extent and depth in situ, by comparing pre- and post-Eco-DRR flood levels either through measurements in the field or from satellite images. Although attribution of hazard reduction to Eco-DRR can be challenging due to potentially multiple compounding factors, measurements on the ground present a way to estimate the flood reduction benefit of Eco-DRR.

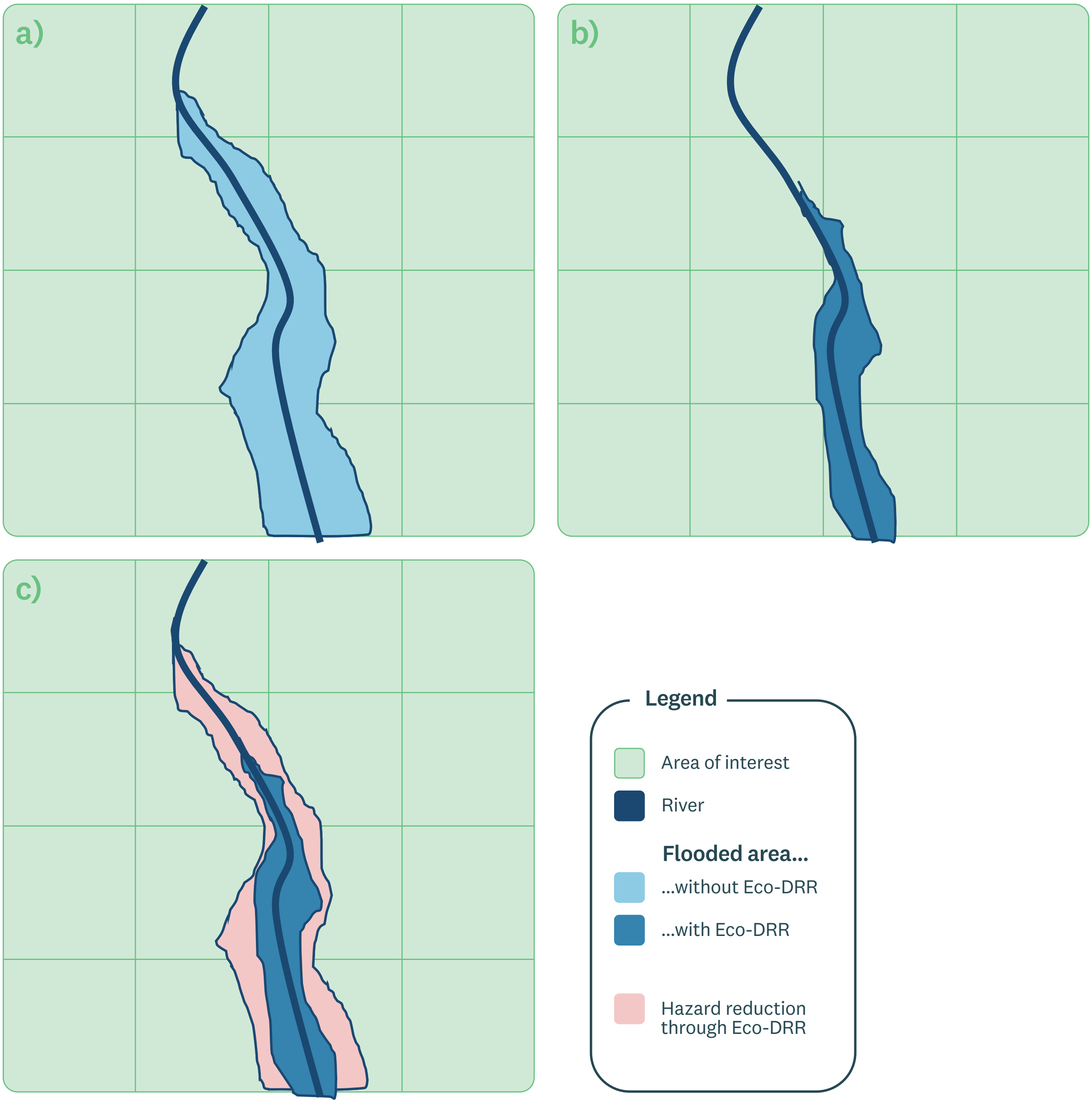


Figure 10 – Conceptual diagram to evaluate Eco-DRR potential in terms of flood hazard reduction, comparing flood extent without Eco-DRR (a) with flood extent after Eco-DRR (b). Figure c shows the comparison and flood hazard reduction obtained through the Eco-DRR measure. Source: UNU-EHS.

5.1.2. Evaluation of exposure reduction

Since exposure is dependent on hazard occurrence and extent, Eco-DRR measures indirectly influence exposure by altering flood hazard, as illustrated in Figure 11. To assess Eco-DRR-induced changes in exposure, use information on the new flood hazard (see 5.1.1.) to overlay exposed elements. Alternatively, visit the flooded field post-Eco-DRR implementation (considering potential time lag between implementation and effects) and record assets exposed as compared to pre-Eco-DRR conditions.

