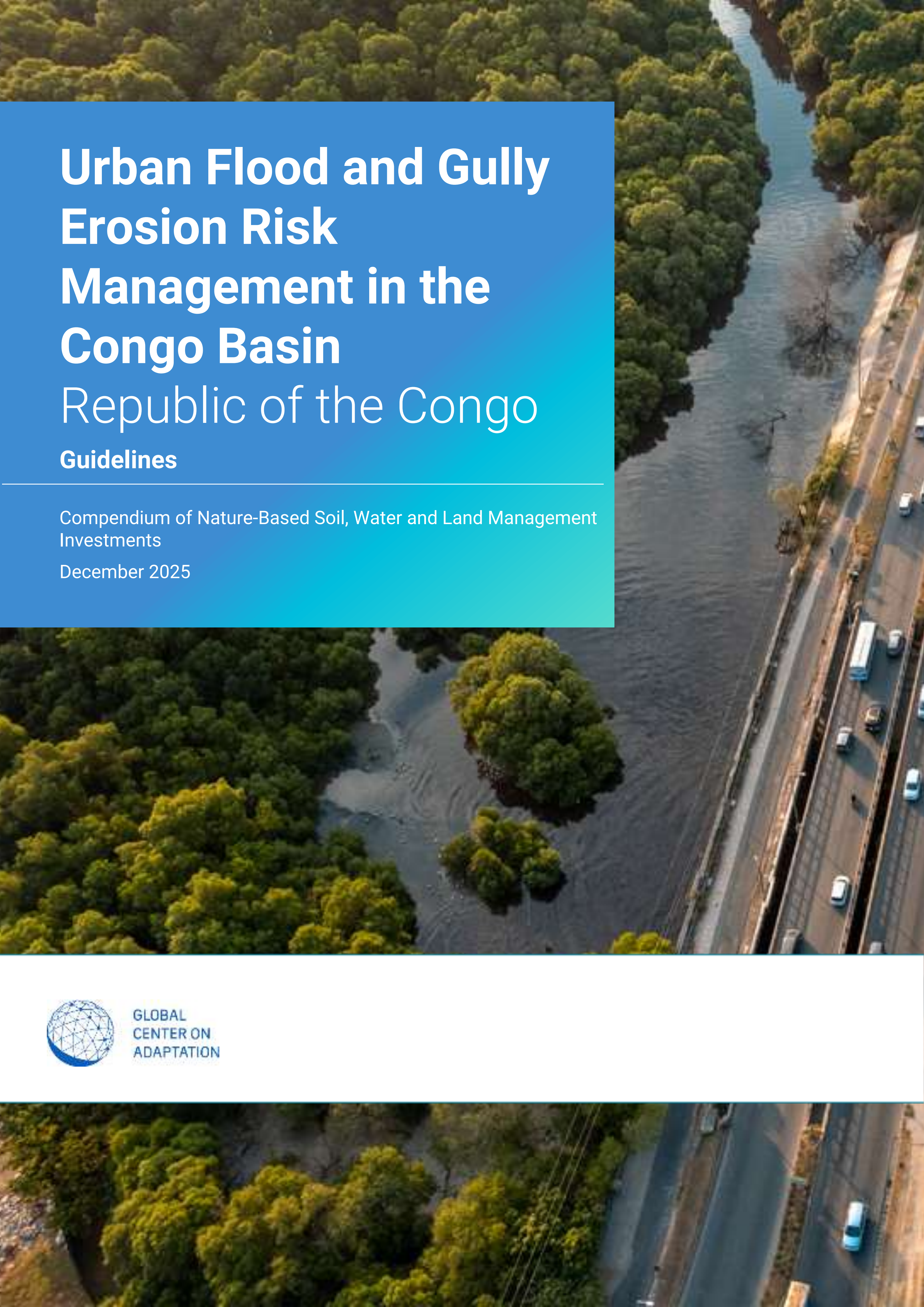


Urban Flood and Gully Erosion Risk Management in the Congo Basin

Republic of the Congo

Guidelines

Compendium of Nature-Based Soil, Water and Land Management Investments

December 2025

GLOBAL CENTER ON ADAPTATION

This report was developed by

Global Center on Adaptation:

Partnerships:
The World Bank

Consultants:

OCA Global (Fabiana Silva, Lluís Torrent, Luis Rojas, Jean L. Mulumba)

GlobalCAD (Frank Müller, Eduardo Pérez)

Meteosim (Rosana Almeida, Ignasi Porras)

ResALLience (Alejandra Castellanos, Emilie Edelblutte)

Climate Change Africa Opportunities (CCAO) (National Teams members: Sandra Makosso and Roldin Ngassaki)

DESCRIPTORS

Sector	Nature-based Solutions
Region	Congo Basin country: Republic of Congo (RoC)
Keywords	Climate Change Adaptation, Climate Risk Assessment, Sustainable Urban Planning, Capacity building
Contact	Info.consulting@ocaglobal.com

ABOUT THE GLOBAL CENTER ON ADAPTATION

The Global Center on Adaptation (GCA) is an international organization, hosted by the Netherlands, which works as a solutions broker to accelerate action and support for adaptation solutions from the international to the local, in partnership with the public and private sector, to ensure we learn from each other and work together for a climate resilient future.

Acknowledgements:

GLOBAL CENTER ON ADAPTATION

In Partnership with:

THE WORLD BANK

Consultants:

TABLE OF CONTENTS

FIGURES

TABLES

ABBREVIATIONS

Acronym	Definitions
AFD	Agence Française de Développement (French Development Agency)
BCR	Benefit–Cost Ratio
CAPEX	Capital Expenditure
CAR	Central African Republic
CBO	Community-Based Organization
CCAO	Climate Change Africa Opportunities
CGDC	Comité de Gestion et de Développement Communautaire (Community Development Committee)
CMIP6	Coupled Model Intercomparison Project Phase 6
DEM	Digital Elevation Model(s)
DRC	Democratic Republic of Congo
EAC	Equivalent Annual Cost
EIA	Environmental Impact Assessment
FCV	Fragility, Conflict and Violence
GCA	Global Center on Adaptation
GPS	Global Positioning System
H/M/L	High / Medium / Low
JBA	Jeremy Benn Associates (JBA) Consulting
MDB	Multilateral Development Bank(s)
NbS	Nature-based Solutions
NbSWLM	Nature-based Soil, Water and Land Management
NGO	Non-Governmental Organization
NPV	Net Present Value
O&M	Operation and Maintenance
OPEX	Operating Expenditure
PACT	Territorial Climate Plan of Brazzaville
PIU	Project Implementation Unit
RAP	Resettlement Action Plan

Acronym	Definitions
RoC	Republic of the Congo
RPF	Resettlement Policy Framework
SEP	Stakeholder Engagement Plan
SIP	Strategic Investment Plan
SNACC	National Climate Change Adaptation Strategy
SSP	Shared Socio-economic Pathway
SURP	Strengthening Urban Resilience Project
SWLM	Soil, Water and Land Management
ToR	Terms of Reference
WB	The World Bank

1. EXECUTIVE SUMMARY

1.1 Background

This document presents a compendium of investments in Nature-based Soil, Water and Land management (NbSWLM) solutions for climate resilience in urban areas of the Republic of the Congo (RoC). The report is part of a regional initiative aiming to identify, prioritise and implement locally adapted Nature-based Solutions (NbS) to strengthen urban climate resilience with additional ecological and socially inclusive benefits.

The report aims to serve as a reference resource for decision-makers, practitioners, and stakeholders involved in climate adaptation and urban resilience planning. It comprises a slender analysis and pre-feasibility assessment of selected investment profiles in three sites: two in Brazzaville and a third one in Pointe Noire. For these sites, specific NbSWLM solutions are proposed. For the site selection, as well as the identification and screening of NbSWLM solutions, a robust methodology was designed, so as to ensure that the proposed practices were technically feasible, socially acceptable, and aligned with institutional priorities.

The methodology comprises three key steps:

1) Identification of investment sites through an evaluation that used evidence-based criteria such as hazard level, range of beneficiaries, low-regret, priority for government and donors.
2) Selection of NbSWLM practices for each site using criteria such as site-specific conditions, social acceptability, complementarity and scalability, among others.
3) Prefeasibility assessment, including an analysis of environmental conditions, technical requirements, cost-benefit estimations, social acceptability and community involvement.

1.2 Priority intervention sites

The investment sites identified in RoC are:

- Site A: Twin riverine junction in the Tsième catchment, Mfilou-Ngambio, Brazzaville, comprising two adjacent erosion gullies in the Ngambio neighborhood, near the P20 road and the Ecole Primaire d'Itsali.

- Site B: Head cut-road valley area in the Tsième catchment, Mfilou-Itsali, Brazzaville, separated from Site A (Twin Riverine Junction) by the P20 road, it lies on the opposite side of the road in the Ngambio neighborhood of Mfilou district.
- Site C: Urban greenway along the final Tchikobo and the Songolo river sections, Pointe-Noire: focusing on a 3.4 km river corridor in Mulumba, a central district of Pointe-Noire, suffering from settlement encroachment.

The selected sites were chosen following a consultative process with stakeholders and built on pre-existing studies[1] that determined these as suitable for "low-regret" investments that deliver lasting benefits under a wide range of future climate scenarios and uncertainties. Sites A and B are located close to each other, within the Tsième catchment at Mfilou-Itsali, Brazzaville. They also suffer from similar hazards; Consequently, an integrated approach has been proposed for these two sites. On the other hand, Site C, located in Pointe Noire, has been selected due to its exposure to flood hazard and increasing vulnerability of adjacent settlements.

1.3 Overview of key findings

All three sites exhibit high exposure to climate-related hazards, such as soil erosion and flooding. They present strong alignment with national priorities and would likely be part of national or municipal investment plans regardless of project-specific priorities. The proposed NbSWLM practices will deliver

[1] Cityscan of Pointe Noire and Brazzaville conducted in 2023 by the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) as part of their City Resilience Program.

cost-effective flood mitigation, erosion control, and multiple co-benefits such as biodiversity enhancement, carbon sequestration, and livelihood support.

Integrated Restoration of Tsième catchment, Mfilou- Ngambio/Itsali, Brazzaville (Sites A and B).

Site A, "Twin riverine junction", comprises the Eastern and the Western Gullies, which drain stormwater from the surrounding urban slopes It constitute one of the most critical erosion hotspots in the Tsième sub-catchment. Both gullies include constructed channels. However, despite these investments, both downstream and head cut erosion continue growing.

Site B on the other hand, is characterized by steep slopes and multiple active gully head cuts, which pose severe erosion and slope instability risks. Unlike Site A, Site B presents a fragmented morphology with three distinct gullies.

For the two sites, a landscape approach is proposed, integrating infiltration swales, gabions at the gully head cuts, gully slopes with vegetated terraces, and wooden check dams at valley floors.

Key findings:

- The implementation of these practices could potentially benefit about 27,000 people directly and about 96,000 indirectly through erosion reduction, improved water retention, and flood mitigation.
- There is a cost-benefit ratio of more than 20 for Rock stilling basin (Site B), nearly 6 for Vegetated infiltration swales and Progressive vegetated terraces with vetiver, 2.63 for vegetated gabions and 1.33 Wooden Check dams (all in both Sites).
- A qualitative assessment demonstrated additional benefits such as carbon storage, biodiversity, water quality, aesthetic value, soil fertility, and livelihood diversification.
- No specific fragility or violent-conflict factors were identified.
- Risks relate primarily to technical implementation rather than social acceptability.
- Recommended mitigation measures to technical implementation risks include:
    - guaranteeing the stability of any gabion structures
    - increasing community awareness and training on maintenance
    - mobilizing CGDC committees to support follow-up and maintenance
    - establishing local teams to ensure ongoing monitoring and timely maintenance.

Linear green corridor, Pointe Noire (site C).

This site includes the final segments of the Tchikobo River (2.7 km), and the Songolo River (0.7 km). It comprises of marshy zones with remnants of natural vegetation. There are also informal settlements and agricultural practices, which are highly exposed to recurring flooding.

A landscape restoration strategy is also proposed. It includes the expansion of the rivers' natural floodplain; the renaturalization of the riverbank/riverbed; and setbacks and restoration of the existing levees. A green corridor along the Avenue Jacques Opangault is also proposed, including tree canopies to improve shade, infiltration, and urban aesthetics.

Key findings:

- Over 40,000 residents are expected to be benefitted with enhanced flood control, erosion reduction, health improvement and food resources.
- Riverbank naturalization yields a cost-benefit ratio of 0.32–2.74 while set back and restoration of potentially existing levees yield a ratio of 0.78–2.17.
- The green corridor along Av. Jacques Opangault offers a relatively negative cost-benefit ratio between 0.37 and 0.81, although for this case a very conservative approach was applied.
- The qualitatively assessed shows that there are additional benefits such as sediment retention, biodiversity, and water quality improvement.
- The overall social risk is assessed as Medium.

- The proposed interventions may require the potential relocation of existing dwellers. Therefore, further analysis and appropriate mitigation measures must be formulated to address these risks.

Table 1. Summary of the interventions.

Location	Intervention	Hazard addressed	Technical feasibility	Risk reduction potential	Co-benefits	Economic viability	Maintenance practicality	Social acceptability
Site A and B: Integrated restoration of Tsième catchment in Mfilou, Brazzaville	Infiltration swales, gabions at the gully head cuts, gully slopes with vegetated terraces; wooden check dams at valley floors, and rock stilling basin.	Hillslope erosion, clayey soils, landslide risk, rapid runoff	M	H	H	H	M	H
Site C: Urban greenway along the final Tchikobo and the Songolo river sections, Pointe-Noire	Expansion of the rivers' natural floodplain; renaturalisation of the riverbank /riverbed, using bioengineering practices; setbacks and restoration of existing levees along the river floodplain; green corridor along the Avenue Jacques Opangault	Pluvial and fluvial flooding; coastal flooding	M	H	M	M	H	M

1.4 Strategic recommendations for decision-makers

A set of recommendations are listed below. Despite the differences across the sites, there are strategic-level actions that can be put in place to facilitate implementation in all three sites.

1. Prioritise Integrated Landscape Packages in Mfilou
   - Implement the full upstream–downstream package in Sites A and B (swales, vegetated gabions, terraces, check dams, rock stilling basins) as a single hydrological system.
   - Focus first on high-Cost-Benefit Ratio measures (rock stilling basins, vegetated terraces) and use wooden check dams as complementary sediment-control structures.
2. Embed Robust Safeguards and Resettlement Frameworks in Pointe-Noire
   - Prepare a Resettlement Policy Framework (RPF) and site-specific Resettlement Action Plans (RAP), backed by detailed land-tenure and conflict analysis, before any clearance of floodplains.
   - Co-design floodplain restoration and relocation options with affected communities and start works in less-occupied stretches to demonstrate benefits and build trust.
3. Strengthen Governance, Local Capacity, and Maintenance Systems

- Clarify and fund municipal responsibilities for NbSWLM operation and maintenance, with simple maintenance plans and response protocols.
- Train Community Development Committees, municipal staff, and contractors on NbS/bioengineering design, safe construction, and regular inspection to avoid failures seen in past projects.

4. Integrate NbSWLM into Urban Planning, Codes, and Financing Streams

- Embed NbSWLM in master plans, zoning, and building rules (setbacks, limits on building on steep sandy slopes, on-plot infiltration requirements).
- Align Urban Resilience Projects and other investments around hybrid green-grey options and refine the Compendium's unit costs/benefits as standard tools for budgeting and financing.

5. Use Pilot Corridors and Monitoring to Enable Scaling and Learning

- Treat Ngambio–Itsali and selected Tchikobo–Songolo segments as pilots, with monitoring of hazard reduction, socio-economic outcomes, and maintenance performance.
- Use pilot results to update national NbSWLM guidelines and design, and to de-risk scaling, including a phased trial of the Avenue Jacques Opangault green corridor[2].

[2] There is an existing manual available to support this.

2. INTRODUCTION

2.1 Background and context of the assignment

The Congo Basin region comprises of countries such as Burundi, the Democratic Republic of Congo, the Central African Republic, the Republic of Congo, and Gabon. These countries face a range of climate risks resulting from exposure to extreme weather events, such as flooding and gully erosion, and increasingly complex vulnerabilities. These risks are compounded by rapid urbanization, environmental degradation, and limited adaptive capacity, affecting particularly low-income populations in urban and peri-urban areas and placing significant pressure on urban infrastructure and services.

In this context, the Global Centre on Adaptation (GCA), launched a regional initiative to promote Nature-based Soil, Water, and Land Management solutions (NbSWLM) in urban and peri-urban areas of the five Congo basin countries. This initiative aims to identify, prioritise, and implement locally adapted Nature-based Solutions (NbS) to support World Bank project implementation to strengthen urban climate resilience and provide additional ecological and socially inclusive benefits.

Republic of the Congo

The Republic of the Congo (RoC) features a diverse landscape composed of coastal plains, river basins, plateaus, and mountainous regions, marked by vast forest cover, wetlands, and fertile valleys. It has three main climatic zones: equatorial in the north, subequatorial in the central regions, and tropical humid in the south and southwest. Rainfall varies by region, with annual averages ranging from 1100 mm to over 2000 mm. The hydrographic network is dense, dominated by the Congo River and its tributaries. The country has an estimated population of 6.2million and is currently experiencing a rapid urbanization process which has contributed to increased exposure and vulnerabilities to the impact of climate -related hazards.

2.2 Objectives of the Compendium

This document portrays a compendium of NbSWLM investments in urban areas of RoC -with a specific focus in Brazzaville and Pointe Noire, developed as part of this regional initiative. It aims to serve as a reference resource for decision-makers, practitioners, and stakeholders involved in climate adaptation and urban resilience planning.

The objectives of this document are:

- Based on existing risk analyses, to evaluate the suitability of selected sites to implement measures for flood risk and gully erosion reduction.
- To identify NbSWLM solutions appropriate for implementation in the selected sites, based on examples already implemented in the local context.
- To determine the practicality and viability of these solutions.
- To identify challenges and opportunities relevant to each site and conditions; and
- To provide clear guidance for subsequent detailed feasibility studies or pilot projects.

This compendium includes the following elements:

- Executive Summary: A concise overview of the key findings, priority interventions, and strategic recommendations for decision-makers.
- Introduction: including information on the country's climate hazards and conditions.
- List of Selected NbSWLM Investment Sites: A catalogue of selected sites where NbSWLM measures are proposed, based on pre-defined criteria for site selection.
- NbSWLM Practices per Site: A description of the proposed NbSWLM measures tailored to each site, including technical and social screening results.
- Pre-feasibility Assessments: Detailed assessments of each intervention or project, covering technical feasibility, environmental and social impacts, cost estimates, implementation and maintenance readiness, modularity and replicability.

- Summary table of NbSWLM: As a synthesis of findings, including a summary table comparing interventions across key criteria, which provides a high-level overview of the relative strengths of each intervention or project.

2.3 Scope and limitations

The scope of this compendium comprises an analysis of early-stage investment profiles, resulting from a screening of NbSWLM solutions inventory validated through national stakeholder inputs. These investment profiles have been prioritized as suitable urban flood and gully-erosion risk management and closely related watershed measures identified by the inventories.

This compendium presents a selection of priority "investment-ready" NbSWLM entries which have been assessed for pre-feasibility. It is not intended to provide detailed engineering designs, procurement-ready documents, full Environmental and Social Impact Assessments, Resettlement Action Plans, or final safeguards clearances. It does not substitute for site-specific feasibility studies required for final investment decisions or for World Bank financing approvals.

Some key limitations of the study include:

- Depth of analysis: The study comprises high-level technical screening, with indicative cost bands and rapid social-environmental screens.
- Data & information limitation: For some sites, limited information was available. Where primary data were not available, the study relied on inventory-level data, secondary studies, rapid field checks, and conservative proxies (expert judgement, regional unit costs). Where relevant, data gaps have been explicitly mentioned for that site or profile.
- Spatial & temporal boundary: profiles have been developed using available information at the time of compilation; they may require updating if site conditions, prices or project boundaries suffer significant changes over time.
- Functionality for decision-making: the Compendium is an evidence-based input for prioritization and pipeline creation purposes. It is not a commitment of finance nor a guarantee of bankability; follow-on investments will require targeted follow-up (detailed design, safeguards, procurement and local validation).
- Safeguarding: Social and environmental safeguards have not been carried out as part of this assignment. Any further design development will need to incorporate safeguarding measures to determine the viability of proposed projects.

2.4 Methodological approach

This compendium was developed using a robust methodology designed to ensure that proposed NbSWLM practices are technically feasible, socially acceptable, and aligned with national priorities. The approach builds directly on the national inventory of NbSWLM practices for RoC, which provided the reference "menu" of candidate measures and was validated through national stakeholder inputs, including a workshop process in Brazzaville.

In addition, a second validation workshop was conducted in Brazzaville (12 November 2025) to confirm the selection of the three priority sites and to validate and refine the initial findings and practice packages presented in this compendium. This was complemented by two days of field-based community training and hands-on demonstrations (13–14 November 2025, Ngamakosso), which provided practical feedback on constructability, Operations and Maintenance realism, and community ownership considerations that are reflected in the pre-feasibility packages.

Finally, the methodology was supported by a training needs assessment process embedded in stakeholder exchanges, workshop discussions and short satisfaction/evaluation tools, which informed the development and delivery of a facilitator training and short training manual used during the workshop and the community field sessions.

The approach follows a three-step process:

1. Identification of potential NbSWLM investment sites

The proposed sites were selected through an evaluation using the following evidence-based criteria (validated by stakeholders, including through the second workshop referenced above):

1. Confirmed hazard presence in the area (flooding, gully erosion, landslides, etc.) and verified in existing risk assessments or hazard maps.
2. The sites lie in priority World Bank investment project cities or towns for the implementation of NbS. This was the primary selection criterion as the scope of the project included the alignment of the pre-feasibility assessments with those investment plans. Among the possible candidates, special focus was placed on those defined as "low-regret investments".
3. The site is considered a priority for intervention by national authorities (e.g., in policy documents) or by the World Bank or represents a context similar to specific targeted investment areas.
4. The site is suitable for implementation of low-regret, modular NbSWLM measures with clear co-benefits and limited investment risks.
5. Priority sites have been identified by applying the following evidence-based criteria together (no single criterion is decisive on its own):
    - Opportunity to complement green and grey infrastructure, maximizing ecosystem and livelihood co-benefits.
    - Number of beneficiaries and significant impact on livelihoods and job opportunities, using estimates where detailed information is not available.

2. Selection of NbSWLM Practices per Site

Once the sites were defined, suitable NbSWLM practices were identified for each site, using the following criteria:

- Site-specific conditions (hazards, soil type, hydrology, land use, etc.), ensuring that the proposed practice is physically and environmentally appropriate for the local context.
- Technical screening, assessing the feasibility, scalability, cost-effectiveness, and environmental compatibility of each practice.
- Social prioritization from stakeholder workshops, considering community acceptance, cultural fit, and potential for local ownership and maintenance.
- Alignment with existing investment plans and policy frameworks, ensuring institutional support, legal feasibility, and integration with national and World Bank priorities.
- Complementarity of green/grey infrastructure, as above, prioritizing hybrid approaches and bio-engineering practices where they offer clear advantages. [3]

Practice identification and shortlisting were conducted using the validated Inventory of NbSWLM practices as the reference framework, ensuring consistency with nationally agreed applicability conditions and implementation considerations. The selected practices, as shown in Figure 1, were reviewed and validated with GCA for pre-feasibility assessment, ensuring that only technically viable, socially accepted, and policy-aligned solutions were considered.

The selected practices, as shown in Figure 1, were reviewed and validated with GCA for pre-feasibility assessment, ensuring that only technically viable, socially accepted, and policy-aligned solutions were considered.

[3] Grey components of the hybrid restoration approaches have not been assessed in terms of technical or financial requirements.

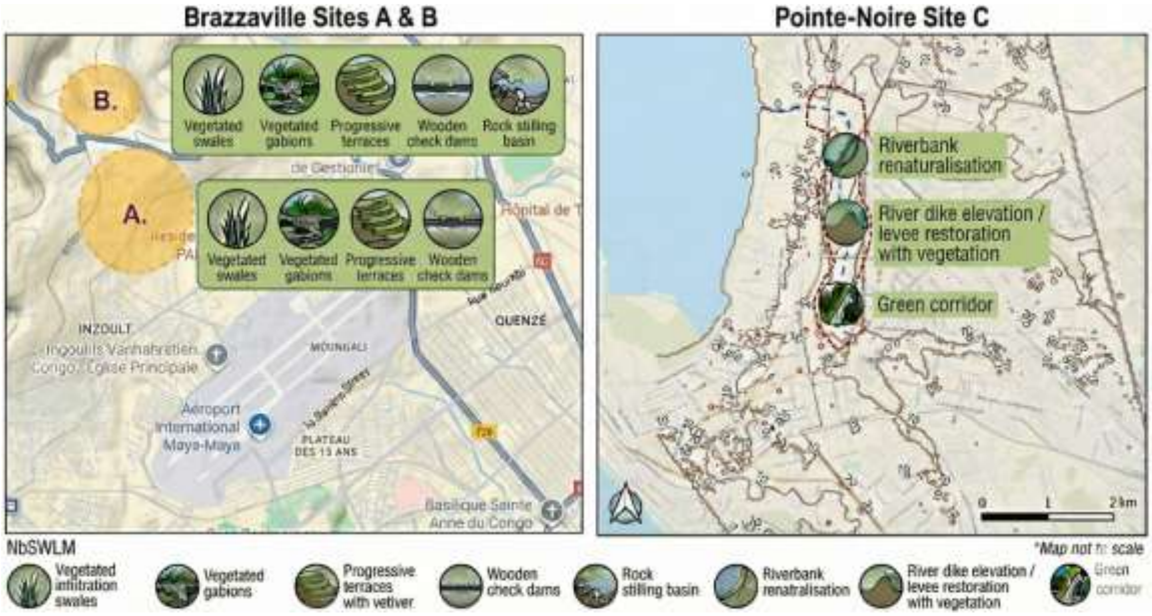


Figure 1. Practices selected for Sites A (Ngambio) and B (Itsali) in Brazzaville, and Site C in Pointe Noire.

3. Pre-feasibility assessment

The selected NbSWLM practices underwent a prefeasibility analysis to determine appropriateness and inform decision-making. The prefeasibility study (PFS) includes an analysis of the existing context (land uses, human settlements) geographic conditions (landscape features, geology, soil types), technical requirements for the practice itself (materials, maintenance requirements), financial aspects (cost-benefit estimations), and social feasibility (acceptability, community implication).

This assessment also included a scalability analysis within the country and the scope of the WB projects, as well as recommendations on next steps and key opportunities to guide the potential feasibility phase.

Where relevant, a landscape approach was proposed, whereby multiple interventions are assessed in areas where hazards are spatially connected or where interventions can complement each other to maximize impact. This approach contributes to strengthen the level of protection or resilience against hazards and enables economies of scale, through integrated planning resulting in more effective coordination of resources and stakeholders.

The prefeasibility assessment was further informed by the field mission community training and demonstrations, which tested practical installation considerations (e.g., sequencing, spacing, basic maintenance routines) and captured community feedback relevant to implementation readiness and long-term stewardship.

Social Feasibility and Beneficiary Estimation

Social feasibility includes estimating the number of potential beneficiaries using a GIS-based approach:

- The selected sites were mapped using a combination of aerial imagery and data from different sources. The area and perimeter of each site were determined using open source QGIS software.
- Information provided by the World Bank was analysed against the selected sites to determine levels of hazard exposure and risk in and around the selected areas. An "influence zone" was determined, encompassing areas exposed to hazards and likely to benefit from interventions.
- Population data, in the form of imagery (raster files), were then collected from WorldPop – University of Southampton (average and estimated total population using 100x100m cells).
- The population data was uploaded on QGIS and intersected with the "influence zone" to estimate beneficiaries. The results were then registered in a table format for each site.

Indicative Cost Profile

Costs are presented qualitatively in two categories: CAPEX and OPEX. High-level qualitative descriptions of the CAPEX and OPEX of each of the interventions are detailed in this section in the form of tables.

The CAPEX section summarizes the one-time costs incurred during the initial implementation phase, providing a brief narrative of the main cost drivers such as site-specific design and planning, land preparation activities, core civil and ecological works, materials and equipment needs, labour requirements, and initial implementation support, such as project management. The OPEX section then outlines the recurring costs expected over the lifespan of the intervention, giving a qualitative overview of anticipated needs for routine and periodic maintenance, monitoring and reporting, replacement of consumables, ongoing labour, training and community support, and administrative overheads.

Economic and financial considerations

This section provides an order-of-magnitude, transparent and defensible set of cost and benefit estimates to inform prioritization and early programming. These provide conservative cost ranges, with documented assumptions and confidence levels, suitable for early planning and decision-making.

Cost ranges are presented for standardized units—primarily USD per hectare, and in some cases USD per 100 m where linear units are more appropriate (e.g. wooden check dams or bioswales). These estimates are based on generic assumptions and do not reflect site-specific conditions, consistent with the scope of a pre-feasibility assessment.

Using standardized units also enables a consistent comparison between costs and benefits, as many benefits (e.g. avoided damage, carbon sequestration) are more readily quantified at the hectare scale. This standardization allows the computation of benefit–cost ratios (BCRs) while maintaining transparency about uncertainty and limitations at this early stage.

Confidence reflects evidence quality: “Low” = few quantitative sources, “Medium” = multiple analogous references, “High” = empirical studies in similar contexts.

This section includes the Benefit-Cost Ratio (BCR), which compares the discounted economic benefits of an intervention to its discounted costs over the project lifetime (estimated at 10 years). The BCR is calculated as:

$$\boldsymbol{BCR} = \frac{\textbf{Present Value of Benefits}}{\textbf{Present Value of Costs}}$$

Present Value represents the value today of future costs and benefits, discounted at a rate of 5% per year to account for the time value of money and the opportunity cost of funds.

Most soil and water conservation practices are characterized by high upfront capital costs (CAPEX) for materials and installation, followed by lower, recurring operation and maintenance costs (OPEX). To enable a consistent comparison with annual benefit streams, upfront CAPEX is converted into an equivalent annual cost over the assumed project lifetime (e.g. 10 years), using the same discount rate applied in the benefit–cost analysis.

We thus used the Equivalent Annual Cost (EAC) formula:

$$EAC = \boldsymbol{C_0} \times \frac{\boldsymbol{r(1+r)^n}}{\boldsymbol{(1+r)^n - 1}}$$

Where:

- C_0= total CAPEX
- $r = 0.05$ (5%)
- $n = 10$ years

To reflect uncertainty, BCR is expressed as a range rather than a single value.

- The minimum BCR is computed by dividing the lowest estimated benefit by the highest estimated cost (conservative scenario).
- The maximum BCR is computed by dividing the highest estimated benefit by the lowest estimated cost (optimistic scenario).

A BCR greater than 1 indicates that benefits exceed costs, meaning the practice is economically viable.

3. LIST OF SELECTED NBSWLM INVESTMENT SITES (1 PAGE)

The location of the three selected sites for developing associated NbSWLM practices focused on supporting the urban resilience strengthening investment projects that the World Bank (WB) is planning in the near future are presented in Figure 2.The sites have been identified in accordance with the following case titles:

- Site A: Twin riverine junction in the Tsième catchment, Mfilou- Ngambio, Brazzaville.
- Site B: Head cut-road valley area in the Tsième catchment, Mfilou-Itsali, Brazzaville.
- Site C: Urban greenway along the final Tchikobo and Songolo river sections, Pointe-Noire.

Figure 2. Location layout of selected pre-feasibility case studies in Pointe-Noire (left) and Brazzaville (right).

Both the Mfilou Ngambio and Itsali district cases are comprised of large gully systems that have generated a general environmental degradation of those urban areas and, particularly in the case of the Itsaly system, have caused collapse of residential buildings. The case A and B gully systems drain respectively south and north-northeast wards, in accordance with the larger catchments in which they are located; those of the rivers Djoue, which drains southwest of the Brazzaville airport, and the Tsième river that drains east of the airport. The gully systems are separated by the P20 road-main street that runs along the hillcrest that separates both catchments. The subsoil of the entire area is comprised of rather loose sand, which explains the erosive capacity of torrential rain here. The population living around the gullies is mainly of humble class, particularly those living around the gullies. The gullies require adequate restoration projects to stabilize their heads and walls so that ongoing erosion is mitigated.

The Pointe-Noire Tchikobo and Songolo rivers case targets the final sections of these rivers, the former is tributary to the latter, as they cross the central area of the city. The floodplains of both rivers, which are reported as flood prone, are densely occupied by residential and potentially some industrial buildings. Overall, the population involved has a rather humble social standard and can be considered as vulnerable. The floodplains are also reported as lacking an efficient waterflow conveyance that should facilitate water drainage towards the sea. It is therefore proposed to recover the original floodplains, implement a resettlement plan for the residents, and conduct a riverbank restoration project.

The sites were selected based on different criteria described in Section 2.4. These criteria are presented in the rationale selection frame presented in Table 2. Overall, it can be indicated that after reviewing some of the hazard and risk assessment documents prepared during different Technical Assistances for the WB and understanding the difficulties associated to identifying the most useful case studies for this entity in combination with the project constraints, it was decided to target those projects that can be classified as 'low (non)-regret investments`. These are interventions that remain beneficial under a wide range of future scenarios and uncertainties. They typically address existing vulnerabilities—such as degraded infrastructure or hazard-prone areas—and would likely be part of national or municipal investment plans regardless of project-specific priorities. These actions provide immediate risk reduction while supporting long-term resilience.

Still, as the table shows, other criteria have also contributed to the site selection. The individual pre-feasibility case studies are further developed in Chapter 6.

Table 2. Rationale frame for selection of practices.

Site	Challenges / Hazards	Selection criteria (referred to Section 2.4)	Selection Rationale
A. Twin riverine junction in the Tsième catchment, Mfilou-Ngambio, Brazzaville	Gully erosion, landslide risk, rapid runoff	1. Hazard Presence 2. WB Investment Project City 3. Identified as Potential Low-regret investment by WB 4. Low-regret investment	The twin riverine junction gully system in the Mfilou-Ngambio district is comprised of three large gullies that come together near the P20 road which runs along a hill crestline. Their drain direction is south. This line separates the catchments of the main rivers Djoue, which drains southwest of the Brazzaville airport and the Tsième river catchment that drains east of the airport. Together with case B ravine system it shared interest from WB and GCA in different projects so that that was the main reason for selecting them over other target gullies of WB across Brazzaville.
B. Head cut-road valley area in the Tsième catchment, Mfilou-Itsali, Brazzaville	Gully erosion, landslide risk, rapid runoff	1. Hazard Presence 2. WB Investment Project City 3. Identified as Potential Low-regret investment by WB 4. Low-regret investment	The head cut road valley area includes a gully system that drains into the Tsième river catchment. Their drain direction is north-northeast. It is separated by the Case A gully-system by the P20 road. The reason for its selection is the same as described for Case A.
C. Urban greenway along the final Tchikobo and Songolo river sections, Pointe-Noire	Floodplain and riverbank degradation, Erosion; occupation of floodplains by households, regardless of being flood prone. This situation represents associated health problems.	1. Hazard Presence 2. WB Investment Project City 3. Included in WB low-regret investments map 4. Low-regret investment 5. Ecosystem/livelihood co-benefits / Job Opportunities / Significant number of beneficiaries	The junction between the final sections of the Tchikobo and Songolo rivers crosses the city center of Pointe-Noire. Their original floodplains show a dense occupation by residential and possibly some industrial buildings. The case includes a complex resettlement and expropriation process to be implemented in case an efficient green corridor is to be developed. The site was selected over others in order to include a different scope to the gully systems addressed in Brazzaville and after receiving information about lack of interest of WB to invest in mangrove forest restoration along the nearby coastal area of Pointe-Noire.

4. NBSWLM PRACTICES PER SITE

This section introduces the set of NbSWLM practices for each investment site of Brazzaville and Pointe Noire. These practices will be further detailed in the next section. The intervention sites are summarized as follows:

- Twin riverine junction in the Tsième catchment, Mfilou-Ngambio, Brazzaville
- Head cut-road valley area in the Tsième catchment, Mfilou-Itsali, Brazzaville
- Urban greenway along the final Tchikobo and Songolo river sections, Pointe-Noire

The proposed practices are based on the NbSWLM national inventory,[4] the results of technical and social prioritization, and the Technical Assistance for identifying potential low-regret investments for Brazzaville and Pointe-Noire in the Republic of Congo,[5] developed for the World Bank in 2025. Additional references from previous projects documenting effectiveness and lessons learned were also considered.

The results of the technical and social prioritization process highlighted the need for integrated and cooperative approaches, combining drainage and routing systems with vegetative stabilization, given the intensity of gully erosion and flood hazard events in RoC. During the validation workshop, participants expressed a preference for solutions such as terracing with vegetated gabions and the use of native species with strong, dense root systems (e.g., vetiver, bamboo). However, social challenges related to the adoption of these species were also noted (see Annex 1 for detailed prioritization results).

Below is the list of proposed solutions for each intervention site. This list includes the rationale for selecting these practices (which may also involve grey measures). These practices will be further examined during the feasibility stage, which falls beyond the scope of this assignment.

Table 3. List of proposed NbSWLM practices per site of intervention in RoC.

Location	Challenges	NbS Families Applicable[6]	Rationale	Proposed Practices
Site A. Twin riverine junction (Ngambio)	Two active head cuts converging, causing severe bank erosion and landslide risk in Ngambio neighborhood of Brazzaville.	Grey measure	Stabilize flow path and prevent further incision by reshaping ravine.	Regrade and combine two head cuts into a horse ravine
		Bioengineering	Protect head cut, by reinforcing soil structure and dissipating flow energy.	Gabion cascade
		Terraces & Slopes	Stabilize gully slopes, by reducing runoff velocity, while enhancing infiltration, and controlling sediment transport.	Vegetated terraces

[4] OCA. 2025. An Inventory of Nature-based Soil, Water and Land Management Solutions in Republic of Congo.

[5] Jeremy Benn Associates (JBA) Consulting. 2024. Initial Investment Planning. Potential short term (low regret) investments Longer term investments

[6] NbS families according to the Catalogue of Nature-based Solutions for Urban Resilience of the World Bank.

Location	Challenges	NbS Families Applicable[6]	Rationale	Proposed Practices
		Bioengineering	Protect the floor with wooden check dams to slow water and trap sediments.	Wooden check dam
		Bioretention Areas	Capture and infiltrate stormwater to improve the road drainage.	Infiltration swales along urban street
Site B. Head cut & road valley area (Itsali)	Active gully head cut causing severe erosion and slope instability, threatening road infrastructure in Itsali neighbourhood.	Terraces & Slopes	Stabilize the initial head-cut and gully, to manage runoff from near surfaced roads	Regrade and terrace slopes with vegetated gabions
		Grey measure	Dissipate flow energy and prevent further incision.	Construct stilling basin
		Grey measure	Reduce flow velocity along road drainage paths.	Shallow speed bumps
		Terraces & Slopes	Improve slope and floor stability using locally available materials.	Reuse local material for land shaping
Site C. Linear green corridor	Highly urbanized corridor with fluvial flood hazard intensified by pluvial flooding.	River & Stream Renaturation	Degraded riverbanks and channels need restoration to reduce bank erosion and flooding.	Riverbank restoration and streambed re-naturalization
		Floodplain rehabilitation	Restore natural flood buffering capacity and reduce flow velocity.	Setting levees back
		Green corridors	Enhance water infiltration along near street	Urban green corridors

5. COUNTRY CLIMATE HAZARDS AND CONDITIONS

The climate hazards and conditions of the Republic of the Congo has been studied to set up a background of the climate variability in the country. RoC has a tropical, humid climate and is highly exposed to severe climate shocks, particularly flooding, gully erosion, and landslides. These hazards are especially acute in the rapidly urbanizing areas of Brazzaville and Pointe-Noire.

The study sites of this pre-feasibility assessment— Mfilou-Ngambio (Site A), Mfilou-Itsali (Site B) in Brazzaville, and the Linear Green Corridor in Pointe-Noire (Site C)—lie in areas with dynamic hydrological behaviour and recurrent hazard exposure. In areas like Mfilou-Itsali in Brazaville, the topography combined with intense rainfall events frequently triggers flash floods and mass movements that threaten settlements. Crucially, the presence of a gully head in Mfilou highlights an active and critical hazard of accelerated erosion and slope retreat.

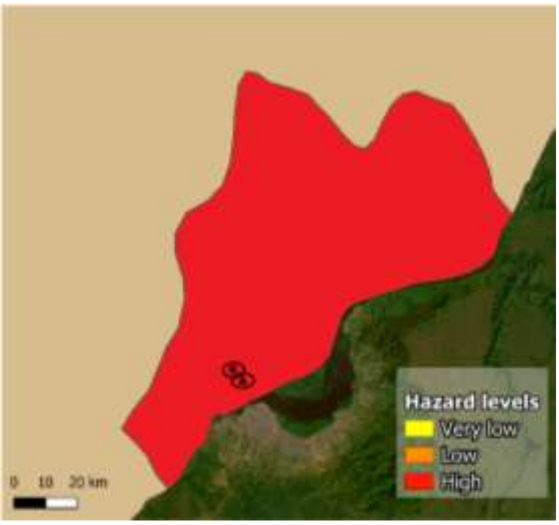
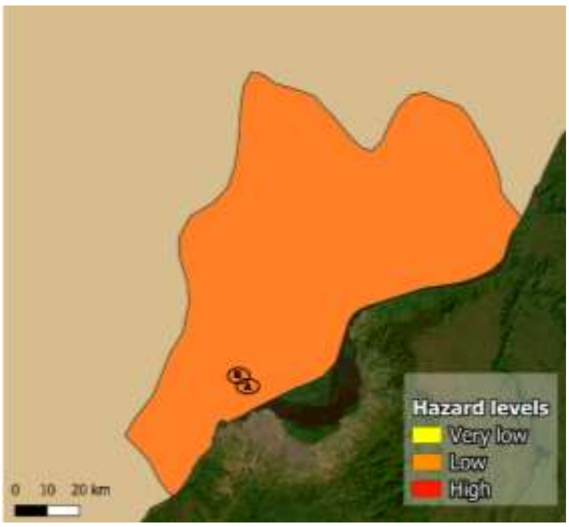
Historical climate and hazard context

Historical climate data for the Republic of the Congo shows a clear long-term warming trend across the country, high interannual rainfall variability with alternating wet and dry cycles, and increased frequency of intense rainfall events, which has intensified fluvial flooding and rapid runoff.

The historical distribution of flood and landslide events in Brazzaville (1980–2018) provides a contextual backdrop for the current geotechnical hazards. The registration of four flood events in Mfilou-Ngambio (Zone A) highlights a significant and recurring water-related hazard in this southern region of the Republic of Congo, where most of the population is concentrated in nearby urban centres.

This historical evidence of four flooding events underscores the high vulnerability of the area. The demographic pressure, driven by the concentration of people in the south, suggests that the impact of these recurring hazards is likely magnified, placing stress on local settlements and essential infrastructure due to the proximity of the affected zone to areas of higher human presence.

Table 4. Susceptibility to River Floods and Landslides in Ngambio (Site A) and Itsali (Site B), in Mfilou district of Brazzaville. Hazard Levels: High/Red, Low/Orange, Very Low/Yellow

Hazards Levels	
River Flood	Landslides
	

Hazards Levels	
River Flood	**Landslides**
Mfilou-Ngambio (A) is classified as high susceptible to river flood. The map reveals that this high-risk classification covers an extensive and contiguous area within the region, indicating a widespread flood hazard. Given that this area is geographically linked to the broader Brazzaville context, this pervasive high susceptibility signifies a significant and constant threat to the local settlements and critical assets situated within or bordering this vast plain flood.	Regional susceptibility to landslides is classified as low, but this broad mapping may not align with specific local conditions. The area is, in fact, critical for slope instability. The physical presence of an active head cut in the study zone acts as direct, localized evidence of accelerated erosion and slope retreat. This overrides the low regional index, signifying a high and immediate danger to local settlements and population.
Mfilou- Itsali (B) is classified as high susceptible to river flood. This classification covers an extensive and contiguous area, signifying a widespread and constant flood hazard. This pervasive high susceptibility is the primary threat to local settlements and critical assets situated within or bordering this vast flood plain	Mfilou- Itsali (B) is classified as low susceptible to landslides. This map suggests that the underlying physical factors (likely steep slopes and fragile soils) pose a significant, widespread, and inherent geotechnical hazard. Given the concentration of the Republic of the Congo's population and infrastructure in the southern region, this high susceptibility presents a major threat to stability and development in the area.

Table 5. Susceptibility to Coastal Floods and Landslides in Pointe Noire (Site C). Hazard Levels: High/Red, Low/Orange, Very Low/Yellow

Hazards Levels	
Coastal Flood	**Landslides**
	
The linear green corridor in Pointe Noire (Zone C) is classified as high susceptible to coastal floods. This high-risk classification covers a major coastal-fluvial zone, signifying a widespread and constant flood hazard. This pervasive high susceptibility is the primary threat to settlements and critical assets adjacent to the stream and port area.	The regional classification for landslides is low. However, local vulnerability persists due to accelerated erosion within the watershed. This residual risk is significantly amplified by projected climatic extremes, including intense rainfall events and rising temperatures.

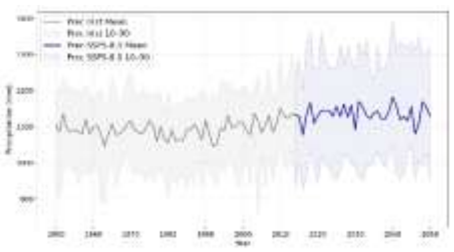
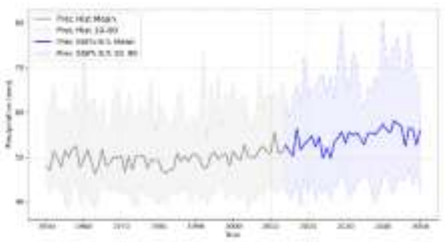
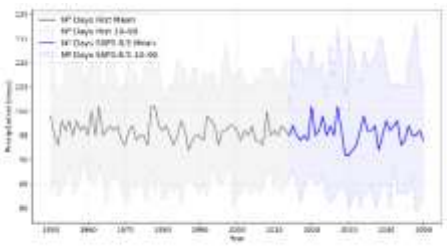
Recent and Projected Climate Trends (1950–2050)

Mean precipitation in the Central African region is highly variable. Projections indicate that, while precipitation may increase or decrease in different parts of the Congo Basin, the monsoon is expected to become longer and more erratic, and extreme rainfall events, though potentially less frequent, will be more violent and intense.

These climatic variations have direct implications on flooding, gully erosion and landslides. Rising temperatures increase soil desiccation, making slopes more vulnerable to erosion and landslides when intense rains return.

Climate projections under the SSP5-8.5[7] scenario (CMIP6[8]) indicate significant changes that will amplify hydro-geomorphological hazards in Brazzaville and Pointe Noire.

Table 6. Climate variables and projected changes (1950–2050).

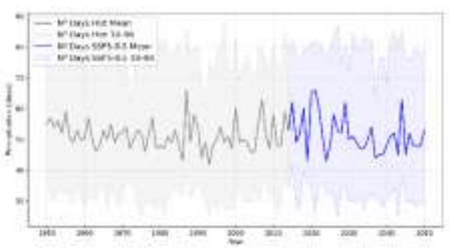
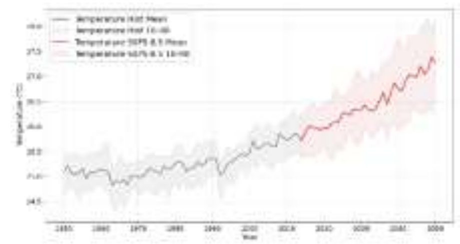
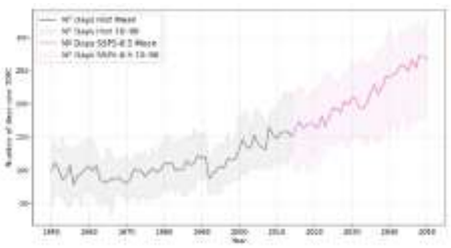
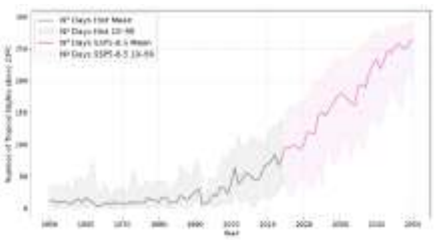
Variables	Graphical distribution	Analysis
Mean Precipitation		The historical record exhibits high interannual variability without a clear long-term trend. The projection until 2050 does not indicate a drastic change in mean annual precipitation but a wider fluctuation year-to-year. This volatility will intensify the cycles of extreme weather, alternating between very wet and very dry periods, potentially increasing the risk of flash floods and overflows.
RX5day[9]		Although the index remained relatively stable historically, projections indicate a clear upward trend in the maximum amount of rain accumulated over a 5-day period. This pattern is a direct indicator of more extreme and intense rainfall events, escalating the likelihood of localized flooding, especially on steep slopes and near watercourses, due to rapid soil saturation.
CDD[10] (Consecutive Dry Days)		The number of consecutive dry days shows high historical variability, but future simulations suggest a slight upward trend by mid-century. This implies more frequent and potentially more intense dry spells. Soils will desiccate more often, which, when combined with subsequent heavy rainfall, will heighten the risk of desiccation and surface erosion.

[7] The CMIP6 (AR6) high-emissions pathway based on fossil fuel-intensive development, projecting a worst-case warming outcome.

[8] Sixth phase of the Coupled Model Intercomparison Project, a global climate modeling framework coordinated by the IPCC.

[9] Maximum total precipitation over any consecutive 5-day period in a year, used to assess extreme rainfall intensity and flood potential.

[10] Maximum number of consecutive days with precipitation below 1 mm, representing the duration of dry spells and drought risk.

Variables	Graphical distribution	Analysis
CWD[11] (Consecutive Wet Days)		The number of consecutive wet days exhibits high historical variability, with future projections showing no clear long-term trend in the *duration* of wet periods. However, the combined effect with increasing rain intensity (RX5day) means these periods of sustained rain will more frequently lead to soil saturation and potential for prolonged fluvial flooding o landslides.
Mean Temperature		The graph reveals an unmistakable warming trend that accelerates sharply after the year 2000. The projection up to 2050 indicates an average temperature rise of approximately 1.5-2°C compared to historical levels. This sustained increase will be the driving force behind enhanced evapotranspiration, reduced soil moisture, and increased heat stress across the region's ecosystems.
N° Hot Days [12](>30°C)		The number of days when the maximum temperature exceeds 30°C shows an explosive and constant growth. The historical average is forecast to escalate significantly by 2050. This indicates a sharp increase in the frequency of intense diurnal heat waves, leading to more severe drought conditions and increasing the land's susceptibility to erosion.
N° Tropical Nights[13] (>23°C)		The frequency of tropical nights rises dramatically from fewer than 60 nights per year historically to over 250 nights projected by 2050. This persistent pattern of nocturnal heat will hinder biological recovery and thermal stress relief for both nature and human settlements, significantly elevating health risks in all study sites.

The combined effect of warmer temperatures (increasing soil desiccation) and much more intense rainfall episodes is expected to amplify hydro-geomorphological hazards. The steep terrain and fragile soils in Mfilou-Itsali make this site particularly vulnerable, accelerating the risk of hillside erosion and the retreat of the head cut during heavy rainfall peaks. Rising temperatures increase soil desiccation, making slopes more vulnerable to erosion when intense rains return.

The combined effect of warmer temperatures, potentially longer dry periods (CDD), and much more intense rainfall episodes (RX5day and CWD) is expected to amplify hydro-geomorphological hazards. The steep terrain and expanding urban surfaces in Itsali and Ngambio make it particularly vulnerable to flash floods and accelerated hillside erosion during heavy rainfall peaks.

The combined effect of warmer temperatures, potentially longer dry periods, and much more intense rainfall episodes is expected to amplify hydro-geomorphological hazards. The linear green corridor area along the stream in Pointe-Noire will need to manage both the increase in fluvial flooding from intensified rainfall (RX5day) and the coastal flood risks associated with extreme weather events.

[11] Maximum number of consecutive days with precipitation equal to or above 1 mm, reflecting the persistence of wet periods that can lead to flooding or landslides.

[12] Number of days per year when the maximum daily temperature exceeds 30°C, indicating heatwave and heat stress frequency.

[13] Number of nights per year when the minimum temperature remains above 23°C, showing persistent nighttime heat and limited cooling.

6. PRE-FEASIBILITY ASSESSMENTS

6.1 Integrated Restoration of Tsième Catchment in Mfilou, Brazzaville (Sites A & B)

The intervention targets two adjacent erosion hotspots within the Tsième catchment, in the Mifilou district of Brazzaville, separated only by the P20 road. Both sites exhibit severe gully erosion, active head cut migration, and slope instability, threatening nearby habitations and critical road infrastructure road located at the highest level. Due to their proximity and hydrological connectivity, a landscape approach is adopted, combining grey and NbSWLM practices to restore ecological function, stabilize slopes, and improve stormwater management.

Figure 3. Aerial view of the Itsali (red) and Ngambio (green) in Mfilou, Brazzaville.

a) b)

Figure 4. a) and b) P20 road in the Mfilou district, dividing the Ngambio and Itsali and neighborhoods.

Socio-economic context

Mfilou district experienced rapid and largely unplanned urbanization. The population density is high, with spontaneous settlements concentrated on unstable slopes and low-lying areas. Housing is predominantly self-built, using simple materials such as wood, sheet metal, and non-stabilized bricks, which increases vulnerability to environmental hazards.

Access to basic infrastructure is limited, water supply is mostly through public standpipes or informal vendors, electricity coverage is partial and unreliable, and roads are predominantly unpaved and severely degraded, becoming difficult to access during the rainy season.

Livelihoods are largely informal, including small-scale trade (food, clothing, phone credit), transport services (moto-taxis, taxis), daily wage labor on construction sites, small workshops (mechanics, carpentry), and seasonal urban agriculture in base-fonds.

Vegetation cover is highly degraded due to deforestation and settlement expansion, leaving slopes exposed and prone to erosion. Land use is dominated by residential plots with minimal green spaces. Settlement morphology is dense and irregular, with houses often located near hazard zones such as ravines and flood-prone bas-fonds.

- Site A-Ngambio: According to the population census of 2023,[14] Ngambio hosts approximately 83,000 inhabitants, with 3,000–5,000 people living near critical erosion zones. The area is marked by high population pressure, spontaneous housing on steep slopes, and limited access to social infrastructure. Vulnerability is compounded by poverty, insecure land tenure, and the absence of drainage systems.
- Site B-Itsali: Itsali is one of the most densely populated neighborhoods in Mfilou, with an estimated 53,000 inhabitants, including 2,000–2,500 people directly affected by erosion near the school site. Livelihoods are similar to Ngambio, dominated by informal trade and services. The proximity of the ravine to the École Primaire en Bonne (offering education services to approximately 600-900) students, poses significant risks to educational infrastructure and community mobility.

Geographic context

Mfilou, the 7e district of Brazzaville, is in the southwestern part of the city. It is characterized by peri-urban expansion, with dense spontaneous settlements and limited infrastructure. The area lies on the Brazzaville plateau and its rear slopes, presenting a dissected relief with alternating hills, depressions, and bas-fonds.

Soil conditions in Brazzaville, as in many regions of the Congo Basin, are influenced by the humid tropical climate and the proximity of the Congo River. The main soil types in this region include sandy-clayey soils, hydromorphic soils, and laterite.[15] In Mfilou, soils are predominantly sandy, derived from Plateau des Cataractes formations, and characterized by low cohesion and high erodibility. The lack of vegetative cover, combined with rapid and uncontrolled urbanization, further accelerates gully formation.

The Ngambio neighborhood is in the southwestern part of Mfilou district, situated in a transitional position between urbanized plateaus and humid lowlands, a characteristic that accentuates erosion and runoff phenomena. Ngambio exhibits a morphology typical of neighborhoods that have spontaneously expanded on the backslopes of the Brazzaville plateau. The area is characterized by steep slopes ranging from 10% to over 35%, altitude between 260–310 m (descending southward), presence of thalwegs acting as natural drainage paths, and several abrupt changes in elevation where the main ravines develop.

The area does not count permanent streams or watercourses, but its hydrography is structured by seasonal runoff networks, longitudinal ravines which act as natural collectors, stagnant areas in the lowlands (leading to the formation of temporary ponds), and a lack of drainage infrastructure, resulting in

[14] Ministère de l'économie du plan et de la coopération. 2024. 5e Recensement général de la population et de l'habitat 2023 (RGPH-5, 2023). Rapport provisoire.

[15] Borrowing Agency. 2025. Environmental and Social Management Framework (ESMF) Strengthening Urban Resilience Project (P179190) (French). Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099090925140554117

frequent urban flooding. Runoff from upstream neighborhoods increases the hydraulic load in the ravines of Ngambio, exacerbating their depth and extent.

The **Itsali neighborhood** is situated on the western periphery of Mfilou, near several secondary roads that connect the neighborhood to the district's activity centers. The urban fabric consists of informal settlements, often built on sloping land, which exacerbates the risks associated with landslides.

The urban unit is distinguished by its hilly topography, marked by alternating small hills and depressions, which make the area highly vulnerable to erosion and gullying.

Itsali terrain is characterized by hills, with slopes ranging from moderate to steep (>15%), alternating small hills and depressions create natural flow paths for runoff, presence of unstable talus and scarps along slopes, and ravines actively developing near school infrastructure.

The area is characterized by a diffuse stormwater runoff network composed of natural gullies, seasonal channels, low-lying accumulation zones, and a near-total absence of formal drainage structures. During rainfall, the concentration of water from upstream dwellings, roofs, sandy tracks, fuels a torrential flow that sustains erosion. The proximity of the shallow phreatic table exacerbates soil fragility.

Figure 5 shows the altitude distribution across the Ngambio and Itsali neighborhoods. The P20 road-traffic corridor clearly runs on the watershed division plateau that geomorphologically separates both areas.

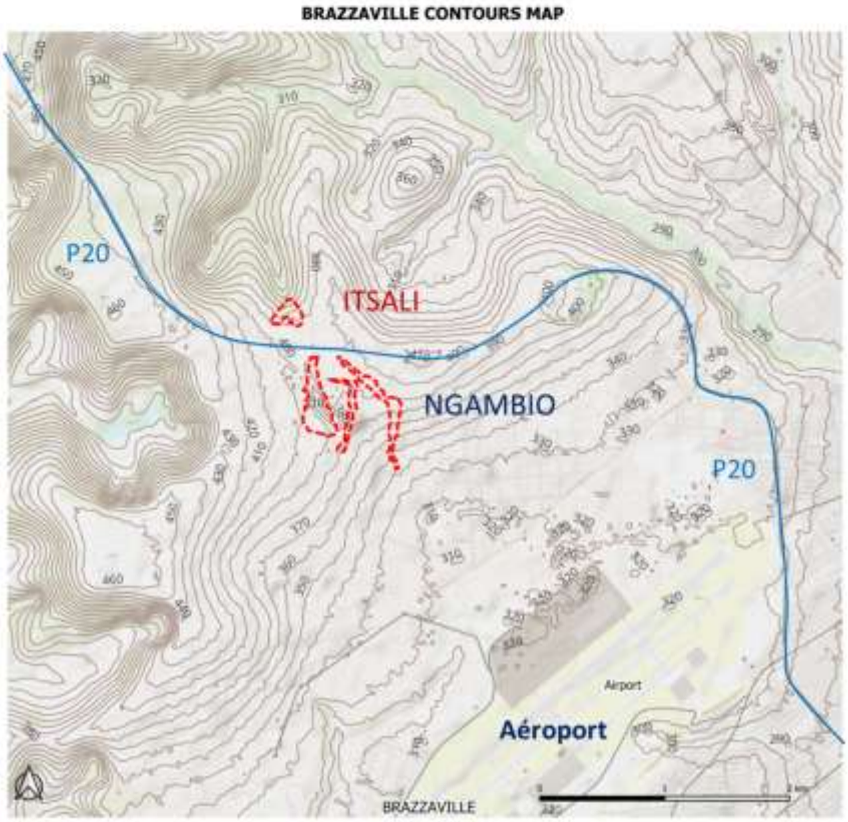


Figure 5. Altitude map for the Cases A and B target areas at the Ngambio and Itsali districts. Source: Authors.

Figure 6 displays the slope map of the same area. The target gully areas are roughly indicated within a range of 0-20 degrees in the southern target area A, and from 0 to 15 degrees for the northern target area B. Yet, it should be noticed that the resolution of the available DEM model was 30 m, and thus not very detailed. Still, the bordering walls of the main gully of case A can be clearly observed.

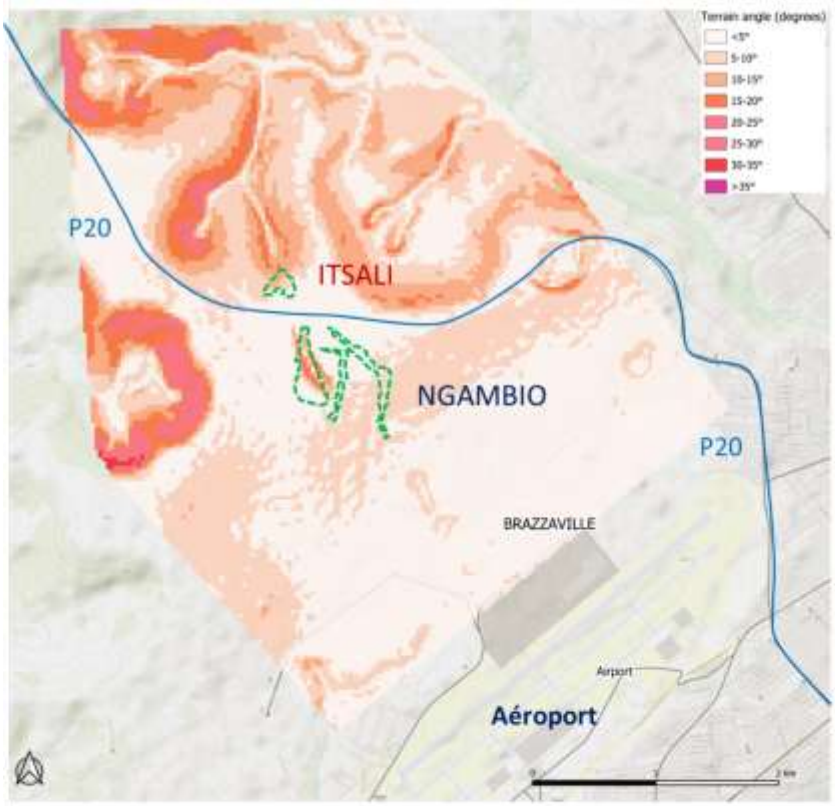


Figure 6. Slope map for the Cases A and B target areas at the Ngambio and Itsali districts. Source: Authors.

Site A: Twin riverine junction

The Twin Riverine Junction comprises two adjacent erosion gullies located in the Ngambio neighborhood, near the P20 road and the Ecole Primaire d'Itsali. These gullies drain stormwater from the surrounding urban slopes and constitute one of the most critical erosion hotspots in the Tsième sub-catchment. Gully characteristics include:

- Eastern gully: This is the deeper and more active gully, positioned immediately next to the P20 road. Its head cut is rapidly advancing toward the road embankment, posing a direct threat to road stability. A concrete collector installed by the Direction des Grands Travaux channels part of the runoff entering the gully; however, it does not intercept all surface flows. Uncaptured runoff continues to erode the gully head and destabilize the lateral slopes.

a) b)

Figure 7. a) Eastern gully near P20; b) Water collector installed on P20 in Ngambio.

- Western gully: Approximately 150 m from P20 road, this gully is more vegetated, with Acacia, bamboo, and other species that provide partial slope protection. The gully includes a constructed channel with a stepped cascade system ("escalier") designed to dissipate water energy. At the downstream end, an unfinished and abandoned dissipation tank temporarily serves as an energy breaker but is insufficient to prevent downstream erosion.

a) b)

Figure 8.a) Western gully with vegetation along slopes; b) Incomplete dissipation tank in Ngambio.

Currently, both gullies exhibit poor infiltration capacity, incomplete drainage infrastructure, and active head cut migration, contributing to rapid stormwater runoff, severe bank erosion, slope instability, and increased risk to nearby habitations and road infrastructure.

Target area:

- **Location**: Ngambio neighborhood of Mfilou, in the peri-urban zone in southwest Brazzaville, Republic of Congo.
- **Spatial scale of the project**: around 11.4 ha of the Tsième catchment in Mfilou district.
- **Administrative units**: Mfilou district of Brazzaville, in the neighborhood of Itsali.

Landscape approach

Given the spatial proximity and strong hydrological connectivity of the two gullies, the intervention follows an integrated landscape approach. Instead of treating each gully independently, measures are deployed across the upper slopes, gully heads, gully walls, and valley floors to restore hydrological function, reduce peak runoff, and stabilize the terrain.

This approach recognizes that:

- **Runoff generated upstream** concentrates at the P20 crossing and fuels head cut retreat.
- **Energy dissipation structures should be arranged in a stepwise sequence**, starting immediately downstream of the water collector outlet and continuing through the entire cascade system.
- **Slope stabilization and vegetation restoration** reduce sediment loads and improve system resilience.
- **Downstream control** is only effective if upstream flows are managed.

Given the intensity of gullies and aggravating factors, a combining approach, merging grey and green (NbSWLM) practices is recommended to stabilize head cuts, reshape gullies, and improve stormwater management. This integrated strategy aims to reduce erosion and improve the drainage system across multiple scales. The proposed measures include:

- **Infiltration swales:** In a larger framework of construction and development of a drainage system on the P20, infiltration swales are proposed along P20 road and near the existing water collector. The main objective of the intervention is to provide an integrated surface drainage management, that currently it is only restricted at conveying water from adjacent parcels to the water collector located at the gully head. In this way, swales would slow runoff, infiltration would be favored before water enters gullies, and peak flows would be reduced before water reaches the gully edge.
- **Gabions at the gully head cuts**: To prevent further gully expansion, at the easter gully, gabions steps would be implemented to dissipate energy below the water collector outlet and halt head cut retreat. At the western gully, gabions cascade will be also used to reinforce existing grey

channel in stepped cascade and complete the unfinished dissipation tank. Vegetation such as vetiver and bamboo, and other deep-rooted plants will be interwoven into gabions to enhance long-term soil anchoring.

- Gully slopes with vegetated terraces: Slopes of the gullies will be regraded and terraced to reduce gradient, improve infiltration, and decrease runoff velocity. Native vegetation will anchor soils and reduce landslide risks.
- Valley floors: Wooden check dams will be placed along the valley floors to trap sediment and slow water flow, improving sediment control and reducing downstream flood risk.

Both twin gullies in Ngambio will be reshaped into a horse-shoe ravine to distribute flow energy over a longer path, reduce erosive intensity, and create a stable, vegetated channel system.

Site B: Head cut & road valley area

Separated from Site A (Twin Riverine Junction) by the P20 road, Site B In Itsali, lies on the opposite side of the road in the Ngambio neighborhood of Mfilou district. The area is characterized by steep slopes and multiple active gully head cuts, which pose severe erosion and slope instability risks in the Ngambio-Itsali sector. Unlike Site A, Site B presents a fragmented morphology with three distinct gullies:

- Eastern section: Two nearly parallel gullies extend downslope, merging at the upper and lower points, forming two erosion corridors separately approximately 10 meters at its largest point. These gullies exhibit sharp head cuts and stripped slopes, with visible remnants of abandoned houses and construction debris along their edges, further destabilizing the terrain.

a) b)

Figure 9. a) Single head cut gully with sandbags in cascade; and b) Abandoned houses in the Ngambio neighborhood.

- Western section: A single, deeply gully with a pronounced head cut and steep flanks, actively eroding toward the valley floor.

To mitigate erosion, two circular concrete collectors have been installed by the community to convey stormwater toward the lower part of the gully. Immediately downstream of these collectors, sandbags in cascade have been placed as a temporary measure to dissipate water energy and reduce erosive force. While these measures provide partial control, they are insufficient to prevent gully expansion and slope failure under intense rainfall.

a) b)

Figure 10. a) Circular channel for water evacuation; and b) sandbags in cascade created by the community.

Target area:

- Location: Itsali neighborhood of Mfilou, in the peri-urban zone on rear slopes of Brazzaville plateau, Republic of Congo.
- Spatial scale of the project: around 2.3 ha of the Tsième catchment in Mfilou district.
- Administrative units: Mfilou district of Brazzaville, in the neighborhood of Ngambio.

Landscape approach

Interventions in Site B follow an integrated landscape approach of bioengineering and hydraulic control measures (as Site A) but adapted to steeper slopes and more fragmented gully morphology. Proposed interventions in Site B must work in sequence across four functional zones: head cuts, steep gully flanks, mid-slope channels, and valley floors. This approach ensures that:

- Head cuts are stabilized first to prevent upward retreat
- Slope gradients are reduced for safety and vegetation establishment
- Runoff energy is dissipated progressively
- Sediment transport is managed along the whole gully corridor

The proposed measures include:

- Vegetated gabions: Replacement of temporary sandbag installed by the community, by vegetated rock gabions at the gully heads. Sandbags are not suitable in the long term as they will break down, and their foundations will be undermined by seeping water. Gabions will dissipate concentrated flow energy more effectively, stabilize head cuts, and prevent head cut expansion. Integration of live stakes and deep-rooted vegetation (such as bamboo, Vetiver or Acacia) will reinforce its long-term structural and ecological stability.
- Rock stilling basins: Installation of stilling basins (with rocks) at the outlet of the gully's head, which currently is creating a chute. The stilling basin aims to dissipate stormwater energy coming sandbags installed by the community at the gully head. These structures would be installed to protect downstream land from and reduce erosive force during peak flows.
- Regrading and terracing of slopes: Slopes are reshaped to reduce steepness and prepare for terracing, which slows runoff velocity and enhances infiltration. Terraces are reinforced with native species such as *Vetiver*, *Bamboo*, and *Acacia* can be used to provide root anchoring and reduce landslide risk.
- Valley floors: Wooden check dams will be placed along the valley floors to trap sediment and slow water flow, improving sediment control and reducing downstream flood risk.

The implementation of these practices will require the use of locally available materials (stones and soil) to reshape valley floors, and smooth eroded sections. These measures will trap sediments, improve infiltration, and enhance slope stability while minimizing external inputs.

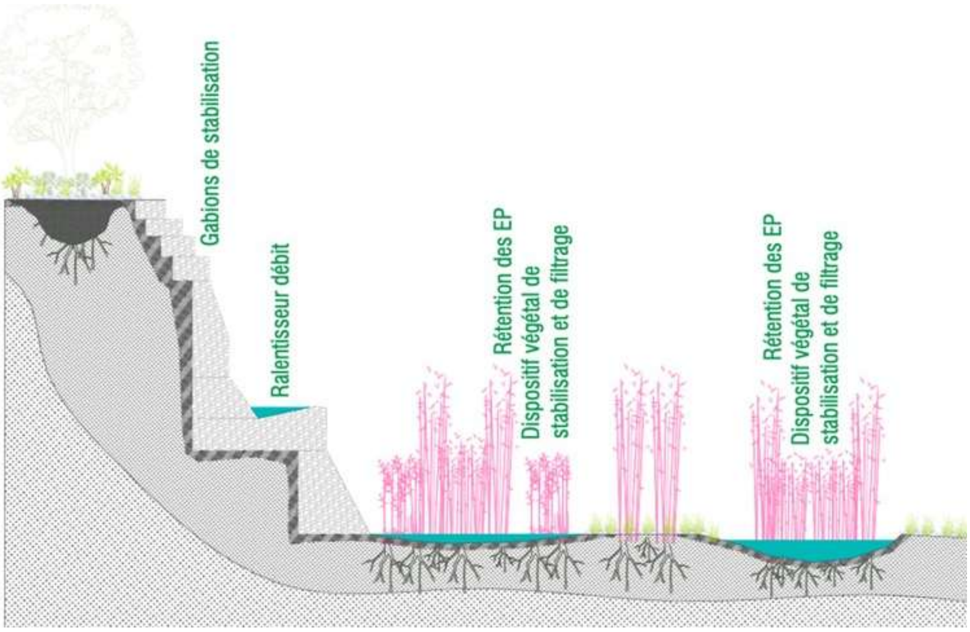


Figure 11. Vertical profile illustrating the sequence of proposed landscape practices for gully stabilization and stormwater management.[16]

Practices proposed across Site A (Ngambio) and Site B (Itsali) in Mfilou-Brazzaville are largely complementary because both areas share similar soil characteristics, hydrological behaviour, geomorphological instability, and socio-economic context. Specific practices proposed on each site (e.g., infiltration swales or stilling basin), correspond to located specifications of the site of implementation. Together, these measures form a coherent, upstream–downstream system for gully stabilization and stormwater regulation.

Technical feasibility

The technical pre-feasibility assessment identifies a suite of integrated NbSWLM practices tailored geomorphological and hydrological conditions of Ngambio and Itsali neighborhoods in Mfilou. Most of these practices are grounded in previous local experiences (details in the inventory of NbSWLM practices of RoC), the availability of locally sourced materials (such as stones, timber, and vegetation), demonstrated community acceptance, and the alignment with the World Bank's Strengthening Urban Resilience Project (SURP), which prioritizes erosion and flood risk reduction in Brazzaville (Mfilou) and Pointe Noire. Measures are presented following the landscape logic used throughout the pre-feseability.

Infiltration swales (Site A and Site B border)

Infiltration swales are shallow, grassed channels that aim the collection, convey, and infiltration of stormwater runoff from adjacent impervious surfaces such as roads. [17] They combine features of grassed swales and infiltration trenches. The swale temporarily stores runoff and allows it to infiltrate through engineered soil layers into the underlying ground and reducing peak flows.

[16] Jeremy Benn Associates (JBA) Consulting. 2024. Initial Investment Planning Consulting services for the development of flood and erosion/landslide risk mitigation actions in two cities in the Republic of Congo Potential short term (low regret) investments. Longer term investments.

[17] World Bank. 2021. A Catalogue of Nature-based Solutions for Urban Resilience. Washington, D.C. World Bank Group

Swales can be trapezoidal or parabolic in cross-section, with gentle side slopes (typically flatter than 3:1) to ensure structural stability and ease of maintenance. Their depth and width are determined based on expected runoff volumes and available space.[18]

In Ngambio and Itsali neighborhoods' border, infiltration swales are proposed along a 500-meter stretch of the P20 road, including the frontage of the Ecole Primaire d'Itsali. Their objective is to intercept and manage runoff before it enters the gully heads. These swales will capture and convey water toward the existing collector and the improved drainage system, while reducing flow velocity, enhancing infiltration and trapping sediments. The design would need to be adapted to local conditions, considering road slope, soil type, and available right-of-way to optimize hydraulic performance and ensure long-term sustainability.

Climate and environmental benefits

Vegetated swales reduce flood risk by slowing runoff, enhancing infiltration, and filtering pollutants through vegetation and soil interaction.[19] Their shallow, vegetated channels mimic natural drainage systems and are particularly effective in urban areas with limited green space. By reducing flow velocity and promoting infiltration, swales help delay peak runoff and reduce pressure on downstream infrastructure.

Evidence shows that vegetated swales can reduce runoff volumes by up to 30–50%,[20] and attenuate peak flows by up to 88%,[21] depending on soil permeability, vegetation density and catchment area.

These combined hydrological benefits confirm the technical feasibility of infiltration swales and their strong suitability for the Ngambio–Itsali border area, especially when incorporated into a broader, integrated stormwater drainage framework for the Mfilou district.

a) b)

Figure 12. Infiltration swales a) during a rain event and b) within 6-12 hours after water is drained or infiltrated.[22]

[18] EPA. 2021. Stormwater Best Management Practice; Grassed Swales. Retrieved from https://www.epa.gov/system/files/documents/2021-11/bmp-grassed-swales.pdf

[19] EPA. 2021. Stormwater Best Management Practice: Grassed Swales. Retrieved from https://www.epa.gov/system/files/documents/2021-11/bmp-grassed-swales.pdf

[20] Kyle W. White. 2012. Vegetated Swales in Urban Stormwater Modeling and Management. Master's Thesis, Virginia Polytechnic Institute and State University.

[21] Wang, X., Zhang, R., Hu, Q., Sun, C., Ikram, R. M. A., Wang, M., & Cheng, G. 2025. Assessment of the Hydrological Performance of Grass Swales for Urban Stormwater Management: A Bibliometric Review from 2000 to 2023. *Water*, *17*(10), 1425. https://doi.org/10.3390/w17101425

[22] EPA. 2022. Semi-Arid Green Infrastructure Toolbox. Biofiltration Swale. Retrieved from https://www.epa.gov/system/files/documents/2022-04/green-infrastructure-toolbox_biofiltration-swale.pdf

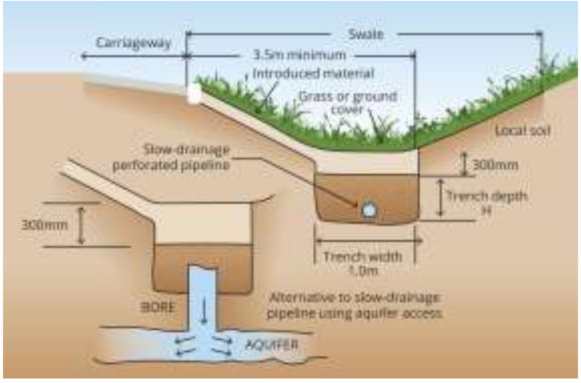


Figure 13. Main components of an infiltration swale.[23]

Design and implementation considerations

To ensure the effectiveness and sustainability of infiltration swales, the following design and implementation aspects should be considered:

- **Components,** the infiltration swale typically includes a sallow, grassed or stone-filled channel bed, also known as bed, that allows water to slow down and percolate; soil and vegetation are also a key component that cover the ground; and sometimes it can include underdrains to assist with water conveyance, especially in areas with less permeable soils.[24]
- **Hydrological and hydraulic** detailed analysis must be conducted, to determine appropriate swales dimensions based on runoff volumes and rainfall intensity and understand seasonal and inter-annual variations in groundwater levels and catchment behavior.[25]
- **Slope and site conditions** must be carefully assessed to ensure technical feasibility. Swales are best suited for gentle slopes: if the terrain exceeds 4%, permeable check dams should be incorporated to reduce flow velocity and prevent erosion; conversely, slopes below 1% may lead to waterlogging, requiring careful grading to maintain effective drainage. The longitudinal profile of the swale should follow the natural topography and existing drainage pathways to ensure consistent flow movement.
- **Soil**, ideally, swales should be constructed in areas with moderately to highly permeable soils, such as sandy loam, which facilitate infiltration and support underdrain systems where necessary. In cases where soils are shallow or overlay impervious rock, swales can still be effective if designed to convey water efficiently toward downstream infrastructure.
- **Layer vegetation,** the selection of plants should prioritize species that are tolerant of periodic wetting and drying, with deep root systems to stabilize the channel and enhance ecological value. The use of native grasses, sedges, and low-maintenance shrubs will support biodiversity and contribute to the visual integration of the swale into the urban landscape. Grasses, ornamental plants or shrubs and small bushes, such as Sporobolus pyramidalis *(African Dropseed)* and others (native shrubs).

Infiltration swales should only be considered within the framework of a broader, integrated stormwater management system of Mfilou. Their feasibility and design must account for health and social risks—such as mosquito breeding (malaria), obstruction of pedestrian corridors, waste accumulation, and potential gully initiation—and include design safeguards like rapid drainage, vegetation cover, and community engagement to ensure functionality and acceptance

[23] Coombes, P., and Roso, S. 2019. Runoff in Urban Areas, Book 9 in Australian Rainfall and Runoff - A Guide to Flood Estimation, Commonwealth of Australia, ©Commonwealth of Australia (Geoscience Australia)

[24] UGREEN. n.d. Bioswale Basics: Transforming Urban Landscapes for Better Water Management. Retrieved from https://ugreen.io/bioswale-basics-transforming-urban-landscapes-for-better-water-management/

[25] WetlandInfo. 2023. Vegetated swales and drains. Retrieved from https://wetlandinfo.des.qld.gov.au/resources/static/pdf/management/vegetated-swales-drains-factsheet-230114-v2.pdf

Gully head cuts with gabions (Site A and B)

To stabilize active erosion at the head cuts of the gully head in Site A and B, a gabion cascade system is proposed. This system would dissipate stormwater energy originating from the P20 road and surrounding parcels, while stabilizing the gully head and preventing further upstream erosion and bank undercutting.

Stone gabions are rectangular baskets made from hexagonal mesh of heavily galvanized steel wire, filled with stones and that can be reinforced with live stakes of native species (e.g., *Vetive, bamboo*). Vegetation could be integrated into the gabion to enhance long-term stability, binds soil behind the structure and promotes natural regeneration.

During installation, live branches—typically 2 to 6 cm in diameter—are incorporated into the gabions by placing stakes or poles through the baskets so they penetrate the stone fill and the native soil behind the gabions. This allows the vegetation to root and grow, enhancing the structural integrity and ecological function of the gabion system. Additionally, the space between the stones in the baskets may also be filled with soil and seeded to promote vegetation growth within and between the baskets and the underlying backfill or soil.[26]

Once positioned, the empty gabions are filled with stones, folded shut, and wired securely at the ends and sides.[27] Gabions can be stacked in layers to form retaining structures, especially effective on steep slopes (typically steeper than 1.5:1) where structural support is needed or where a low wall is required to stabilize the bank.

Climate and environmental benefits

Vegetated stone gabions reduce erosion and flood risk through a combination of structural stability and ecological reinforcement. As engineered barriers, they absorb and deflect the energy of flowing water, protecting gully head cuts from scouring and high-velocity currents. The stone-filled cages provide immediate slope stabilization by resisting hydraulic forces and preventing soil displacement.[28]

Over time, vegetation established within and around the gabion structure enhances these protective effects. Deep-rooted plants such as Vetiver and Acacia bind the soil, reducing shallow slope failures and increasing the overall resilience of the gully system. Vegetation also increases surface roughness, which slows runoff, promotes sediment deposition, and improves water infiltration. These processes contribute to both flood mitigation and ecological restoration.[29] Previous works in Brazzaville, notably in Ngamakso have proven their efficiency in protecting the national road (see Case 6 and 7 in National Inventory)[30], however, the maintenance of the structure is key to ensuring its long-term efficiency (see Case 6 in National Inventory).