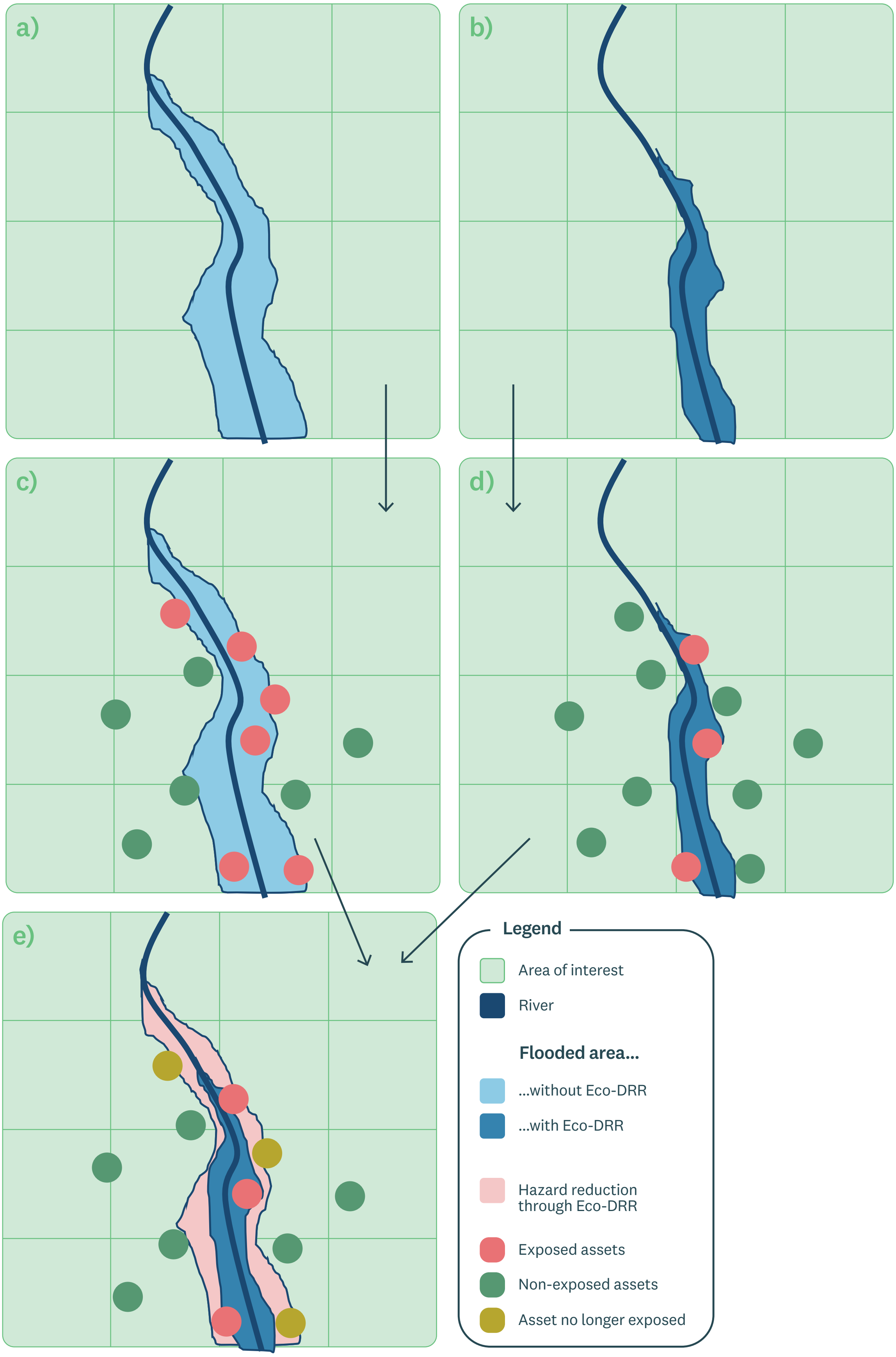


Figure 11 – Conceptual diagram illustrating the change in hazard exposure as a result of Eco-DRR implementation. The diagram shows a) flood hazard status quo, b) flood hazard with Eco-DRR, c) exposure to flood under status quo, d) exposure to floods under Eco-DRR and e) change in hazard-exposure as a result. Source: UNU-EHS.

5.1.3. Evaluation of vulnerability reduction

Eco-DRR measures provide services that reduce people's and ecosystem's vulnerability to floods which may enhance their coping and adaptive capacities (Shah et al. 2020; Walz et al. 2021). The illustration below (Figure 12) shows the change in service provision obtained going from cropland to agroforestry systems.

Assess the impacts of Eco-DRR on vulnerability by comparing ecosystem service provision before and after Eco-DRR implementation. This involves reviewing literature or consulting experts to establish the link between the Eco-DRR measure and previous land use to ecosystem services. Collect information on ecosystem services provided by different land use forms for a better overview (see Janzen et al. (2024) for methodology and exemplary collection format).

After assessing the impacts of the Eco-DRR measure(s) on the vulnerability to floods, compare its results with the pre-implementation vulnerability as assessed in 2.2. to evaluate the effectiveness of the measure on vulnerability.

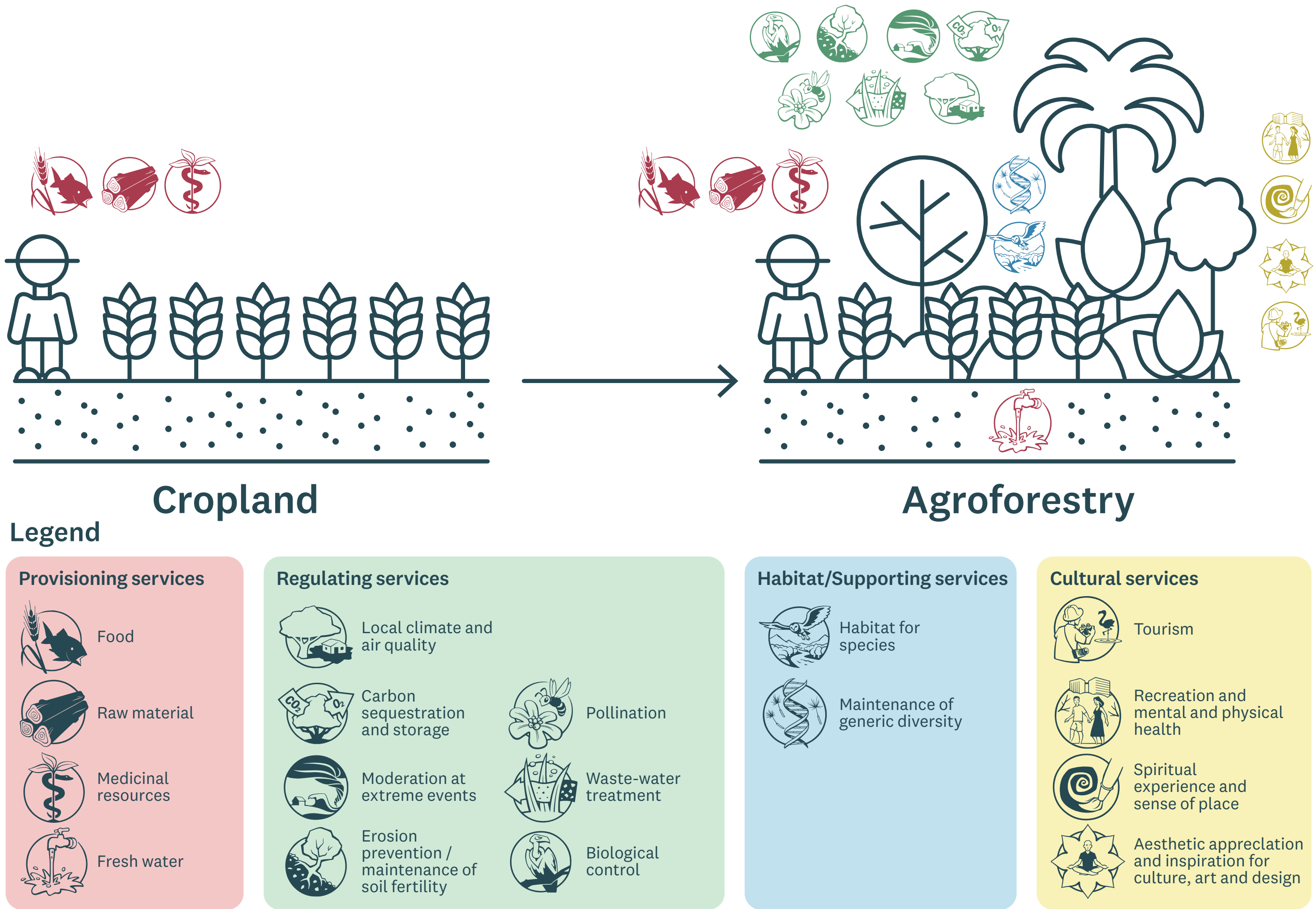


Figure 12 - Illustration of change in and emergence of ecosystem service provision (following the TEEB classification) as a result of going from cropland (left) to agroforestry (right). Icons: TEEB. Based on Janzen et al., 2024.

5.1.4. Evaluation of Eco-DRR for risk reduction

After understanding and evaluating the effects of Eco-DRR on hazard, exposure and vulnerability, conduct the flood risk assessment and compare "flood risk status quo" to "flood risk with Eco-DRR". Tools like KalypsoIndicatorRisk (Björnsen Beratende Ingenieure GmbH 2024) can facilitate direct risk comparison, generating a detailed visualization of the outcome, as illustrated in Figure 13. The flood risk status quo (on the left) can easily be compared to the flood risk with Eco-DRR implementation (on the right) and shows areas where hazard-exposure, vulnerability and as a result, flood risk have been reduced (surrounded in green).

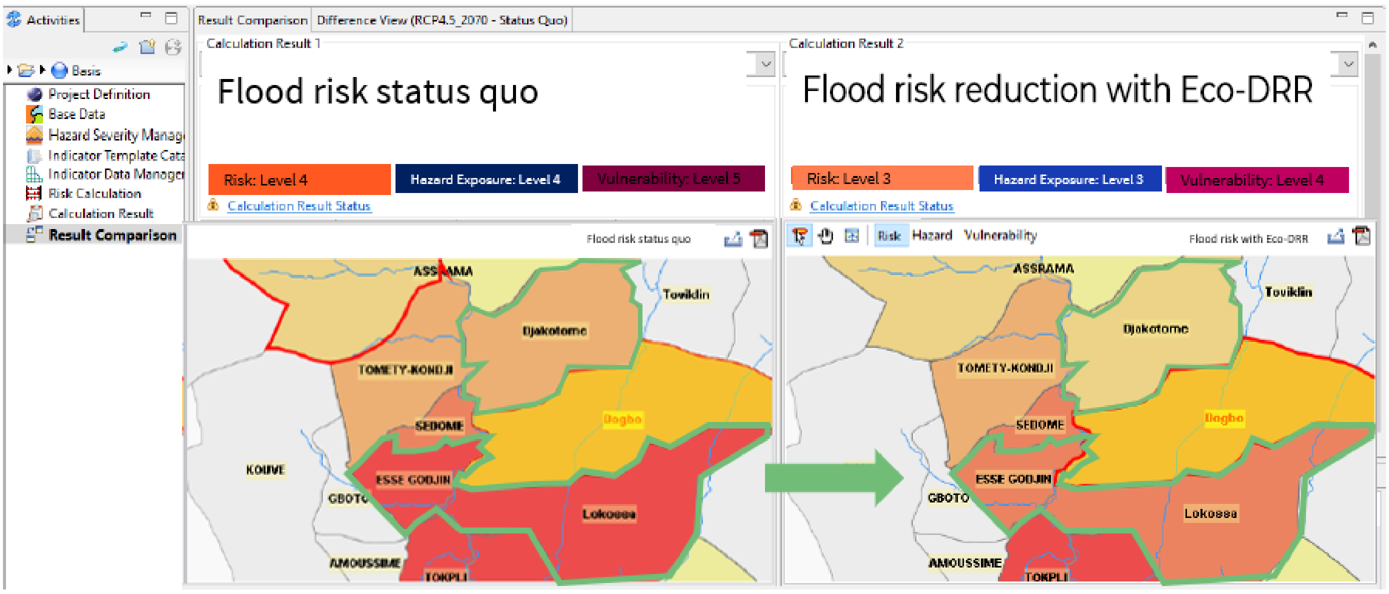


Figure 13 – Example of a risk assessment result comparison in KalypsoIndicatorRisk with flood risk status quo (left) and flood risk with Eco-DRR (right) and areas where flood risk has been reduced surrounded in green. Adapted from Schudel et al., 2022.

Additional resources:

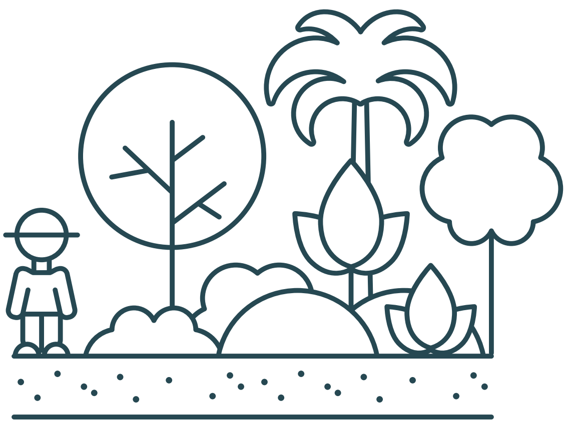
- European Commission 2021 Evaluating the impacts of Nature-based Solutions

6. Example of Eco-DRR application in a rural context of West Africa: Agroforestry for flood risk reduction in the Ouémé basin, Benin

By the end of this chapter you will know about:

- The process of selecting and strategically placing an Eco-DRR measure.
- The comprehensive evaluation of agroforestry in the context of flood risk in the Oueme River Basin, Benin

The example of implementation and evaluation of agroforestry for flood risk reduction in a rural setting is set in the Ouémé basin, Benin (see Figure 14). For detailed information on the initial flood risk assessment as an underlying basis see Balzer et al., 2024.



Regional Eco-DRR literature and plans were reviewed to gain an understanding of Eco-DRR options in West Africa. Subsequently, Eco-DRR measures were prioritized through an expert survey (see Figure 15). Therefore, agroforestry was identified as the most appropriate Eco-DRR measure in the local context.