Design and implementation considerations

During the feasibility phase, several critical design and site-specific criteria must be verified to ensure the effectiveness and durability of the gabion system:

- **Design** must account for foundation stability, including both geotechnical and shear forces acting on the structure. The shear forces that the gabion face must be calculated based on expected flow velocities; and protection measures should be included for the toe and flanks of the structure to prevent undermining lateral erosion.[31]
- **Soil compatibility**, the underlying soil must be capable of anchoring the gabion structure and supporting vegetation rooting. In loose or sandy soils, additional stabilization measures such as

---

[26] Ibid.

[27] LARIMIT. Vegetated gabions (Hybrid)- Category: Retaining structures to improve the slope stability. Retrieved from https://www.larimit.com/mitigation_measures/1032/

[28] BFG & BAW. 2018. Technical-biological Bank Protections Applied on Inland Waterways. Vegetation Gabions. Retrieved from https://izw.baw.de/publikationen/alu/0/KB-Vegetationsgabionen_FEB-2018_(V2)_EN_a.pdf

[29] LISA. n.d. Vegetated gabions. Retrieved from: https://lisa.icem.com.au/nbs/vegetated-gabions/

[30] OCA. 2025. An Inventory of Nature-based Soil, Water and Land Management Solutions in Republic of Congo.

[31] LISA. n.d. Vegetated gabions. Retrieved from: https://lisa.icem.com.au/nbs/vegetated-gabions/

geotextile underlayers, compacted backfills, or soil amendment may be required to improve structural integrity and infiltration.

- Gabions should be placed continuously along eroded sections to ensure uniform protection. A minimum length-to-width ratio of 2:1 is recommended for stability. Units may be stacked vertically to form retaining walls, with proper interlocking and anchoring to resist hydraulic forces and soil pressure.
- A stone toe or apron should be installed at the base to prevent undermining from concentrated flows. Gabions must be securely anchored using stakes or tie-downs, especially on unstable or steep banks.
- Ensure that gabion structures use corrosion-resistant materials (e.g., galvanized wire mesh for baskets) to prevent premature failure, as observed in past projects.

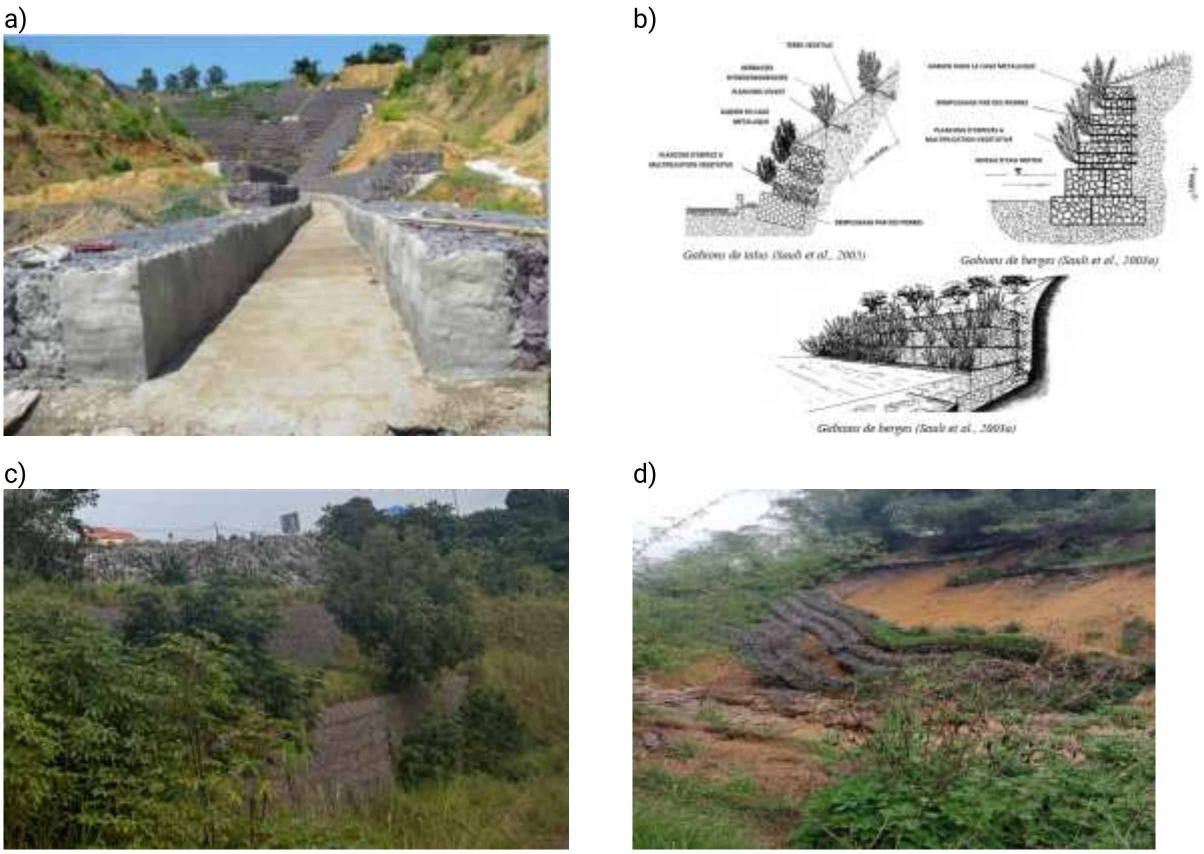


Figure 14. a) Stabilization of a gully head in Kinguari at Brazzaville, [32] b) Schema type of vegetated gabions, [33] and c) Stabilization of talus with gabions in Ngamakoso's road,[34] and d) gabions system failed installed in Talangai.

Gully slopes with vegetated terraces (Site A and B)

Vegetated terraces are structural and ecological interventions designed to stabilize gully slopes, reduce surface runoff, and enhance infiltration. These terraces are particularly suitable for stripped or degraded surfaces with steep gradients, which are highly susceptible to landslides and erosion. [35] Similar to berms and embankments, terraces interrupt the downslope movement of water, reduce its velocity, and create conditions that promote soil retention and vegetation growth.

[32] Ndona and Truong. 2006. "Ravine rehabilitation in Brazzaville, Congo". Vetiver Network International Seminary. 15 p

[33] DAGRI. 2021. Manuel de gestion des bassins versants au Burundi pour le ministère de l'Environnement, de l'Agriculture et de l'Elevage.

[34] OCA. 2025. An Inventory of Nature-based Soil, Water and Land Management Solutions in Republic of Congo.

[35] Vignerot B. and Rolland G. 2012. Guide des bonnes pratiques pour limiter l'érosion des terres en contexte de travaux et d'aménagement urbain à Mayotte. BRGM. Retrieved from https://risques-naturels.ac-mayotte.fr/IMG/pdf/guide_urbain.pdf

Terraces are constructed by reshaping steep or eroding slopes into a series of horizontal or gently sloped steps. Each step acts as a micro-catchment, allowing water to infiltrate rather than run off, thereby improving soil moisture and supporting plant establishment. There are two types of terraces that can be considered for the project, progressive terraces and radical (bench) terraces.[36] Progressive terraces are formed gradually through the construction of contour bunds, which, over time and under the influence of sheet erosion, develop into semi-horizontal benches suitable for cultivation or revegetation. Radical terraces, on the other hand, are created through deliberate earthworks that form reverse-slope benches. These are stabilized with vegetation and reinforced with a soil bund (typically 5–10 cm high and 20–30 cm wide) along the terrace edge. Stone or wooden retaining walls may be used for additional support, although simple earth walls can suffice on smaller or less steep slopes. These techniques are similar to the Fanya Juu and Fanya Chini methods widely used in East Africa.[37]

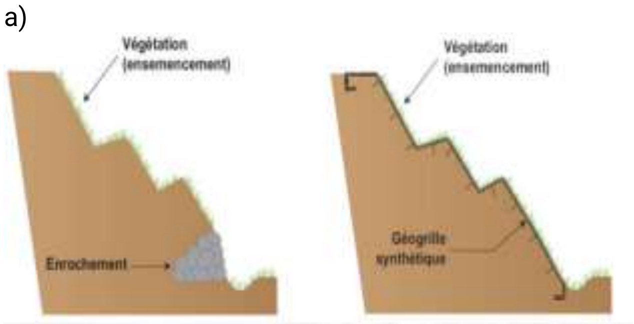
Given the proximity of the gullies to habitations in Ngambio, radical may be recommended due to their superior structural control and effectiveness in steep terrain. However, a detailed slope gradient assessment is necessary to confirm the most appropriate terracing approach.

The construction process involves excavating and compacting terrace platforms along contour lines. Terrace width and spacing are determined based on slope steepness, soil type, and expected runoff volume. On steeper slopes, terraces should be narrower and more closely spaced to ensure stability and effective water control. The terrace edges are reinforced with vegetation—typically deep-rooted plants—that bind the soil and prevent slippage. Species such as Vetiver grass (*Chrysopogon zizanioides*), Bamboo (*Bambusa spp.*), and Acacia (*Acacia spp.*) have been successfully used in previous projects in Brazzaville (see more details in Country inventory)[38] and are well-suited for this purpose due to their adaptability to tropical conditions, rapid growth, and strong root systems.

Climate and environmental benefits

Vegetated terraces stabilize steep gully slopes by reshaping them into a series of horizontal or gently sloped steps that interrupt water flow, reduce velocity, promote infiltration, and trap sediments. Each terrace acts as a micro-catchment, improving soil moisture and supporting vegetation growth. This intervention is particularly effective in areas with stripped or degraded surfaces prone to landslides.[39] Evidence demonstrates that terraces and vegetation reduce sediment yield by up to 53.85% and runoff by 71.86% in sloped catchments.[40]

a)



b)

[36] The World Bank. 2018. Burundi landscape restoration and resilience project. Retrieved from https://documents1.worldbank.org/curated/en/946311523671259769/pdf/BURUNDI-PADrev-03232018.pdf

[37] Greener.Land. n.d. Terracing. Retrieved from https://www.greener.land/terracing/

[38] OCA. 2025. An Inventory of Nature-based Soil, Water and Land Management Solutions in Republic of Congo.

[39] The World Bank. 2018. Burundi landscape restoration and resilience project. Retrieved from https://documents1.worldbank.org/curated/en/946311523671259769/pdf/BURUNDI-PADrev-03232018.pdf

[40] Bai, J., Yang, S., Zhang, Y., Liu, X., & Guan, Y. 2019. Assessing the Impact of Terraces and Vegetation on Runoff and Sediment Routing Using the Time-Area Method in the Chinese Loess Plateau. *Water*, *11*(4), 803. https://doi.org/10.3390/w11040803

c)

Figure 15. a) Terracing techniques in very steep slopes (greater than 50%) using seeding on the upper part and with riprap or vegetated gabions at the toe of the slope (left), or seeding of the entire sloping surface, reinforced by geotextiles or synthetic geogrids (right); [41] b) Vetiver plantation within sandbags in Brazzaville;[42] and c) Terracing example in steeper slopes in Kikwit, DRC.[43]

In Brazzaville, species such as Vetiver grass, Bamboo, and Acacia have been successfully used in past slope stabilization projects. Their deep root systems reinforce terrace edges, reduce soil erosion, and enhance slope resilience.

Design and implementation considerations

Key consideration for feasibility assessment include:

- Comprehensive site characterization must be conducted, including topography (slope gradient, elevation, and flow paths), soil type and stability (texture, permeability). Conduct a geotechnical study to assess soil instability risks before designing terraces or other earthworks.[44]
- Hydrology assessment of the area, including rainfall patterns, runoff volumes, seasonal variations, and groundwater behavior; and identify flow concentration zones and potential sediment transport paths.
- Ensure design includes excavations and structures (e.g., terraces,) are integrated into the natural topography to minimize disturbance.
- Consider scheduling construction during the dry season to reduce risks of landslides, soil compaction, and plant stress,[45] and plan for temporary erosion control measures during work (e.g., mulching, silt fences).
- Terracing requires significant labor and input costs, assessing the availability of local materials (e.g., stones, timber, plants) and skilled labor.
- Consider the ecological footprint of large-scale terracing, including habitat disruption and vegetation loss, and propose mitigation measures such as replanting, buffer zones, and biodiversity corridors.[46]
- Identify community groups or cooperatives that could be mobilized for earthworks, planting, and maintenance, and consult preferred and familiar plant species (e.g., *Vetiver*, *Bamboo*, *Acacia*) that

---

[41] Vignerot B. and Rolland G. 2012. Guide des bonnes pratiques pour limiter l'érosion des terres en contexte de travaux et d'aménagement urbain à Mayotte. BRGM. Retrieved from https://risques-naturels.ac-mayotte.fr/IMG/pdf/guide_urbain.pdf

[42] Ndona and Truong. 2006. ''Ravine rehabilitation in Brazzaville, Congo''. Vetiver Network International Seminary. 10 p

[43] JBA Consulting: Jeremy Benn Associates (JBA) Consulting. 2024. Services de conseil en planification des investissements initiaux pour le développement d'actions d'atténuation des risques d'inondation, d'érosion et de glissement de terrain dans deux villes de la République du Congo.

[44] Vignerot B. and Rolland G. 2012. Guide des bonnes pratiques pour limiter l'érosion des terres en contexte de travaux et d'aménagement urbain à Mayotte. BRGM. Retrieved from https://risques-naturels.ac-mayotte.fr/IMG/pdf/guide_urbain.pdf

[45] DAGRI. 2021. Manuel sur le terrassement et la restauration des paysages. Ministère de l'Environnement, de l'Agriculture et de l'Elevage. Bujumbura.

[46] Greener.Land. n.d. Terracing. Retrieved from https://www.greener.land/terracing/

have been used successfully in past projects. This is key that community representatives or cooperatives are involved as they could facilitate coordination efforts and technical advice.

- If bags are used for subtract support, it is recommended to avoid those in plastic and prefer those in biodegradable fibers due to long-term microplastic impacts.

Wooden check dams (Site A and B)

Wooden check dams are bioengineering structures constructed using locally sourced tree branches, poles, and posts, strategically placed across gullies to slow down concentrated water flows, trap sediments, and retain moisture.[47] These structures play a vital role in rehabilitating degraded gullies by dissipating flow energy and stabilizing the bed and banks, thereby limiting scouring and preventing downstream sedimentation. Their integration with vegetation further enhances structural stability and accelerates the natural regeneration of riverbanks.

To install wooden check dams into the valley floor, a shallow trench should be first excavated across the gully bed, perpendicular to the direction of water flow. Vertical posts—typically made from durable hardwood—are driven into the trench and embedded into the gully bed at regular intervals. Horizontal branches or logs are then woven or stacked between these posts to form a porous barrier. The structure is often curved slightly upstream in a shallow "V" shape to direct water toward the center and reduce pressure on the flanks. The upstream side is backfilled with soil, stones, or organic material to enhance stability and promote sediment deposition.

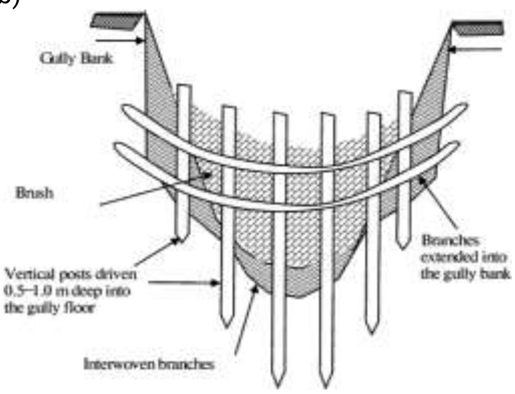
Climate and environmental benefits

Wooden check dams reduce water flow velocity in gullies and concentrated channels, minimizing the erosive force of runoff. By breaking the slope into smaller segments, they prevent gully formation, stabilize the landscape over time, and increase residence time, allowing more infiltration, reducing peak discharge, and improving sediment settling.

Check dams further enhance slope stability by reinforcing soil with root systems and reducing surface scouring. In steep terrains, wooden check dams dissipate energy and reduce sediment transport, preserving topsoil and preventing downstream degradation. When combined with vegetated hedges, check dams can significantly reduce sediment load downstream and contribute to long-term catchment restoration.[48] In small gullies, the check dams may reduce up to 50% of sediment yield.[49]

a)

b)



[47] GIZ. 2013.Training package on Biophysical Gully Control and Rehabilitation Measures. Part One. Retrieved from https://www.moa.gov.et/wp-content/uploads/2024/11/201312_Technical-Manual-for-Physical-Gully-Control-and-Rehabilitation-Measures_Part-1-compressed-1.pdf

[48] EPA. Stormwater Best Management Practice: Check dams. https://www.epa.gov/system/files/documents/2021-11/bmp-check-dams.pdf

[49] Kumar Shit P., Sankar Bhunia G, Maiti R. 2013. Assessing the performance of check dams to control rill-gully erosion: Small catchment scale study. International Journal of Current Research.

c)

d)

Figure 16. a) Wooden check dams after few rainy events,[50] and b) Gully control structures design details,[51] c) and d) Installation of wooden check dams by the community in Ngamakosso during training activities of this project, led by OCA in November 2025.

Design and implementation considerations

Key criteria to consider during the feasibility assessment include:

- The maximum drainage area above the check dam shall not exceed 0,80 ha.[52]
- Timber for check dams can be sourced from local suppliers.
- The spacing of the check dams depends on the slope and gully depth of the channel,[53] and they shall be spaced as necessary.[54]
- Live vegetation, such as rooted cuttings or branches of native species like *Vetiver grass*, can be inserted into the structure and surrounding soil to encourage rooting and long-term stabilization.

Rock stilling basin (Site B)

A rock stilling basin, or an erosion-resistant surface installed at the outlet of a pipe, spillway or chute to reduce high-velocity flows and prevent erosion is technically not a NbS. Still, it is proposed here integrated as part of the landscape approach as a hybrid solution relevant to the specific site conditions of this gully system. At Site B, these basins would be constructed at each active gully head cut to immediately dissipate stormwater energy and halt further incision and head cut migration (Figure 17. a).

These basins are open, permeable structures designed to absorb kinetic energy through turbulence and interlocking rock mass. They are typically built using large angular rocks, concrete, or gabion mattresses but in small catchments, vegetation may provide sufficient stability (Figure 17.b).[55]

Each basin should be in the gully bed downstream of the head cut on a stable subgrade. Excavation lowers the basin invert below the existing gully bed to create a controlled drop and enhance energy dissipation. A typical basin consists of three zones: Inlet transition to guide flow into the basin, dissipation pool

---

[50] Agate-La bibliothèque numérique patrimoniale INAE. n.d. Live brush check dams, grass seeding and reforestation, indirect protection. Retrieved from https://agate.inrae.fr/agate/en/content/live-brush-dams-grass-seeding-reforestation-indirect-protection

[51] Singh, R. (2023). Gully Control Structures. In: Soil and Water Conservation Structures Design. Water Science and Technology Library, vol 123. Springer, Singapore. https://doi.org/10.1007/978-981-19-8665-9_7

[52] Schuyler County Soil and Water Conservation District. n.d. Standard and specifications for check dam. Retrieved from https://www.schuylerswcd.com/uploads/1/1/5/2/11520284/check_dam_specs.pdf

[53] FAO. n.d. Basic gully treatment measures. Retrieved from: https://www.fao.org/4/ad082e/AD082e02.htm

[54] LARIMIT. n.d. Live/rock check dams (NBS). Category: Modifying the surface water regime – Surface drainage. Retrieved from https://www.larimit.com/mitigation_measures/1029/

[55] Queensland Government. 2016. Soil conservation guidelines for Queensland. Chapter 13 Gully erosion and its control.

armored with angular rock to absorb energy, and downstream apron keyed into the bed to prevent scouring.

Climate and environmental benefits

Rock stilling basins serve as energy dissipaters at the outlets of chutes and drop structures, reducing high-velocity flows to stable, non-erosive conditions downstream. By slowing water and minimizing turbulence, they prevent soil erosion and protect surrounding ecosystems. These basins often incorporate natural materials such as rock, gabions, or Reno mattresses, blending structural stability with ecological compatibility. Proper design—such as adequate side walls, flared wing walls, and recessed placement—enhances energy dissipation and reduces flow depth and velocity. This approach not only safeguards infrastructure but also supports long-term soil and water conservation, contributing to climate resilience and sustainable land management.

a) b)

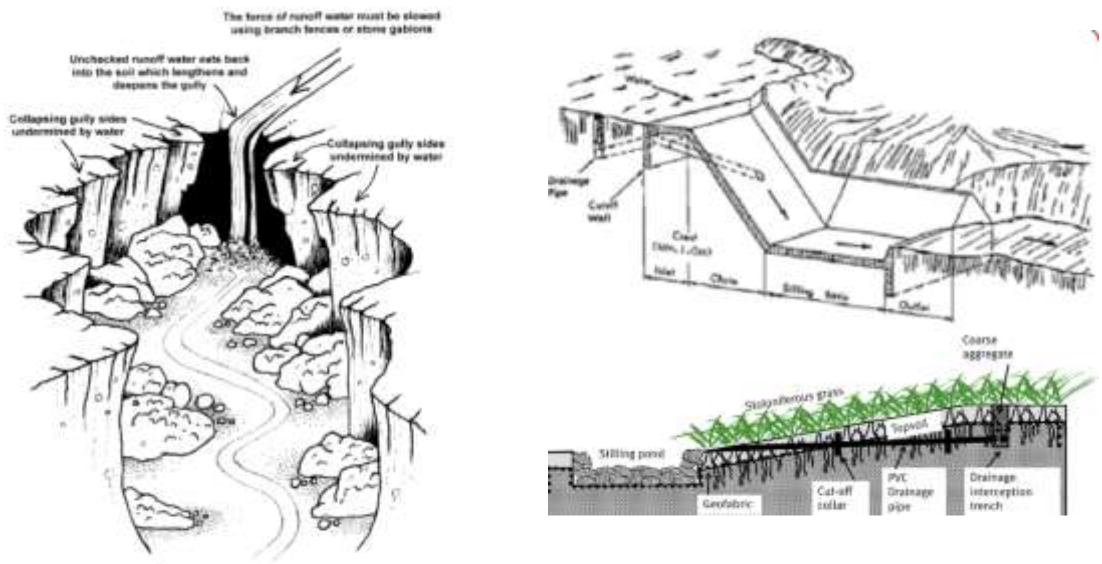


Figure 17. a) Example of a gully head cut showing the recommended location for installing a rock stilling basin,[56] and b) Cross-section views showing the components of a typical chute,[57] as the one observed in Site B.

Design and implementation considerations

Below a list of key principles to consider when designing and implementing stilling basin is presented. These principles would need to be adjusted to the expected flow, the weir height, the size of rock, the land slope and the downstream condition of the channel.

- Length: The basin should be long enough to contain the turbulent zone and prevent concentrated jets from reaching unprotected bed downstream. A practical rule is to make the basin two to three times the gully width at the head cut. For example, if the gully is 2 meters wide, the basin should be about 4 to 6 meters long. Larger gullies may require lengths up to 10 meters. However, for verification purposes it is recommended to use the equation to determine the length of a stilling basin developed by Stephens (1989), which establishes[58]:

$$L = F(2.28\, h/F \; + \; 0.52)$$

  Where L is the length of the stilling basin (m), F is the depth from the crest of chute to top of end sill (m), and h is the depth of notch (or head of water over the crest) (m).

[56] ReStory. 2022. Guidelines for practical soil erosion control in rural Africa. Retrieved from https://restory.co.za/2022/03/10/guidelines-for-practical-soil-erosion-control-in-rural-africa/

[57] Queensland Government. 2016. Soil conservation guidelines for Queensland. Chapter 13 Gully erosion and its control.

[58] Ibid.

- Width: The width of the basin should match or slightly exceed the gully width at the head cut. This ensures that all concentrated flow enters the basin without bypassing along the sides. If banks are unstable, widen the basin slightly and regrade the sides to tie into stable ground.
- Depth: The basin floor should be excavated 0.6 to 1.0 meters below the existing gully bed at the head cut. This creates a vertical drop into the basin, forcing water to slow down and spread out. Without this drop, energy dissipation will be insufficient, and erosion will continue downstream.
- Rock Size: Use durable, angular rock (riprap) sized to resist the design flow velocity. The median stone size (D50) should be between 150 mm and 300 mm, with larger key stones included for stability. Higher velocities or steeper slopes require larger stones.
- Layer Thickness: The rock layer should be thick enough to absorb turbulence without exposing the subgrade. A minimum thickness of 1.5 times D50 is required, increasing to 2 times the D50 in high-energy zones.
- Foundation: Place a geotextile underlay beneath the rock to prevent soil piping and loss of fines. If the subgrade is soft or highly erodible, add a bedding layer of gravel or coarse sand to distribute loads and protect the geotextile.
- Apron: Extend an apron downstream of the basin for 1.5 to 2 meters. This apron should be keyed into the subgrade and armored with oversized rock at the toe to prevent undermining and end scour.

Key criteria to consider during the feasibility assessment of rock stilling basin include:

- Confirm design flow for sizing rock and basin dimensions.
- Measure width, depth, and slope at each head cut to determine excavation and basin footprint.
- Assess soil bearing capacity and erodibility; soft soils require bedding and deeper keying.
- Verify equipment access for excavation and rock placement without destabilizing adjacent slopes.
- Ensure supply of durable angular rock in required size range and geotextile.
- Check tailwater depth and scour potential; adjust apron length accordingly.
- Confirm ability to inspect and repair basins after storm events.
- Verify rock availability, as this may be a limiting factor on the design of the basin.

It is recommended to define and implement walkways, jointly with the community. If this is not implemented, NbSWLM practices risk rapid deterioration or damage, because of spontaneous population frequent passage, as it has been observed in other communes (e.g. Ngamakosso).

To complement the detailed technical descriptions provided earlier, Table 7 summarizes the key implementation requirements for each proposed NbSWLM practice. It consolidates essential information on materials and inputs, local availability, indicative quantity ranges, and potential logistical constraints. This synthesis offers a practical reference for planning and resource allocation, ensuring that interventions are not only technically sound but also feasible within the local context.

Table 7. Summary of key materials and inputs, local availability, indicative quantity and potential logistics constraints for practices proposed in Ngambio and Itsali, Brazzaville.

Practice	Key Materials & Inputs	Local Availability	Indicative Quantity Range	Logistics Constraints
Infiltration swales	Engineered soil, grass seed, geotextile (optional), shovels, hoes, stakes, string, wheelbarrows	Moderate – Soil and tools locally available; grass seed may be sourced from nurseries.	~500 m of swale length (1–2 m wide)	Requires coordination with road drainage; excavation during dry season recommended
Gully head cuts with gabions	Galvanized wire mesh, stones, live stakes (e.g., Vetiver), crowbars, wire cutters, shovels	High – Stones and vegetation available locally; wire mesh may need to be sourced. Numerous examples across the country.	~30–50 gabion units (depending on head cut size and slope)	Manual transport of stones; skilled labor needed for assembly; access to gully heads may be difficult
Gully sloped with vegetated terraces	Hoes, picks, shovels, wheelbarrows, machetes, axes, measuring tape, string, crowbar, GPS, notebook; vegetation (Vetiver, Bamboo, Acacia)	High – Tools and labor available locally; vegetation such as Vetiver and bamboo are largely used in past projects.	~ 3.85 ha of slope area; terrace spacing and number depend on slope gradient and layout	Labor-intensive; requires slope survey and contour layout; vegetation establishment must align with rainy season
Wooden check dams	Materials include timber logs, stakes, binding materials (e.g., wire, rope), vegetation for reinforcement (e.g., grasses), and basic construction tools (wheelbarrows, hoes, rocks, bricks). Labor is needed for site preparation, assembly, and vegetation planting.	High – Timber and vegetation (such as the bamboo) are available locally	~10–20 units (for 1.1 km of gullies, spaced every 50–100 m)	Manual assembly; access to valley floor may be limited during rainy season; erosion risk during installation
Rock stilling basin	Angular riprap (150–300 mm), oversized key stones, geotextile underlay, bedding layer (gravel/sand), excavation tools. Labor is needed for site preparation and site set up.	Moderate – Stones available locally; geotextile may need to be sourced	~2 basins (each ~10 m long × 5 m wide × 1 m deep; 30–40 m^3 rock per basin)	Requires excavation below gully bed; heavy rock transport and placement; equipment access may be limited on steep slopes

Feasibility note: These measures are only viable when implemented within the framework of an integrated drainage system, which should include upstream runoff management and land-plot solutions such as infiltration pits (puits d'infiltration) constructed with local materials, as currently practiced in Don Bosco Ngamakoso (see more details in national inventory of RoC)[59]. This integrated approach ensures that structural measures like gabions and terraces are not overwhelmed by uncontrolled stormwater flows.

Figure 18. Infiltration pits installed on residential plots for runoff control near gully in Don Bosco.

- **Local capacity**:

Municipal technical teams and local NGOs in Brazzaville have prior experience with slope stabilization, tree planting, and erosion control using gabions and species such as Vetiver, Bamboo, Acacia and Fausse Canne. These species have been successfully used in past urban restoration projects. Gabions combined with vegetation planting are widely applied in Brazzaville as complementary measures for gully stabilization and slope protection.

However, specialized bioengineering techniques—such as the installation of vegetated gabions and wooden check dams—require targeted training and technical supervision. **A critical lesson learned from the national NbSWLM inventory is the failure of gabions installed in Ngamakosso**, mainly due to inadequate foundation preparation and insufficient anchoring. This highlights the need for rigorous geotechnical assessment, proper installation protocols, and corrosion-resistant materials to ensure long-term stability. Community involvement remains feasible and encouraged, particularly for labor-intensive tasks like terracing, vegetation planting, and maintenance. A geotechnical firm should be consulted to assess slope stability and ensure interventions do not inadvertently increase landslide risk or compromise nearby infrastructure.

- **Infrastructure and logistics requirements**:

The site is accessible via the P20 and secondary roads, but terrain steepness and narrow gully paths may make the transport of heavy materials such as stones or wire mesh difficult. Manual transport and on-site assembly will likely be required for gabions and check dams. Temporary staging areas for tools, vegetation, and construction materials should be identified near the intervention zones.

Construction activities should be scheduled during the dry season to minimize disruption and reduce risks associated with erosion and waterlogging.

- **Risks of Implementation**:

Several risks must be considered during the design and implementation phases:

  - Hydraulic and hydrological modelling is essential to determine appropriate dimensions for natural drainage and hydraulic structures, such as the infiltration swales or the rock stilling basin.
  - Soil instability due to loose or sandy subsoil may increase the risk of slope failure if terraces or gabions are improperly designed or constructed
  - Seasonal rain could delay excavation, planting, and stabilization efforts, especially in valley floors and steep slopes.

[59] OCA. 2025. An Inventory of Nature-based Soil, Water and Land Management Solutions in Republic of Congo.

- Vegetation establishment may be hindered by poor soil conditions or lack of access to quality seedlings.
- Community engagement may be limited if interventions are not aligned with local priorities or land use practices.
- Structural failure risk for gabions if foundations are not properly keyed into stable subgrade or if wire mesh corrodes over time. Lessons from Ngamakosso highlight the importance of using corrosion-resistant materials and ensuring adequate anchoring.
- Systemic risk if measures are implemented in isolation without complementary drainage solutions; uncontrolled runoff can undermine localized interventions.

These factors must be carefully evaluated to determine the final feasibility of each proposed solution.

Adverse impacts and safeguards triggers

While the proposed NbSWLM practices offer significant benefits for erosion control and flood mitigation, it is essential to assess potential adverse environmental and social impacts. This section outlines plausible risks associated with each intervention and identifies safeguard triggers that may require specialist review or mitigation measures.

The analysis draws on lessons learned from the national inventory of NbSWLM in RoC, or similar tropical urban catchments, local ecological assessments, and peer-reviewed literature.

Table 8. Plausible adverse impacts and safeguards triggers of practices implementation in Ngambio and Itsali in Mfilou.

Practice	Plausible Adverse Impacts	Safeguard Triggers
Infiltration swales	• Waterlogging in areas with poor drainage or low slopes, leading to reduced infiltration and plant stress. • Invasive species risk if non-native plants are introduced. • Soil erosion may occur under high flow volumes or velocities, especially if vegetation is sparse or poorly established. [60] • Stagnant water may cause mosquito breeding and odor problems. • Improper disposal of vegetative debris and sediment may lead to blockages or environmental harm.	• Compliance with local zoning and stormwater management regulations is required. • Environmental Impact Assessment (EIA): it may be necessary to assess ecological impacts. • Hydrology specialist review: Recommended if slope exceeds 4%, as rapid runoff velocities can cause erosion and reduce contact time for infiltration and pollutant filtering. • Biodiversity specialist or urban forestry experts should guide species selection and planting layout. • Maintenance protocols must include regular clearing of debris and sediment, with designated disposal areas.
Gully Head cuts with Gabions	• Improper installation may destabilize slopes or redirect flows unsafely.	• Geotechnical assessment required for slope stability.

[60] EPA. 2012. Storm Water Technology Fact Sheet Vegetated Swales. Retrieved from https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=200044A8.txt

Practice	Plausible Adverse Impacts	Safeguard Triggers
	• Rainfall events and erosion can damage gabions. • Wire mesh corrosion or stone displacement over time. • Vegetation failure may reduce long-term effectiveness. • Risk of injury during manual transport and assembly.	• Geology specialist review: Consult for design and technical planning of the structure dimensions. • Use corrosion-resistant materials and proper anchoring. • Vegetation plan must include native, deep-rooted species. • Safety protocols for labor and transport.
Vegetated Terraces	• Poorly designed terraces may increase landslide risk. • Excessive earthworks may disturb habitats or cause sediment runoff. • Vegetation failure may lead to erosion and terrace collapse. • Labor-intensive construction may face delays or community resistance.	• Slope gradient and soil stability must be assessed before design. • EIA may be required for large-scale earthworks. • Use proven species (e.g., Vetiver, Bamboo, Acacia) with strong root systems. • Community engagement and training to support implementation.[61]
Wooden Check dams	• Downstream flow redistribution, due to sediment retention and flow slowing, may impact water accessibility for agriculture, or water users downstream. • Sediment accumulation upstream may alter channel morphology. • Risk of structural failure if not properly designed or maintained, causing sudden sediment release or erosion. • Fire hazard in vegetated areas due to accumulation of biomass and dry vegetation, especially in dry seasons.	• EIA: Recommended if the intervention affects protected areas, involves significant vegetation changes, or alters hydrological regimes. • Geology specialist review: Consult for design and technical planning of the structure dimensions. • Hydrology specialist review: Necessary to assess flow dynamics, sediment transport, and downstream water availability impacts. • Biodiversity specialist review: Advisable if revegetation involves species selection, or if the area is near biodiversity hotspots or protected zones.
Rock stilling basin	• Improper excavation or placement may destabilize gully bed or adjacent slopes. • Concentrated flows bypassing the basin can cause downstream scour. • Rock displacement during extreme events may lead to structural failure. • Geotextile damage or loss of fines may undermine foundation.	• Geotechnical assessment for subgrade stability. • Hydraulic design verification to ensure adequate energy dissipation. • Use durable, angular rock sized for design flow velocity. • Install geotextile underlay and key apron into subgrade.

[61] The community training developed in the framework of this technical assistance includes details on implementation and maintenance activities.

Practice	Plausible Adverse Impacts	Safeguard Triggers
		• Post-construction inspection after major storms.

Maintenance considerations

Maintenance is a key aspect in the long-term efficiency of the practices proposed. As demonstrated in the national inventory of NbSWLM practices in RoC developed in the framework of this technical assistance, some practices were installed and they performed during first years of implementation, but due to absence of maintenance and regular inspections the structures failed years later.

This section outlines the key maintenance tasks, recommended frequency, capacity needs, responsible parties, and potential risks for each NbSWLM practice.

- Infiltration swales

Infiltration swales require frequent monitoring of vegetation health, soil infiltration capacity, and flow pathways. Regular care prevents issues such as clogging, overgrowth, and reduced efficiency. Key maintenance tasks include:

- Clearing debris and waste from swale channels to prevent blockages and maintain flow efficiency.
- Pruning and replanting vegetation to ensure coverage and prevent erosion, especially in high-flow zones.
- Monitoring for waterlogging or poor drainage, particularly in low-slope areas, and adjusting grading or installing underdrains if necessary.
- Soil health monitoring, checking any signs of erosion or sediment build-up and add fresh soil or mulch as needed to maintain optimal filtration.
- Sediment removal from swale beds to maintain infiltration and prevent nutrient buildup.
- Weed and pest control, with emphasis on avoiding chemical treatments that could harm beneficial species or pollute runoff.

Maintenance should be integrated into municipal landscaping schedules, with clear responsibilities assigned to local teams or contracted service providers. Community engagement in planting and upkeep can further support long-term viability.

- Vegetated stone gabions

Effectiveness of vegetated gabions depends on regular inspection and upkeep to ensure both the gabion structure integrity and the successful establishment of vegetation.

- Check gabion baskets for signs of corrosion, displacement, or deformation (e.g., broken wires) especially after heavy rainfall or flooding events.
- Inspect the base of the gabions and reinforce with additional material if needed, to prevent gabion undercutting and subsequent failure.
- Monitor that planted species within and around the gabions are thriving; replace failed plants and manage growth.
- Remove accumulated sediments and debits that may obstruct flow or reduce gabion effectiveness. This may include any large woody vegetation starts to grow in the gabions.

- Gully slopes with vegetated terraces

Terraces degrade naturally by erosion and sediment, so its effectiveness is highly dependent on maintenance.

- Annual inspection of terrace walls and outlets.[62] The best time to check is after rains, when erosion, sedimentation, and unevenness in elevation are easiest to see.[63]
- Weeding and thinning of vegetation, annually in the first years and then biannually.[64]
- Manure or compost application to support plant growth (seasonally).
- Grass trimming and channel cleaning (quarterly).
- Repair of damaged risers and regarding uneven terraces (as needed).
- Cleaning of channels and drains.
- The local community groups with technical support from municipal teams or NGOs could be mobilized for the maintenance of the terraces

- <u>Wooden check dams</u>

To ensure the long-term efficiency and stability of wooden check dams integrated with vegetation, regular and systematic maintenance is essential. Structural measures should be maintained for a minimum of two years following the initial treatment, with treated areas at least once annually.[65]

Vegetative components—such as trees, shrubs, and grasses established in gully catchment areas—must be protected from threats including fire, illegal wood cutting, uncontrolled grazing, and land encroachment.

Maintenance activities may include:

- Thinning of trees or shrubs to promote healthy growth and allow for the harvesting of wood and fodder.
- Replacement of dead or damaged wooden poles to maintain structural integrity.
- Widening or reinforcing barriers where erosion or sediment accumulation has compromised their effectiveness.
- Regular inspections, especially following heavy rainfall events, to assess the resistance and functionality of the check dams and to identify any necessary repairs.

- <u>Rock stilling basin</u>

Rock stilling basins are robust but require periodic checks, especially after implementation, to ensure and maintain energy dissipation and prevent scour. Additionally, maintenance should be adapted to flow velocity and rock size. Key tasks may include:

- Inspect rock placement and interlocking after major storms; reset displaced rocks.
- Check aprons and toes for signs of scour or undermining; re-key rocks if necessary.
- Inspect geotextile underlay for exposure or damage; replace if compromised.
- Remove excessive sediment accumulation in the dissipation pool to maintain hydraulic performance.

---

[62] CTCN. n.d. Terracing. Retrieved from https://www.ctc-n.org/technologies/terracing

[63] Kansas State University. n.d. Terrace Maintenance. Departments of Agronomy C-709 Conservation Farming and Biological and Agricultural Engineering. Retrieved from https://www.coffey.k-state.edu/crops-livestock/crops/conservation/Terrace%20Maintenance.pdf

[64] Wheaton and Monke. n.d. Terracing as a 'Best Management Practice' for Controlling Erosion and Protecting Water Quality. Agricultural Engineering.

[65] FAO. n.d. Basic gully treatment measures. Retrieved from: https://www.fao.org/4/ad082e/AD082e02.htm

By combining structural upkeep with ecological stewardship, these measures help ensure the durability and multifunctionality of check dams as part of integrated watershed management.[66]

Table 9. Maintenance activities of practices proposed in Ngambio and Itsali in Mfilou.