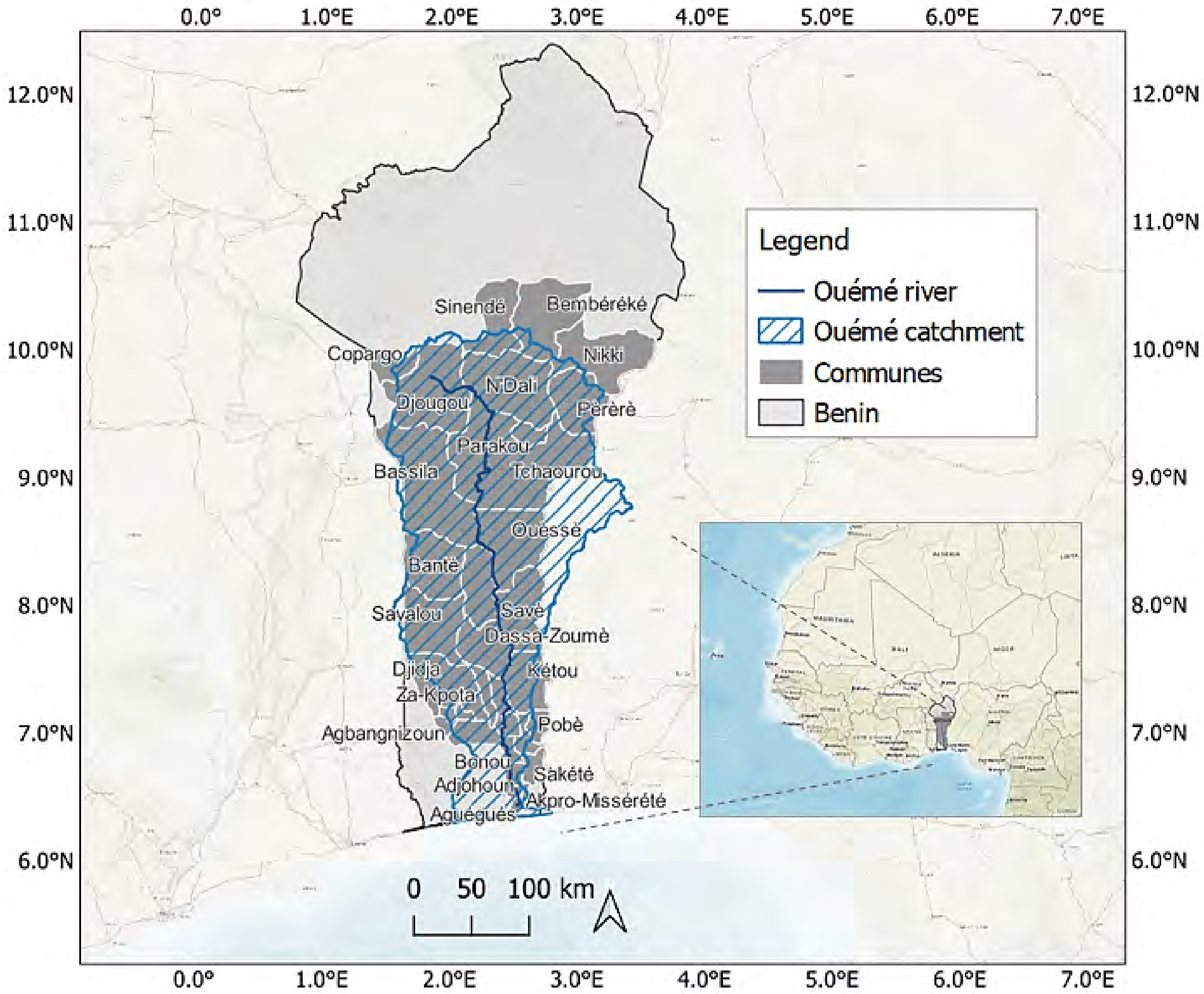


Figure 14 - Map of Ouémé catchment. Source: Janzen et al., 2024

Question 2: How relevant are these measures to reduce flood risk in Benin / Ouémé basin in your opinion? Please attribute a score of 1 to 5 to each measure, with 1 being not relevant for flood risk reduction and 5 being very relevant.

	1 - Not relevant	2 - Somewhat relevant	3 - Relevant	4 - Very relevant	5 - Extremely relevant
Wetland protection	☐	☐	☐	☐	☐
Agroforestry	☐	☐	☐	☐	☐
Riparian forest management	☐	☐	☐	☐	☐
Forest management	☐	☐	☐	☐	☐
Watercourse restoration	☐	☐	☐	☐	☐
Green spaces	☐	☐	☐	☐	☐
Mangrove conservation	☐	☐	☐	☐	☐

Figure 15 – Example of question from the expert survey for the selection of Eco-DRR measure in the Ouémé basin.

6.1. Agroforestry implementation site

Agroforestry was placed in the upper basin, considering the measure's retention function and capacity to hold water in the soil, thus reducing the discharge and surface run-off. Its strategic site choice considered risk hotspots, underlying vulnerabilities and current land use (Figure 16).

Furthermore, the selection of the commune of Tchaourou was greenlit by local stakeholders.

The entire cropland in the commune was hypothetically converted to incorporate tree systems to enhance the landscape's capacity to retain floodwaters, while benefiting the local communities.

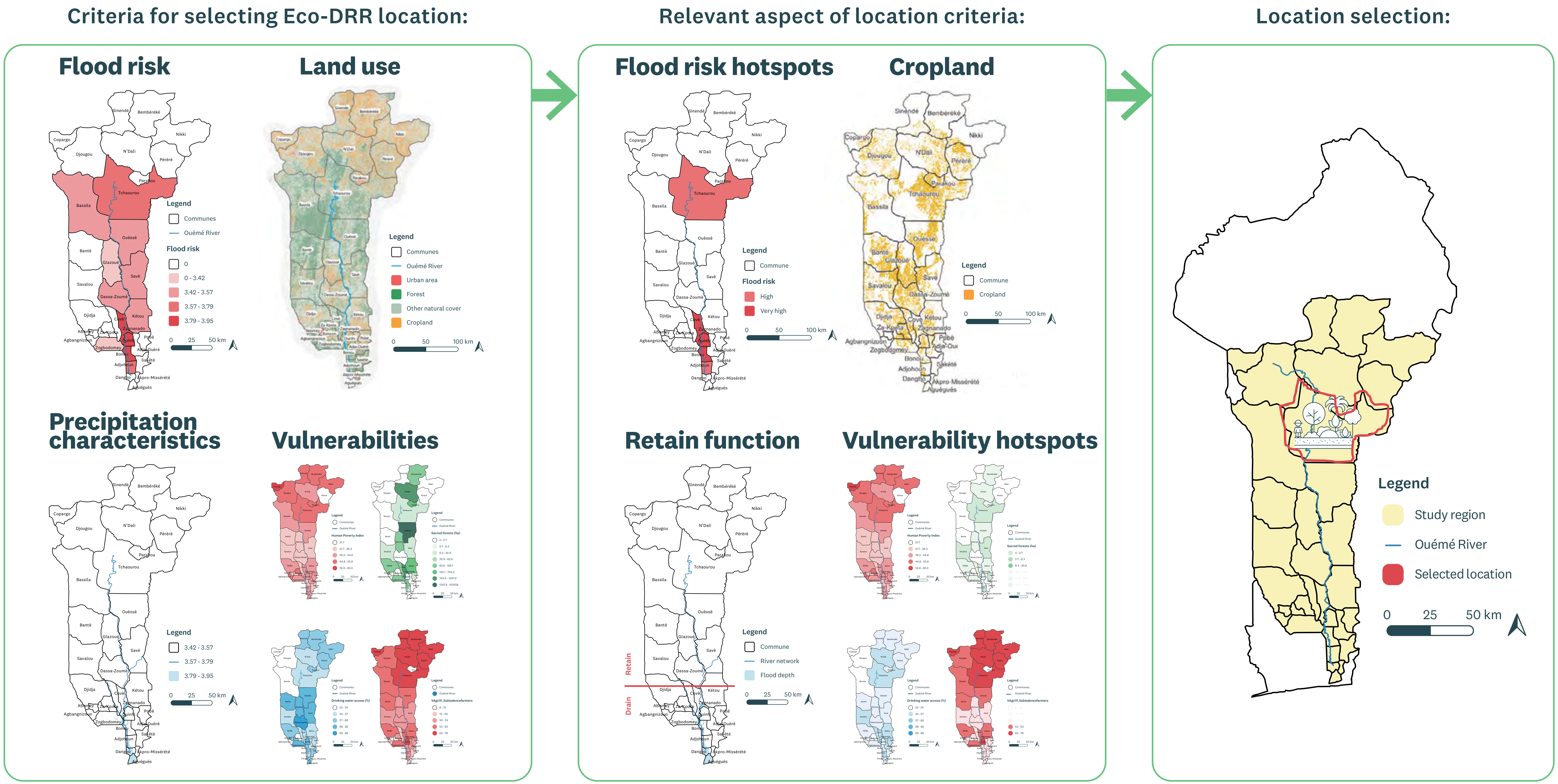


Figure 16 - Illustration of aspects considered for the selection of agroforestry location (left) and the commune identified as strategic for the agroforestry implementation (right). Risk hotspots, agricultural land, retention functions and existing vulnerabilities (middle) resulted in the commune of Tchaourou being chosen for the Eco-DRR implementation.