Practice	Activity	Frequency	Responsible Party	Potential Risks
Infiltration Swales	Clear debris, litter, and solid wastes	Monthly	Municipal teams / contracted services	Blockages, reduced infiltration, mosquito breeding if stagnant water
	Prune and replant vegetation	Quarterly	Municipal teams / community groups	Erosion, invasive species
	Monitor waterlogging and drainage	Biannually	Municipal engineers	Waterlogging, poor drainage, and mosquito breeding
	Soil health check and sediment removal	Biannually	Municipal teams / NGOs	Reduced filtration, nutrient buildup
	Weed and pest control	Quarterly	Municipal teams / community groups	Harm to beneficial species, runoff pollution
Vegetated Gabions	Inspect for corrosion, displacement, and damage	After heavy rains/ Biannually	Municipal engineers / NGOs	Structural failure, redirected flows
	Reinforce base and anchor points	As needed	Skilled labor / contractors	Undermining, erosion
	Monitor vegetation health and replace failed plants	Biannually	Community groups / NGOs	Reduced effectiveness
	Remove sediment and obstructive debris	Quarterly	Municipal teams / community groups	Flow obstruction, vegetation damage
Vegetated Terraces	Inspect terrace walls and outlets; repair risers and regrade terraces	After heavy rains/ Annually	Municipal engineers / community groups	Landslide risk, erosion, and structure failure
	Inspect survival of planted stakes; remove invasive species, weed and thin vegetation; and apply manure or compost	Seasonally	Community groups / NGOs	Poor plant growth, sediment buildup, infiltration reduction and terrace collapsing.

[66] Gully Rehabilitation Stem Cuttings – Greener.Land. Retrieved from https://www.greener.land/gully-rehabilitation-with-stem-cuttings/

Practice	Activity	Frequency	Responsible Party	Potential Risks
Wooden Check dams	Inspect structure and resistance	Annually / post-rainfall	Municipal engineers / community groups	Structural failure, sediment release
	Replace damaged wooden poles	As needed	Community groups/ NGOs	Erosion, collapse
	Thinning vegetation and reinforcing barriers	Biannually	Community groups/ NGOs	Fire hazard, sediment accumulation
	Protect vegetation from fire, grazing, and encroachment	Continuous monitoring	Community groups/ local authorities	Vegetation loss, reduced stability
Rock stilling basin	Inspect rock placement and interlocking; reset displaced rocks	After heavy rains / Biannually	Municipal engineers / skilled labor teams	Structural failure, downstream scour
	Check apron and toe for scour; re-key rocks if necessary	Biannually	Municipal engineers / contractors	Undermining, erosion
	Inspect geotextile underlay for exposure or damage; replace if compromised	Annually	Municipal engineers	Loss of fines, foundation instability
	Remove excessive sediment accumulation in dissipation pool	Biannually	Municipal teams / NGOs	Reduced hydraulic performance

In the Republic of Congo (RoC), local institutional mechanisms such as Community Development Committees (CGDC – *Comités de Gestion et Développement Communautaire*) or similar bodies are formally designated to oversee monitoring and maintenance (O&M) of local development initiatives, including education, infrastructure, and community services. Within the maintenance framework for NbSWLM practices, these organizations could be mobilized to strengthen community involvement and engagement.

However, experience shows that these committees often lack operational capacity and are not consistently effective. To address this gap and ensure sustainable maintenance of NbSWLM interventions, the following recommendations are proposed:

- **Define clear responsibilities** for CGDCs for each NbSWLM practice (e.g., swale upkeep, inspection of structures, vegetation monitoring) in their internal statutes and provide written terms of reference endorsed by municipal authorities to legitimize their actions.
- **Empower CGDCs to collect basic post-project data**, such as changes in land use, infrastructure encroachment, drainage blockages, misuse of channels, and adverse impacts on communities. Develop simple reporting templates to trigger timely corrective actions (e.g., reinforcing gabions, clearing vegetation, repairing basins).
- **Conduct a national-level assessment** of existing CGDCs to identify active and effective committees. Based on findings, reinforce promising committees and consider establishing new, practice-specific working groups where CGDCs are lacking.

- **Allocate a dedicated budget** to CGDC for O&M responsibilities, covering different routine activities such as inspections, vegetation management, sediment removal, minor repairs, etc.

These tailored recommendations aim to create a more grounded and realistic framework for ensuring ongoing maintenance and adaptive management of NbSWLM investments through strengthened community participation and institutional support.

In addition to strengthening CGDC capacity and ensuring adequate budget transfers for O&M, the project should actively explore partnerships with organized private-sector groups, such as Corporate Social Responsibility committees (comités RSE). These committees, commonly established by companies to fulfill social and environmental commitments, can provide financial support, technical expertise, and in-kind contributions (e.g., tools, vegetation materials) for NbSWLM maintenance.

Social feasibility

Ngambio and Itsali are situated along the same road corridor in Mfilou, share similar socio-economic characteristics, and experience similar erosion and flooding dynamics. The areas are heavily affected by runoff-driven sand deposition, particularly in the Mouhoumi, Ngambio and Base neighborhoods, where homes become buried during the rainy season as erosion from the upper Sadelm area moves sediments downslope. This environmental dynamic contributes to the urgency and relevance of the proposed interventions at both sites. The nature-based approaches planned for both sites are quite similar, combining bio-engineering techniques (such as gabion-based stabilization), and terracing and slope control approaches (such as vegetated terraces) for the control and rehabilitation of gullies.

In both locations, the intervention is associated with partial social concerns based on the technical requirement that gabions must rest on a stable base. Meeting this requirement is essential for slope stabilization and shapes community perceptions regarding long-term effectiveness. Apart from this, the interventions are considered essential by the communities to mitigate the impacts households experience. Residents express desperation about the situation, despite themselves sometimes contributing to degradation through unregulated construction, and call for government support. The municipal committees (Comité de Gestion et de Développement Communautaire - CGDC), responsible for community-level monitoring, do not always have the mobility or resources necessary to fulfill their support role.

Socio-economically, both neighborhoods are highly vulnerable. Many households have settled informally on lowlands or unstable slopes, making them highly exposed to the erosion, to structural collapse of homes and the loss of assets. Women, youth, Indigenous peoples and displaced persons were all identified as groups affected. Communities report substantial disruption of livelihoods, particularly for commercial activities such as small traders and households engaged in market gardening, whose incomes are frequently interrupted by erosion and sediment deposition.

Regarding sensitive or contested sites, no cultural or sacred sites were identified. However, potential land tensions may arise in both locations. As erosion has destroyed plots and houses, some residents hope to restore and re-occupy the land once stabilization works take effect. This expectation carries a risk of disputes around restored land if not managed transparently.

Overall, the social risk is rated Low for both sites. The interventions are perceived as necessary and beneficial. No specific fragility or violent-conflict factors were identified. Risks relate primarily to technical implementation rather than social acceptability. For this reason, recommended mitigation measures include i) guaranteeing the stability of any gabion structures, ii) reinforcing community awareness and training on maintaining vegetative cover and stabilizing terraces, and iii) mobilizing CGDC committees to support follow-up and maintenance and establishing rapid-response and oversight teams to ensure ongoing monitoring and timely maintenance.

Taken together, the two locations form a coherent intervention zone with aligned social dynamics and risks. Given the severity of erosion, the recurrent losses experienced by households, and the communities expressed need for State-supported stabilization, the proposed measures are both timely and socially relevant. Ensuring clear communication, transparent decision-making and technically sound implementation will be essential to maintain community trust and support throughout the project cycle.

Data confidence for this rapid assessment is medium, as evidence is based on local expert assessment and prior field knowledge, without detailed community consultations.

Note: Regarding Indigenous People, it should be noted that their identification at this stage is based on local expert input, not on quantitative data or a detailed in situ socio-cultural assessment. While some households in the area may self-identify as belonging to Indigenous Congolese groups, the presence and safeguard relevance of such groups within the project area have not been formally verified. Should the project advance to full feasibility and financing, this aspect would need to be carefully assessed in line with World Bank standards and procedures, as any confirmed applicability could entail additional analytical requirements, consultation processes, and associated time and cost implications during project preparation.

Estimated number of beneficiaries

To calculate the number of beneficiaries, a geospatial analysis was conducted. Open-source digital elevation data, satellite imagery, and hazard & risk data from the World Bank were used to determine project extension area, slopes as well as settlement patterns. These datasets were overlaid with raster data obtained from the source Gridded Population of the World collection[67], which provides approximate population estimates (1kmx1km tiles). The analysis determined that approximately 27,000 people can directly benefit from reduced erosion resulting from reshaped and stabilized slopes, as well as protected head cuts using a mix of natural and bio-engineered interventions.

In addition, the combined interventions have a multiplier effect that extends beyond the project sites, benefiting indirectly about 96,000 inhabitants of the Ngambio and Itsali districts, protecting existing roads and reducing runoff.

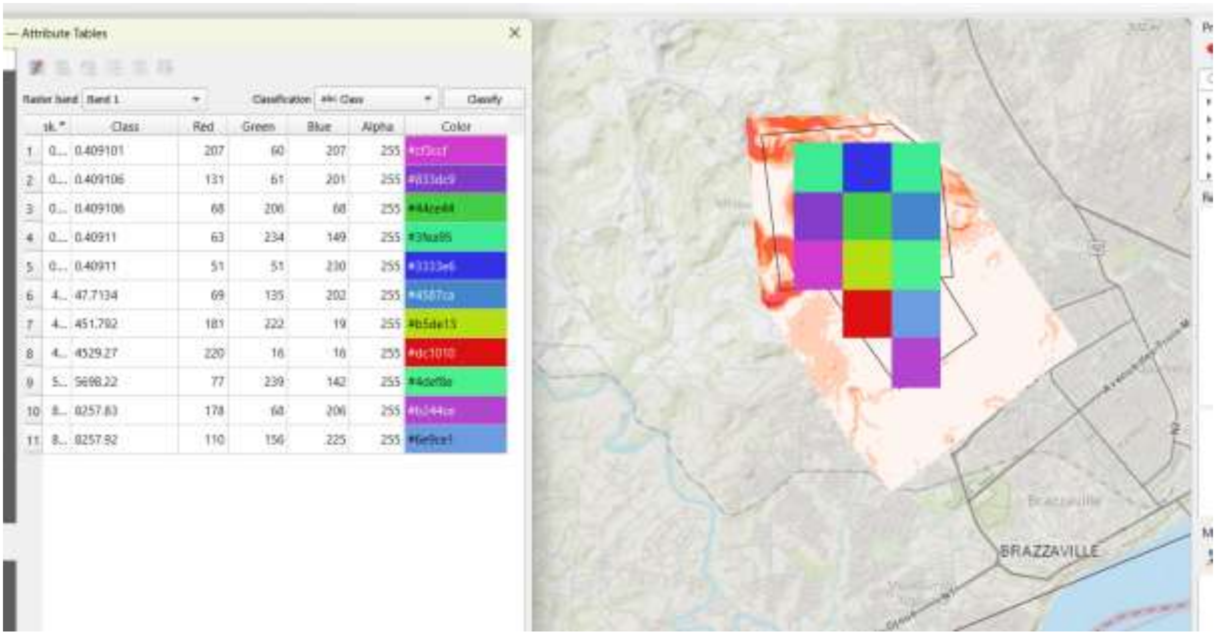


Figure 19. Estimation of the number of beneficiaries in Mfilou.

Co-benefits

Beyond direct risk reduction, the intervention delivers a range of environmental and socio-economic co-benefits. These have been qualitatively assessed and scored (High/Medium/Low) based on available evidence and contextual relevance.

[67] Available at https://www.earthdata.nasa.gov

Table 10. List of potential co-benefits provided by the practices in in Ngambio and Itsali in Mfilou.

Benefits	Mechanism of actions	Score
Carbon sequestration (Regulation)	Vetiver is recognized as one of the most efficient carbon-sequestering grasses, with four mature plants sequestering as much carbon as a fast-growing poplar tree. Its biomass contributes to organic matter accumulation, improving soil fertility and structure.[68] Likewise, reforestation and agroforestry further enhance carbon storage through tree biomass and soil organic matter.	H
Temperature regulation (Regulation)	Vegetated surfaces such as shrubs and grasses can provide localized cooling through evapotranspiration, reducing heat accumulation on bare ground. In peri urban area of Brazzaville, where impervious surfaces and exposed soils intensify heat stress, these measures contribute to reduce localized heat effects.	L
Water quality improvement (Regulation)	Treatment of stormwater quality by pollution removal through sedimentation and nutrient uptake[69] is a primary co-benefit of the vegetated swales. Check dams and vegetative terracing also trap sediment and filter runoff, reducing turbidity and nutrient pollution downstream.[70]	H-M
Groundwater Recharge (Regulation)	Vegetated swales enhance percolation of water into the ground, contributing to some groundwater recharge. However, there is a risk of groundwater pollution if runoff water is polluted and if the water table is not deep enough. [71]	M
Biodiversity enhancement (Support)	By incorporating native plants, bioretention areas and green corridors provide habitats for local wildlife, including birds, insects, and small mammals. This supports biodiversity and contributes to the ecological health of urban areas.[72]	H
Soil fertility and productivity (Support)	Organic matter from vegetated terraces and sediment retention improves soil structure and nutrient cycling, enhancing agricultural productivity.	M-H
Job creation and livelihood	Community involvement in labor-intensive tasks (e.g., planting and vegetation maintenance, sediment removal) can generate short-term employment and income streams.	M-H

[68] Teshale, E. 2022. The Effects of Vetiver Grass (VetiverZizanodesL.) on Soil Fertility Enhancement, Soil Water Conservation, Carbon Sequestration and Essential oil Productions A: Review. https://www.arcjournals.org/pdfs/ijfh/v8-i1/4.pdf

[69] Office of Administration of Missouri. n.d. Detention Ponds and Basins. Chapter 5. Retrieved from https://oa.mo.gov/sites/default/files/fg05_07_stormwaterman.pdf

[70] P.K. Yoon, The Vetiver Network International. n.d. Vetiver Grass Technology for Soil and Water Conservation. Retrieved from https://www.vetiver.org/vetiver-grass-technology/

[71] EPA. 2012. Storm Water Technology Fact Sheet Vegetated Swales. Retrieved from https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=200044A8.txt

[72] Nature4Cities. 2018. NBS multi-scalar and multi-thematic typology and associated database. Retrieved from https://www.nature4cities.eu/_files/ugd/55d29d_8813db2df690497e80740537b6a8a844.pdf

Benefits	Mechanism of actions	Score
opportunities: (Cultural)	Proper management of wooden check dams over several years can yield additional benefits, such as the sustainable production of fuelwood from tree plantations and fodder from grass and fodder tree species.	
Aesthetic value (Culture)	Bioretention solutions and green corridors in urban spaces can enhance the visual appeal of urban landscapes if well implemented and maintained.	H

Indicative Cost Profile

Practice 1 – Vegetated infiltration swales (Site A and B border)

Table 11. Indicative cost profile of vegetated infiltration swales

	Cost category	Description / What to include	Cost drivers
CAPEX	Transport and Logistics	Covers delivery and handling of materials and plants to the swale-type installation site. Includes transport of compost, sand-gravel aggregates, vegetation, underdrain components, and coordination with nurseries.	Supplier proximity, plant sensitivity, road access
CAPEX	Site Preparation	Involves excavating soils down to 0.5 m depth, grading and shaping of vegetation surface to ensure proper slope and drainage. Includes removal of existing vegetation, soil mixture with sandy gravel, and layout marking.	Slope gradient, soil permeability, existing land use
CAPEX	Materials	Refers to all inputs required for the swale-type restoration and planting. Includes compost, sand-gravel, native grasses, sedges, shrubs, underdrains, and erosion control fabric.	Material compatibility, infiltration needs, ecological goals
CAPEX	Labor and Equipment	Covers workforce and tools for swale-type creation. Includes grading crews, planting teams, manual tools, irrigation setup, and erosion control installation.	Labor skill level, equipment type, planting density
CAPEX	Design Supervision and Project Management	Encompasses planning, technical oversight, and coordination. Includes expert for hydraulic modelling, vegetation layout design, supervision of grading and planting	Design complexity, vegetation mix, urban integration
CAPEX	Contingency	Provides financial buffer for unexpected construction challenges. Includes allowances for poor soil conditions, plant failure, and erosion control adjustments.	Seasonal timing, soil surprises, plant availability
OPEX	Routine Inspection and Maintenance	Ensures the swale-type runoff infiltration and drain system functions as intended through regular checks and upkeep. Includes visual inspections for erosion, blockages, and vegetation health; removal of debris and minor repairs. Typically conducted monthly, with additional checks after heavy rainfall events.	Rainfall frequency, urban debris load, accessibility of swale locations, and availability of trained personnel.
OPEX	Vegetation Management	Maintains healthy plant cover to support infiltration and pollutant filtration. Includes pruning, replanting, pest control, and irrigation during dry periods. Conducted quarterly, with replanting as needed based on plant survival and seasonal stress.	Plant species selection, climate variability, pest outbreaks, and irrigation needs.

Cost category		Description / What to include	Cost drivers
	Sediment Removal	Prevents clogging and maintains infiltration capacity by removing accumulated sediment, both from upper vegetated surface and concrete drain channel. Includes manual or mechanical removal of sediment from swale-type strips and inlet zones. Typically required once or twice per year, depending on runoff volume and sediment load.	Sediment accumulation rate, upstream land use, frequency of storms, and ease of access for removal.
	Monitoring and Reporting	Tracks performance and informs adaptive management decisions. Includes labor and equipment for hydraulic testing, vegetation health assessments, and documentation of maintenance activities. Conducted semi-annually or annually, depending on project requirements.	Monitoring frequency, number of swales, data collection tools, and technician wages.
	Field Supervision and Administrative Support	Oversee maintenance activities and coordinates operations. Includes wages or stipends for supervisors, office coordination, transport, and communication. Ongoing throughout the year, more intensive in early years.	Staffing levels, administrative structure, transport logistics, and communication needs.
	Safety and Access Control	Ensures safe public interaction with swale-type corridors and protects infrastructure. Includes installation and upkeep of signage, fencing, access paths, and barrier vegetation. Inspections conducted quarterly, with repairs as needed.	Public safety standards, vandalism risk, visibility of swale locations, and material durability.
	Long-Term Rehabilitation	Restores swale functionality after years of use or damage. Includes labor and equipment for full replacement of soil media, regrading, and replanting of vegetation. Typically required every 10–15 years depending on performance decline.	Extent of degradation, soil and vegetation condition, and availability of rehabilitation funding.

Practice 2 - Vegetated gabions (Site A and B)

Table 12. Indicative cost profile of vegetated gabions

	Cost category	Description / What to include	Cost drivers
CAPEX	Transport and Logistics	Covers the movement of materials, equipment, and personnel to and from the site. Includes vehicle rental, manual transport of wire mesh and stones, delivery of live stakes and soil amendments, coordination with suppliers, and logistical planning for access to remote or steep riverbanks.	Distance to site, road access, material weight, supplier location, terrain difficulty
	Site Preparation	Involves preparing the land for gabion installation and ensuring proper slope stability. Includes clearing vegetation, stabilizing steep slopes, compacting soil, marking placement zones, and preparing foundations for gabion anchoring.	Slope steepness, soil cohesion, erosion risk, existing vegetation
	Materials	Refers to all physical inputs required for gabion construction and ecological reinforcement. Includes galvanized wire mesh, stones of appropriate size and durability, live stakes or poles (2–6 cm diameter), soil for backfill, geotextiles, and seed mixes for vegetation establishment.	Material specifications, availability, durability, ecological compatibility
	Labor and Equipment	Covers human resources and machinery needed for construction and installation. Includes skilled labor for gabion assembly, unskilled labor for stone filling and vegetation placement, manual tools, safety gear, and equipment for slope stabilization and anchoring.	Labor availability, skill level, equipment rental cost, site conditions
	Design Supervision and Project Management	Encompasses technical planning, oversight, and coordination throughout the project lifecycle. Includes hydraulic modeling, structural design, supervision of installation, geotechnical analysis, and project coordination with stakeholders.	Project scale, technical complexity, team expertise, regulatory requirements
	Contingency	Provides a financial buffer for unexpected costs or delays during implementation. Includes allowances for equipment breakdowns, slope failure, material shortages, weather-related disruptions, and unforeseen site conditions.	Site unpredictability, seasonal conditions, inflation risk, material volatility
OPEX	Routine Inspection and Maintenance	Covers regular checks to ensure gabion integrity and vegetation health. Includes visual inspections of structural stability, erosion signs, vegetation growth, and anchoring effectiveness, typically conducted monthly or after major rainfall events.	Rainfall frequency, sediment load, accessibility, technician availability
	Monitoring and Reporting	Tracks performance and environmental impact through data collection and analysis. Includes labor and equipment for flow velocity measurement, erosion monitoring, vegetation surveys, and documentation of structural performance.	Monitoring frequency, number of parameters tracked, equipment availability, technician wages

Cost category		Description / What to include	Cost drivers
	Field Supervision and Administrative Support	Oversees maintenance activities and coordinates operations. Includes wages or stipends for supervisors, office coordination, transport for field teams, and communication with stakeholders.	Staffing levels, administrative structure, transport needs, project complexity
	Long-Term Rehabilitation	Restores full functionality after years of use or degradation. Includes labor and equipment for replacing damaged gabions, reshaping slopes, replanting vegetation, and repairing anchoring systems, typically required every 10–15 years.	Extent of degradation, age of infrastructure, vegetation failure rates, soil condition

Practice 3 – Progressive terraces (Site A and B)

Table 13. Indicative cost profile of progressive terraces

	Cost category	Description / What to include	Cost drivers
CAPEX	Nursery production and planting materials	Propagation or procurement of vetiver slips, bamboo and acacia cuttings Includes seedlings, propagation, irrigation, potting materials, organic compost (farm-yard manure), pest control, and packaging for transport	Cost per slip and cuttings varies by local nursery capacity, propagation success rate, and transport distance to sites
CAPEX	Transport and logistics	Loading, transporting, and handling plant material and equipment to the planting zones. Includes vehicle rental or fuel, temporary storage or holding areas, and watering during transport	Accessibility of sites (terrain, road condition) and distance from nurseries
CAPEX	Site preparation and layout	Manual labor for clearing existing vegetation, marking contour lines, and carrying out trenching or light tillage to loosen soil. Includes purchase or rental of tools (hoes, shovels, pickaxes, contour-marking devices), supply and transport of mulch or compost for soil improvement, and wages for field workers conducting these tasks.	Soil type, slope gradient, vegetation density, and available tools/mechanization
CAPEX	Planting labor and field tools	Manual labor for aligning, planting, backfilling, and initial watering of slips and cuttings Includes purchase or rental of hoes, spades, machetes, marking ropes, safety equipment for workers, and wages for field workers conducting these tasks	Labor productivity, wage levels, and the proportion of mechanization
CAPEX	Design, supervision, and project management	Technical and managerial support needed to plan and implement the intervention. Includes design and layout preparation, supervision by agronomists or engineers, coordination of field teams, wages for project staff, procurement and quality control, logistics and transport for supervision, reporting, and administrative support.	Required level of expertise, number of sites, and duration of the initial phase.
CAPEX	Contingency	Financial risk buffers. Includes a contingency allowance (typically 10–20%) for unforeseen labor, input, or logistics costs.	Inflation, exchange rates, and field-level variability.
OPEX	Routine trimming and rejuvenation	Maintains hedgerow height and density. Includes labor for watering, trimming or mowing, disposal or reuse of biomass (mulch/fodder), and any small tools required. Typically performed once or twice per year depending on growth rate and rainfall.	Labor rates, hedgerow growth rate, seasonality, and terrain accessibility.
OPEX	Gap-filling and replacement planting	Replaces missing or damaged plants to maintain continuous hedges. Includes sourcing and transporting slips, planting labor, watering, and small tools. Mainly required in the first 2–3 years, occasional thereafter.	Survival rate of plants, drought, pests, and seasonal conditions.

Cost category		Description / What to include	Cost drivers
	Weed control and vegetation management	Controls competing vegetation and reduces fire risk. Includes manual weeding, mulching, labor, and hand tools. Performed every 3–6 months during the growing season.	Labor availability, weed pressure, and herbicide cost/efficacy.
	Soil and slope maintenance	Repairs minor erosion and maintains contour lines. Includes light earthworks, labor, small equipment, and transport. Typically, after heavy rainfall events or once annually.	Rainfall intensity, slope steepness, and soil erodibility.
	Monitoring and reporting	Tracks hedge performance and environmental impact. Includes field surveys, measuring growth and erosion control, data recording, GPS equipment, and wages for technicians. Performed biannually to annually.	Number of plots, frequency of monitoring, labor and equipment costs.
	Field supervision and administrative support	Oversees maintenance activities and coordinates operations. Includes wages or stipends for supervisors, office coordination, transport, and communication. Ongoing throughout the year, more intensive in early years.	Number of sites, travel distances, and staff availability.
	Long-term rejuvenation or replanting	Ensures hedgerow vigor over time. Includes labor and materials for partial replanting or regeneration. Typically, every 10–15 years.	Plant survival, climate stress, and availability of slips.

Practice 4 - Wooden check dams (Site A and Site B)

Table 14. Indicative cost profile of wooden check dams

	Cost category	Description / What to include	Cost drivers
CAPEX	Structural materials	All materials used for dam construction. Includes timber logs, stakes, binding materials (wire, rope), and any transport to sites.	Material availability, local timber species, cost variability, and transport difficulty.
	Vegetation production and planting materials	Propagation or procurement of reinforcing vegetation. Includes seedlings, propagation, irrigation, potting materials, organic compost, pest control, and packaging for transport	Species survival, nursery availability, transport, and labor productivity.
	Transport and logistics	Loading, transporting, and handling plant material and equipment to the site. Includes vehicle/fuel costs, temporary storage at site, wheelbarrows or trolleys for manual transport, and handling labor.	Site accessibility, slope steepness, and distance from material/vegetation sources.
	Site preparation and layout	Prepares gullies for dam construction. Includes clearing debris and vegetation, marking dam alignment, minor excavation or trenching for foundations, wages for field crew, and hand tools (hoes, spades, machetes, ropes).	Gully slope, sediment load, vegetation density, and labor productivity.
	Construction labor and tools	Manual labor for assembly of dams. Includes manual labor for positioning logs, tying bindings, and planting vegetation. Tools include hammers, saws, machetes, wheelbarrows, and safety equipment.	Labor availability, technical skills of workers, and dam complexity.
	Design, supervision, and project management	Technical and managerial support needed to plan and implement the intervention. Includes technical design and spacing of dams, supervision by engineers, field team coordination, procurement oversight, reporting, documentation, and wages for technical staff.	Expertise level, number of gullies, and duration of construction.
	Contingency	Financial risk buffer. Includes contingency (10–20%) for unforeseen labor, material, or site conditions.	Material price fluctuations, inflation, and site access challenges.
OPEX	Routine inspection and maintenance	Ensures dam functionality and structural stability. Includes manual labor for checking for log displacement, erosion around the dam, damage from floods, removing excess sediment, and minor repairs. Performed after heavy rains or at least twice per year.	Flood intensity, timber durability, labor availability, sediment load, rainfall patterns, and gully slope

Cost category		Description / What to include	Cost drivers
	Vegetation management	Maintains reinforcing vegetation planted on or around dams. Includes replacing or reinforcing grasses/other plants, applying mulch if needed, and associated labor. Typically, annual or semi-annual.	Plant survival, seasonality, and access to vegetation material.
	Gap-filling and minor repairs	Replaces damaged or missing structural elements. Includes cost for additional stakes, logs, binding material, and labor. Usually needed after extreme weather events or every 2–3 years.	Extreme weather, wood degradation, and local material availability.
	Monitoring and reporting	Tracks dam performance and sediment retention. Includes flow measurement, erosion assessment, photographs, data recording, and technician wages. Performed annually or biannually.	Number of monitoring points, frequency, and labor/equipment costs.
	Field supervision and administrative support	Oversees maintenance activities and coordinates operations. Includes wages or stipends for supervisors, transport, office coordination, and communication. Ongoing throughout the year.	Number of dams/sites, distance between sites, and supervisor availability.
	Long-term dam renewal	Ensures dam integrity over the long term. Includes partial reconstruction or full replacement of logs and bindings, replanting of reinforcing vegetation, and associated labor/material costs. Typically every 10–15 years or after severe events.	Timber decay rate, extreme weather events, and material availability.

Practice 5 - Rock stilling basin (Site B)

Table 15. Indicative cost profile of rock stilling basin

	Cost Category	Description / What to include	Cost Drivers
CAPEX	Transport and Logistics	Covers delivery and handling of rock, geotextile, and equipment to the gully head cut sites. Includes transport of riprap, geotextile rolls, and any machinery required for excavation and placement.	Distance to site, road access, rock weight and size, supplier proximity, terrain difficulty
	Site Preparation	Involves excavation and shaping of the basin footprint at each gully head cut. Includes clearing debris, excavating to design depth, grading side slopes, and preparing subgrade for geotextile placement.	Gully depth and width, soil stability, slope gradient, accessibility
	Materials	Refers to all physical inputs required for basin construction. Includes angular riprap (150–300 mm), oversized key stones, geotextile underlay, and bedding layer if needed.	Rock size and quality, material availability, geotextile specifications
	Labor and Equipment	Covers workforce and machinery for excavation and rock placement. Includes unskilled labor for layout and interlocking rock, skilled labor for handling, and equipment such as excavators and loaders.	Labor availability, skill level, equipment rental cost, site conditions
	Design Supervision and Project Management	Encompasses technical planning and oversight during construction. Includes hydraulic design verification, supervision of excavation and rock placement, and coordination with contractors.	Design complexity, number of basins, technical expertise required
	Contingency	Provides financial buffer for unexpected challenges during implementation. Includes allowances for unforeseen soil conditions, rock shortages, and weather-related delays.	Site unpredictability, seasonal conditions, material price fluctuations
OPEX	Routine Inspection and Maintenance	Ensures basin functionality and stability through regular checks. Includes inspection for rock displacement, apron scour, and minor repairs after heavy rainfall events.	Rainfall intensity, sediment load, accessibility, technician availability
	Monitoring and Reporting	Tracks basin performance and erosion control effectiveness. Includes flow checks, scour assessment, and documentation of maintenance activities.	Monitoring frequency, number of basins, technician wages
	Field Supervision and Administrative Support	Oversees maintenance operations and coordinates logistics. Includes wages for supervisors, transport for field teams, and communication costs.	Staffing levels, travel distances, administrative structure

	Long-Term Rehabilitation	Restores basin integrity after years of use or damage. Includes labor and equipment for replacing displaced rock, repairing apron, and re-keying margins. Typically required every 10–15 years.	Extent of degradation, rock durability, frequency of extreme events

Economic Assessment

- Cost

Practice 1 – Vegetated infiltration swales (Site A and Site B border)

Table 16. Cost range of vegetated swale/green corridor

	Cost Category	Key Assumptions	Indicative Cost Range[73] (USD/100m)	Confidence level	Data Source
CAPEX	Material and equipments	• Assumed dimensions of site: Length = 100m, wide = 2m. Total surface = 200m²: • Material and equipment required: o Excavation o Engineered soil (imported or custom mix) o Gravel o Softscaping o Include equipments and transport • Cost based on unit cost in India of rate/meter of 888 rupees for a 2m wide swale, adjusted to the cost of living in Roc. • Due to high material and import cost, limited local availability of engineered soil and less developed supply chained, the estimated rate per meter is of USD 20–35 • Total cost = 20*200 to 435*200	USD 4,000 – USD 7,000	Low	EPA. 2021. Stormwater Best Management Practice: Grassed Swales. Internal source from NbS firm in India Local expertise
	Labor	• Assume basic tools, unskilled labor, and no machinery.	USD 325 – USD 2,650	Low	EPA. 2021. Stormwater Best Management Practice: Grassed Swales.

[73] Estimate costs are from local expertise and international cost estimates that are scaled using GDP per capita (PPP) ratios to approximate local labor and implementation costs. While this method introduces uncertainty, it is commonly used in preliminary economic assessments and allows for consistent comparison across intervention

	Cost Category	Key Assumptions	Indicative Cost Range[73] (USD/100m)	Confidence level	Data Source
		• 45–70 worker-days[74] of unskilled labor • Supervision of skilled labor = 2 – 5 worker-days • Rate of unskilled labor: 5 –20 USD/day • Rate of skilled labor = 50 – 250 USD/day • Total cost = 45*5 + 2*50 to 70*20 + 5*250			Local expertise
	Design & Engineering	• Site survey and assessment, Hydrologic/hydraulic design, engineering drawings and specs, permitting and coordination, project management and supervision • Estimated à 30 days at 50 - 250 USD/day • Total cost = 30*50 to 30*250	USD 1,500 – USD 7,500	Low	Sustainable Technologies Evaluation. Enhanced Swales. n.d. Life Cycle Costs. Local expertise
	Contingency	• For landscaping and NbS measures at the prefeasibility stage = usually 20% – 30% • Total cost = 20% of lower bound of sum of materials + labor + equipment and tools + design and engineering, and 30% of upper bound of same categories	USD 1,165 – USD 5,145	High	Report-Toolbox-on-Financing-Nature-Based-Solutions.pdf View of NbS experts
	Total CAPEX		USD 6,990 – USD 22,295		

[74] Worker-day refers to the amount of labor provided by one worker in one day. It's a unit of labor measurement (e.g., 0.5 worker-days means half a day of one person's work).

	Cost Category	Key Assumptions	Indicative Cost Range[73] (USD/100m)	Confidence level	Data Source
OPEX	Routine operations & maintenance	• Activities include: Grass cutting, weeding, sediment removal, minor reshaping. • Unskilled labor = 10 worker-days/month => 120 worker-days/year • Skilled labor = 1 worker-days/month => 12 worker-days/year • Total cost range = 12*50 + 120*5 to 12*250+120*20	USD 1,200 – USD 5,400	Medium	https://wjarr.com/sites/default/files/WJARR-2019-0138.pdf Local expertise
	Major repairs	• Light earthworks after heavy rains (2 events/year) • No heavy machinery; manual + small equipment • Total labor: 5 –10 worker-days depending on severity • 1 skilled supervisor days/year • Rate of unskilled labor: 5 –20 USD/day • Rate of skilled labor = 50 – 250 USD/day • Total cost = 5*5 + 1*50 to 10*20+1*250	USD 75 – USD 450	Medium	
	Monitoring & reporting	• Skilled labor: 0.5 worker-days/month • Total labor: 6 worker-days: • Total cost = 6*50 to 6*250	USD 300 – USD 1,500	Medium	
	Total OPEX		USD 1,575 – USD 7,350		

These cost ranges indicate that vegetated infiltration swales/green corridors are a moderate CAPEX intervention per 100 m (USD 6,990–22,295), with a non-trivial recurrent OPEX envelope (USD 1,575–7,350/year) that can quickly determine whether performance is sustained or lost. In practical terms, this makes swales well-suited for progressive roll-out along priority road segments (e.g., where runoff concentration is driving gully initiation), because construction can be phased while standard designs and local supply chains are refined; however, they should only be scaled where municipalities can credibly fund and organise routine upkeep (sediment removal, vegetation management, inspections after heavy rain) to avoid clogging and loss of infiltration function.

Practice 2 – Vegetated gabions (Site A and Site B)

Table 17. Cost range of vegetated gabions

Cost Category		Key Assumptions	Indicative Cost Range (USD/100m)	Confidence level	Data Source
CAPEX	Materials, tools, and labor	According to an Indian study, estimated costs range from USD 35 to 43 per cubic meter, covering all materials, labor, tools, and technical support, **excluding vegetation**. When adjusted for RoC's lower cost of living, the corresponding cost is approximately USD 25–35 per cubic meter. Key Estimations • Length : 100m • Height : 2m • Basket size: 2 m × 1 m × 1 m → 2 m^3 per basket • Tier 1: 100 m ÷ 2 m = 50 baskets × 2 rows = 100 baskets • Tier 2: 50 baskets • Total baskets: 150 • Total volume: 150 × 2 m^3 = **300 m^3** Cost: 300 × $25 = **USD 7,500** / 300*35 = **USD 10,500** Adding assumptions for vegetation: Calliandra seedlings: • Price: **USD 0.60 each** • Assume 1 seedling every 2 m → ~50 seedlings for 100 m • Cost: **USD 30** Vetiver slips: • Price: **USD 0.05– USD 0.10 each** • Assume 4 slips per m → 400 slips for 100 m • Cost: **USD 20– $40** Napier grass • Price: ~ USD 0.07– USD 0.10 per cutting • Assume 600–800 cuttings → **USD 42–USD 80** Total vegetation cost: USD 92– USD 150	USD 7,592 – USD 10,650	Low	23-6-3-08-JGS2025Julyproceeeding_1_.pdf Manuel du génie vegetal, 2023. Ministère de l'Environnement du Burundi Eofabrics - The Maccaferri Gabion Guide – Rev: October 2019 Local expertise

	Cost Category	Key Assumptions	Indicative Cost Range (USD/100m)	Confidence level	Data Source
	Design & Engineering	Site survey and assessment, hydrologic/hydraulic design, engineering drawings and specs, permitting and coordination, project management and supervision Estimated 50 days at 50 - 250 USD/ day	USD 2,500 – USD 12,500	Low	Local expertise
	Contingency	For landscaping and NbS measures at the prefeasibility stage = usually 20% – 30% Total cost = 20% of lower bound of sum of materials + labor + equipment and tools and 30% of upper bound of same categories	USD 2,028 – USD 6,945	High	Report-Toolbox-on-Financing-Nature-Based-Solutions.pdf View of NbS experts
	Total CAPEX		USD 12,110 – USD 30,095		
OPEX	Routine operations & maintenance	**Activities:** • Vegetation care: Watering during dry season, weeding, replacing dead plants. • Minor gabion checks: Tightening wires, checking for rust. • Debris removal: Clearing sediment and vegetation blocking drainage. **Frequency:** 4 times/year **Labor :** • 1 skilled labor × 1 day per visit → USD 50– USD 250 per day • 2 unskilled labor × 1 day per visit → USD 5– USD 20 per day each • 4 visits/year → USD 240 – USD 1,160 per year for labor **Vegetation replacement (estimating 10% mortality rate):** • Calliandra replacement: 5 seedlings/year → USD 0.60 each = USD 3 per year • Vetiver replacement: 40 slips/year → USD 0.05– USD 0.10 each = USD 2– USD 4 per year • Napier replacement: 70 cuttings/year → USD 0.07– USD 0.10 each = USD 5– USD 7 per year • Labor for replanting: 1 unskilled × 0.5 day → USD 1.5– USD 2.5/year	USD 251 – USD 1,176	Low	Manuel du génie vegetal, 2023. Ministère de l'Environnement du Burundi Eofabrics - The Maccaferri Gabion Guide – Rev: October 2019 Local expertise

	Cost Category	Key Assumptions	Indicative Cost Range (USD/100m)	Confidence level	Data Source
	Major repairs	Activities: • Replace damaged gabion baskets or wires. • Refill displaced stones. • Replant vegetation after landslides or washouts. Frequency: Every 5–10 years or after extreme events. Assumptions: • 5–10% of gabion length affected per major repair event. • Gabion basket replacement: 10–20 baskets → USD 8– USD 15 each = USD 80– USD 300 • Stone refill: ~15–30 tons → USD 30– USD 50/ton = USD 450– USD 1,500 • Skilled labor: 2 workers × 3 days → USD 300 – USD 1,500 • Unskilled labor: 4 workers × 3 days → USD 60 – USD 240 • Vegetation replanting: 10% of original → USD 20– USD 40	USD 910 – USD 3,580	Low	Manuel du génie végétal, 2023. Ministère de l'Environnement du Burundi Eofabrics - The Maccaferri Gabion Guide – Rev: October 2019 Local expertise
	Monitoring & reporting	Activities: • Visual inspections of gabion structure and vegetation. • Photo documentation and simple erosion checks. • Prepare short monitoring reports. Frequency: Twice per year Assumptions: • 1 skilled labor × 1 day per visit → USD 50–USD 250 per day • Transport and basic tools → USD 5–USD 10 per visit	USD 110 – USD 520	Low	Manuel du génie végétal, 2023. Ministère de l'Environnement du Burundi Eofabrics - The Maccaferri Gabion Guide – Rev: October 2019 Local expertise
	Total OPEX		USD 1,271– USD 5,276		

The gabion ranges confirm a comparatively higher upfront CAPEX (driven by materials, transport, and engineering/supervision) and a maintenance profile that is operationally manageable but non-optional (inspection, debris removal, and vegetation survival). This makes vegetated gabions most appropriate as a targeted structural "anchor" for sites where toe protection and head cut control are essential to stop rapid slope retreat—provided design quality is assured (foundation depth, drainage provisions, correct basket sizing, and appropriate rock gradation). Given the low confidence level of the unit costs, the table also highlights the value of early market testing with local suppliers/contractors to reduce uncertainty before committing to scale.

Practice 3 - Vegetated progressive terraces with vetiver (Site A and Site B)

Table 18. Cost range of vegetated progressive terraces with vetiver

	Cost category	Key Assumptions	Indicative cost range[75] (USD / ha)	Confidence Level	Data source
CAPEX	Materials	• Vetiver slips purchased from a nursery (no cost related to the establishment of the nursery – assumed existing nursery within 10-15km from the site) • Hedge spacing: 2 m vertical interval on 20% slope → 10 rows per hectare. • Planting density: 2–3 slips per station, 10 cm apart → 20,000–30,000 slips per hectare. • Unit cost: USD 0.05–0.1 per slip. • Total cost = 20,000 * 0.05 to 30,000*0.1	USD 1,000 – USD 3,000	High	Vetiver Grass Technical Specification Local expertise Fanya Juu – Greener.Land
	Equipment & Tools	• Transport of slips from nursery to site (estimated within a radius of 10–15 km): truck rental for 10-15 days including fuel (USD 250 - 400/truck-day) • Field tools for digging trenches, planting and preparation: shovels, hoes, spades, machetes, ropes, gloves, etc. Estimated flat cost: 500–700 USD for 1 ha. • Total cost = 250*10 + 500 to 400*15+700	USD 3,000 – USD 6,700	Low	Vetiver Grass Technical Specification Lorry & Truck leasing, Machinery Hire in Congo | Car Rental Congo Local expertise Fanya Juu – Greener.Land
	Labor	• Activities includes: digging the trenches, clearing, contour marking, light tillage, mulching, planting, watering. • Estimated at 100 worker-days/ha • Unskilled rural labor rate: 5 – 20 USD/day • Skilled labor for supervision: 7 worker-days for 1 ha. • Skilled labor rate: 50–250 USD/day • Total cost = 100*5+7*50 to 100*20+7*250	USD 850 – USD 3,750	Medium	Vetiver Grass Technical Specification Local expertise Fanya Juu – Greener.Land

[75] Estimate costs are from local expertise and international cost estimates that are scaled using GDP per capita (PPP) ratios to approximate local labor and implementation costs. While this method introduces uncertainty, it is commonly used in preliminary economic assessments and allows for consistent comparison across intervention

<table>
<tr><th></th><th>Cost category</th><th>Key Assumptions</th><th>Indicative cost range[75] (USD / ha)</th><th>Confidence Level</th><th>Data source</th></tr>
<tr><td rowspan="2"></td><td>Contingency</td><td>• For landscaping and NbS measures at the prefeasibility stage = usually 20% – 30%
• Total cost = 20% of lower bound of sum of materials + labor + equipment and tools and 30% of upper bound of same categories</td><td>USD 970 – USD 4,035</td><td>High</td><td>Report-Toolbox-on-Financing-Nature-Based-Solutions.pdf

View of NbS experts</td></tr>
<tr><td colspan="2">Total CAPEX</td><td>USD 5,820 – USD 17,485</td><td></td><td></td></tr>
<tr><td>OPEX</td><td>Routine operations & maintenance</td><td>Watering:
• Every day for 2 weeks after planting → 14 events, then twice per week for 6 weeks → 12 events. Total watering events: 26.
• Labor per event: 0.25–0.62 worker-days/event.
• Total worker-days for watering: 6.5–16.1 worker-days.
• Worker-day rate for unskilled labor = USD 5–20/day
• Total cost = 7*5 to 20*16 → USD 35 - 320

Replacing Dead/Damaged Plants (estimating 95% survival rate):
• Replacements required: 5% of initial slips = 1,000–1,500 slips
• Timing: Within the first month (planting + immediate follow-up).
• Using planting productivity as stated above: Worker days range ≈ 1 – 5 worker days
• Total cost = labor(1*5) + replacement slips (1,000*0.05) + to labor(5*20) + replacement slips (1,500*0.1) → USD 55 - 250

Weeding
• Frequency: 1–3 rounds in Year 1
• Productivity: 50–100 m of hedge per worker-day.
• Total hedge length: 1,000 m → 10–20 worker-days per round.
• Worker-days range: 20–60 worker-days.
• Total cost = 20*5 to 60*20 → USD 250 – USD 1200

Pruning
• Timing: 1–2 trims in the first 10 months (depends on growth).</td><td>USD 390 – USD 2,170</td><td>Low</td><td>Vetiver Grass Technical Specification

Local expertise

Fanya Juu – Greener.Land</td></tr>
</table>

	Cost category	Key Assumptions	Indicative cost range[75] (USD / ha)	Confidence Level	Data source
		• Worker-days for pruning: 10–20 worker-days/year. • Total cost = 10*5 to 20*20 → USD 50 – USD 400			
	Major repairs	• Light earthworks after heavy rains (2 events/year) • No heavy machinery; manual + small equipment • Total labor: 10–60 worker-days depending on severity • 2 skilled supervisor days/year • Total cost = 10*5 + 2*50 to 60*20+2*250	USD 150 – USD 1,700	Medium	Manuel de gestion des bassins versants au Burundi, 2021 Local expertise
	Monitoring & reporting	• Skilled labor: weekly for 6 weeks, then monthly for remainder of year. • Total labor: 16 worker-days: • Total cost = 16*50 to 16*250.	USD 800 – USD 4,000	Low	Manuel de gestion des bassins versants au Burundi, 2021 Local expertise
	Total OPEX		USD 1,340 – USD 7,870		

The USD 5,820–17,485/ha CAPEX range confirms that progressive vetiver terraces sit in the low-to-moderate investment bracket for slope stabilisation in Mfilou, with a cost structure dominated by logistics/equipment (notably truck hire and transport duration) and labour rather than specialised materials. This profile makes the practice well suited for progressive roll-out on priority slopes, because most inputs can be mobilised locally (slips, hand tools, community labour), while still delivering meaningful runoff and erosion control when correctly laid out on the contour. In practical terms, vetiver terraces are a strong "workhorse" measure to deploy early—provided the project reduces the main uncertainty drivers through quick market testing (truck/day rates, realistic mobilisation days, wage assumptions) and ensures basic technical quality control (contour marking, spacing, trench depth, and early watering/mulching to secure establishment and avoid rework).

Practice 4 - Wooden Check dams (Site A and Site B)

Table 19. Cost range of wooden check dams

	Cost category	Key Assumptions	Indicative cost range (USD/100m)	Confidence Level	Data source

CAPEX	Materials	• **Cost profile calculated for a 100m linear stretch**
		• **Ravine geometry**: 3 m width, 2 m depth, total length considered = 100 m.
		• **Total surface** : 300 m^2
		• **Total volume:** 600m^3
		• **Spacing**: 1 dam every 5 m → 21 dams.
		• **Design**:
		  o Posts: hardwood, 1.5–2 m length, diameter ≥8 cm; 6 posts/dam → 126 posts.
		  o Bamboo culms: 3 per dam → 63 logs.
		  o Binding wire: ~105 m total.
		  o Vegetative reinforcement Bamboo cuttings or rhizomes for stabilization: 30 per dam
		• **Unit costs:**
		  o Posts: USD 6–12 each.
		  o Bamboo culms: USD 4–7 each.
		  o Binding wire: USD 0.5 – 1 per meter
		  o Bamboo cuttings: USD 0.05–0.1 each.
		
		Total cost = post(126*6) + bamboo culms(63*4) + binding wire(105*0.5) + added vegetation(630*0.05) to post(126*12) + bamboo culms(63*7) + binding wire(105*1) + added vegetation(630*0.1)
			Posts: $756–$1,512
			
			Bamboo culms: $252–$441
			
			Binding wire and rope: $52–$105
			
			Bamboo cuttings: $31–$63
			
			Material total estimate: USD 1,091– USD 2,121
				Medium	FAO watershed management field manual
					
					Directives et bonnes pratiques de gestion durable des terres au Burundi, 2016
					
					Manuel de gestion des bassins versants au Burundi, 2021
					
					Manuel sur les risques hydrogéologiques et inondations au Burundi, 2021
					
					Bamboo Price in Republic of the Congo - November 2025 Market Prices (Updated Daily)
					
					Overview of timber sector of the Republic of the Congo
					
					Local expertise

	Equipment & Tools	• Purchase/utilization of wheelbarrows, shovels, pickaxes, saws, hammers, etc. estimate USD 500-800 for the project • Transport of logs and other materials + cuttings from nursery to site (estimated within a radius of 10–15 km): truck rental for 5-10 days including fuel at USD 250 - 400/truck-day • Total cost = 500 + 5*250 to 800 + 10*400	USD 1,750 – USD 4,800	Low	Lorry & Truck leasing, Machinery Hire in Congo | Car Rental Congo Local expertise

	Cost category	Key Assumptions	Indicative cost range (USD/100m)	Confidence Level	Data source
	Labor	**Productivity**: • 1 worker installs 2 dams/day → 0.5 worker-days per dam. **Total worker-days:** • Unskilled = 10.5 worker-days (rate = 5 – 20 USD/day) • Skilled = 1–2 worker-days for supervision (rate = 20 – 250 USD/day) **Total cost** = 10.5*5 + 1*50 to 10.5*20 + 2*250	USD 102 – USD 710	Low	Manuel de gestion des bassins versants au Burundi, 2021 Manuel sur les risques hydrogéologiques et inondations au Burundi, 2021 Local expertise
	Contingency	• For landscaping and NbS measures at the prefeasibility stage = usually 20% – 30% • Total cost = 20% of lower bound of sum of materials + labor + equipment and tools and 30% of upper bound of same categories	USD 589 – USD 2,289	High	Report-Toolbox-on-Financing-Nature-Based-Solutions.pdf View of NbS experts
	Total CAPEX		**USD 3,533 – USD 9,920**		
OPEX	Routine operations & maintenance	• **Bamboo maintenance**: 3–10 worker-days/year (unskilled) • **Dam maintenance**: 10–20 worker-days/year (unskilled) • **Supervision**: 5 worker-day/year (skilled) **Daily wages:** • Skilled labor: $50 - $250 • Unskilled labor: $5 - $20. **Total cost =** (3+10)*5 + 5*50 to (10+20)*20 + 5*250	USD 315 – USD 1,850	Low	Manuel de gestion des bassins versants au Burundi, 2021 Manuel sur les risques hydrogéologiques et inondations au Burundi, 2021 Local expertise
OPEX	Major repairs	• Light earthworks after heavy rains (2 events/year) • No heavy machinery; manual + small equipment • Total labor: 5–30 worker-days depending on severity • 2 skilled supervisor days/year • Total cost = 5*5 + 2*50 to 30*20+2*250	USD 125 – USD 1,100	Low	Manuel de gestion des bassins versants au Burundi, 2021 Manuel sur les risques hydrogéologiques et inondations au Burundi, 2021 Local expertise

Cost category	Key Assumptions	Indicative cost range (USD/100m)	Confidence Level	Data source
Monitoring & reporting	• Skilled labor: weekly for 6 weeks, then monthly for remainder of year. • Total labor: 16 worker-days: • Total cost = 16*50 to 16*250	USD 800 – USD 4,000	Low	Manuel de gestion des bassins versants au Burundi, 2021 Manuel sur les risques hydrogéologiques et inondations au Burundi, 2021 Local expertise
Total OPEX		USD 1,240 – USD 6,950		

Wooden check dams remain a relatively low-to-moderate CAPEX option per treated gully length, particularly when posts/bamboo can be sourced locally and construction relies on local labour. The cost structure is dominated by installation, with periodic but predictable O&M (repairs after storm events, sediment clearing, and supervision). This points to check dams as a strong early-phase sediment-control measure in the most active gullies, especially when paired with upstream runoff controls (e.g., swales/hedgerows) to avoid repeated blowouts and to extend asset life.

Practice 5 - Rock stilling basin (Site B)

Table 20. Cost range of rock stilling basin

	Cost Category	Key Assumptions	Indicative Cost Range[76] (USD/450m³)	Confidence Level	Data Source
CAPEX	Materials	Key assumptions of basin characteristics • Assume 1 basin for each gully head cut = 3 basins. • Each gully is large, approximately 4 m wide and 2 m deep at the head cut. • Each basin will measure about 10 m in length, 5 m in width, and 1 m in depth (excavated below the existing bed) = 150m2 footprint, 150m3 excavation. • Total surface for cost profile = 450m³ Materials • Rock requirement per basin: 30–40 m³ of angular riprap (D50 = 200–300 mm) = 90–120 m³ at USD 35–50/m³. • Cost range = (90*35) to (120*50) = USD 3,150 to USD 6,000 • Geotextile requirement per basin: 50–60 m² → 150–180 m² at USD 2–4/m². • Cost range = (150*2) to (180*4) = USD 300 to USD 720 • Bedding layer: 15–30 m³ at USD 20–30/m³. • Cost range = (45*20) to (90*30) = USD 900 to USD 2,700	USD 4,350 - USD 9,420	Medium	8. Feasibility-level Cost and Implication Analysis.pdf Rip Rap Cost Guide: Typical Price Ranges in the U.S. – Adnan Painting and Remodeling Prix en République du Congo de m² de Géotextile tissé. Générateur de prix de la construction. CYPE Ingenieros, S.A. How Much Is Geotextile Price Per Square Meter – Geotextile, Geotextile Fabric, Non Woven Geotextile, Woven Geotextile https://www.fao.org/4/ad082e/AD082e00.htm https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/PAP/PAP-0790.pdf https://directives.nrcs.usda.gov/sites/default/files2/1712931137/7360.pdf https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1800012227_UCM2018_User_Guide.pdf
	Equipment & Transport	Transport: • Truck rental for 10 - 15 days including fuel at USD 250 - 400/truck-day • Cost range = (10*250) to (15*400) → USD 2,500 to USD 6,000 Equipments • Excavator for 3–5 days per basin → 9–15 days at USD 250–400/day.	USD 4,750 – USD 12,000	Low	

[76] Estimate costs are from local expertise and international cost estimates that are scaled using GDP per capita (PPP) ratios to approximate local labor and implementation costs. While this method introduces uncertainty, it is commonly used in preliminary economic assessments and allows for consistent comparison across intervention

	Cost Category	Key Assumptions	Indicative Cost Range[76] (USD/450m³)	Confidence Level	Data Source
		• Cost range = (9*250) to (15*400) → **USD 2,250 to USD 6,000**			Lorry & Truck leasing, Machinery Hire in Congo | Car Rental Congo (PDF) stilling basin Design & construction Local expertise
	Labor	• 20–30 worker-days per basin for unskilled labor and 5–10 skilled days for supervision. • Unskilled: 60–90 worker-days at USD 5–20/day. • Skilled: 15–30 worker-days at USD 50–250/day. • Total cost range = 60*5 + 15*50 to 90*20 + 30*250	USD 1,050 – USD 9,300	Low	
	Design & Engineering	• Hydraulic design and supervision: 30–40 days at USD 50–250/day.	USD 1,500 – USD 10,000	Low	
	Contingency	• For landscaping and NbS measures at the prefeasibility stage = usually 20% – 30% • Total cost = 20% of lower bound of sum of materials + labor + equipment and tools and 30% of upper bound of same categories	USD 2,330–USD 12,216	High	Report-Toolbox-on-Financing-Nature-Based-Solutions.pdf View of NbS experts
	Total CAPEX		USD 12,980 – USD 52,936		
OPEX	Routine Maintenance	• Inspection by skilled labor 6/year • Minor rock resetting: 6–12 worker-days/year. • Cost range = 6*50 + 6*5 to 6*250 + 12*20	USD 330 – USD 1,740	Low	8. Feasibility-level Cost and Implication Analysis.pdf Rip Rap Cost Guide: Typical Price Ranges in the U.S. – Adnan Painting and Remodeling Prix en République du Congo de m² de Géotextile tissé. Générateur de prix de la construction. CYPE Ingenieros, S.A.
	Major Repairs	• Assume 1 once a year after extreme events: replace 10–15% rock (9–18 m³) and re-key apron. • Labor: 10–15 worker-days unskilled + 2–3 worker-days skilled. • Coste range = 10*5 + 2*50 to 15*20 + 3*250	USD 150 – USD 1,050	Low	

	Cost Category	Key Assumptions	Indicative Cost Range[76] (USD/450m³)	Confidence Level	Data Source
	Monitoring & Reporting	• Twice/year visual checks and documentation. • Skilled labor: 2 worker-days/year	USD 100 – USD 500	Low	How Much Is Geotextile Price Per Square Meter - Geotextile, Geotextile Fabric, Non Woven Geotextile, Woven Geotextile https://www.fao.org/4/ad082e/AD082e00.htm https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/PAP/PAP-0790.pdf https://directives.nrcs.usda.gov/sites/default/files2/1712931137/7360.pdf https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1800012227_UCM2018_User_Guide.pdf Lorry & Truck leasing, Machinery Hire in Congo | Car Rental Congo (PDF) stilling basin Design & construction Local expertise
	Total OPEX		USD 580 – USD 3,290		

Rock stilling basins show moderate CAPEX with cost sensitivity driven mainly by rock volume, geotextile needs, and equipment/transport duration. This profile supports their use as high-priority head cut stabilization works where gully heads threaten houses, roads, or critical drainage lines—because performance benefits depend disproportionately on getting the geometry, excavation, and armoring correct. The table's "medium" confidence level also signals that site-specific surveys (gully dimensions, access constraints, rock availability) are likely to shift costs meaningfully; these should be treated as a required next step before final design and procurement.

- Benefits

Table 21. Benefits monetization of practices in Tsième Catchment in Mfilou, Brazzaville

Practice	Benefit	Key Estimations	Indicative Cost Range	Confidence Level	Source
Vegetated infiltration swales (Site A)	Avoided damage	Infiltration swales reduce peak runoff and localized flooding by enhancing infiltration and slowing stormwater flow. • Assume baseline flood damage ≈ USD 1,000/ha/yr • => Conversion from ha to 200 m2 (surface of the project) → 20 USD/yr • Add USD 300–500/ha/yr for avoided road and drainage system repairs • => Conversion from ha to 200 m2 → 6 – 20/yr	26 – 300 USD/100m/yr	Low	https://www.epa.gov/green-infrastructure/mitigate-flooding https://documents1.worldbank.org/curated/en/336371560797230631/pdf/Underutilized-Potential-The-Business-Costs-of-Unreliable-Infrastructure-in-Developing-Countries.pdf
	Carbon sequestration	• Infiltration swales with dense vegetation can sequester carbon, though less than wetlands. • Estimated sequestration ≈ 1.2 t C/ha/yr (~4.4 t CO_2/ha/yr). • Monetized at USD 50/t CO_2. • Based on general bioswale vegetation estimates and extrapolated from wetland studies => Conversion from ha to 200 m2: 4.4×0.02=0.088 t CO2/yr => Monetized value: 0.088×50=USD 4.4/yr	4 - 5 USD/100m/yr	Low	https://www.epa.gov/system/files/documents/2022-04/green-infrastructure-toolbox_biofiltration-swale.pdf
	Jobs gain	• Annual OPEX and one-off CAPEX (not annualized) = Skilled labor = 40 - 42 worker-days Unskilled labor = 170 – 200 worker days	2,850 – 14,500 USD/100m/yr	Low	Cost table
	Total		**2,880 – 14,805 USD/100m/yr**		
	Avoided damage	Hillsides with recurrent runoff/erosion; wall protects ~0.5–1 ha of adjacent cropland and farm access tracks.	700–1,500 USD/100m/yr	Low	B. Fidan, Y. Yenginar, and M. Olgun, "A CASE STUDY: COST-BENEFIT

Practice	Benefit	Key Estimations	Indicative Cost Range	Confidence Level	Source
Vegetated gabions (Site A and Site B)		• Prevented crop losses due to slope failure/runoff: USD 500–USD 1,000 per yr (typical smallholder income at risk). • Avoided repair of farm tracks/ditches and sediment clean-up: USD 200–USD 500 per yr. • Assumes 3–5 heavy rain events/yr; gabion + vegetation reduces face erosion and toe scour (consistent with NbS outcomes observed locally—see sources).			AND RISK ANALYSES OF GABION WALL FOR ROCKFALL PROTECTION METHOD IN BOZKIR, TURKEY", KONJES, vol. 12, no. 4, pp. 865–885, 2024, doi: 10.36306/konjes.1510650. Kumar, S., Garg, N., Das, S.K., Pandey, M. (2025). The Role and Impact of Gabion Weirs in River Management: A Systematic Review. In: Pandey, M., Umamahesh, N.V., Ahmad, Z., Valyrakis, M. (eds) Flood Forecasting and Hydraulic Structures. HYDRO 2023. Lecture Notes in Civil Engineering, vol 546. Springer, Singapore. https://doi.org/10.1007/978-981-97-9168-2_4 Local expertise Cost table
	Carbon sequestration	Species: Napier/Vetiver/Calliandra on/beside gabions; herbaceous/short shrubs store limited biomass; primary function is root reinforcement, not carbon. • Net sequestration effect considered non-material relative to forests or woodlots; monitoring would likely show ≈ 0 tCO_2/yr.	0 USD/100m/yr	Low	
	Jobs gain	CAPEX (Design + Construction) • Site survey, design, permitting, supervision: — 50 skilled worker-days at USD 50–USD 250/day — USD 2,500 – USD 12,500 • Construction labor (estimating local materials and light excavation): — Skilled labor: 20–25 worker-days at USD 15–USD 20/day → USD 300 – USD 500 — Unskilled labor: 100–120 worker-days at USD 3–USD 5/day → USD 300 – USD 600 OPEX: • Unskilled labor: 20 worker-day/year • Skilled labor: 12 worker-day/year	2,009 –5,955 USD/100m/yr	Low	
	Total		2,709 – 7,455 USD/100m/year		

Practice	Benefit	Key Estimations	Indicative Cost Range	Confidence Level	Source
Vegetated progressive terraces with vetiver (Site A and Site B)	Avoided damage	• Hedgerows reduce runoff and erosion; field evidence shows ~40–50% yield increase. • Baseline crop revenue ≈ USD 1,000/ha/yr → avoided loss ≈ USD 400–500/ha/yr. • Add USD 50–100/ha/yr for minor avoided infrastructure repairs.	450–600 USD/ha/yr	Low	Vetiver grass—most cost-efficient soil erosion control doubles crop yield -
	Carbon sequestration	• Vetiver ≈ 2 t C/ha/yr (~7.3 t CO_2/ha/yr). • Monetized at USD 50/t CO_2.	365 USD/ha/yr	Low	Carbon sequestration – The Vetiver Network International
	Jobs gain	CAPEX (Design + Construction) • Unskilled labor: Estimated: 100 worker-days/ha • Skilled labor: 7 worker-days/ha OPEX: • Unskilled labor: 161.1 worker-days/year • Skilled labor: 18 worker-days/year	2,555 – 11,472 USD/ha/yr	Low	Cost table
	Total		3,370 –12,437 USD/ha/yr		
Wooden Check dams (Site A and Site B)	Avoided damage	• Check dams + vetiver slow runoff, trap sediment, protect farmland/infrastructure. • Typical avoided damage: USD 500–1,000/100m/yr.	500–1,000 USD/100m/yr	Low	https://www.encardio.com/blog/modern-check-dams-benefits-challenges-success https://topsoil.nserl.purdue.edu/isco/isco13/PAPERS%20R-Z/TRUONG.pdf
	Carbon sequestration	• Sediment trapping buries: 17.2 t CO_2/ha/year → scaled to 100 m = 0.172 t CO_2/year • Bamboo adds:	12 USD/100m/yr	Low	Carbon balance in the life cycle of wood: targeting a timber check dam | Journal of Wood Science | Full Text Substantial role of check dams

Practice	Benefit	Key Estimations	Indicative Cost Range	Confidence Level	Source
		~7.3 t CO_2/ha/year → scaled to 100 m = 0.073 t CO_2/year • Combined: ~24 t CO_2/ha/year → scaled to 100 m = 0.24 t CO_2/year • Value at USD 50/t: 0.24 × 50 = USD 12/year per 100 m			in sediment trapping and carbon sequestration on the Chinese Loess Plateau https://topsoil.nserl.purdue.edu/isco/isco13/PAPERS%20R-Z/TRUONG.pdf
	Jobs gain	For CAPEX and OPEX: • Total unskilled: ≈ 24–91 worker-days/year • Total skilled: ≈ 4.1–4.2 worker-days/year	325–2,870 USD/10m/yr	Low	Cost table
	Total		**1,720–2,260 USD/100m/yr**		
Rock stilling basin (Site B)	Avoided damage	• Assume number of households at risk: 30 homes located near gully heads. • Average damage per household if gully expands: Studies in DRC and Nigeria show homes lost to gully erosion often cost \$4,000–\$5,000 per household in property damage and relocation costs. • Assume numbers of road segments at risk: 10 segments (local roads or culverts). • Average repair cost per damaged road segment: Road failure due to gully erosion can cost \$10,000–\$50,000 per segment depending on severity and length. • Assume a one-time cost avoided over 10 years • 30 households × \$4,000–\$5,000 = \$120,000–\$150,000 → \$12,000–\$15,000 for 1 year • 10 road segments × \$10,000–\$50,000 = \$100,000–\$500,000 → \$10,000–\$50,000 for 1 year	22,000–65,000 USD/450m³/yr		Mapping urban gullies in the Democratic Republic of the Congo | Nature Economic impacts of an urban gully are driven by land degradation | Natural Hazards The cost of soil erosion in sub-Saharan Africa: Why the time to act is now - CGIAR Effectiveness of measures aiming to stabilize urban gullies in tropical cities: Results from field surveys across D.R. Congo - ScienceDirect chapter 14 JM
	Carbon sequestration	No vegetation associated to the practice	0 USD/450m³/yr		

Practice	Benefit	Key Estimations	Indicative Cost Range	Confidence Level	Source
	Jobs gain	• 1 off: CAPEX: 60–90 unskilled + 15–30 skilled worker-days • OPEX: ~16–23 unskilled + 4 - 5 skilled worker-days	385 – 1,392 USD/450m³/yr	Low	Cost table
	Total		22,385 – 66,392 USD/450m³/yr		

The monetized benefit estimates suggest that—across practices—avoided damage is likely to represent the main contributor to the economic rationale (asset protection, avoided repair costs, reduced loss exposure). Carbon values appear relatively small at the unit scales assessed (100 m / ha), and employment effects are present but are best considered as socio-economic co-benefits rather than a core economic driver. Given that the avoided-damage component plays a major role in shaping the overall benefit envelope, interventions are generally expected to be most compelling in areas with higher exposure and where physical performance can realistically be maintained (e.g., feasible maintenance access and workable institutional arrangements).

It should be kept in mind that these interpretations depend on multiple assumptions and therefore carry a natural degree of uncertainty, which is typical at a prefeasibility stage. The results are therefore indicative, helping to guide prioritisation rather than providing definitive valuations.

- <u>Benefit-Cost Ratio</u>

Table 22. Annual benefits, costs and BCR of each practice in the Tsième Catchment in Mfilou, Brazzaville

Practice	Total CAPEX ($)	Annualized CAPEX ($/yr)	OPEX ($/yr)	Total Annual Cost ($/yr)	Annual Benefit ($/yr)	BCR Low	BCR High
Vegetated infiltration swales (Site A and Site B border)	6,990 – 22,295 (USD/100m)	905 – 2,889 (USD/100m)	1,575 – 7,350 (USD/100m)	2,480 – 10,239 (USD/100m)	2,880 – 14,805 (USD/100m)	0.28	5.97
Vegetated gabions (Site A and Site B)	12,110 – 30,095 (USD/100m)	1,568 – 3,900 (USD/100m)	1,271.50 – 5,276.50 (USD/100m)	2,839 – 9,176 (USD/100m)	2,709 – 7,455 (USD/100m)	0.3	2.63
Progressive vegetated terraces with vetiver (Site A and Site B)	5,820 –17,485 (USD/ha)	754 – 2,267 (USD/ha)	1,340 – 7,870 (USD/ha)	2,094 – 10,137 (USD/ha)	3,370 –12,437 (USD/ha)	0.33	5.94
Wooden Check dams (Site A and Site B)	3,533.5 – 9,920 (USD/100m)	458 – 1,285 (USD/100m)	1,240 – 6,950 (USD/100m)	1,698 – 8,235 (USD/100m)	1,720–2,260 (USD/100m)	0.21	1.33
Rock stilling basin (Site B)	12,980 – 52,936 (USD/450m^3)	1,681 – 6,859 (USD/450m^3)	580 – 3,290 (USD/450m^3)	2,261 – 10,149 (USD/450m^3)	22,385 – 66,392 (USD/450m^3)	2.21	20.36

According to the BCR estimates for the proposed interventions (Table 22), the practices show significant variability in economic viability:

- Vegetated infiltration swales have a BCR range of 0.28–5.97. While the upper bound suggests strong economic justification under favorable conditions, the lower bound is well below 1, indicating that costs may outweigh benefits in conservative scenarios. This wide range is mainly due to large variations in cost estimates, particularly daily wages for skilled labor, which range from USD 50 to 250—and material prices. Such variability introduces uncertainty because the true cost could fall anywhere within this broad interval.
- Vegetated gabions exhibit a BCR range of 0.30–2.63, suggesting moderate economic potential. The high-end scenario indicates viability, but the low-end scenario is below 1. Again, the wide range reflects uncertainty in both cost and benefit assumptions, driven by inconsistent data sources and generic estimates rather than site-specific figures.
- Vetiver terraces show a BCR range of 0.33–5.94, indicating that benefits can significantly exceed costs under favorable conditions. However, the large spread between low and high values signals sensitivity to assumptions about avoided damage and co-benefits, combined with variability in labor and material costs.
- Wooden check dams have a BCR range of 0.21–1.33, suggesting limited economic viability except in optimized scenarios or when combined with complementary interventions. The low-end scenario is well below 1, highlighting the importance of careful site selection and cost control.
- Rock stilling basins stand out with a BCR range of 2.21–29.36, indicating very high potential benefits relative to costs. However, these results should be interpreted with caution. The high BCR is largely driven by extensive data availability for the quantification of co-benefits—especially avoided damage—for this type of grey infrastructure, which is better documented than nature-based solutions.

The BCR ranges indicate clear differentiation between (i) measures that are robustly viable under most scenarios and (ii) measures that are viable only under favorable assumptions (high realized benefits and/or lower delivered costs). This strongly supports a phased investment strategy: start with the measures that show the strongest BCRs and implementation readiness, then expand into complementary measures once (a) safeguards and land access are secured, (b) detailed designs have reduced cost uncertainty, and (c) an O&M system is demonstrably operational.

Implementation (Governance, Legal, and Institutional Aspects)

Description of governance and institutional roles, legal and policy alignment and potential funding and readiness.

To establish an implementation framework for the implementation of NbSWLM practices in Ngambio and Itsali, it is necessary to understand its administrative organization. Both neighborhoods fall under the 7e district of Brazzaville (Mfilou), administered by:

- Arrondissement Municipality (Mairie)
- Chefs de quartiers and chefs d'unités, supported by local notables
- Community committees, often active on environmental issues and mobilization

These authorities play a key role in regulating land occupation and construction, mediating land disputes and managing relocation during environmental risks, mobilizing residents for erosion and flood prevention initiatives, and collaborating with the municipality and technical partners.

Regarding the stakeholders' landscape and aligned with the stakeholder engagement plan of SURP[77], it can be establishing the following stakeholders:

- Primary affected groups: Local communities in Ngambio and Itsali (Mfilou-Brazzaville)
- Sub-groups: Customary and religious authorities, men and women from beneficiary communities, youth organizations, NGOs, civil society, transport associations, and vulnerable groups
- Secondary stakeholders: PIU, technical teams, contractors, and partner enterprises

Based on this, it is possible to define governance coordination mechanism for the implementation of NbSWLM practices in both sites of Mfilou, guided by existing national legal frameworks and climate adaptation policies, and local urban plan managements.

- Lead Agency: Municipality of Brazzaville (Mfilou), supported by the Direction des Grand Travaux (PIU under the World Bank SURP).
- Key actors and their roles are:
    - Municipality: Charged of procurement, supervision, integration with drainage works
    - CGDCs (Comités de Gestion et Développement Communautaire): Local monitoring of practices, minor maintenance, and reporting of damages and necessary interventions.
    - Chefs de quartiers and unit leaders: Community mobilization and conflict resolution
    - NGOs/CBOs: Training and technical support.

It is important to ensure that all stakeholders are engaged. If full mobilization is not possible, CGDCs could be involved as local monitoring bodies. Each NbSWLM practice could be linked to a rapid response mechanism (*who, what, how*) in the framework of a maintenance plan, to establish intervention teams (group of training community representative) for urgent repairs or emergencies. For this, short training modules for CGDCs and municipal teams can be delivered on NbSWLM maintenance.

Likewise, to ensure legacy of the practice it is necessary to strengthen awareness campaigns on the role of nature to mitigate flood and erosion, to secure community buy-in and ensure durability of works.

---

[77] Borrowing Agency. 2025. Stakeholder Engagement Plan (SEP) - Strengthening Urban Resilience Project - P179190 (English). Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099100525220020214

The governance structure will operate within the framework of national laws on environment, water management, urban planning, and decentralization, ensuring compliance and legitimacy. Currently, the RoC count on legal and policy frameworks that support the implementation of the proposed interventions. Some of these frameworks are:

- Law No. 003-1991 on Environmental Protection (Loi sur la Protection de l'Environnement), which establishes principles for environmental conservation and sustainable land use; supports interventions aimed at reducing soil erosion, protecting water resources, and restoring degraded ecosystems; and requires EIA for projects involving earthworks or vegetation changes—relevant for terraces, gabions, and stilling basins.
- Law No. 16-2000 on Water Management (Code de l'Eau), regulates water resources and drainage systems, aligns with NbSWLM practices that improve stormwater management (e.g., infiltration swales, check dams, stilling basins) and encourages measures that prevent flooding and protect water quality.
- Law No. 6-2009 on Urban planning and land tenure regulations (Code de l'Urbanisme et de l'Aménagement du Territoire), provides rules for land use and construction in urban areas; supports slope stabilization and erosion control measures as part of integrated urban development plans; and requires coordination with municipal authorities for interventions in informal settlements.
- National Climate Change Adaptation Strategy (SNACC), promotes NbS for climate resilience, and encourages integrated watershed management and green infrastructure—directly relevant to your NbSWLM practices.
- Forest and vegetation management law (Loi sur la Forêt et la Biodiversité), supports reforestation and vegetation-based stabilization (e.g., vetiver, bamboo, Acacia), and provides guidelines for species selection and biodiversity conservation.
- Decentralization Law (Loi sur la Décentralisation), empowers local authorities and community committees (CGDC) to manage environmental risks, and creates an enabling framework for community-based maintenance agreements and participatory governance. This law legitimizes CGDC involvement in monitoring and maintenance of NbSWLM practices.

The initiative of development of NbSWLM practices proposed in this compendium, are aligned with the principles and objective of the Territorial Climate Plan of Brazzaville (PACT), which is currently under development, by the Brazzaville City Hall and the French Agency of Development (AFD); and where the preparation of the city to the impacts of the climate change stands as a priority action to protect and ensure the long term sustainability of the territory.

Some funding and partnership options for financing NbSWLM implementation and maintenance may include municipal budgets, subventions from MDBs such as the AFD, or World Bank through the SURP project, donor grants, climate adaptation windows, or community co-finance and NGO contributions.

To facilitate decision-making and ensure a smooth transition from this Compendium to implementation, the following table outlines high-level next steps for the integrated restoration activities of Tsième catchment in Ngambio and Itsali. These steps provide a clear roadmap for sequencing activities, assigning responsibilities, and estimating indicative timelines. While detailed engineering and safeguards planning will follow during the feasibility stage, this overview helps stakeholders understand the immediate actions required to operationalize the proposed NbSWLM interventions.

Table 23. Next steps for implementation of NbSWLM practices for restoration of Tsième catchment.

Activity	Description	Responsible Entity	Indicative Timing
Detailed Feasibility study	Conduct hydrological modeling, geotechnical surveys, and finalize design for integrated NbSWLM package (swales, gabions,	Direction des Grands Travaux with municipal engineers; support could be provided by World Bank or AFD	6–12 months

Activity	Description	Responsible Entity	Indicative Timing
	terraces, check dams, stilling basins).		
	Assess viability of infiltration swales only within an integrated stormwater management system, considering malaria risk, pedestrian access, waste disposal, and potential gully initiation. Include design safeguards or propose alternatives if risks are high.	Direction des Grands Travaux, Brazzaville municipality	4 months
Define Governance & Maintenance Mechanism	Establish clear roles for implementation oversight and long-term O&M of each practice; include CGDC budget transfer and private-sector engagement (CSR).	Municipality of Brazzaville (Mfilou District) in coordination with the Direction of Grand Travaux, and support from NGOs and technical partners	3-4 months (parallel to feasibility stage)
Safeguards & Land Access	Validate land tenure and community agreements.	Municipality of Brazzaville (Mfilou District) and Social Safeguards Specialists	Parallel to feasibility stage
Budget Allocation & Financing	Secure funding for CAPEX and OPEX; define CGDC budget transfer mechanism; explore co-financing options (municipal + donors).	Municipality of Brazzaville (Mfilou District), Ministry of Finance	6 months
Capacity Building	Train CGDCs and municipal teams on NbSWLM maintenance, financial management, and rapid-response protocols.	Municipality + NGOs + Technical Partners Before implementation of practices (2–3 months)	Year 1
Community Validation	Engage local communities to review proposed designs, especially for practices affecting mobility (e.g., terracing), and incorporate feedback into final plans.	CGDCs + Social Safeguards specialists of municipality	Parallel to feasibility stage

Activity	Description	Responsible Entity	Indicative Timing
Monitoring & Adaptive Management	Establish performance indicators (erosion reduction, infiltration rates, maintenance compliance); update designs based on lessons learned.	Municipality of Brazzaville (Mfilou District)	Continuous

Modularity, replicability and enabling conditions

NbSWLM interventions in Ngambio and Itsali are designed to be modular, allowing phased implementation and integration with future drainage infrastructure or urban development plans. Modular approaches provide flexibility in contexts where investment plans are evolving, enabling:

- Phased deployment starting with critical erosion hotspots.
- Independent replication of components such as infiltration swales, vegetated terraces, gabions, and stilling basins.
- Integration with larger-scale works (e.g., collectors, retention basins) under SURP or other programs.

This modularity ensures adaptability to budget constraints and facilitates scaling across similar urban catchments.

The conditions observed in Ngambio and Itsali—steep slopes, sandy soils, uncontrolled runoff, and high exposure of informal settlements—are representative of many peri-urban areas in Brazzaville and Pointe-Noire. Demonstrating successful implementation here provides strong proof of concept for replication in other sites with similar geomorphological, environmental, and socio-economic characteristics. Key assumptions for replication include:

- Environmental suitability: Similar hazard context (gully erosion, flash floods) and soil types (sand).
- Land tenure: Feasible land access and absence of major conflicts.
- Institutional capacity: Presence of municipal structures and community committees (CGDCs) for maintenance.
- Policy alignment: Compliance with national laws on environment, water management, and decentralization.
- Community engagement: Willingness of residents to participate in maintenance and protect vegetative cover.
- Technical resources: Availability of local materials (stones, vegetation) and trained labor.

Scaling NbSWLM practices require technical guidelines and training materials for municipalities and CGDCs (the community training manual developed in the framework of this technical assistance, including implementation and maintenance activities can be used for this purpose), demonstrated effectiveness through monitoring of pilot sites in Ngambio and Itsali, policy endorsement under the National Climate Change Adaptation Strategy and urban planning frameworks and capacity-building mechanisms for local actors and integration into municipal budgets or donor programs.

Subject to data availability, potential replication sites can be identified using hazard maps and the World Bank's investment site list, prioritizing areas with similar topography and erosion dynamics.

6.2 Linear green corridor, Pointe Noire (Site C)

The proposed intervention focuses on a 3.4 km river corridor in Mulumba, a central district of Pointe-Noire. This corridor includes the final segments of the Tchikobo River (2.7 km, flowing south–north) and the Songolo River (0.7 km, flowing east–west), which converge near the city center before reaching the Atlantic Ocean (Figure 20). The rivers cross densely populated neighborhoods and are flanked by floodplains that have been progressively occupied by residential and industrial developments, increasing flood risk.

Following the natural waterflow along the Tchikobo river, the starting point of the target area is located at the Case du Parti and it ends at the point along the Songolo river where its floodplain widens into a mangrove forest. Within the target area the river segments are crossed by two main traffic bridges, the Saint-Christophe et le Pont Songolo bridges, respectively crossing the Tchikobo and Songolo segments. Additionally, aerial imagery (Google Earth) reveals several pedestrian crossings along the Tchikobo section.

Figure 20. (left) Urban map of Pointe-Noire city center with Tchikobo and Songolo river stretches comprising target area C and (right) District map of the city District. Source: www.lepratiqueducongo.com/plan-de-pointe-noire/.

Socio-economic context

The intervention area lies in a high-density urban zone of Pointe-Noire, characterized by high population density, sustained demographic growth, and strong real estate pressure exerted by the unplanned expansion of housing. The study area covers three administrative sectors:

- Songolo neighbourhood with a population of approximately 6,000 inhabitants (Mongo-Mpoukou district)
- Saint-Christophe neighbourhood with a population of a little over 12,000 (Mvou-Mvou district)
- The Mayaka market area and Mvou-Mvou market with a population of around 12,000 inhabitants (fringe between Mvou-Mvou and Loandjili)

Based on the average densities of these neighborhoods and the linear footprint of the project, the population directly or indirectly concerned is estimated between 10,000 and 25,000 inhabitants. The population is characterized by a high representation of young people (approximately 55% are under 25) and a strong presence of school-age children (public and private schools, catch-up centers). The active population mainly develops its work informally, in small commerce (Saint-Christophe and Songolo roads), food commerce around transport routes, small craft workshops and garages, urban transport (moto-taxi), and informal sand mining in certain sections. A strong presence of women traders around the Mayaka market should be noted.

Households are characterized by their large size, with the following aspects observed:

- 5 to 7 people on average
- Often several families sharing the same plot or house
- Presence of vulnerable populations: Precarious workers households in the flood zone, tenants without formal contracts, female-headed households, and dependent elderly people

In conclusion, despite being the economic capital of the country, Pointe-Noire, the population residing in the area in and around the study zone, very likely in the dwellings occupying the areas susceptible to flooding along the Tchikobo River, can be classified as vulnerable.