6.2. Evaluating agroforestry

For the evaluation of agroforestry, the effect of agroforestry on each of the risk components was assessed individually, following the approach described in section 5.1.

The effect of agroforestry on the flood hazard was evaluated by studying its impact on hydrological parameters compared to traditional cropland (for methods and results see Janzen et al. 2024). The hydrological model SWAT was rerun with data adjusted for agroforestry impacts. Compared to the flood hazard status quo, a reduction in run-off was found, as seen in the hydrograph showing discharge over time (Figure 17).

These changes led to a quantifiable reduction in flood exposure, supported by a reassessment of exposure using updated hazard inputs. The outcomes in Figure 18 demonstrate the effectiveness of agroforestry in reducing exposure to floods, particularly in the southern part of the basin based on this model approach, where the communes Ouinhi, Bonou and Zagnanado see significant changes in a number of exposed assets (see Table 1).

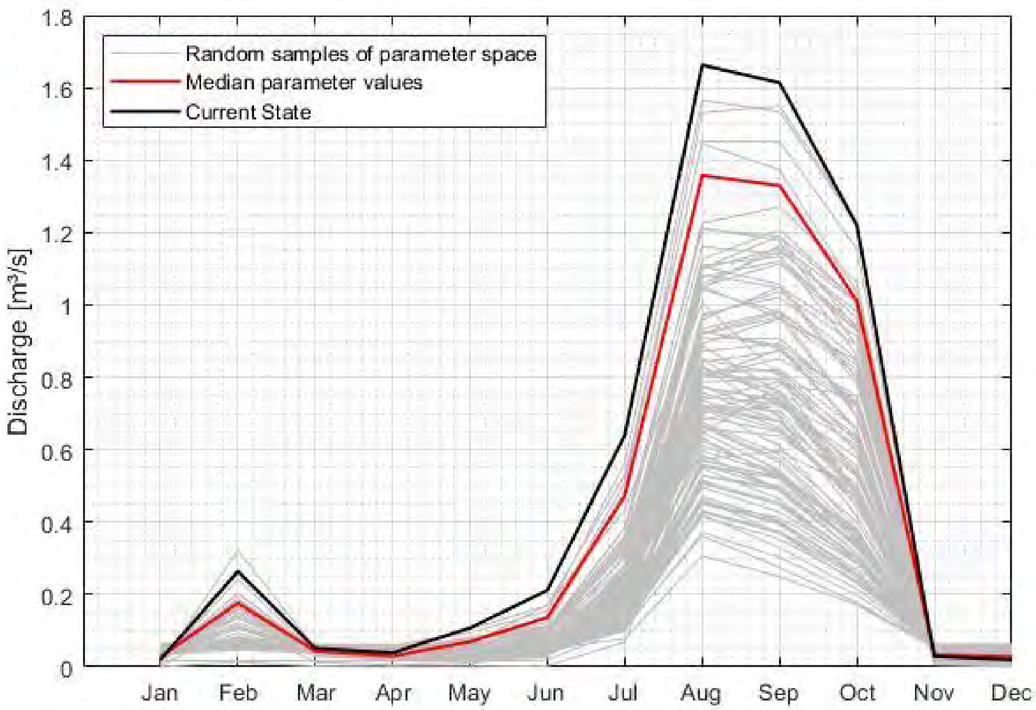


Figure 17 - Hydrograph comparing flood hazard at Bonou status quo and under random samples of agroforestry. Source: Janzen et al. forthcoming.

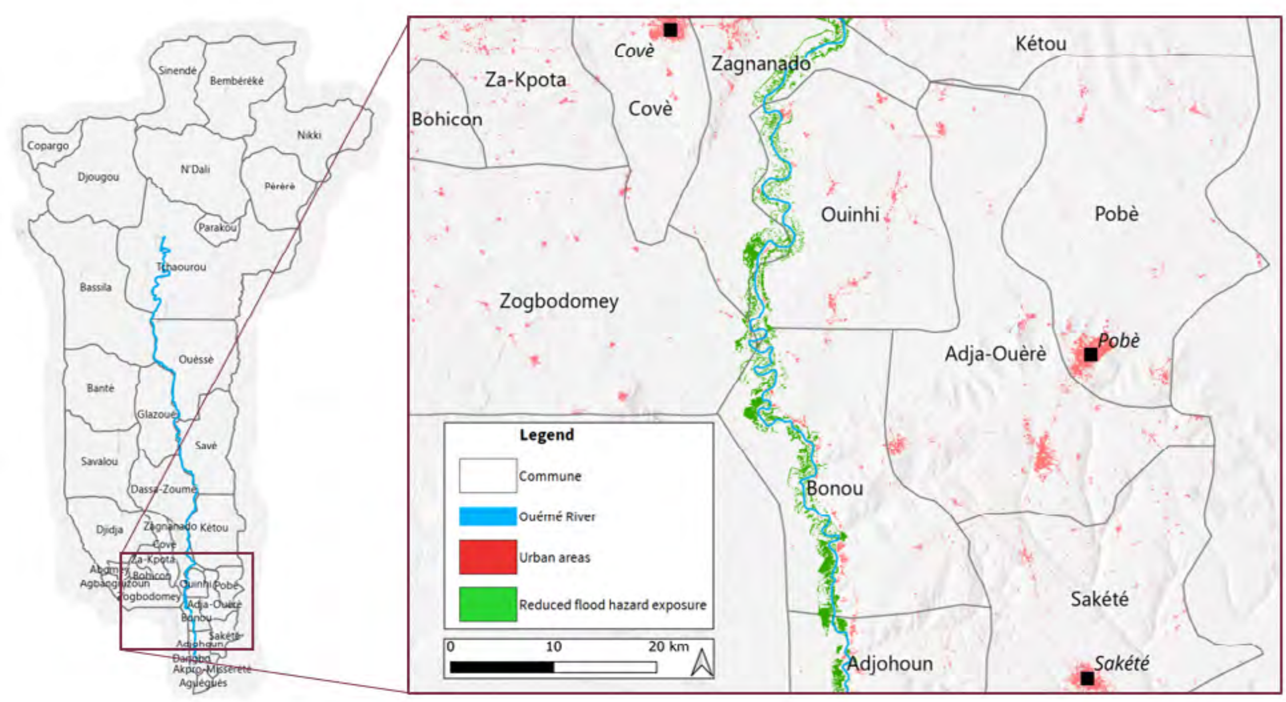


Figure 18 - (left) Illustration of hazard-exposure change under agroforestry, with zoom into the southern part of the Ouémé catchment, highlighting areas that are no longer exposed to floods in green compared to the status quo scenario. (right)

Table 1 - Quantitative change in hazard-exposure under agroforestry in the communes Ouinhi, Bonou and Zagnanado.