Density and Land Use

The housing, which is dense and often informal, has been built progressively without an urban plan. There is a close proximity to the Tchikobo riverbed, with dwellings installed on the flood plain. The plots are small (80–200 m²), with maximum land occupation, and a low presence of open spaces or green areas. Downstream, toward Songolo, the density decreases slightly but remains high.

The social issues/stakes associated with developing the green corridor along the watercourse would be:

- The mitigation of the high exposure to floods and bank collapses.
- Health risks related to river pollution.
- The need for a participatory project to avoid expropriation conflicts.
- A major opportunity to create accessible green spaces in a dense area.

It should be indicated that the surroundings of the target area are of high mobility by local residents. This flow results in intense movement between the districts of Loandjili and Mvou-Mvou, with residents crossing the river daily via the Saint-Christophe and Songolo bridges.

Geographic context

The Tchikobo and Songolo river segments that comprise the target area of this case are located in the Lumumba District of Pointe-Noire, in the center of the town. The area is characterized by a flat, low-lying catchment with gentle slopes trending east-west direction toward the sea, and south north from Case du Parti to the Songolo bridge. The Saint Christophe bridge is also a higher component within the comprehensive topographical pattern. Figure 21 illustrates the altitude distribution, conforming the overall flat morphology with slight elevation changes.

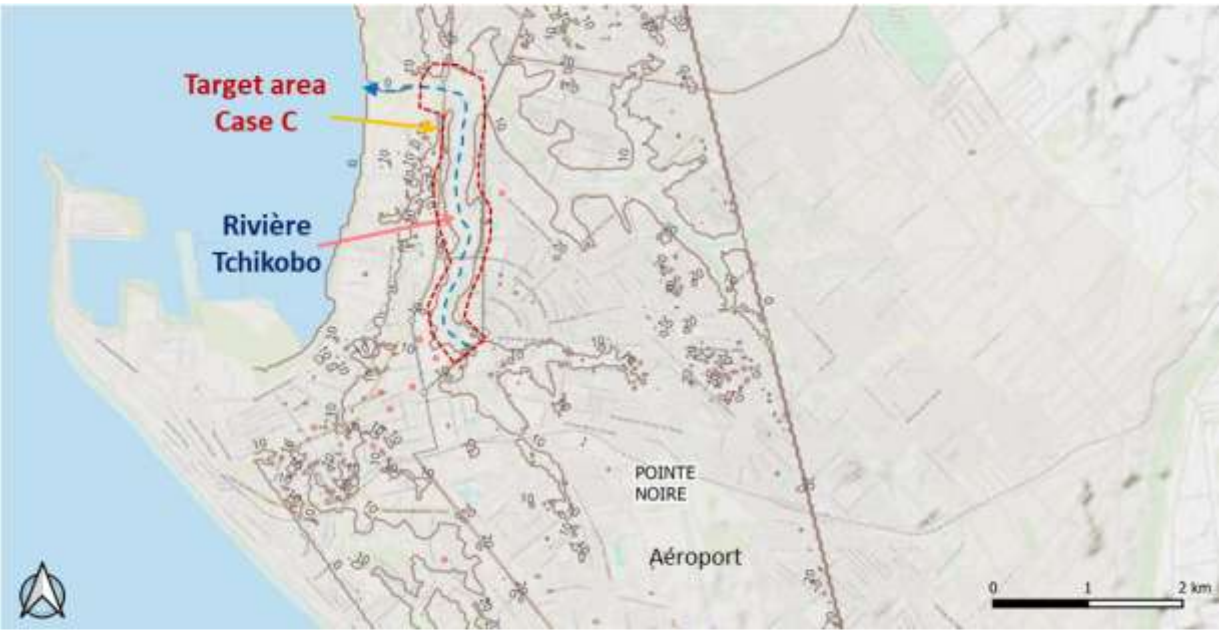


Figure 21. Altitude map for the Case C target area along the Tchikobo and Songolo rivers. Source: Authors.

Figure 22 shows the slope map, which indicated gradients mostly below 5º, with occasional narrow highlighted linear strips reaching 5 to 10º. These alignments, observed along the river course and the site C of intervention, suggest the presence of elevated floodplain borders. Combined with dense urbanization, this topography creates high susceptibility to rapid flooding and unmanaged runoff.

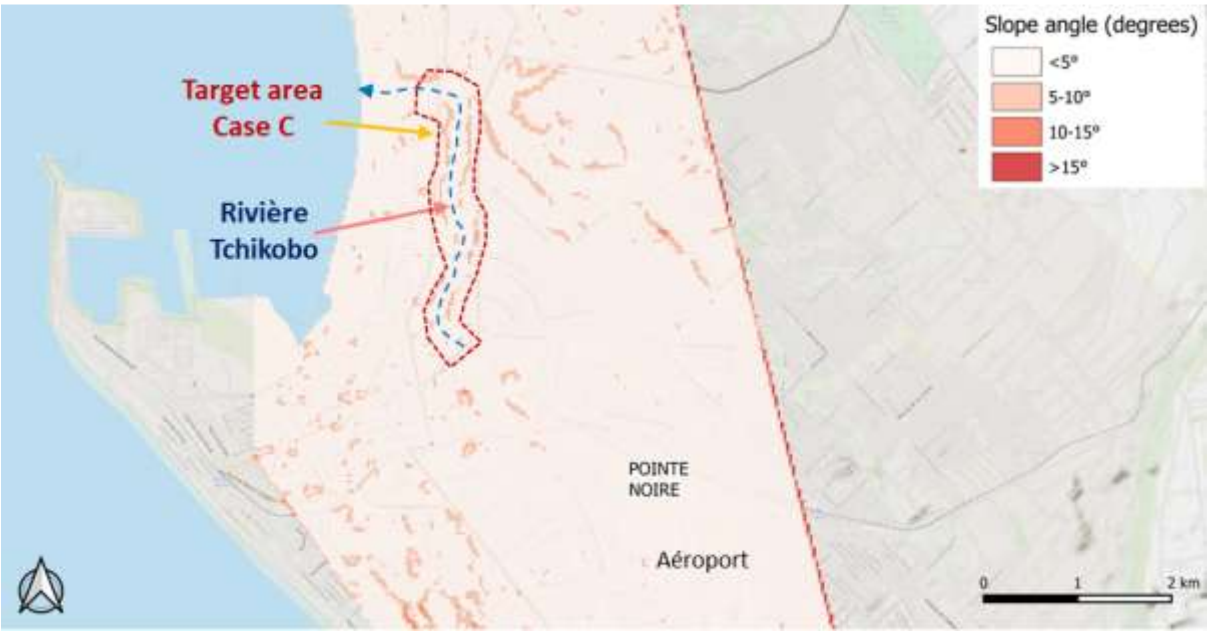


Figure 22. Slope map for the Case C target area along the Tchikobo and Songolo rivers. Source: Authors.

The targeted watercourses cross other administrative neighborhoods, in addition to Lumumba: 202, 201, 501, and 505 of the Loandjili district, as well as Mongo-Mpoukou and Mvou-Mvou in Pointe-Noire. This natural axis constitutes a strategic, highly urbanized, and heavily degraded runoff corridor, but one that offers major potential for the development of a multifunctional ecological corridor.

The morphology of the sector is characterized by:

- An incised riverbed, sometimes very narrow and obstructed.
- Heavily eroded banks in densely populated areas.
- An urban valley forming a natural corridor from the Case du Parti toward the coastal zone.
- Expansion onto the coastal plain in the downstream section, before the mouth.
- Secondary water courses coming from the 201, 202, and Songolo neighbourhoods.

The hydrodynamics of the study area are characterized by highly variable seasonal flows, frequent obstructions (waste, sand deposits, informal structures), and reduced connectivity with the floodplain due to embankments. Inflows from natural drains in neighborhoods 501 and 505 further complicate drainage.

Regarding the local geology, the area is mainly composed of highly permeable coastal sands downstream, clayey sands and silts in the intermediate sections, hydromorphic soils near the mouth, and unstable areas with risks of bank collapse. These soils favor erosion and the formation of urban gullies/ravines.

Although some areas remain green, aerial imagery shows that these strips are irregular in width (from a few meters to about 80 m) and include marshy zones with remnants of natural vegetation. Other sections from the original floodplain occupied for apparently irregular urban developments, both for residential and industrial uses (Figure 23). Additionally, other sections are used for agriculture or agroforestry.

a) b)

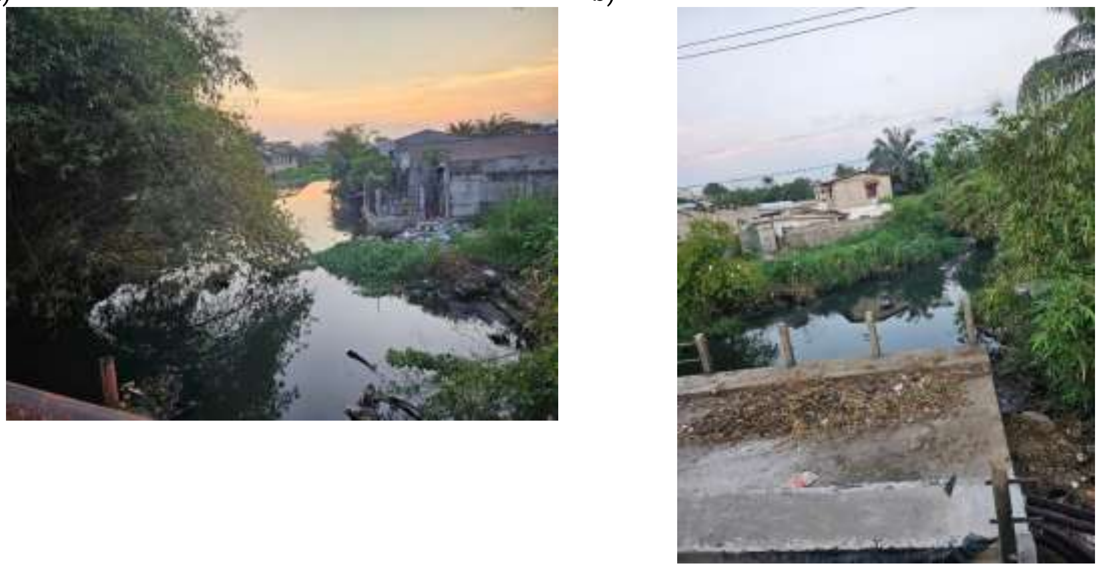


Figure 23. a) and b) Riverbank and floodplain occupation for residential and industrial uses along the Songolo river course. Source: Authors.

Figure 24 shows the mangrove forest covering the marshy area that opens in the transition zone between the target area defined and the river mouth. This transition zone should not be addressed as part of this green corridor project as it shows a rather natural conservation. It is therefore not included in the study area. Yet, the recommendation to enforce the legal 25-meter no-build buffer zone strictly (including through relocations and evictions) applies there as well.

a) b)

Figure 24. a) and b) Mangrove vegetation on the Songolo riverbank where the floodplain opens into a wider marshy transition zone connecting with the beach. Source: Authors.

Administrative Framework

As previously explained, the Tchikobo and Songolo river segments comprising target area C flow along the administrative neighborhoods: 202, 201, 501, and 505 of the Loandjili district, as well as Mongo-Mpoukou and Mvou-Mvou, in the central urban area of Pointe-Noire. In the next box the baseline administrative framework for the proposed project is presented.

Administrative Framework **City**: Pointe_Noire **Departement**: Pointe-Noire **Districts**: Lumumba, Mongou-Mpoukoiu; Mvou-Mvou and Loandjili (see Figure 20) **Affected Neighborhoods**: 201, 202, 501 and 505 **Institutional Stakeholders involved**: • Directorate-General for the Environment • Ministry of Spatial Planning • Agency for Major Works • Pointe-Noire Prefecture • Loandjili Town Hall • Traditional Chiefdoms and Neiborhood Committees

Target area:

- **Location**: Pointe-Noire, République du Congo
- **Spatial scale**: Tchikobo River, 2.7 km, Songolo River, 0.7 km river embankment; total ~ 3.4 km
- **Administrative units:** Pointe-Noire, Mulumba, Mongou-Mpoukoiu, Mvou-Mvou and Loandjili Districts

Landscape approach

The proposed intervention aims to restore the natural floodplain and hydrological function along 3.4 km of river corridor (2.7 km of Tchikobo and 0.7 km of Songolo). Historically, these floodplains have been heavily encroached by residential and industrial structures, increasing flood risk. Achieving restoration requires clearing these occupied areas and re-establishing a continuous buffer zone to allow water to spread naturally during peak flows. This action will require a displacement and expropriation process for the residents and properties involved, applying the appropriate safeguards and best practices derived from recent urban resilience experiences in the Republic of Congo[78]. At least a minimum 25 m buffer on each riverbank is recommended, in line with national regulations. At the feasibility stage, this width should be validated against flood recurrence maps and historical flood records and adjusted if necessary to ensure adequate flood storage capacity.

The landscape restoration strategy in Pointe Noire site includes the following NbSWLM practices, distributed along the river streams in accordance with the convenience perceived:

- **Expand the rivers' natural flood space**. The extension of the river' natural floodplain provides more space to the river, resulting reduction of the flow velocity, which is one of the initial restoration objectives included in the documents shared by WB[79].
- **Renaturalization of the riverbank/riverbed,** using bioengineering practices where needed; the restoration would consist in planting locally adapted vegetation, such as bamboo and phragmites, eventually applying stabilization mattresses, and installing live-fencing barriers along the river to prevent erosion.
- **Set back and restore existing levees along the river floodplain**; this would contribute to generating a larger consolidated flood space for the river, this way the impacts of future flood events would be mitigated.

Additionally, a green corridor along the Avenue Jacques Opangault is proposed. This major traffic artery in the center of the town runs parallel to the Tchikobo river (160 m east) and crosses the Songolo section. The intervention will focus on tree canopy corridors along sidewalks and the central median, creating shade, improving infiltration, and enhancing urban aesthetics.

It should be noticed that the documents regarding potential "low-regret investments" shared by WB indicate regarding this case two other measures. First, the scaling of the flow by improving culvert

[78] Urbaconsulting – Hydroconseil - EDAU Scp Congo- Comète (2024) : Programme de drainage des eaux pluviales de Brazzaville, phase II Plan d'Action de Réinstallation

[79] JBA Consulting (2025) FRA RoC – Hazard Risk Management (Powerpoint presentation)

sections and, second, raising and protecting road crossing. These are the traffic bridges connecting both sides of the rivers Tchikobo and Songolo within the target area. However, these practices are grey-engineering approaches and will therefore not be further developed in this study, although this does not rule out their possible suitability.

Although the interventions follow a landscape approach, implementation could be initiated following a trial approach, initially targeting those river sections that are already free of buildings, to test different approaches for implementing the above indicated practices. This way, once the dismantling process of the buildings would be completed a better focused upscaling could be developed.

This spatial logic supports the overall goal of restoring floodplain functionality, reducing flood risk, and enhancing ecological resilience along the target river segment.

Technical feasibility

The proposed NbSWLM interventions aim to restore floodplain functionality along the in the final sections of the Tchikobo and Songolo rivers, which are occupied by vulnerable populations and show signs of riverbanks erosion and structural instability. In addition to reducing flood risk, the project seeks to create a natural green corridor that integrates the rivers into the urban landscape, providing recreational space and ecological connectivity to the nearby beach. This section aims to present numerous reflections for the implementation of NbSWLM interventions in the target area.

Restoration of the rivers' natural flood space

Figure 25 illustrates the current conditions: Tchikobo and Songolo floodplains are densely occupied by residential and industrial buildings; while remaining open patches retain marshy vegetation and agriculture. These areas are unsuitable for construction and represent the last remnants of natural floodplain.

Figure 25. Illustration of the occupation by buildings and premises of the original Tchikobo river floodplain. Source: Authors.

To achieve meaningful restoration and reduce flood risk, occupied spaces must be cleared. Two approaches are considered for defining the recovery zone[80]:

1. **Apply national buffer regulations:** Maintain a minimum 25 m construction-free strip on each riverbank, as required by Law No. 6-2019 on Urban planning and land tenure regulations.
2. **Recover the entire natural floodplain:** This option offers greater hydraulic and ecological benefits but requires detailed analysis. Since the original floodplain boundaries are difficult to identify due to long-standing encroachment, flood footprint maps like the one shown in Figure 26 will guide the delineation. This type of maps serves for estimating the number of affected structures and residents, informing resettlement planning.

Figure 26. Fluvial 20-year flood footprint along the Tchikobo and Songolo river segments comprised within target area C. Source: Authors.

The return period (RP) of the footprint shown is 20 years. This means that, on average, this area can be expected to be flooded once every 20 years. As compared to higher return period maps such as the 50 or 100-year RP maps, which would represent rather extreme events, this 20-year target area seems a reasonable compromise for the pursued scope of generating a green fluvial corridor while reducing to the extent possible the number of residents subject to being displaced.

[80] Regardless of the extent of expropriations, a consultative, legal and fair process must be applied to safeguard affected population, building on previous experience in Brazzaville.

Due to the lack of the original GIS layers that comprise the above flood map a manual count of the number of premises has been conducted. The rough estimate of the number of premises included within this 20-year RP footprint is around 700, including different ones which represent industrial uses. Assuming a potential occupation range for the premises of 4-6, it can be estimated that the total number of residents subject to be displaced from the area would lie in the range of 2,800 – 4,200, although, of course, a more detailed counting should be done during the feasibility assessment stage of the project. Figure 27 that was taken from households along the Songolo river, where it crosses its beach section, offers a representative building typology of riverbank settlements. The pictures show a rather humble construction type, which is indicative of the poor living conditions of the residents along the rivers´ floodplains.

After compiling an estimate of the number of premises and affected residents, an adequate resettlement project must be developed. This process needs to follow the legal protocols of the country and guarantee fair compensation for the owners as part of the expropriation process to be implemented.

a) b)

Figure 27. a) and b) Detail of construction type nearby Songolo river mouth. Source: Authors.

After recovering the former floodplain, the next step is to improve connectivity of the floodplain along the entire corridor. This will require increasing the flow capacity at existing barriers, particularly the two main traffic bridges and pedestrian crossings. These adjustments are essential to ensure hydraulic continuity and prevent bottlenecks during peak flows. However, such measures involve grey engineering solutions—including structural redesign and hydraulic modeling—which fall outside the scope of this NbSWLM-focused pre-feasibility study. They are mentioned here only to provide a comprehensive picture of the restoration process.

Renaturalization of the riverbank/riverbed, including bioengineering practices where needed

Riverbank naturalization is a restoration technique aimed at rehabilitating degraded riverbanks by reintroducing native vegetation and reshaping the bank profile to mimic natural conditions. This practice reduces erosion, stabilizes soil, improves water quality, and enhances ecological connectivity along the river corridor.

In the simplest cases, where minimal soil preparation is sufficient, revegetation is generally limited to seeding bare areas with a mixture of herbaceous plant seeds. More advanced techniques such as cuttings and planting of shrubs or trees require better-prepared soil and are used when conditions allow for deeper rooting and higher survival rates. Tree planting should be considered only on flat terrain or gently sloping embankments, due to the risk of uprooting caused by their weight and structure.[81]

For the Tchikobo and Songolo Rivers, naturalization will focus on stabilizing eroded banks and improving infiltration in floodplain zones. Over time, naturalized banks develop layered root systems that enhance resilience to flooding and erosion. Recommended species for naturalization include native, fast-rooting species with multifunctional benefits (e.g., fodder, crafts), reflecting local needs and cultural practices, such as bamboo (Bambusa spp.), common reed (Phragmites australis), elephant grass (Pennisetum sp.) and other deep-rooted grasses (Acacia sp., Andropogon gayanus) or shrubs. These species are proposed for their ability to bind soil through extensive root systems[82], intercept rainfall, and reduce surface runoff velocity (Figure 28.a).

Where necessary, live stakes (cut branches or tree cuttings) can be used to stabilize the bank (Figure 28.b). These stakes root and grow above ground, reinforcing the soil structure. They can be sourced from nurseries or harvested from existing vegetation on-site. Likewise, if the slope is too steep, it is necessary to soften the slope of the embankment, depending on the type of soil: transforming the slope of the vertical banks into a trapezoidal shape.

a)

b)

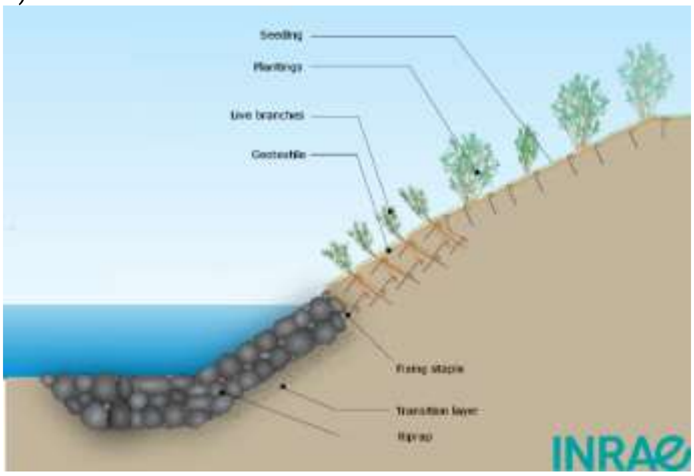


Figure 28. Vegetation of Tchikobo riverbank, and riverbank renaturalization with plants at the top of the bank. [83]

Based on the local pictures of the riverbank shown above, it can be inferred that bioengineering practices, such as the ones shown in Figure 29 could be implemented at specific areas along the riverbanks. The live fencing bank stabilization approach that is traditionally applied in western countries by willow spiling[84] could be implemented by substituting this higher latitude tree-type by local alternatives such as bamboo. The horizontal rods driven into the riverbed could consist of (chinese) bamboo living stakes and the horizontal braid trenches could be made with the thinner and more flexible bamboo sections. Using living stakes as anchor rods, the riverbank stabilization fence would subsequently grow, and this would guarantee long term and sustainable riverbank consolidation.

On the other hand, the riverbank stabilization mattress shown is an example of the geotextile layer shown in the riverbank naturalization scheme shown in Figure 28. For environmental protection it is recommended to apply natural-fiber mattresses, such as those made up of coco fiber.

[81] DAGRI. 2021. Manuel de gestion des bassins versants au Burundi pour le ministère de l'Environnement, de l'Agriculture et de l'Elevage.

[82] PCCP. n.d. Riverbank stabilization using vegetation and bioengineering. Retrieved from https://ebatool.pacificclimatechange.net/node/107

[83] INRAE. n.d. Main techniques used for riverbank development. Retrieved from https://genibiodiv.inrae.fr/en/main-techniques-used-for-riverbank-development/

[84] https://www.peaktraditionalfencing.co.uk/our-services/willow-spiling/

a) b)

Figure 29. Live-fencing riverbank barrier (a) and organic soil stabilization mattress to be installed in combination with living stakes (b).

Climate and environmental impacts

Riverbank restoration through native vegetation planting is a solution that stabilizes soil and improves hydrological function. Deep-rooted species such as Acacia sp. and Bamboo reinforce the bank structure by binding soil with their roots, reducing shallow slope failure and resisting undercutting during high flows. Grass contributes to surface roughness, slowing runoff and enhancing infiltration.[85]

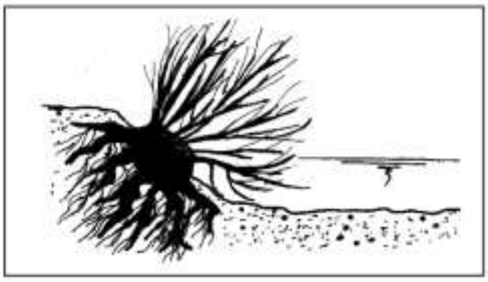


Figure 30. Willow branches arranged like a comb help reduce toe-of-bank erosion by flexibly resisting water flow.

The layered root systems of these plants increase soil cohesion and organic matter, improving resilience to flooding and reducing sediment transport. Vegetation also intercepts rainfall and buffers surface flow, delaying peak runoff and enhancing water retention along the river corridor.

Design and implementation considerations

Some conditions to evaluate during the feasibility analysis of the realization of the Tchikobo and Songolo rivers can include:

- Slope and soil preparation: Steep or unstable slopes may need regrading to improve stability and planting success. Likewise, soil should be assessed for moisture retention and root penetration capacity. Organic amendments may be added where necessary, although the floodplain seems to consist of highly organic soils.
- Revegetation can be achieved through seeding, cuttings, and/or planting. If live stakes are considered, they should be spaced 0.5 to 1 meter apart (increase spacing for bamboo), brush layering should be spaced vertically 1–2 meters, and fascines placed in trenches 2–3 meters apart, bamboo clumps 1–2 meters along the bank and phragmites and grasses 0.3 to 0.5 m part for dense coverage. Note that spacing values are indicative and must be adjusted based on species growth habits, bank slope, and hydrological conditions. Overplanting is recommended to ensure survival, especially in high-flow zones.
- Mats, geotextiles, or preferably biodegradable fiber rolls may be used to protect young vegetation and reduce surface runoff during establishment.
- Live fencing barriers may be placed along riverbank strips that show evidence of ongoing erosion at their borders in contact with the water course.
- Engaging local communities in planting and maintenance enhances sustainability and ownership.

[85] Agence de l'eau Rhin-Meuse. 2000. Guide de gestion de la végétation des bords des cours d'eau.

Set back and restoration of potentially existing levees along the river floodplain

Given the dense occupation of a large portion of the floodplains along the Tchikobo and Songolo rivers it is not clear what the original configuration of the entire morphological unit looked like and why particular spaces were occupied versus others that remain relatively open and covered with dense vegetation. What seems clear, though, is that the still open patches, such as those indicated in Figure 31, represents the original floodplain. Along these areas some sort of levee elevation may be in place. It is therefore suggested to conduct a detailed visual inspection of these areas to assess the feasibility of setting those dykes back within the available flood space, and particularly where the river channel seems too narrow in order to increase the available flood space for both rivers.

Figure 31. Illustration of still open and densely vegetated areas of the original floodplains of both rivers. Source: Authors.

Climate and environmental impacts

Setting back river dikes in flood-prone zones enhances flood containment capacity, while vegetative covering improves slope stability and erosion resistance. Vegetation reinforces the dike structure through root anchoring, which reduces the risk of embankment failure during high-flow events. The plants also intercept rainfall and reduce surface runoff velocity, minimizing erosion on the face of the dike. By increasing infiltration and evapotranspiration, vegetated dikes contribute to peak flow attenuation and improve the ecological integration of flood control infrastructure. This dual approach strengthens climate resilience by combining engineered elevation with nature-based reinforcement.

Design and implementation considerations

The process begins by determining the required elevation of the dike crest through hydraulic modeling, which considers flood return periods, expected flow volumes, and downstream risk exposure. Once the target elevation is established, the dike crest is raised using suitable fill material, that should include clays, ensuring proper compaction to maintain geotechnical stability. Soil cohesion and compaction requirements should be assessed beforehand to prevent structural failure under saturated conditions.

After the crest is elevated, the next step is sloping stabilization. The slopes of the dike should be graded to a safe angle, ideally not steeper than 1.5 horizontal to 1 vertical, with a recommended slope of 2.5 to 1 for long-term stability. To reinforce these slopes and reduce erosion, native vegetation is introduced as a bioengineering solution. Vetiver grass is particularly recommended because it tolerates prolonged submergence and high-water velocity, traps eroded sediment and remains upright in flows as deep as 0.6 to 0.8 meters. Its leaves bend under strong currents, reducing flow velocity and protecting surface soil. When planted on dikes, Vetiver hedgerows also help decrease wave run-up and dissipate energy from flowing water.

The planting layout should be carefully planned to maximize stabilization and flow reduction. Vetiver rows are arranged in two directions: horizontally, parallel to the flow, to stabilize the bank, and vertically, perpendicular to the flow, to slow water movement. The first horizontal row is placed at the crest of the dike, and subsequent rows are spaced down the slope, with the last row positioned at the low-water mark. This arrangement creates a living barrier that strengthens the dike structure and reduces erosion during high-flow events.

Through implementation, attention must be paid to soil preparation for planting, ensuring adequate moisture and nutrient conditions for root establishment. Regular monitoring is essential to confirm plant survival and growth, as well as to evaluate the structural integrity of the dike after elevation. By combining engineering design with vegetative reinforcement, this approach provides a cost-effective and ecologically sound solution for flood mitigation and long-term riverbank protection.

Eventually, as a complementary element to the projected green corridor and pursuing the best possible integration of this into the lives of the residents of the surrounding neighborhoods, these dykes could be designed with a width that would allow for the placement of a pedestrian path on their crest to be connected to each other, along the corridor's route and, from a perspective of maximum integration, on both banks. This action would elevate the green corridor's design to a level almost comparable to that typically presented in river and urban restoration projects in developed countries or those shown, for example, in the images of the World Bank's own SfN catalog that served as the framework guide for this project. However, since the feasibility of such continuity for the future dykes is still very difficult to anticipate at this stage of the study, it has been decided here not to proceed with the detailed elaboration of this proposal.

Development of a Green Corridor along the Avenue Jacques Opangault

The idea of proposing a separate but associated restoration project for the Avenue Jacques Opangault comes from the fact that this street is located within the range of influence of the Tchikobo-Songolo target area C, as it runs parallel to this water course at just 160 m west. Secondly, as Figure 32 shows, the avenue, although quite an important central traffic artery of Congo´s second major city, shows rather basic urban development lacking almost any green features that would generate a comfortable living environment for the surrounding residents. The picture shows also an apparent lack of a runoff drain system along its west-east profile. This would suggest that pluvial flooding may occur along the street during heavy rain events. Yet, addressing also that problem would be out of the scope of this project as that would require a grey hydraulic engineering approach.

As a matter of fact, as Figure 33 shows, the urban area of Pointe-Noire has a significant lack of green spaces. The only strips that can be identified as such consist in the watercourses that cross the city, no relevant green parks can be observed. A closer look at the city center further illustrates that the appearance of the Avenue Jacques Opangault is very characteristic of most streets and principal avenues that cross the city center, the pattern consisting of two paved roadways, two unpaved sidewalks and the central separation strip repeat again.

Thus, the proposal to project a complementary greening approach for this nearby artery as part of this pre-feasibility study, also pursues to inspire the local authorities to progressively adopt the same climate resilience strengthening strategy for the rest of the city´s urban area.

Figure 32. Google Street view of Avenue. Source: Google Earth.

Figure 33. Aerial image of Pointe-Noire, showing the lack of green spaces. Source: Google Earth.

Figure 34 shows alternative designs of green corridor implementation in urban contexts as suggested by WB in the NbS Catalogue that constitutes the baseline frame for identifying and clustering them, street tree canopies, green avenues and urban green corridors but, of course, many different options to combine these approaches, among those presented or with other practices presented in the document can be implemented.

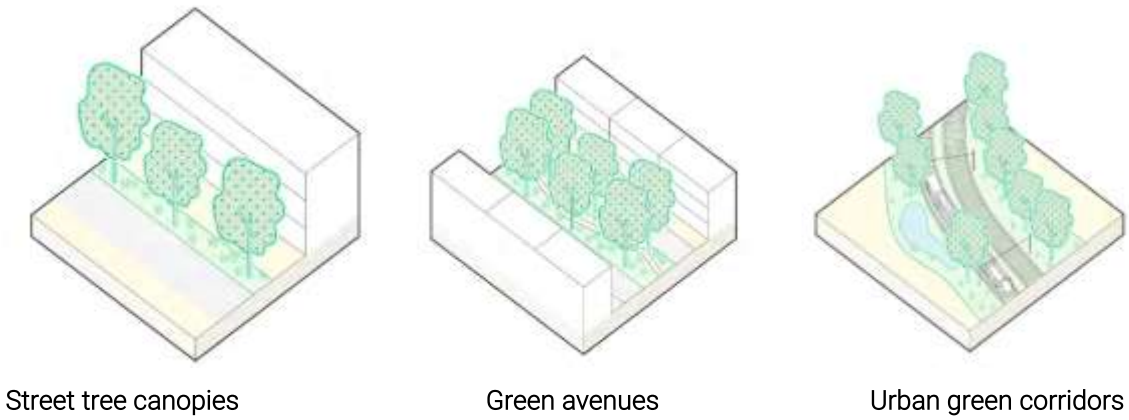


Figure 34. Alternatives of green corridor implementations: Source: WB, 2021.[86]

Figure 35. View of the Av. Jacques Opangault proposed for green corridor restoration. Source: Authors.

[86] World Bank, 2021. A Catalogue of Nature-based Solutions for Urban Resilience. Washington, D.C. World Bank Group

Figure 35 shows the section of the Avenue Jacques Opangault the runs along the target area and is proposed to be complemented as green corridor. In total, the stretch is about 2,500 m long. The width of the street is about 20-21 m, although irregularly distributed along the entire stretch. This cross section includes the lateral parking space for vehicles on both sides. The roadways are each one about 6 m wide and the central separation strip around 1 m, as can be observed on Figure 32. This leaves about 2.5 m, estimated, strips along both sideways that could be developed into integrated pedestrian lanes provided with tree and grass vegetation lines. The suggested walkways would be around 1.5 m wide, a little wider if possible, and the vegetation strips around 1 m. The remaining space could be reserved for parking space along the avenue.

The objective of the green corridor is twofold, first, to generate a more comfortable living environment for the nearby residents and, two, reducing the runoff by increasing evapotranspiration, by the vegetation, and water infiltration to the subsoil. In this regard, the water infiltration capacity of the current soil along the sidewalks and central strip is unknown. Therefore, it could be convenient to adapt them by mixing the first 0.5 m with sandy gravels, in case an adequate alluvial gravel quarry is located near Pointe-Noire in order not to increase the overall green corridor cost significantly.

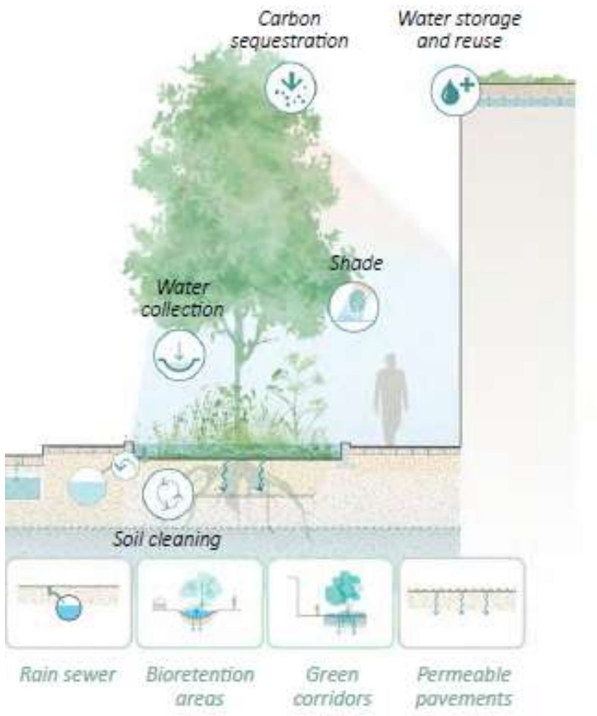


Figure 36. Concept of urban green corridor along a street, including its co-benefits (WB, 2021)

Figure 36 shows a baseline design for an urban corridor, including the co-benefits of the practice, in accordance with the description and designs that are presented for this concept in World Bank´s NbS Catalogue.

As can be observed on this figure the sidewalk should be provided with a tree canopy and an unpaved vegetation strip, covered with grass strips and different plant types, along the tree line, and also a corridor fit for walking which preferentially should consist of pervious pavement. The design includes water collection and drainage lines that can be added although the costs would possibly not be justified outside their integration with the general urban drain system. Therefore, these features remain on hold as part of this proposal until an expert engineering team assesses the drain system network in the district. Consequently, the green corridor proposed for the target avenue is suggested to adopt a baseline approach, consisting of amending the first 0.5 m of soils and planting 1 m wide vegetation strips along 1.5 m pervious pavement walkways.

Figure 37 provides a simplified visual projection of how the target avenue would look like upon developing the suggested green corridor. It should be noted that the trees and shrubs shown should ideally be selected from different species.

Figure 37. Simplified projection of how Av. Jacques Opangault could look like after implementing the proposed green corridor. Source: Authors.

A preliminary material needs and logistics assessment is presented in Table 24. Given the status of understanding of the river sections and the feasibility to actually empty the constructed floodplains the estimates for materials have been presented in terms of potential local target areas, around 300 m stretches, instead of planning for addressing the entire river target section.

Table 24. Summary of key materials and inputs, local availability, indicative quantity and potential logistics constraints for each practice proposed for the floodplains along the Tchikobo and Songolo rivers.

Practice	Key Materials & Inputs	Local Availability	Indicative Quantity Range (per hotspot)	Logistics Constraints
Riverbank Naturalization	Materials for bioengineering applications Native plant species (e.g., bamboo, phragmites), compost, soil amendments, and basic planting tools. Manual labor required for implementation of bioengineering measures, planting and maintenance.	Moderate – Living stakes and live fencing materials easy to produce from surrounding vegetation. Organic fiber geotextiles may require supplies from external sources (countries) Native species (Bamboo and Phragmites) available through local nurseries or informal suppliers.	Live fencing: 2 living bamboo rods/m = 600 / 300 m stretch. Additional thin braid trenches for horizontal mesh: ~ 300 m2 / 300 m riverbank stretch Stabilization mattress ~ 900 m2 / 300 m riverbank stretch. ~3,000–5,000 plants for 300 m stretch (spacing adapted to slope and species)	Identification of sustainable sources for extraction of vegetal materials. Purchase of stabilization mattress in case considered convenient. Access to degraded banks may be limited; planting should align with rainy season for establishment.

Practice	Key Materials & Inputs	Local Availability	Indicative Quantity Range (per hotspot)	Logistics Constraints
		Compost may be locally sourced. available locally.		
Set back and restoration of potentially existing levees	Earthworks materials (soil, clay), native vegetation, erosion control fabric, and basic tools. Labor needed for construction and planting.	The consistency of the clays along the target river sections to be assessed. Alternatively, external supplies may be required, although these should be from legally exploited quarries.	~300 m stretch per hotspot (crest raised by 0.5–1 m); convenient height of levees to be established through modelling of river hydraulics.	Earthworks may require machinery. Transport of clays, in case not adequately available on the flood plain may be necessary.
Green Corridor along Av. Jacques Opangault	Small Excavator and manual excavation tools for extracting soils along the unpaved strips to be excavated to 0.5 m depth / in total up to 7,500 m3 to be excavated	Construction contractors should have this equipment in-house.	Depending on the pursued work pace, two to four could be sufficient.	It is important to previously identify any potential subsoil infrastructures located along the suggested green corridor strips. In case any drain pipelines or electrical wires are in place the excavation plan should be adapted and eventually reduced.
	Provision of sandy gravel aggregates;	Should be obtained from a regular gravel quarry nearby Point-Noire	Based on the length and width of the central strips and lateral pedestrian sidewalk it is estimated that around 3.750 m3 of aggregates should be supplied	The supply of the sandy gravel aggregates should be arranged with local transport contractors. Only the daily required quantities should be provided in order to avoid the occupation of space that may limit fluent traffic conditions

Practice	Key Materials & Inputs	Local Availability	Indicative Quantity Range (per hotspot)	Logistics Constraints
	Cement mixer for efficiently producing the clay/sandy gravel soil fill for the excavated trenches	Construction contractors should have this equipment in house.	One per working team (to be arranged by the contractor)	Not relevant
	Implementation involves soil grading and preparation, planting of native and ornamental species (e.g., vetiver grass, papyrus, sedges), and optional installation of underdrains in low-permeability soils. Vegetation must be suited to periodic wetting and drying and sourced from local nurseries or municipal landscaping programs. Soil amendments (e.g., compost, sand) may be used to improve infiltration.	Moderate – plant species are available through local nurseries or informal suppliers; soil amendments may require sourcing from nearby agricultural zones.	One big development tree each 15 m, ~ 500 big trees; grass and shrub cover along the remaining green corridor strips, 7,000 m2 to cover, one native shrub species every 2 m, ~3,500 shrub seedlings ~ 0.5 m2 open surface / shrub seedling. Grass surface, remaining 5,250 m2	Planting should be timed with seasonal rainfall; coordination with nurseries and transport of live plants may require advance planning.
	Pervious pavement; concrete elements	Probably locally available; otherwise, the pavement components could be produced locally by means of developing an adequate mold	Considering a 1.5 m broad walkway, around 11,250 m2 of pavement units should be produced	It is assumed that local contractors should be able either to purchase or produce their own adequate pervious pavement elements

- Local capacity:

The residents of the Tchikobo and Songolo river plains and adjacent areas could participate in the implementation of those restoration works that do not require mechanical machinery, excavators, etc., although given the context they should receive capacity building and guidance from experts. Regarding bioengineering practices, although community members could ultimately develop or participate in those works, it may be convenient to hire contractors specialized in fluvial restorations which could provide trained staff. This way the quality of the work implemented could be better guaranteed.