Percentage change in exposed elements under agroforestry	Ouinhi	Bonou	Zagnanado
People (#)	-36.9	- 56.5	-50.9
Industry ($)	-30.8	-35	-37.6
Schools (#)	0	0	-4.4
Livestock (#)	-1.4	-6.3	-18.5
Roads (#)	0	-14.3	-47.4
Green spaces (ha)	-30.6	-35.9	-37.4

Based on the change in ecosystem service provision from cropland to agroforestry systems, the reassessment of vulnerability supported evaluating the effect of agroforestry on vulnerability (for methods and results see Janzen et al. 2024). The outcome, illustrated in Figure 19, shows a reduction in ecological vulnerability in Tchaourou from 0.92 to 0.02. Compared to cropland, agroforestry presents a less altered land use with greater biodiversity, timber provision and soil fertility, which benefits inhabitants of Tchaourou by sustaining their livelihoods and well-being.

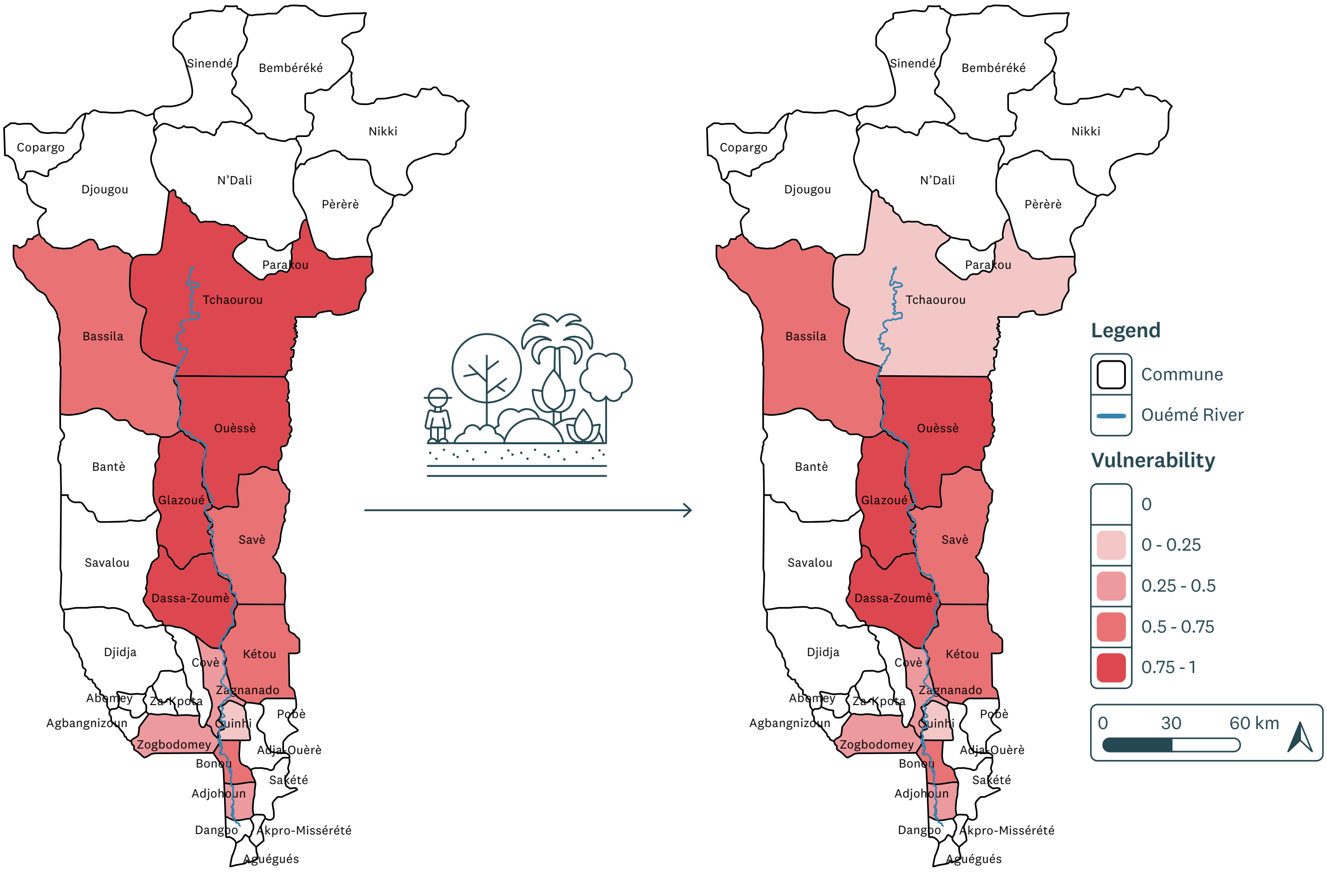


Figure 19 - Comparison of ecological vulnerability in the Ouémé basin status quo (left) and agroforestry implementation in the commune of Tchaourou (right) showing a decrease in vulnerability in Tchaourou. Source: Janzen et al. forthcoming.

Finally, combining the three new components – hazard, exposure and vulnerability – in the agroforestry scenario defined the overall flood risk under agroforestry. Comparing risk status quo to risk under agroforestry shows a noticeable reduction in flood risk in the southern part of the catchment (see Figure 20). It demonstrates the effectiveness of agroforestry particularly in reducing the hazard and related exposure. The results, furthermore, show the interconnection of the basin, with agroforestry implementation in the northern part of the catchment resulting in hazard-exposure benefits, particularly in the southern part of the catchment. Hence, it could be interesting to consider a "payment for ecosystem services" (PES) scheme for the upper catchment "providers" of the benefit to continue sustaining the benefit to the lower catchment "beneficiaries".