- Infrastructure and logistics requirements:

The proposed practices will require access to earthmoving equipment for excavation and shaping; construction materials, such as soil stabilization mattress-geotextile, live stakes and living fence mesh vegetation; and nurseries for native vegetation.

Accessibility conditions should be reviewed to ensure efficient transport and deployment of materials. Given the dense space occupation along the Tchikobo river it may be convenient to identify a nearby open space which could serve as central storage area for materials and machinery. This way the works along the flood plains could be implemented in a more ordered way.

- Risks of Implementation:

Several risks must be considered during the design and implementation phases:

  - Hydraulic and hydrological modelling is essential to determine appropriate dimensions for structures such as bridge dimensions and elevated dikes, ensuring they function effectively under expected flow conditions.
  - A topographical survey would be necessary to estimate wall height and slope of the riverbanks and the river direction to assess the most convenient local approach among those described above.
  - Ecological risks may arise from the use of invasive species or poor vegetation survival if planting is not properly managed. Involvement of local botanical experts is recommended to guide species selection and planting strategies.
  - Regulatory constraints must be addressed, particularly those related to current flood plain uses, such as cropping or agroforestry and others.

These factors must be carefully evaluated to determine the final feasibility of each proposed solution.

Adverse impacts and safeguards triggers

It is essential to anticipate and mitigate potential adverse impacts that may arise during implementation of the proposed practices. Table 25 summarizes plausible risks associated with each proposed intervention along the Tchikobo and Songolo target sections and identify safeguards triggers.

Table 25. Plausible adverse impacts and safeguards triggers of practices implementation along the Tchikobo and Songolo target sections.

Practice	Plausible Adverse Impacts	Safeguard Triggers
Liberation of buffer zone along target river floodplain segments	• Expropriation/resettlement plan should be developed. • This process could encounter resistance from community/residents.	• Previous experience in the country in addressing similar cases. • Detailed process report on similar Brazzaville case has been developed and shared by AFD. This document provides an adequate guide on how to address the complex process in order to cover all aspects to be considered and social impacts to be compensated.

Practice	Plausible Adverse Impacts	Safeguard Triggers
Riverbank naturalization	• Overgrowth may obstruct the minor riverbed, impede flow and increase debris accumulation. • Risk of invasive species or non-native genotypes altering local biodiversity. • Potential redistribution of flow due to vegetation density.	• Hydrology specialist review: To assess flow dynamics and obstruction risks. • Biodiversity specialist review: To verify species selection and prevent planting of exotic and invasive spread. • Vegetation management plan: Regular pruning and monitoring of vegetation spread and habitat impacts.
Riverbank set back and dike elevation	• Potential water-use conflicts due to altered infiltration and retention. • May negatively affect the surrounding landscape. • May increase the magnitude of peak flow downstream, thus amplifying flood hazard and risk downstream.	• Hydrology specialist review: To model flow redistribution and flood risk. • Community consultation: To address water-use and land management concerns.
Green Corridor along Av. Jacques Opangault	• Invasive species risk if non-native plants are introduced. • Once adequately implemented and the vegetation fully developed, the green corridor will require regular maintenance in the form of common gardening practices. This should be conducted also to prevent the trees and shrubs planted to invade the traffic and pedestrian spaces.	• Revegetate only with local species already tested in previous urban development projects. • Biodiversity specialists or urban forestry experts should guide species selection and planting layout.

Maintenance considerations

Clear and strict maintenance activities of the practices proposed along the Tchikobo and Songolo final river sections are necessary to ensure their long-term effectiveness. Each practice requires different operational needs that should be addressed through routine inspection, vegetation management, structural maintenance and reparation, and community engagement. Here after, a list of maintenance considerations is proposed for each practice[87]:

- Riverbank naturalization

Riverbank naturalization relies on the successful establishment of vegetation to stabilize. Maintenance is critical during the early years to ensure plant survival, prevent flow obstruction, and maintain slope integrity. Key maintenance activities include:

- After leaf-out, inspect the site to assess survival rates of planted stakes, and make repairs and replanting where needed.

[87] The community training developed in the framework of this technical assistance includes details on implementation and maintenance activities.

- Regularly evaluate slope conditions and ensure erosion control blankets (if used) remain secure.
- Provide supplemental watering during dry periods to support plant establishment.
- Prune or thin excessive growth to prevent obstruction of the minor riverbed and accumulation of debris.
- Monitor for and remove non-native or aggressive species that may outcompete native vegetation.
- Install fencing to protect young plants from trampling by people or animals; remove once vegetation is well established (typically after 2–3 years).
- Involve local communities in monitoring and maintenance to foster stewardship and ensure sustainability.

- <u>Riverbank set back and dike elevation</u>

Maintenance of dikes with vegetation is essential to ensure both dike's integrity and controlled growth of vegetation. Main maintenance actions are:

- Regular structural inspections to assess signs of erosion, settling, or breaches, especially after heavy rainfall or flooding events.
- Track the health and spread of vegetation, to ensure that they reinforce the dike without displacement of native species.
- Remove any non-native plant that may colonize the area.
- Engage local community in routine inspection and vegetation management to support long-term sustainability.

- <u>Green corridors:</u>

Green corridors, like the one proposed along Avenue Jacques Opangault require frequent monitoring of vegetation health, soil infiltration capacity, and runoff flow pathways. Regular care prevents issues such as waterproofing of organic to player which will reduce infiltration efficiency, and overgrowth. Key maintenance tasks include:

- Removing sediments and litter from vegetation strips to maintain their adequate development condition.
- Pruning and replanting vegetation to ensure coverage and prevent erosion, especially in high-flow zones.
- Soil health monitoring, checking any signs of erosion or sediment build-up, including along the runoff drain channel, and add fresh soil or mulch as needed to maintain optimal filtration.
- Weed and pest control, with emphasis on avoiding chemical treatments that could harm beneficial species or pollute runoff.
- Irrigate during long draught events or normal dry seasons if convenient.

Maintenance should be integrated into municipal landscaping schedules, with clear responsibilities assigned to local teams or contracted service providers. Community engagement in planting and upkeep can further support long-term viability. Similar practices can be considered for the lateral green corridor strip.

Table 26. Maintenance activities of practices along the Tchikobo and Songolo Green Corridors

Practice	Activity	Frequency	Responsible Party	Potential Risks
Riverbank Naturalization	Inspect survival of planted stakes; replant gaps; check erosion control mats; prune excessive growth; remove invasive species; maintain fencing	Monthly in first year; quarterly thereafter	Local communities with support from municipal teams	Plant mortality; invasive species spread; obstruction of minor riverbed; fire risk if vegetation unmanaged.
Riverbank retreat and dike elevation	Inspect dike integrity for erosion or breaches	After heavy rains/ Quarterly	Municipal engineering	Structural failure during peak flows
	Monitor vegetation health and remove non-native species	Biannually	Community groups	Invasive species colonization and vegetation loss reducing the slope stability.
	Maintain slope stability.	After heavy rains	Municipal engineering with the support of local community	
Green Corridor along Av. Jacques Opangault	Remove debris and litter from vegetation strips	Quarterly; more frequent in rainy season	Municipal landscaping team, and community	Debris and litter affect the correct development of the vegetation strips
	Prune and replant vegetation to maintain coverage and infiltration capacity	Annual	Municipal landscaping team, and community	Vegetation die-off reducing infiltration; invasive species spread
	Sediment removal from swale bed and inlet zones if ponded water does not draw down within 48 hours.	As needed	Municipal water drainage team	Reduced infiltration; clogging of underdrains
	Pest and weed control	Quarterly	Municipal landscaping team	Pest outbreaks damaging vegetation; chemical misuse harming water quality

The project should actively explore partnerships with organized private-sector groups, such as Corporate Social Responsibility committees (CSR) to establish adequate maintenance budget. This budget could be used by CGDC, so they can develop maintenance activities of each practice. These committees, commonly established by companies to fulfill social and environmental commitments, can provide financial support, technical expertise, and in-kind contributions (e.g., tools, vegetation materials) for NbSWLM maintenance.

Pointe-Noire offers a particularly favorable context for such partnerships due to its structured industrial landscape and concentration of companies with CSR programs. Engaging these actors can diversify funding streams, reduce reliance on municipal budgets, and foster shared responsibility for climate resilience.

Social feasibility

The proposed intervention in the Pointe-Noire Linear Green Corridor zone presents partial social concerns due to the need to free retention basins and implement "blue solutions" such as flood-expansion zones. While these measures are relevant and technically justified, they imply the physical liberation of areas currently occupied by vulnerable residents, raising tangible social sensitivities. Urban poverty, high unemployment (33% according to UN-Habitat) and a lack of effective spatial planning have historically pushed poorer households to settle on riverbanks and marshlands, where they face recurring floods and exposure to water-borne diseases. Additionally, rapid urban expansion and climate change effects, particularly sea-level rise, further increase exposure to flood and coastal erosion risks, underscoring the urgency of action.

Several particularly vulnerable groups are directly affected by recurrent flooding and poor sanitation conditions, including women, youth, Indigenous peoples and displaced persons. Low-lying coastal and lagoon-adjacent communities are particularly exposed to cholera and other water-borne health risks. While the intervention aims to reduce the latter vulnerabilities, the potential displacement of riverside households due to dike retreat and basin clearing represents a possible negative impact. The precarious socio-economic context, combined with youth unemployment reaching 42%, amplifies vulnerability and heightens the complexity of any intervention requiring land clearance.

The area also contains sensitive or contested sites, given the presence of traditional resource-use areas such as mangroves and fishing sites. More importantly, land conflicts are widespread in Pointe-Noire's peri-urban expansion zones. The local land-tenure system remains dual (customary versus civil law), frequently leading to parcel-level disputes. The intervention could, thus, trigger tensions or violent conflict, especially if households with unstable or undocumented land rights perceive the project as threatening their tenure or livelihoods. During the workshop conducted on 19 November 2025 in Brazzaville it was emphasized that potential displacement might lead to conflicts that could involve physical threats.

Given these dynamics, the overall social risk is assessed as Medium. Land pressure, latent tenure disputes, customary use rights (fishing, small agriculture) and the lack of transparent land acquisition processes represent substantial risks. These, however, are considered to remain manageable with strong mitigation measures, provided that the project engages inclusively and transparently with all affected groups.

Fragile and Conflict-Affected Context (FCV) red flags include potential tensions arising from non-transparent land acquisition, the exclusion of vulnerable fishing and farming households, and the presence of a fragile tenure context despite the absence of armed conflict. These concerns underscore the need for careful management of land issues and transparent engagement with all affected groups.

The rapid assessment therefore recommends two essential mitigation measures: (i) the mandatory preparation of a Resettlement Policy Framework (RPF) to guide any potential displacement or compensation needs, and (ii) the immediate undertaking of a dedicated Land Conflict Analysis specific to the Green Corridor zone before any technical design progresses, combined with a comprehensive land- and social-risk review, including verification of formal titles and customary user rights, in order to prevent conflict or involuntary displacement. These are necessary steps to avoid escalation of tensions and to ensure fairness.

The next chart presents a summary of the data extracted from documents on specific similar processes that were provided by the French Development Agency (AFD)[88] in order to understand the feasibility and protocols to be complied with in case a similar approach would be launched.

[88] Artelia – Comète (2017) : - Mission de Maitrise D´œuvre : Schéma Directeur – Etude de Faisibilité, APS-APD, PGES, DCE - Passation de Marchés et Supervision du Projet de Drainage des Eaux Pluviales de la Ville de Pointe-Noire – TF5 Rapport D´APS

DISPLACEMENT AND EXPROPRIATION PROCESS FOR THE RESTORATION OF FLOODPLAINS

To facilitate the understanding of the process to be followed concerning the premises expropriation and population displacement necessary for implementing the recovery of the Tchikobo and Songolo river floodplain sections located within Study Zone C, the French Development Agency (AFD) shared three documents. Two of these reports focus on the city of Pointe-Noire and deal with the improvement of its drainage network, while the third describes in detail the compensation study process calculated for residents affected by the redevelopment of the Tsième River channel in Brazzaville, also in relation to the need to mitigate impacts caused by deficient stormwater drainage.

The two documents focused on Pointe-Noire address the management of the city's drainage through the river network that crosses its center. Essentially, they provide a detailed analysis of the characteristics of various rivers—including the sections of the Tchikobo and Songolo rivers within Study Zone C—and the type of redevelopment to be carried out on the different identified channel, bank, and floodplain profiles. However, the proposed redevelopment practices consist of "grey measures" fundamentally centered on channelization using masonry stone and cement lining, along with the creation of unpaved service roads along both banks. It is also proposed to adapt traffic crossings over the riverbeds using larger bridges.

The action proposals are based on river water depths calculated for return periods of 10 and 20 years for the channel redevelopment and traffic crossings, respectively. This implies a level of intervention for the floodplain that is, in principle, more limited than the one proposed in the current river restoration proposal.

Due to its nature as a "grey infrastructure" project, the costs are significantly higher regarding the redevelopment of the floodplains (two scopes are offered: intervention on the area affected by a 10-year return period or limiting the intervention to a 25m strip on both sides of the channel). The project considers the relocation of residents currently living in flood-prone areas. The list of inhabitants and reported relocation costs for the sections affected by the 10-year return period strip (including all suggested works) would be:

Songolo River estuary zone: 2,585 inhabitants – Cost: ~€16.1 M; and

Tchikobo River section: 1,944 inhabitants – Cost: ~€3.9 M.

Thus, in 2017, the number of residents to be relocated was estimated at approximately 4,500 at a cost of about 20 million euros. While the order of magnitude of affected residents is similar to that established by the manual estimate conducted for this project, the significant proportional increase in relocation costs for the estuary Songolo section compared to the Tchikobo section (which is considerably longer) remains unclear. In any case, it is noted that the proposed action for the Songolo estuary covers a much wider area than suggested in the current plan; therefore, the compensation amounts may not be directly comparable.

On the other hand, the report regarding stormwater drainage in Brazzaville describes the mitigation plan for economic and social impacts associated with the implementation of a drainage network redevelopment plan in neighborhoods along the Tsième River, aimed at reducing the flood risks they suffer. The proposed works are of various types—mainly grey infrastructure—focusing on the river channel and its banks, affecting many residents and their properties. The document provides a detailed description of the expropriation process to be followed. Topics covered include:

Legislative provisions regarding land tenure and property rights.

Applicable law regarding expropriation for public utility.

Applicable law regarding compensation for affected assets.

Artelia – Comète (2018) : Mission de Maitrise D´œuvre : Schéma Directeur – Etude de Faisibilité, APS-APD, PGES, DCE - Passation de Marchés et Supervision du Projet de Drainage des Eaux Pluviales de la Ville de Pointe-Noire – TF3 – Rapport de Phase 2 du Schema Directeur – Etude de Faisibilité

Urbaconsulting – Hydroconseil - EDAU Scp Congo- Comète (2024) : Programme de drainage des eaux pluviales de Brazzaville, phase II Plan d'Action de Réinstallation

Estimation of the number of Project Affected Persons (PAPs) and their assets (residences, businesses, agricultural land, fruit trees, etc.).

Administrative organization and governance.

Compensation and livelihood restoration strategy.

Valuation methods for impacted assets (land/plots, buildings by type).

Consideration of vulnerable households and individuals.

The total compensation project, across the various identified categories, amounts to approximately 10.5 million euros. The project affects 378 buildings (residential and other types), as well as 3.1 hectares of agricultural land and 80 businesses. The total number of affected people is approximately 2,600, of whom 1,450 would need to be relocated.

The reported amounts addressing the reported economic and social impacts associated with the necessary floodplain recovery projects in Pointe-Noire and Brazzaville are indicative of the order of magnitude of the potential compensation costs that may be associated with the proposed target area C fluvial landscape restoration process. The final amount would depend on the width of the floodplain corridor that would be established as project scope, a 25 m buffer zone or a 10 or 20-year RP floodprint stretch. Yet, with the currently available information it is difficult to anticipate a reliable cost projection.

A second important conclusion that should be drawn from this assessment is that displacement and expropriation processes like the one suggested for target area C have been implemented before in RoC and have also recently been developed for near-future investment projects. There is both an existing legal frame for supporting it and an established due process to be complied with to ensure a robust outcome.

In summary, the social-feasibility screening for the Pointe-Noire Green Corridor identifies the intervention as necessary and broadly relevant but socially sensitive, given the likelihood of displacement when clearing retention basins and retreating dikes. While no open opposition was observed, the fragile land-tenure context and the risk of excluding vulnerable riverside households present clear FCV red flags. These sensitivities underscore the need for conflict-sensitive planning and clear, equitable procedures to avoid misunderstandings or tensions during implementation.

Data confidence is rated low, as the assessment relied primarily on local experts' general knowledge of urban and land issues in Pointe-Noire and on workshop notes, without access to detailed social impact assessments or specific site-level studies.

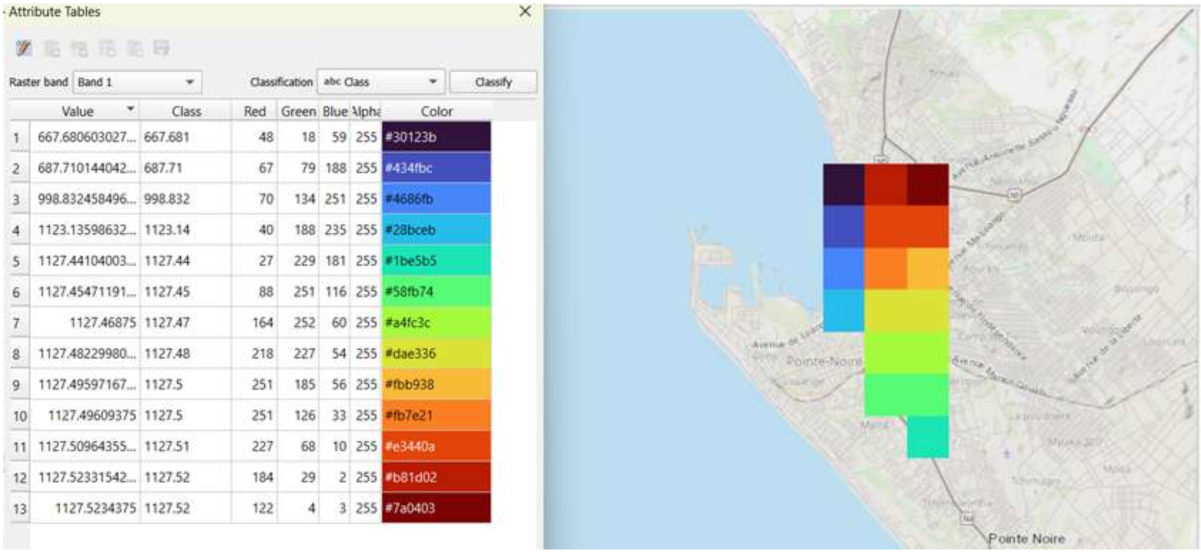
Estimated number of beneficiaries

To calculate the number of beneficiaries, a geospatial analysis was conducted. Open-source digital elevation data, satellite imagery, and hazard & risk data from the World Bank were used to determine project extension area, slopes as well as settlement patterns. These datasets were overlaid with raster data obtained from the source Gridded Population of the World collection[89], which provides approximate population estimates (1kmx1km tiles).

The analysis determined that approximately 13,000 people living along the Tchikobo and Songolo rivers can directly benefit from reduced flood risk reduction, coastal and soil erosion.

In addition, approximately 30,000 people of Mulumba and surrounding districts can indirectly benefit from increased wellbeing, biodiversity, livelihoods and reduced heat effect, as a result of the interventions.

[89] Available at https://www.earthdata.nasa.gov



	Value	Class	Red	Green	Blue	Alpha	Color
1	667.680603027...	667.681	48	18	59	255	#30123b
2	687.710144042...	687.71	67	79	188	255	#434fbc
3	998.832458496...	998.832	70	134	251	255	#4686fb
4	1123.13598632...	1123.14	40	188	235	255	#28bceb
5	1127.44104003...	1127.44	27	229	181	255	#1be5b5
6	1127.45471191...	1127.45	88	251	116	255	#58fb74
7	1127.46875	1127.47	164	252	60	255	#a4fc3c
8	1127.48229980...	1127.48	218	227	54	255	#dae336
9	1127.49597167...	1127.5	251	185	56	255	#fbb938
10	1127.49609375	1127.5	251	126	33	255	#fb7e21
11	1127.50964355...	1127.51	227	68	10	255	#e3440a
12	1127.52331542...	1127.52	184	29	2	255	#b81d02
13	1127.5234375	1127.52	122	4	3	255	#7a0403

Figure 38. Estimation on the number of beneficiaries in the districts along the Tchikobo and Songolo target sections.

Co-benefits

Table 27 summarizes the potential co-benefits that the practices proposed to be implemented within target area C would represent.

Table 27. List of potential co-benefits provided by the practices along the Tchikobo and Songolo target sections.

Benefits	Mechanism of actions	Score
Groundwater recharge (Regulation)	Riverbank vegetation promotes infiltration, especially in floodplain zones, contributing to shallow aquifer recharge.	M
Carbon sequestration (Regulation)	Native vegetation (e.g., *Acacia*, *Bamboo*, *Phragmites*) contributes to biomass accumulation and long-term carbon storage.	M
Sediment retention (Regulation)	Stabilized banks trap sediment, reducing downstream siltation and protecting aquatic habitats.	H
Water quality improvement (Regulation)	Riverbank naturalization reduces sediment transport and filter runoff, improving water clarity and reducing nutrient loads.	H
Biodiversity enhancement (Support)	Restoration of floodplain riverbanks with native species creates habitat corridors for birds, insects, and aquatic life. Likewise, river bypass can become home of aquatic life.	H
Livelihood diversification (Cultural)	Labor-intensive installation and maintenance (e.g. planting, dike reinforcement) generate short-term employment; improved flood control supports agriculture and infrastructure.	M

Benefits	Mechanism of actions	Score
Aesthetic and cultural value (Cultural)	Naturalized riverbanks and vegetated structures enhance landscape quality and may support recreational or educational use. Urban green corridor would strongly increase the well-being perception of residents along Avenue Jacques Opangault.	H

Indicative Cost Profile

Practice 1 – Riverbank naturalization

Table 28. Indicative costs of riverbank naturalization.

	Cost category	Description / What to include	Cost drivers
CAPEX	Transport and Logistics	Covers the movement of materials, equipment, and personnel to and from the riverbank restoration site. Includes vehicle rental, fuel, and coordination for transporting native plants, soil amendments, erosion control materials, and tools to remote or difficult-to-access riverbank areas.	Distance to site, road access, material weight, supplier location
	Site Preparation	Involves preparing the riverbank for naturalization and ensuring proper slope and soil conditions. Includes clearing invasive vegetation, reshaping and grading slopes, compacting soil, adding organic amendments, and marking planting zones.	Topography, soil type, existing vegetation, drainage layout
	Materials	Referring to all physical inputs required for ecological restoration and stabilization. Includes native plant species (e.g., bamboo, phragmites), seeds, live stakes, compost, geotextiles, biodegradable mats, and erosion control fabrics.	Material specifications, availability, durability, ecological compatibility
	Labor and Equipment	Covers human resources and tools needed for planting and slope stabilization. Includes skilled and unskilled labor, manual tools, safety gear, and equipment for slope regrading and vegetation installation.	Labor availability, equipment rental cost
	Design Supervision and Project Management	Encompasses technical planning, ecological design, and oversight throughout the implementation phase. Includes hydrological and botanical expertise, slope stability analysis, supervision of planting activities, and coordination with stakeholders.	Project scale, technical complexity, team expertise
	Contingency	Provides a financial buffer for unexpected costs or delays during implementation. Includes allowances for poor vegetation survival, soil instability, equipment breakdowns, material shortages, and weather-related disruptions.	Site unpredictability, seasonal conditions, inflation risk
OPEX	Routine Inspection and Maintenance	Covers regular checks to ensure vegetation health and slope stability. Includes visual inspections of plant survival, erosion signs, slope integrity, and invasive species presence, typically conducted monthly or after major rainfall events.	Rainfall frequency, erosion risk, accessibility of site, availability of trained personnel
	Vegetation Management	Ensures healthy plant growth and ecological function through seasonal care. Includes trimming, replanting, pest control, irrigation during dry periods, and replacement of failed vegetation.	Plant species used, climate variability, pest outbreaks, irrigation needs

Cost category		Description / What to include	Cost drivers
	Monitoring and Reporting	Tracks ecological performance and environmental impact through data collection and analysis. Includes vegetation surveys, soil stability assessments, infiltration rate measurements, and documentation of restoration outcomes.	Monitoring frequency, number of parameters tracked, equipment availability, technician wages
	Field Supervision and Administrative Support	Oversees maintenance activities and coordinates operations. Includes wages or stipends for supervisors, office coordination, transport, and communication with local stakeholders.	Staffing levels, administrative structure, transport needs
	Long-Term Rehabilitation	Restores full functionality after years of use or degradation. Includes labor and equipment for reshaping slopes, replacing vegetation and soil media, and repairing erosion control structures, typically required every 10–15 years.	Extent of degradation, age of intervention, vegetation failure rates, soil condition

Practice 2 - Set back and restoration of potentially existing levees

Table 29. Indicative costs of setback and restoration of potentially existing levees, including river dike elevation.

	Cost category	Description / What to include	Cost drivers
CAPEX	Transport and Logistics	Covers the movement of materials, equipment, and personnel to and from the site. Includes vehicle rental, fuel, and coordination for transporting soil, clay, erosion control fabrics, native vegetation, and construction tools to the dike location.	Distance to site, road access, material weight, supplier location
	Site Preparation	Involves preparing the land for dike elevation and ensuring proper grading and compaction. Includes clearing vegetation, reshaping and compacting the dike body, marking planting zones, and stabilizing slopes prior to vegetation.	Topography, soil type, existing vegetation, slope angle
	Materials	Refers to all physical inputs required for dike elevation and stabilization. Includes soil, clay, erosion control fabrics, native vegetation (e.g., bamboo, reeds, grasses), and geotextiles for slope reinforcement.	Material specifications, availability, durability, ecological compatibility
	Labor and Equipment	Covers human resources and machinery needed for construction and planting. Includes skilled and unskilled labor, earthmoving equipment, manual tools, safety gear, and planting crews for vegetation establishment.	Labor availability, equipment rental cost, skill level
	Design Supervision and Project Management	Encompasses technical planning, oversight, and coordination throughout the project lifecycle. Includes hydraulic modeling, engineering design, supervision of earthworks and planting, and project coordination meetings.	Project scale, technical complexity, team expertise
	Contingency	Provides a financial buffer for unexpected costs or delays during implementation. Includes allowances for equipment breakdowns, slope failure, poor vegetation survival, material shortages, and weather-related disruptions.	Site unpredictability, seasonal conditions, inflation risk
OPEX	Routine Inspection and Maintenance	Covers regular checks to ensure structural and ecological functionality of the dike. Includes visual inspections of dike integrity, vegetation health, erosion signs, and slope stability, typically conducted monthly or after major rainfall events.	Rainfall frequency, erosion risk, accessibility of site, availability of trained personnel
	Vegetation Management	Ensures healthy plant growth and erosion control through seasonal care. Includes trimming, replanting, pest control, and irrigation during dry periods, conducted quarterly or seasonally depending on plant type and climate.	Plant species used, climate variability, pest outbreaks, irrigation needs

Cost category		Description / What to include	Cost drivers
	Monitoring and Reporting	Tracks performance and environmental impact through data collection and analysis. Includes labor and equipment for flood containment monitoring, vegetation surveys, infiltration rate measurement, and documentation, conducted semi-annually or annually.	Monitoring frequency, number of parameters tracked, equipment availability, technician wages
	Field Supervision and Administrative Support	Oversees maintenance activities and coordinates operations. Includes wages or stipends for supervisors, office coordination, transport, and communication, ongoing throughout the year with higher intensity in early years.	Staffing levels, administrative structure, transport needs
	Long-Term Rehabilitation	Restores full functionality after years of use or degradation. Includes labor and equipment for recompacting dike slopes, replacing vegetation and soil media, and repairing structural components, typically required every 10–15 years.	Extent of degradation, age of infrastructure, vegetation failure rates, soil condition

Practice 3 – Green corridor along pedestrian strip along Av. Jacques Opangault

Table 30. Indicative cost of green corridor

	Cost category	Description / What to include	Cost drivers
CAPEX	Transport and Logistics	Covers delivery and handling of materials and plants to the green corridor. Includes transport of compost, sand-gravel aggregates, vegetation, underdrain components, in case finally implemented, and coordination with nurseries.	Supplier proximity, plant sensitivity, road access
	Site Preparation	Involves excavating soils down to 0.5 m depth, grading and shaping of vegetation surface to ensure proper slope and drainage. Includes removal of existing vegetation, soil mixture with sandy gravel, and layout marking.	Slope gradient, soil permeability, existing land use
	Materials	Referring to all inputs required for green corridor development and planting. Includes compost, sand-gravel, native grasses, sedges, shrubs, underdrains, and erosion control fabric.	Material compatibility, infiltration needs, ecological goals
	Labor and Equipment	Covers workforce and tools for green corridor development. Includes grading crews, planting teams, manual tools, irrigation setup, and erosion control installation.	Labor skill level, equipment type, planting density
	Design Supervision and Project Management	Encompasses planning, technical oversight, and coordination. Includes expert for hydraulic modelling, in case a runoff drain system is finally included, vegetation layout design, supervision of grading and planting	Design complexity, vegetation mix, urban integration
	Contingency	Provides financial buffer for unexpected construction challenges. Includes allowances for poor soil conditions, plant failure, and erosion control adjustments.	Seasonal timing, soil surprises, plant availability
OPEX	Routine Inspection and Maintenance	Ensures the green corridor functions as intended through regular checks and upkeep. Includes visual inspections for erosion, blockages, and vegetation health; removal of debris and minor repairs. Typically conducted monthly, with additional checks after heavy rainfall events.	Rainfall frequency, urban debris load, accessibility of swale locations, and availability of trained personnel.
	Vegetation Management	Maintains healthy plant cover to support infiltration and pollutant filtration. Includes pruning, replanting, pest control, and irrigation during dry periods. Conducted quarterly, with replanting as needed based on plant survival and seasonal stress.	Plant species selection, climate variability, pest outbreaks, and irrigation needs.
	Sediment Removal	Prevents clogging and maintains infiltration capacity by removing accumulated sediment on upper vegetated surface.	Sediment accumulation rate, lateral roadway sediment input

Cost category		Description / What to include	Cost drivers
		Includes manual or mechanical removal of sediment from lateral traffic roadways. Typically required once or twice per year, depending on runoff volume and sediment load.	frequency of storms, and ease of access for removal.
	Monitoring and Reporting	Tracks performance and informs adaptive management decisions. Includes labor and equipment for hydraulic testing, in case drain system added, vegetation health assessments, and documentation of maintenance activities. Conducted semi-annually or annually, depending on project requirements.	Monitoring frequency, eventual runoff drain lines to be inspected and cleaned, data collection tools, and technician wages.
	Field Supervision and Administrative Support	Oversees maintenance activities and coordinates operations. Includes wages or stipends for supervisors, office coordination, transport, and communication. Ongoing throughout the year, more intensive in early years.	Staffing levels, administrative structure, transport logistics, and communication needs.
	Safety and Access Control	Ensures safe public interaction with green corridor and protects infrastructure. Includes installation and upkeep of signage, fencing, access paths, and barrier vegetation. Inspections conducted quarterly, with repairs as needed.	Public safety standards, vandalism risk, visibility of swale locations, and material durability.
	Long-Term Rehabilitation	Restores green corridor functionality after years of use or damage. Includes labor and equipment for full replacement of soil media, regrading, and replanting of vegetation. Typically required every 10–15 years depending on performance decline.	Extent of degradation, soil and vegetation condition, and availability of rehabilitation funding.

Economic Assessment

- Cost

Practice 1 – Riverbank naturalization

Table 31. Cost range of riverbank naturalization

Cost category		Key assumptions	Indicative cost range (USD/ ha)	Confidence Level	Data source
CAPEX	Materials	General assumptions • Intervention area: 1 ha = 10,000 m² • Average width of riparian buffer: 10 m • Equivalent treated length: ~1,000 m of riverbank (both sides → 2,000 m total) • Slope: Moderate • Local sourcing of plant material Planting assumptions • Native seeds for herbaceous cover: 150–200 kg. USD 8– USD 12 per kg => USD 1,200– USD 2,400 • Bamboo clumps: 1–2 m spacing: 1,000–2,000. USD 2– USD 4 per clump => USD 2,000– USD 8,000 • Live stakes: 0.5–1 m spacing: 2,000–4,000. USD 0.5– USD 1 => USD 1,000– USD 4,000 • Geotextile mats: 2,000 m × 1 m: 2,000 m. USD 2– USD 3 per m => USD 4,000– USD 6,000 • Fiber rolls for toe protection: 700–1,000 roll. USD 8– USD 12 per roll => USD 5,600– USD 12,000 • Soil amendments: compost/manure: 20–30 m³. USD 20– USD 30 per m³ => USD 400– USD 900	USD 14,200– USD 33,300	Low	Riparian Forest Buffer Cost Estimate. CONSERVATION INFORMATION SHEET - Forestry Series, 2002. Natural Resources Conservation Service Michigan Cost Estimate to Restore Riparian Forest Buffers and Improve Stream Habitat in the Willamette Basin, Oregon. 2010. Water Quality Division, Watershed Management Section. State of Oregon Mississippi Watershed Management Organization. 2010. *A Guide to Bank Restoration Options for Large River Systems: Part II Bioengineering Installation Manual.* MWMO Watershed Bulletin 2010-3. 95 pp. Watershed management and climate resilience improvement project (PABVARC) - Project Appraisal Report. 2019. World Bank Manuel de gestion des bassins versants au Burundi, 2021
	Equipment & Tools	• Excavator: Slope regrading → 10–15 days. USD 150– USD 250 per day => USD 1,500– USD 3,750 • Transport of plants from nursery to site (10–15 km): truck rental for 10-15 days including fuel (~USD 150–250 per day)	USD 3,200 – USD 7,800	Low	

	Cost category	Key assumptions	Indicative cost range (USD/ ha)	Confidence Level	Data source
		• Field tools for planting and preparation: hoes, spades, machetes, ropes, gloves, etc. Estimated flat cost: USD 200–300 per ha.			Sustainable Asset Valuation of Waterway Rehabilitation in Cape Town, South Africa. 2025. Nature-Based Infrastructure (NBI) Global Resource Centre. Local expertise
	Labor	• Skilled supervisor: 1 person × 20 days. USD 15– USD 20 per day => USD 300– USD 400 • Unskilled labor: 50 workers × 20 days = 1,000 days. USD 3 - $5 per day => USD 3,000 - USD 5,300	USD 3,300 – USD 5,400	Low	
	Total CAPEX per ha	Assuming normal working conditions, availability of slips in nearby nursery and local labor, and no additional land preparation beyond contour marking and light tillage.	**USD 20,700 – USD 46,500**		
OPEX	Routine operations & maintenance	**Frequency:** Quarterly maintenance (4 times/year) **Activities:** • Weed control and invasive species removal • Replacement of dead plants (5–10% mortality annually) • Minor soil amendment and mulching **Labor: USD 120– USD 200** • 5 workers × 2 days per visit × 4 visits = 40 person-days • Skilled supervisor: 1 person × 8 days/year **Materials: USD 150– USD 300** • Replacement plants: ~100–200 clumps or stakes/year • Mulch or compost: 5–10 m³/year **Equipment: USD 50– USD 100** • Basic hand tools (already purchased in CAPEX, minimal renewal)	USD 320– USD 600	Low	Riparian Forest Buffer Cost Estimate. CONSERVATION INFORMATION SHEET - Forestry Series, 2002. Natural Resources Conservation Service Michigan Cost Estimate to Restore Riparian Forest Buffers and Improve Stream Habitat in the Willamette Basin, Oregon. 2010. Water Quality Division, Watershed Management Section. State of Oregon Mississippi Watershed Management Organization. 2010. *A Guide to Bank Restoration Options for Large River Systems: Part II Bioengineering Installation Manual.* MWMO Watershed Bulletin 2010-3. 95 pp. Watershed management and climate resilience improvement project

Cost category	Key assumptions	Indicative cost range (USD/ ha)	Confidence Level	Data source
				(PABVARC) - Project Appraisal Report. 2019. World Bank Manuel de gestion des bassins versants au Burundi, 2021 Sustainable Asset Valuation of Waterway Rehabilitation in Cape Town, South Africa. 2025. Nature-Based Infrastructure (NBI) Global Resource Centre. Local expertise
Major repairs	**Frequency:** Once every 5 years (storm damage, erosion control failure) **Activities:** • Reinstallation of fiber rolls or geotextiles on damaged sections (~10–20% of length) • Replanting bamboo/live stakes in eroded zones **Labor: USD 300– USD 500** • 10 workers × 10 days = 100 person-days • Skilled supervisor: 1 person × 10 days **Materials: USD 1,500– USD 3,000** • Fiber rolls: 70–100 units • Geotextile: 200–400 m • Plants: 500–1,000 units **Equipment: USD 500– USD 1,000** • Excavator rental for 3–5 days	USD 460 – USD 900 (USD 2,300– USD 4,500/major repair)	Low	
Monitoring & reporting	**Frequency:** Twice per year (dry and wet season) **Activities:** • Vegetation survival survey • Photo documentation and erosion assessment • Simple water quality sampling (optional) **Labor: USD 80– USD 120** • 2 technicians × 2 days × 2 visits = 8 person-days**Equipment: USD 50– USD 100**	USD 170– USD 280	Low	

Cost category	Key assumptions	Indicative cost range (USD/ ha)	Confidence Level	Data source
	• GPS, camera (assumed available) • Basic sampling kits (flat cost amortized) Reporting: USD 40– USD 60 • Data entry and report preparation: 2 days/year			
Total OPEX per ha over the first year		USD 950 – USD 1,780		

These cost ranges confirm that riverbank naturalization is a medium-to-high CAPEX intervention per hectare, largely driven by the quantity of planting material (bamboo clumps, live stakes, seeds) and the need for toe and surface protection (e.g., fiber rolls/geotextiles) across long linear banks. While the annual O&M requirement remains manageable relative to the initial investment, performance and cost-effectiveness depend heavily on establishment success (survival rates) and on avoiding rework after storm events. In practical terms, this supports a phased approach: prioritize the most erosion-active reaches first, apply standardized cross-sections and planting palettes, and front-load supervision to protect the initial CAPEX and limit future rehabilitation costs.

Practice 2 - Set back and restoration of potentially existing levees

Table 32. Cost range of setbacks and restoration of potentially existing levees

	Cost Category	Key Assumptions	Indicative Cost Range (USD/100m)	Confidence Level	Data Source
CAPEX	Material and equipments	General assumptions: **Length:** 100 m • **Width of crest:** assume 3 m (typical for small dikes). • **Existing height:** 2 m; **New height:** +1 m. • **Slope:** 2.5:1 (horizontal:vertical). • **Fill material:** locally sourced soil. • **Compaction:** manual + light equipment Assumptions for elevation: • **Fill Material Volume:** 550 m³ (trapezoid section: top width 3 m, bottom width 8 m, height 1 m) : unit cost **USD 2– USD 4 per m³** (includes fuel, operator) • **Transport:** 55 truckloads (10 m³/trip), truck rental USD 150–USD 250/day, 5 trips/day → 11 days. • **Compaction Equipment:** Small roller rental USD 100–USD 150/day × 5 days. Assumptions for planting vetiver slips : • **Horizontal rows:** 10 rows × 100 m × 10 stations/m × **3 slips** = 3,000 slips. • **Vertical Rows:** 100 rows × 10 stations × **3 slips** = 3,000 slips. **Total Slips:** 6,000 slips @ USD 0.05–USD 0.10/slip → USD 300–USD 600.	USD 4,050 – USD 7,100	Low	Vetiver Grass Technical Specification **Focks, D.J. & Algera, A.**. (2006). VETIVER GRASS FOR RIVER BANK PROTECTION. Barman, Jyotirmoy & Kumar, Bimlesh. (2022). Turbulence in a compound channel with the combination of submerged and emergent vegetation. Physics of Fluids. 34. 10.1063/5.0086739. Marteau, Baptiste & Gibbins, Chris & Batalla, Ramon J & Vericat, Damia. (2018). Review of good practice in managing riverbank instability and erosion - A WWF-Malaysia Report. AUS_River_bank.pdf JICA. The Detailed Design Study for the Pasig-Marikina River Channel Improvement Project (Phase IV). 1000043553_02.pdf USDA. 2022. CONSERVATION PRACTICE STANDARD DIKE AND LEVEE. Local expertise
	Labor	**Total Labor:** Includes excavation, spreading, compaction assistance, planting horizontal + vertical rows with 3 slips/station. • **Earthwork:** 10 unskilled workers × 15 days × USD 3–USD 5/day → USD 450–USD 750. • **Planting Vetiver:** 5 workers × 12 days × USD 3–USD 5/day → USD 180–USD 300 (extra time for more slips). • **Skilled Supervision:** 1 foreman × 15 days × USD 15–USD 20/day → USD 225–USD 300	USD 1,035 – USD 1,590	Low	

	Cost Category	Key Assumptions	Indicative Cost Range (USD/100m)	Confidence Level	Data Source
		• **Additional Skilled for Planting Layout:** 1 foreman × 12 days × USD 15–USD 20/day → USD 180–USD 240.			
	Design & Engineering	• Hydraulic modeling : 4 person-days • Topographic survey & soil investigation : 3 person-days • Engineering design drawings : 2 person-days • Planting layout design : 1 person-day • Quality control & supervision planning : 1 person-day • Skilled labor rate: USD 15–USD 20/day	USD 500 – USD 700	Low	
	Total CAPEX		**USD 5,585 – USD 9,390**		

OPEX	Annual Maintenance	**Watering :**
		• **Frequency:**
		  o Daily for 2 weeks → 14 events
		  o Twice per week for 6 weeks → 12 events
		  o **Total watering events = 26**
		• **Labor per event:** 2–3 worker-days/event
		• **Total worker-days:** 26 × (2–3) = **52–78 worker-days**
		• **Cost:** USD 3–USD 5/day → **USD 156–USD 390**
		Replacing Dead/Damaged Plants
		• Survival rate = 95% → 5% replacements
		• Initial slips = 6,000 → replacements = 300 slips
		• Planting productivity similar to initial planting:
		  o 6,000 slips took 5 workers × 12 days = 60 worker-days
		  o For 300 slips → (300 ÷ 6,000) × 60 = 3 worker-days
		• **Cost:** 3 × USD 3–USD 5 = **USD 9–USD 15**
		Weeding
			USD 174–USD 465	Low	Vetiver Grass Technical Specification[90]
					
					Focks, D.J. & Algera, A.. (2006). VETIVER GRASS FOR RIVER BANK PROTECTION.
					