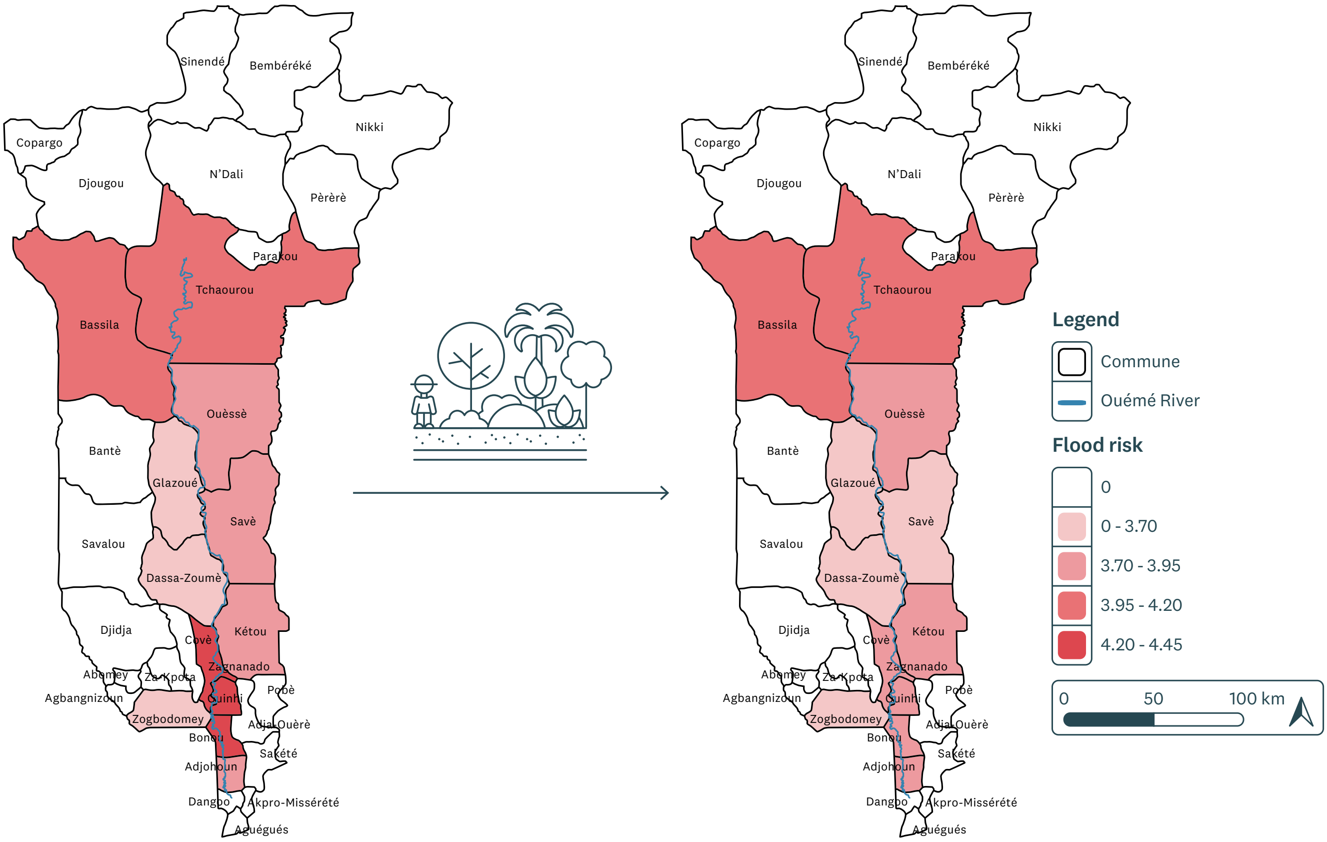
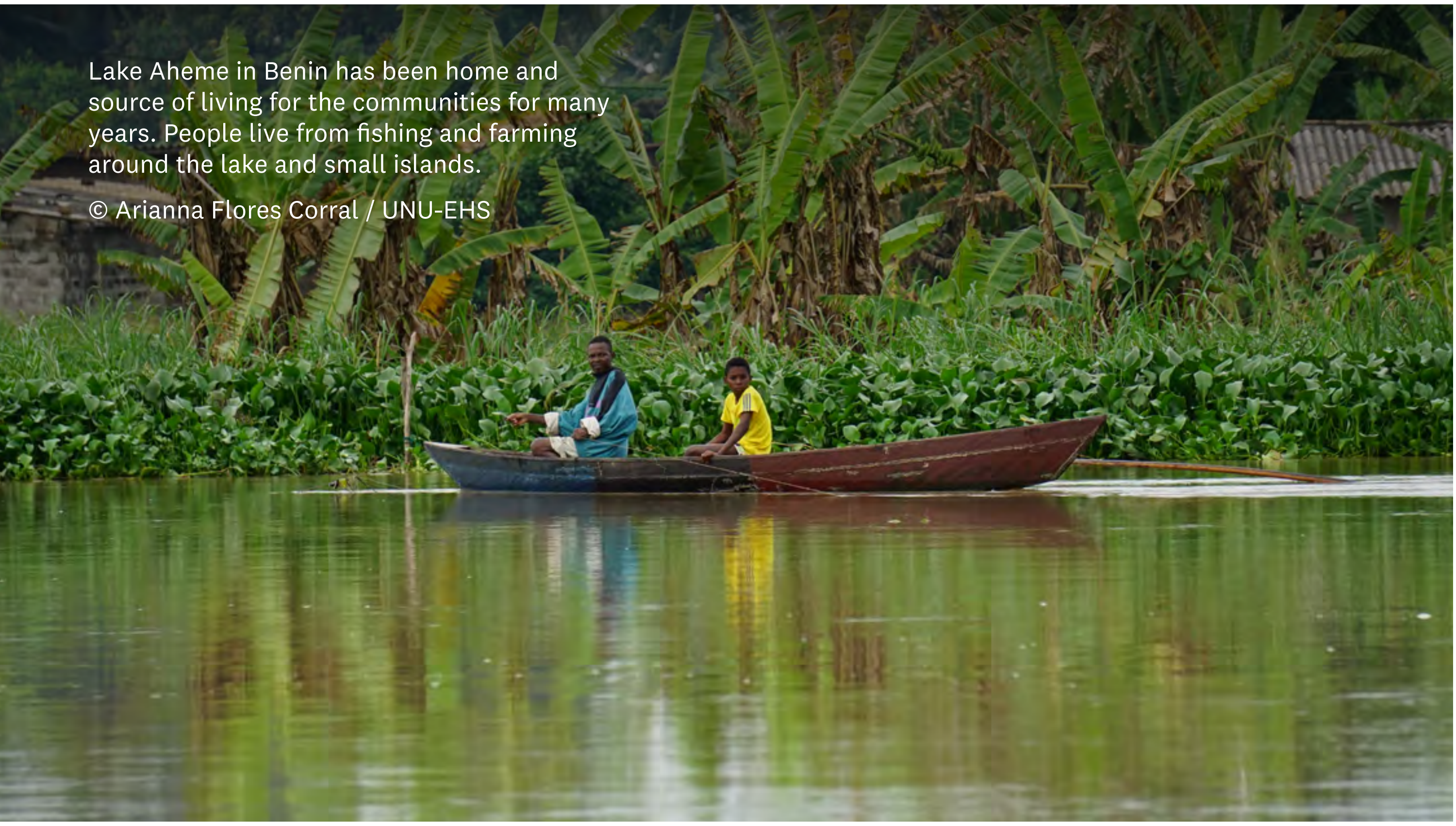


Figure 20 - Change in flood risk as a result of agroforestry implementation illustrating risk assessment "status quo" (left) and risk assessment under agroforestry (right). Source: Janzen et al. forthcoming.



Lake Aheme in Benin has been home and source of living for the communities for many years. People live from fishing and farming around the lake and small islands.

Lake Aheme in Benin has been home and source of living for the communities for many years. People live from fishing and farming around the lake and small islands.

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7. Conclusion and recommendations

Eco-DRR measures are utilized across West Africa to reduce flood risk in both urban and rural settings. As these measures can effectively reduce all three components of flood risk, their uptake is expected to increase. This guidebook facilitates the selection of measures, strategic locations and the steps to take to comprehensively evaluate Eco-DRR measures to support their effective use for flood risk reduction. It shows the importance of local stakeholder involvement at all stages to understand the local context, challenges and feasibility, as well as to create ownership. It also reveals the multi-disciplinary nature of the involved steps. The application of the guidebook to agroforestry in rural settings serves as a practical model.

Key recommendations

Flood risk assessments:
Use a flood risk assessment as the basis for any Eco-DRR placement and evaluation. Such assessment can be conducted in different ways, depending on time and resources.

Context-specific Eco-DRR selection:
Choose Eco-DRR measures based on specific local needs and conditions.

Strategic locations:
Identify locations for Eco-DRR measures that maximize their impact on reducing overall flood risk. This involves understanding the specificities of each area and finding a compromise between several aspects that come into play.

Comprehensive evaluation:
Assess the effects of Eco-DRR on all three components of flood risk to finally combine them to to evaluate overall risk reduction benefits of an Eco-DRR measure.

Stakeholder involvement:
Actively involve local stakeholders in the selection, locating and evaluation of Eco-DRR. This engagement is crucial for gaining local insight, enhancing buy-in and ensuring the sustainability of the measure.

Multi-disciplinary team:
Considering the interdisciplinary nature of the task, involve hydrologists, geoscientists, ecologists, meteorologists, planners, risk scientists, sociologists, etc. to benefit from the different expertises and perspectives for an enhanced outcome.

Heavy rain in Togo and Benin caused the Mono River to overflow in 2019, affecting thousands of people living close to the river.

Annex

This annex summarises existing and planned Eco-DRR measures in West Africa. It illustrates the measures' potential function, vulnerability-reducing services and potential implementation sites in table 1 and provides a short overview of each measure (see page 43 and 44).

Table 2 - Summary of existing and planned Eco-DRR measures in West Africa, as identified through a literature review and targeted project and policy review.

Eco-DRR measure		Reference	Hazard function		Vulnerability-reducing services				Land use for implementation				
			Retain	Drain	Provisioning	Regulating	Habitat	Cultural	Cropland	Grassland	Forest	Urban	Wetland
	Agroforestry	Jalloh & Diof, 2014	●		●	●	●	●	●	●		●	
	Forest management (reforestation, afforestation, sustainable management)	Idinoba et al., undated; NAP Togo; PANORAMA; Bessah et al., 2021; Afriyie et al., 2021; Acreman et al., 2021; IUCN 2015; WB, 2023	●		●	●	●	●		●	●	●	
	Gallery forests	GCA, 2022; NDC Benin	●		●	●	●	●			●	●	●
	Watercourse restoration (renature riparian area, path restoration)	Montcho et al., 2022; Sahani et al., 2019		●	●	●	●	●	●	●	●	●	●
	Green spaces	Sahani et al., 2019		●	●	●	●	●				●	
	Wetland protection and restoration	Montcho et al., 2022; Sahani et al., 2019		●	●	●	●	●	●	●	●	●	●

Brief overview of existing and planned Eco-DRR measures in West Africa

Agroforestry

Agroforestry is an agroecosystem characterized by the integration of crop, with or without livestock production, with tree or shrub compositions (Mosquera-Losada et al. 2009; Ramil Brick et al. 2022). It is commonly sub-categorized into agrosilviculture (e.g., alley cropping, riparian buffers, parklands) and silvopasture (i.e. trees in pasture) (Brown et al. 2018). In Sub-Saharan Africa, agroforestry is recognized for its potential to enhance biodiversity, prevent soil degradation and mitigate floods and droughts while promoting the sustainable development of rural communities (Boffa 1999; Thorlakson and Neufeldt 2012; Mbow et al. 2014; Quandt et al. 2017).

Forest management

Foret management refers to any planned human intervention in a forest ecosystem to achieve specific goals. Its sustainable management aims at maintaining or enhancing environmental, economic and social benefits obtained from the forest without compromising future benefits (MacDicken and others, 2015; fsc.org, 2024).

While reforestation refers to the restocking of existing forests that had been depleted or degraded, afforestation refers to the conversion of degraded or abandoned land into forests. Both approaches are used in Sub-Saharan Africa and their potential to improve soil structure and water infiltration, while enhancing carbon storage is well recognized (Noulèkoun, 2020).

Gallery forests

Gallery forests, also referred to as "riverine", "fringing" or "riparian" forests, are forests that stretch along the banks of a river or wetlands.

These forests are critical for the ecological, hydrological and geomorphological functioning of watercourses and provide numerous ecosystem services that benefit human well-being.

Additionally, they serve as forest refugia, providing important habitats for endangered plant and animal species, therefore playing an important role for biodiversity conservation in Sub-Saharan Africa (Habel and Ulrich, 2021; Adjossou and others, 2022).

Watercourse restoration

Watercourse restoration returns rivers and streams to their original and natural state to improve their ecological status and ensure their sustainable development.

Natural or near-natural watercourses meander, contributing to habitat formation and enjoyable landscape-forming elements. Additionally, their meandered course reduces the risk of flooding for downstream users, as water is slowed down.

Green spaces

Green spaces are open-space areas reserved for parks and other green spaces. Due to a variety of reasons related to urbanization and governance, they are increasingly disappearing from cities in Sub-Saharan Africa (Seth and others, 2023). Yet, they underpin the provision of ecosystem service in cities and are therefore indispensable for human wellbeing.

Green spaces contribute to maintaining biodiversity, help to mitigate hazards such as floods and urban heat island effects and contribute to improving residents' health by providing a space for recreation (Guenat and others, 2021).

Wetland management

Wetlands are permanent or temporary areas of swamps and fens with water and vegetation (Ramsar Convention on Wetlands). They are vital for humans, with more than a billion people across the world depending on wetlands for their livelihoods (United Nations, 2024) Wetlands are also critical for our climate, providing essential ecosystem services such as water regulation, including flood control and water purification (Duku and others, 2022).

Yet, wetlands are among the ecosystems with the highest rates of decline, loss and degradation. Recognising their importance, mangroves are being protected and restored to ensure the sustained provision of ecosystem services.

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Authors
Sally Janzen (United Nations University Institute for Environment and Human Security (UNU-EHS))
Jana Balzer (UNU-EHS)
Fabian Merk (Technical University of Munich (TUM))
Jonas Hansohm (UNU-EHS)
Yvonne Walz (UNU-EHS)

Reviewers
Andrea Ortiz-Vargas (UNU-EHS)
Andreas Fink (Karlsruhe Institute of Technology)
Emmanuel Nketiah Ahenkorah (Ghana Water Company)
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Karen Sudmeier-Rieux (KSR consulting)
Raymond Djangma (Water Resources Commission)
Udo Nehren (Technische Hochschule Köln)

Editor
Haylee Lunt

Graphic design
Imre Sebestyén (Unit Graphics)

Figures
Caitlyn Eberle (UNU-EHS)

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Arianna Flores Corral / UNU-EHS

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