					Barman, Jyotirmoy & Kumar, Bimlesh. (2022). Turbulence in a compound channel with the combination of submerged and emergent vegetation. Physics of Fluids. 34. 10.1063/5.0086739.
					
					Marteau, Baptiste & Gibbins, Chris & Batalla, Ramon J & Vericat, Damia. (2018). Review of good practice in managing riverbank instability and erosion - A WWF-Malaysia Report.
					
					AUS_River_bank.pdf

[90] https://www.vetiver.org/TVN_technicalspecs.htm

Cost Category	Key Assumptions	Indicative Cost Range (USD/100m)	Confidence Level	Data Source
	• Frequency: 1–3 rounds in Year 1 • Productivity: 50–100 m per worker-day • Hedge length = 100 m → 1–2 worker-days per round • For 1–3 rounds → **1–6 worker-days** • **Cost:** USD 3–USD 5/day → **USD 3–USD 30** Pruning • Frequency: 1–2 trims in first 10 months • Worker-days per trim: 2–3 • Total: 2–6 worker-days • **Cost:** USD 6–USD 30			JICA. The Detailed Design Study for the Pasig-Marikina River Channel Improvement Project (Phase IV). 1000043553_02.pdf USDA. 2022. CONSERVATION PRACTICE STANDARD DIKE AND LEVEE. Local expertise
Major repairs	Assume **every 5 years**, 10% of dike length needs re-compaction and replanting Cost ≈ 10% of initial CAPEX → USD 560–USD 940 per 100 m (spread over 5 years) Annualized: USD 112–USD 188/year	USD 112–USD 188	Low	
Monitoring & reporting	Quarterly site visits: 4 visits/year Each visit: 1 skilled person-day @ USD 15–USD 20/day	USD 60–USD 80	Low	
Total OPEX		USD 346 – USD 733		

The table shows that levee set-back/elevation with vegetative stabilization is relatively cost-efficient per 100 m, with costs dominated by earthworks logistics (fill volume, haulage, and compaction) and only a secondary share attributable to vetiver planting materials. This means that project economics will be primarily determined by access, haul distance, and construction productivity, rather than by specialized inputs. In practical terms, the measure is well-suited for rapid deployment in priority stretches—provided that hydraulic design parameters are validated and that vegetation establishment (vetiver rows and maintenance) is treated as integral to the structural function, not an optional add-on.

Practice 3 – Green corridor along pedestrian strip along Av. Jacques Opangault

Table 33. Indicative cost of green corridor

Cost Category		Key Assumptions	Indicative Cost Range (USD/100m)	Confidence Level	Data Source
CAPEX	Material and equipments	• Assumed dimensions of site: Length = 100m, wide = 2 x 2.5 m lateral + 1 x 1 m central strips. Total surface = 600 m^2 • 150 m^3 of sandy gravel to be supplied and mixed with local subsoil / to be locally compensated with organic soil (trees, shrubs and grass rooting) • 20 big tree seedlings / 140 shrubs seedlings / 5.250 m^2 of grass-cover (seeds) • 300 m^2 of pervious pavement components • Material and equipment required: o Excavation o Engineered soil (imported or custom mix) o Gravel o Softscaping o Include equipment and transport. • Estimated rate per square meter of green corridor is of USD 10–15 • Total cost = 10*600 to 15*600	USD 6,000 – USD 9,000	Low	Projected from EPA. 2021. Stormwater Best Management Practice: Grassed Swales WB-GFDDR (2024)[91] - Senegal-Dakar Green Corridor Green Corridor Budget Local expertise
	Labor	• Assume basic tools, unskilled labor, and no machinery. • 140–180 worker-days of unskilled labor • Rate of unskilled labor: USD 8 – 12 USD/day • Supervision of skilled labor = 15 – 20 worker-days • Rate of skilled labor = 20 – 25 USD/day • Total cost = 140*8 + 15*20 to 180*12 + 20*25	USD 1,420 - USD 2,660	Low	Projected from WB-GFDDR (2024) - Senegal-Dakar Green Corridor Green Corridor Budget Local expertise
	Design & Engineering	• Site survey and assessment, Hydrologic/hydraulic design, engineering drawings and specs, permitting and coordination, project management and supervision • Estimated at 30 days at 15 – 20 USD/day	USD 450 – USD 600	Low	Sustainable Technologies Evaluation. Enhanced Swales. n.d. Life Cycle Costs. Local expertise

[91] World Bank, 2024. The Nature-Based Solutions Opportunity Scan: Leveraging Earth Observation Data to Identify Investment Opportunities in NBS for Climate Resilience in Cities and Coasts across the World. © World Bank, Washington, DC. License: CC BY 3.0 IGO

	Cost Category	Key Assumptions	Indicative Cost Range (USD/100m)	Confidence Level	Data Source
		• Total cost = 30*15 to 30*20			
	Contingency	• For landscaping and NbS measures at the prefeasibility stage = usually 20% – 30% • Total cost = 20% of lower bound of sum of materials + labor + equipment and tools and 30% of upper bound of same categories	USD 1,580 – USD 3,700	High	Report-Toolbox-on-Financing-Nature-Based-Solutions.pdf View of NbS experts
	Total CAPEX		USD 9,450 – USD 15,960		
OPEX	Routine operations & maintenance	• Activities include: Vegetation trimming, sediment removal, inspection, and replanting. • Unskilled labor = 10 worker-days/month => 60 worker-days/year • Skilled labor = 1 worker-days/month => 12 worker-days/year • Total cost range = 12*15 + 60*8 to 12*20+60*12	USD 660 – USD 9600	Medium	https://wjarr.com/sites/default/files/WJARR-2019-0138.pdf Local expertise
OPEX	Major repairs	• Light earthworks after heavy rains (2 events/year) • No heavy machinery; manual + small equipment • Total labor: 5 –10 worker-days depending on severity • 1 skilled supervisor days/year at 15–20 USD/day • Total cost = 8*12 + 1*15 to 12*12+1*20	USD 55 - USD 140	Medium	Projected from WB-GFDDR (2024) - Senegal-Dakar Green Corridor Green Corridor Budget Local expertise
OPEX	Monitoring & reporting	• Skilled labor: 0.5 worker-days/month • Total labor: 6 worker-days: • Total cost = 6*15 to 6*20	USD 90 - USD 120	Medium	Projected from WB-GFDDR (2024) - Senegal-Dakar Green Corridor Green Corridor Budget Local expertise
	TOTAL OPEX		USD 660 – USD 1,030		

These ranges confirm that a street-level green corridor is a moderate CAPEX measure per 100 m when implemented as a defined vegetated/pervious strip (600 m² per 100 m section), with costs driven by soil/media preparation and soft landscaping, plus a meaningful contingency consistent with prefeasibility-stage uncertainty. The OPEX profile is comparatively predictable and modest, reflecting routine trimming, sediment removal, inspections, and limited periodic repairs—

suggesting that the key determinant of sustainability is not the absolute maintenance burden but institutionalization of who does what, when, and with which budget line. In practical terms, this makes the corridor a suitable pilot-and-standardize investment: implement an initial segment with strict QA/QC (grading, soil mix, planting density), then replicate using the same "bill of quantities per 100 m" to control costs and outcomes at scale.

- <u>Benefits</u>

Table 34. Benefits monetization of practices along the Tchikobo and Songolo target sections.

Practice	Benefit	Key Assumptions	Indicative Cost Range	Confidence Level	Source
Riverbank renaturalization	Avoided damage	• Riparian buffer reduces bank erosion and flood risk; evidence from African NbS measures shows 15–30% reduction in sediment load and localized flood damages. • Baseline: smallholder crop revenue ≈ USD 1,000/ha/yr; typical flood/erosion losses ≈ 40–50% during severe events. • Add avoided dredging and minor infrastructure repairs (culverts, rural roads) ≈ USD 50–100/ha/yr. • Computed over 25 yrs at 8% discount.	810–3,940 USD/ha/yr	Low	Sustainable Asset Valuation of Waterway Rehabilitation in Cape Town, South Africa. 2025. Nature-Based Infrastructure (NBI) Global Resource Centre. Sustainable Asset Valuation of Nature-Based Flood Mitigation Infrastructure in Drakenstein, South Africa. 2025. Nature-Based Infrastructure (NBI) Global Resource Centre. And other reports from IISD, NBI Global Resource Center Local expertise
	Carbon sequestration	• Mixed riparian planting (bamboo, native trees, herbaceous cover) sequesters ≈ 9–16 tCO_2e/ha/yr (East Africa FLR benchmarks). • Monetization scenarios: – Voluntary carbon market: USD 5–9/tCO_2e. • Assumes permanence and no leakage.	45–144 USD/ha/yr	Low	
	Jobs gain	Annual OPEX and one-off CAPEX (not annualized) = Skilled labor = 38 worker-days Unskilled labor = 560 worker days	1,125 - 2,800 per USD/ha/yr	Low	
	Total		**1,980–6,884 USD/ha/yr**		
Set back and restoration	Avoided damage	**Dike elevation (+1 m)** significantly reduces overtopping risk for return periods up to 10–20 yrs.	450–600 USD /100m/yr	Low	Vetiver grass—most cost-efficient soil erosion control doubles crop yield[92] –

[92] https://farmbizafrica.com/vetiver-grass-the-most-cost-efficient-control-for-soil-erosion-increases-yield-40/#:~:text=Vetiver%20grass%E2%80%94most%20cost%2Defficient%20soil%20erosion%20control%20doubles%20crop%20yield,-3%20min%20read&text=Vetiver%20grass%20is%20classed%20as,vetiver%20hedges%20on%20their%20farms.

Practice	Benefit	Key Assumptions	Indicative Cost Range	Confidence Level	Source
of potentially existing levees		Assume it avoided crop loss and minor infrastructure damage similar to flood protection projects. Baseline crop revenue ≈ USD 1,000/ha/yr; avoided loss ≈ USD 400–USD 500/ha/yr. Add USD 50–USD 100/ha/yr for minor infrastructure repairs. Area protected by 100 m dike: assume **0.1 ha** (10 m width of floodplain). Vetiver hedges reduce wave run-up by 55–60%, further lowering erosion risk. => (400–500 + 50–100) × 0.1 = USD 45–USD 60/yr. PLUS elevation benefit: If overtopping avoided during major flood (every 10 yrs), assume USD 5,000 damage avoided → annualized USD 500/yr.			Focks, D.J. & Algera, A.. (2006). VETIVER GRASS FOR RIVER BANK PROTECTION. Marteau, Baptiste & Gibbins, Chris & Batalla, Ramon J & Vericat, Damia. (2018). Review of good practice in managing riverbank instability and erosion - A WWF-Malaysia Report.
	Carbon sequestrati on	Although : Vetiver ≈ 2 t C/ha/yr (~7.3 t CO_2/ha/yr), it is negligeable on a 100m stretch	0 USD/100m/yr	Low	Carbon sequestration – The Vetiver Network International[93]
	Jobs gain	Annual OPEX and one-off CAPEX (not annualized) = Skilled labor = 32 worker-days Unskilled labor = 150 – 200 worker days	930 – 1,640 USD/100m/yr	Low	Local expertise Cost table
	Total		1,380 –2,240 USD/100m/yr		

The benefits table indicates that the monetized value proposition for the river-corridor package is driven mainly by avoided damage (erosion/flood impacts and minor infrastructure repair), with additional but smaller contributions from carbon sequestration and jobs gain. Importantly, the confidence ratings are largely low, which implies the figures are best interpreted as order-of-magnitude decision support—useful for comparing options and prioritizing segments—rather than as precise appraisal values. In practical terms, this supports prioritizing interventions where exposure is highest and avoided-damage mechanisms are most credible (e.g., active erosion banks, repeatedly flooded edges), while simultaneously strengthening monitoring so that future phases can replace conservative assumptions with site evidence.

[93] https://www.vetiver.org/vetiver-system-applications/other-uses/carbon-sequestration/

Table 35. Benefits of monetization of practices associated to a green corridor along Av. Jacques Opangault

Practice	Benefit	Key Assumptions	Indicative Cost Range (USD/100m/yr)	Confidence Level	Source
Vegetated swale / Green Corridor	Carbon sequestra tion	• Green Corridors with dense vegetation can sequester carbon, though less than wetlands. • Estimated sequestration ≈ 1.2 t C/ha/yr (~4.4 t CO_2/ha/yr). • Monetized at USD 50/t CO_2. • Based on general bioswale vegetation estimates and extrapolated from wetland studies => Conversion from ha to 600m2: 4.4×0.06=0.264 t CO2/yr => Monetized value: 0.264×50=USD 13,2/yr	USD 12 – USD 14	Low	https://www.epa.gov/green-infrastructure
	Jobs gain	• Annual OPEX and one-off CAPEX (not annualized) = Skilled labor = 20 Unskilled labor = 65 – 70 worker days	USD 820 – USD 1,140	Low	Cost table

This table makes it explicit that the green corridor's monetized benefits are highly conservative, largely limited to a small carbon value and a jobs/labor component, which structurally constrains the economic case if judged only on monetized returns. The practical implication is that the corridor should be positioned primarily as an urban service and resilience measure (stormwater control, microclimate/heat mitigation, streetscape quality, safety and accessibility), with the monetized lines treated as partial indicators rather than full accounting. In other words, the corridor is most defensible when embedded in broader urban upgrading objectives and financed accordingly, rather than evaluated as a narrow "carbon project."

- <u>Benefit-Cost Ratio</u>

Table 36. Annual benefits, costs and BCR of each practice along the Tchikobo-Songolo final river sections

Practice	Total CAPEX ($)	Annualized CAPEX ($/yr)	OPEX ($/yr)	Total Annual Cost ($/yr)	Annual Benefit ($/yr)	BCR Low	BCR High
Riverbank renaturalization	13,260 – 33,670 (USD/ha)	1,717 – 4,360 (USD/ha)	800 – 1,740 (USD/ha)	2,517 – 6,100 (USD/ha)	1,980 – 6,884 (USD/ha)	0.32	2.74
River dike elevation with vegetation	5,326 – 8,011 (USD/100m/yr)	686 – 1,032 (USD/100m)	345 – 733 (USD/100m)	1,031 – 1,765 (USD/100m)	1,380 – 2,240 (USD/100m)	0.78	2.17
Green Corridor along Avenue	9,450 – 15,960 (USD/100m)	615 – 1,038 (USD/100m)	805 – 1,220 (USD/100m)	1,420 – 2,258 (USD/100m)	832 – 1.154 (USD/100m)	0,37	0,81

* The 100 m unit for the Green Corridor along the Av. Jacques Opangault refers to the defined green strip dimensions of this measure along a 100 m section of this street; this is equivalent to 600 m^2 of vegetized/pervious pavement surface.

According to the BCR estimation of the interventions proposed for the green corridor along the Tchikobo and Songolo final river sections (Table 36), the three practices show distinct levels of economic performance, reflecting differences in investment scale, maintenance needs, and the magnitude of monetized benefits:

- Riverbank renaturalization exhibits a BCR range of 0.32–2.74. While the high-end scenario indicates strong economic viability—particularly when ecosystem services such as avoided erosion, flood mitigation, and biodiversity benefits are realized—the low-end scenario falls below 1. This suggests that the practice is economically viable primarily under favorable cost and benefit assumptions. Its wide BCR range reflects uncertainty in benefit valuation, but its multiple co-benefits strengthen its case from a resilience and sustainability perspective.

- Set back and restoration of potentially existing levees demonstrates a BCR range of 0.78–2.17, indicating moderate to strong economic viability. Although the low-end scenario is slightly below 1, the high-end scenario suggests that benefits can clearly exceed costs. Compared to large structural measures, this intervention offers a relatively cost-effective flood risk reduction option, particularly when combined with vegetative stabilization that provides additional erosion control and ecological co-benefits.

- Green Corridor along Av. Jacques Opangault, shows a rather low BCR range of 0,37-0,81, indicating rather low economic viability in terms or economic turn-around. Yet, it should be noted that due to the basic design proposed, from a conservative point of view, additional benefits such as pluvial flood mitigation, heat reduction, human wellbeing and potential activity increase along the avenue have not been added.

  This avenue falls outside the original green corridor area suggested in the WB documents shared with the consulting team and the idea of including it in this scope proposal is to promote the future greening of the city center of Pointe-Noire to strengthen its future climate resilience. The suggested avenue could be upgraded in accordance with the available funding.

Overall, the Riverbank renaturalization shows the widest spread (BCR 0.32–2.74), implying it becomes strongly viable under favorable benefit realization and controlled costs, but can underperform where establishment fails or benefits are conservatively captured. River dike elevation with vegetation is more consistently attractive (BCR 0.78–2.17), suggesting it is a pragmatic near-term option where engineering access and safeguards conditions allow. By contrast, the Av. Jacques Opangault green corridor remains below 1 in this conservative framing (BCR 0.37–0.81), reinforcing that its justification depends on co-benefits not monetized here and on strategic alignment with municipal infrastructure planning. Overall, the table supports a sequenced portfolio: prioritize levee/riverbank works in high-exposure segments as early risk-reduction anchors, while piloting and refining the avenue corridor as an urban upgrading measure with broader outcome tracking.

Nature-based and hybrid solutions such as riverbank renaturalization and vegetated dikes show strong potential when co-benefits are considered, while other, apparently less urgent measures like green corridors along the city´s urban center may probably need to be considered from the perspective of the intangible values they provide, principally related to human wellbeing. These findings underscore the importance of accounting for uncertainty, local context, and non-monetized benefits in early-stage planning and prioritization of flood risk management and river restoration interventions.

Implementation (Governance, Legal, and Institutional Aspects)

Establishing an effective implementation framework for NbSWLM practices in Pointe-Noire requires a clear governance structure, legal compliance, and institutional coordination. The proposed interventions—riverbank naturalization, floodplain restoration, levee setback, and green corridor development—must align with national laws and local administrative systems while ensuring inclusive stakeholder engagement.

The intervention area falls under the administrative jurisdiction of Pointe-Noire, specifically the districts of Lumumba, Mongo-Mpoukou, Mvou-Mvou, and Loandjili. Key actors and their roles include:

- Municipality of Pointe-Noire: Responsible for procurement, supervision, and integration of NbSWLM practices with urban drainage and road infrastructure works.
- Prefecture of Pointe-Noire and Loandjili marie: Oversight of land-use planning, coordination with technical agencies, and enforcement of buffer zone regulations.
- Directorate-General for the Environment & Ministry of Spatial Planning: Ensure compliance with environmental laws, water management codes, and urban planning regulations.
- Community Development Committees (CGDCs) and neighborhood Committees: Mobilize residents for maintenance, monitor interventions, and report damages or misuse.
- NGOs and CBOs: Provide technical support, training, and facilitate community engagement.

The implementation of NbSWLM practices in Pointe-Noire is supported by the following national frameworks (same as Brazaville):

- Law No. 003-1991 on Environmental Protection (Loi sur la Protection de l'Environnement), which establishes principles for environmental conservation and sustainable land use.
- Law No. 16-2000 on Water Management (Code de l'Eau), regulates water resources, drainage systems, and flood mitigation practices.
- Law No. 6-2019 on Urban planning and land tenure regulations (Code de l'Urbanisme et de l'Aménagement du Territoire), provides rules for land use and construction in urban areas, including interdiction of construction within 25 m buffer of river courses; and requires coordination with municipal authorities for interventions in informal settlements.
- National Climate Change Adaptation Strategy (SNACC), promotes NbS for climate resilience, and encourages integrated watershed management.
- Decentralization Law (Loi sur la Décentralisation), empowers local authorities and community committees (CGDC) to manage environmental risks.

Given the need to clear floodplains and restore natural buffers, a Resettlement Policy Framework (RPF) and Land Conflict Analysis are mandatory before any displacement or compensation process begins. These instruments ensure compliance with national law and World Bank safeguards, while preventing social tensions.

Institutional Coordination

A multi-tiered coordination mechanism is recommended:

- Lead Agency: Municipality of Pointe-Noire, supported by the Direction de Grand Travaux, and if applicable, the Project Implementation Unit (PIU) under the World Bank SURP.
- Technical Partners: National agencies, NGOs, and specialized contractors for bioengineering and earthworks.
- Community Engagement: CGDCs and local committees to participate in planting, maintenance, and monitoring.

To facilitate decision-making and ensure a smooth transition from this Compendium to implementation, Table 37 outlines high-level next steps for the integrated restoration activities along the Tchikobo and Songolo rivers target segments. These steps provide a clear roadmap for sequencing activities, assigning responsibilities, and estimating indicative timelines. While detailed engineering and safeguards planning will follow during the feasibility stage, this overview helps stakeholders understand the immediate actions required to operationalize the proposed NbSWLM interventions.

It should be noted that with regard to the details of the resettlement and expropriation process to be developed for liberating the floodplain space only a rough process components line is presented with some of the administrative stakeholders involved and very indicative timing projections. These processes can extend in duration due to many factors, although the AFD Brazzaville case document before-mentioned should provide a useful guide in order to streamline the process and reduce its preparation and implementation timeline as much as possible. This process is presented in the table in first position as it is considered that without clarifying and addressing this key component of the entire landscape restoration process the actual NbS feasibility assessment and implementation processes cannot be completed. Yet, considering the potentially quite long period necessary for completing the liberation process of the floodplains, quite some overlap between the social and technical components could be pursued.

Table 37. Next steps for implementation of NbSWLM practices for restoration of final Tchikobo and Songolo river segments.

Activity	Description	Responsible Entity	Indicative Timing
Development of Resettlement Action Plan	Assessment of necessary resettlement and expropriation needs and development of an action plan report in accordance, for instance with the example shared by AFD for this project	Republic of Congo Government	12-24 months
Stakeholder Engagement and Public Consultation Process	Involved administrative and local stakeholders, including the affected residents, need to be informed of the process planned and engaged in order to know their vision and suggestions	Republic of Congo Government, Ministère de l'Aménagement du Territoire, La Délégation Générale aux Grands Travaux (DGGT)	12-24 months
Implementation of Resettlement Plan	Implementation of the resettlement process of the residents affected by the plan	Republic of Congo Government, Ministère de l'Aménagement du Territoire,	12-24 months
Implementation of construction removal Plan	Removal of constructions from the floodplains and restoration of original surface morphology (earthworks) / Environmental	La Délégation Générale aux Grands Travaux (DGGT)	12-24 months

Activity	Description	Responsible Entity	Indicative Timing
	safeguards to be addressed (waste management, etc.)		
Detailed Feasibility study	Conduct hydrological modeling, high resolution DEM model, geotechnical surveys, and finalize design for integrated NbSWLM package (riverbank renaturalization, river dikes retreat-restoration, green corridor).	Direction des Grands Travaux with municipal engineers; support could be provided by World Bank or AFD	6–12 months
	Assess viability of infiltration swales only within an integrated stormwater management system, considering malaria risk, pedestrian access, waste disposal, and potential gully initiation. Include design safeguards or propose alternatives if risks are high.	Direction des Grands Travaux, Pointe-Noire municipality	4 months
Define Governance & Maintenance Mechanism	Establish clear roles for implementation oversight and long-term O&M of each practice; include CGDC budget transfer and private-sector engagement (CSR).	Municipality of Pointe-Noire (involved Districts: Lumumba, Mongou-Mpoukoiu; Mvou-Mvou and Loandjili) in coordination with the Direction of Grand Travaux, and support from NGOs and technical partners	3-4 months (parallel to feasibility stage)
Safeguards & Land Access	Validate land tenure and community agreements.	Municipality of Pointe-Noire (involved Districts) and Social Safeguards Specialists	Parallel to feasibility stage
Budget Allocation & Financing	Secure funding for CAPEX and OPEX; define CGDC budget transfer mechanism; explore co-financing options (municipal + donors).	Municipality of Pointe-Noire (involved Districts), Ministry of Finance	6 months
Capacity Building	Train CGDCs and municipal teams on NbSWLM maintenance, financial management, and rapid-response protocols.	Municipality + NGOs + Technical Partners Before implementation of practices (2–3 months)	Year 1
Community Validation	Engage local communities to review proposed designs, especially for practices affecting mobility (e.g., terracing), and	CGDCs + Social Safeguards specialists of municipality	Parallel to feasibility stage

Activity	Description	Responsible Entity	Indicative Timing
	incorporate feedback into final plans.		
Monitoring & Adaptive Management	Establish performance indicators (erosion reduction, infiltration rates, maintenance compliance); update designs based on lessons learned.	Pointe-Noire (involved Districts)	Continuous

Modularity, replicability and enabling conditions

The set of NbSWLM practices proposed along the Tchikobo and Songolo river sections and Avenue Jacques Opangault aims to create two green corridors, one along the water courses and one along the traffic avenue, to restore their environmental services and contribute to strengthening the urban resilience of Pointe-Noire against climate risks. Although the displacement of residents along the river sections will be necessary, it is believed that in the long run the benefits of the restoration investments will become clear to the surrounding residents and that the combined green corridors will represent a milestone for the future urban development of the city.

The 25-meter buffer zone along watercourses in the Republic of Congo is established under the national Water Code, specifically:

- Law No. 13-2003 of 10 April 2003 (Code de l'eau), which provides the legal foundation for water resource management.
- This buffer is detailed in Decree No. 2017-256 of 2017, titled "Décret fixant les périmètres de protection des ressources en eau et des installations", which defines protection perimeters (périmètres de protection) around watercourses and hydraulic infrastructures, including the requirement for a minimum 25-meter buffer zone on each side.

Taking into consideration that several conditions observed in Pointe-Noire—flat floodplains, informal settlements, and high exposure to fluvial and coastal flooding—are common in other coastal cities of the Congo Basin. Successful implementation of such practices would serve as a proof of concept for replication in other districts of Pointe-Noire with similar hazard profiles, and coastal urban centers in the Republic of Congo and neighboring countries facing comparable socio-environmental challenges.

6.3 Conclusions and Recommendations

5.3.1 Conclusions

This Compendium confirms that Nature-based Soil, Water and Land Management (NbSWLM) solutions constitute a robust, cost-effective and scalable response to the growing challenges of urban flooding and gully erosion in the Republic of the Congo, particularly in Brazzaville (Mfilou district) and Pointe-Noire. Across all three assessed sites—Tsième catchment (Sites A and B) and the Tchikobo–Songolo corridor (Site C)—current exposure to climate-related hazards is already high and is projected to intensify under future climate scenarios, driven by increasing rainfall intensity, longer dry spells and sustained warming trends.

The analyses demonstrate that the primary drivers of risk are closely linked to rapid and largely unplanned urban expansion on fragile sandy or hydromorphic soils, encroachment into floodplains, and the absence of integrated stormwater and erosion-control systems. In this context, NbSWLM interventions offer a credible alternative or complement to conventional grey infrastructure, delivering not only risk reduction but also multiple co-benefits related to ecosystem services, public space quality, livelihoods and climate mitigation.

In Brazzaville's Mfilou district, the pre-feasibility assessment confirms that an integrated upstream–downstream landscape approach—combining infiltration swales, vegetated gabions, terracing with deep-rooted species (such as vetiver), wooden check dams and rock stilling basins—is technically feasible and well adapted to local geomorphological and social conditions. When implemented as a connected system rather than as isolated measures, these interventions can significantly reduce hillslope erosion, stabilize active gullies and attenuate flash-flood peaks affecting downstream neighborhoods. The estimated direct and indirect beneficiary population is substantial, and social acceptability is high, with communities largely perceiving the interventions as necessary and overdue.

From an economic perspective, the results clearly indicate strong performance for several core measures. Rock stilling basins and vegetated terraces exhibit particularly high benefit–cost ratios, reflecting their effectiveness in reducing infrastructure damage and sediment transport at relatively moderate cost. While wooden check dams show more marginal economic performance when assessed in isolation, they play an important complementary role in sediment control and system stability when integrated into a broader treatment train. Beyond avoided damage, the interventions generate significant co-benefits, including improved water quality, soil fertility, carbon storage, biodiversity enhancement and short-term employment during construction and maintenance phases.

In Pointe-Noire, the proposed linear green corridor along the lower Tchikobo and Songolo rivers addresses one of the city's most structurally vulnerable flood-risk contexts: densely occupied floodplains with limited hydraulic capacity and high exposure to both fluvial and pluvial flooding. The proposed package—comprising floodplain liberation, riverbank renaturalization through bioengineering, and the setback and reinforcement of levees—shows moderate to strong economic viability and high risk-reduction potential, while also restoring critical ecological functions. The complementary green corridor along Avenue Jacques Opangault further illustrates how NbSWLM can be embedded within dense urban fabrics to improve drainage, thermal comfort and overall urban liveability.

At the same time, the Pointe-Noire case highlights the importance of robust social safeguards and institutional coordination. Floodplain restoration necessarily entails the relocation of exposed households and economic activities, making early preparation of resettlement instruments, land-tenure clarification and participatory design processes indispensable preconditions for success. The Compendium confirms that the national legal framework—particularly the Water Code and associated buffer-zone regulations—provides a solid basis for such interventions, but effective implementation will depend on strong municipal leadership, inter-agency coordination and sustained engagement with affected communities.

Overall, the Compendium demonstrates that NbSWLM solutions in the RoC are not only technically and economically viable, but also strategically aligned with national climate-adaptation priorities and urban-development objectives. When designed as integrated systems and supported by appropriate governance and maintenance arrangements, they represent "low-regret" investments capable of delivering durable benefits under a wide range of future climate conditions.

5.3.2 Recommendations

Building on the evidence generated through the pre-feasibility assessments, the following strategic recommendations are proposed to guide the transition from early-stage concepts to implementable investment pipelines:

1. Prioritise Integrated Landscape Packages in Mfilou

Decision-makers should prioritise the rapid implementation of the integrated NbSWLM package in Sites A and B, where social risk is low and cost-effectiveness is demonstrably high. Investments should treat the Tsième sub-catchment as a single hydrological system, with measures deliberately sequenced from upstream runoff control (e.g. infiltration swales and road-speed and drainage management), through head cut and gully stabilization (vegetated gabions and rock stilling basins), to slope and valley-floor interventions (terracing and check dams). Measures with the strongest economic performance—particularly rock stilling basins and vegetated terraces—should anchor initial investment phases, while wooden check dams should be deployed as complementary structures to enhance sediment retention and system resilience rather than as standalone solutions.

2. Embed Robust Safeguards and Resettlement Frameworks in Pointe-Noire

For Site C, no physical works should proceed in the absence of a dedicated Resettlement Policy Framework and site-specific Resettlement Action Plans that are fully consistent with national legislation and the World Bank Environmental and Social Framework. A detailed land-tenure and conflict analysis is required to identify formal and customary rights, clarify eligibility and compensation principles, and anticipate potential disputes. The technical design of floodplain restoration—including corridor footprint, buffer widths and levee alignments—should be co-developed with affected communities, explicitly linking relocation packages to demonstrable improvements in safety, access to services and livelihood opportunities. Implementation sequencing should prioritise early interventions in already open or lightly occupied river sections, allowing visible benefits to be demonstrated quickly and trust to be built progressively.

3. Strengthen Governance, Local Capacity, and Maintenance Systems

The long-term performance of NbSWLM interventions depends critically on sustained operation and maintenance. Municipal authorities in Brazzaville and Pointe-Noire should formalise institutional responsibilities, budget allocations and accountability mechanisms for NbS maintenance, supported by simple but enforceable maintenance plans and response protocols. Community Development Committees (CGDCs) and local associations should be trained, formally mandated and resourced to carry out routine inspections—such as checks on gabion stability, terrace integrity and vegetation survival—and to report issues through clearly defined rapid-response channels. In parallel, targeted capacity building is required for municipal engineers, contractors and community leaders on bioengineering design, slope stability and safe construction practices, drawing explicitly on lessons learned from past infrastructure failures, including inadequately founded or poorly maintained structures.

4. Integrate NbSWLM into Urban Planning, Codes, and Financing Streams

NbSWLM approaches should be systematically mainstreamed into city-level master plans, zoning instruments and building regulations. This includes enforcing mandatory setbacks from rivers and drainage corridors, restricting construction on steep or erosion-prone sandy slopes, and promoting or incentivising on-plot infiltration and runoff retention measures. Future infrastructure investments—particularly under the Strengthening Urban Resilience Project and related programmes—should be required to assess hybrid green–grey solutions as part of standard project appraisal. Financing strategies should combine national and municipal budget allocations with World Bank and other multilateral development bank instruments, while exploring opportunities for climate finance and co-financing from private developers or utilities that directly benefit from reduced flood and erosion risks. The unit cost and benefit parameters developed in this Compendium should be progressively refined and institutionalised as standard decision-support tools for planning, budgeting and prioritisation.

5. Use Pilot Corridors and Monitoring to Enable Scaling and Learning

Implementation in the Ngambio–Itsali system and in selected, conflict-sensitive segments of the Tchikobo–Songolo corridor should be explicitly framed as learning-oriented pilot interventions. A modest but adequately resourced monitoring framework should be established to track physical performance (e.g. erosion rates, flood frequency and extent), socio-economic outcomes (affected households, livelihood impacts and perceived benefits), and maintenance effectiveness over time. Monitoring results should be systematically documented and used to update national NbSWLM guidelines, training materials and design standards, enabling replication in other vulnerable catchments and urban centres. In Pointe-Noire, a phased pilot—potentially along a shorter section of the Avenue Jacques Opangault green corridor—could be implemented to test design assumptions and refine cost and benefit evidence before committing to full-scale rollout.

7. SUMMARY TABLE OF THE PROPOSED NBSWLM EVALUATION CRITERIA

Throughout the pre-feasibility study, the three interventions have been qualitatively evaluated according to six criteria:

- Technical feasibility
- Risk reduction potential
- Co-benefits
- Economic Viability
- Maintenance complexity
- Social acceptability

For each criterion, scoring ranks between Low, Medium or High. A further explanation is provided below:

Technical feasibility

- The intervention will score **High** if the assessment has demonstrated that it can be easily implemented using local techniques and locally available resources.
- The intervention will score **Medium** if the assessment has demonstrated a moderate technical complexity.
- The intervention will score **Low** if the assessment has demonstrated that it requires a high level of technical capacity, or if the level of complexity makes it difficult to implement or scale up in the local context.

Risk reduction potential

- The intervention will score **High** if the assessment has demonstrated that it highly contributes to reducing the risk related to the identified hazard.
- The intervention will score **Medium** if the assessment has demonstrated a moderate contribution
- The intervention will score **Low** if the assessment has demonstrated that the risk still persists after the intervention.

Co-benefits

- The intervention will score **High** if the assessment has demonstrated that it offers several socioeconomic and environmental benefits beyond the primary benefit of reducing urban flooding and gully erosion
- The intervention will score **Medium** if the assessment has demonstrated a moderate contribution of additional benefits
- The intervention will score **Low** if the assessment has demonstrated minimal or non-existing additional socio-economic and environmental benefits.

- Economic Viability
- The intervention will score **High** if the assessment has shown an average cost-benefit ratio greater than 5.
- The intervention will score **Medium** if the assessment has shown an average cost-benefit ratio between 3-5
- The intervention will score **Low** if the assessment has shown an average cost-benefit ratio lower than 3.

Maintenance practicality

- The intervention will score **High** if the assessment has demonstrated that it can be low-cost maintenance using local labour and simple techniques.
- The intervention will score **Medium** if the assessment has demonstrated a moderate maintenance complexity.

- The intervention will score Low if the assessment has demonstrated that the maintenance and operational requirements are highly complex.

Social acceptability

- The intervention will score High if the assessment has demonstrated that it is a common and acceptable practice within local communities and it is strongly supported by national and local policy.
- The intervention will score Medium if the assessment has demonstrated that it is an acceptable practice with some government support.
- The intervention will score Low if the assessment has demonstrated that it has little community or government support.

Table 38. Summary of the NbSWLM interventions proposed.

Location	Intervention	Hazard addressed	Technical Feasibility	Risk Reduction Potential	Co-benefits	Economic Viability	Maintenance Practicality	Social Acceptability
Site A and B: Integrated Restoration of Tsième Catchment in Mfilou, Brazzaville	Infiltration swales, gabions at the gully head cuts, gully slopes with vegetated terraces; wooden check dams at Valley floors, and rock stilling basin	Hillslope erosion, clayey soils, landslide risk, rapid runoff	M	H	H	H	M	H
Site C: Urban greenway along the final Tchikobo and the Songolo river sections, Pointe-Noire	Expansion of the rivers' natural floodplain; renaturalisation of the riverbank /riverbed, using bioengineering practices; setbacks and restoration of existing levees along the river floodplain; green corridor along the Avenue Jacques Opangault	Pluvial and fluvial flooding; coastal flooding	M	H	M	M	H	M

Annex I- Technical and social prioritization results

Figure 39. Processed technical and social prioritization results of NbSWLM practices inventory cases.

Site	Practice	Description	Typology	Average Technical Scoring	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	SUM Criteria 1-5
8. Urban Agriculture in Talangaï, Brazzaville	Traditional crop farming	Urban farming	Plot farming	**44**	2,7	2,3	2,3	2,7	3,0	**13,0**
10. Ngamakosso's Agroforestery and fish ponds, Brazzaville	Flood plain restoration	River /stream renaturation	Retention Basins, Agroforestry, Raised beds	**42**	2,3	2,7	1,7	2,3	3,0	**12,0**
1. Restoration of the Mazra Mangrove, Songolo, Pointe-Noire	Mangrove forest restoration	Mangrove forests	Planting or Sowing	**41,25**	2,7	3,0	2,7	3,0	3,0	**14,3**
5. Erosion Control in Tchimana, Mongo-Poukou, Pointe-Noire	Vetiver hedges/bamboo planting + sandbag gabions	Terraces and slope	Hybrid approach for slope stabilization- Grey techniques (gabions, collectors, channels…) and renaturation	**39,75**	2,0	2,0	2,0	2,0	3,0	**11,0**
4. Participatory Erosion Defence in Ngouabouchi and Tchiloulou, Pointe-Noire	Vetiver hedges + sandbag gabions	Terraces and slope	Hybrid approach for slope stabilization- Grey techniques (gabions, collectors, channels…) and renaturation	**38,5**	2,7	2,3	2,3	2,7	3,0	**13,0**
6. Erosion Stabilization in Ngamakosso, Brazzaville	Vetiver hedges/bamboo planting + Vegetated stone gabions	Terraces and slopes	Hybrid green and grey infrastructure, including civil works, vegetated gabions and reforestation	**38,5**	3,0	3,0	2,3	3,0	3,0	**14,3**
7. Anti-Erosion Works at Ngamakosso Water Tower, Brazzaville	Vetiver hedges/bamboo planting + Vegetated stone gabions	Terracees and slope	Hybrid approach- green and grey infrastructure, vegetated gabions and reforestation	**38,25**	3,0	2,7	2,3	2,7	3,0	**13,7**
9. Integrated Erosion Management at Don Bosco Center, Brazzaville	Vetiver hedges/bamboo planting + rain water collection and drainage system	Terracees and slope	Hybrid green and grey infrastructure - Civil and mechanical approaches and restoration	**37,5**	1,7	1,7	1,7	2,0	2,7	**9,7**
3. Coastal Protection of Loango Bay at Pointe-Indienne, Pointe-Noire	Rock dikes and vegetation planting	Sandy shores	Hybrid Coastal Defense- Grey techniques and renaturation	**31,5**	1,3	2,0	2,3	2,7	3,0	**11,3**
2. Coastal Protection of Loango Bay, Matombi, Pointe-Noire	Rock block and sandbag barriers; bamboo planting	Sandy shores	Hybrid Coastal Defense- Grey techniques and renaturation	**29,5**	1,7	1,3	1,0	2,0	2,3	**8,3**

Table 39. Criteria used for stakeholder prioritization.

Criteria	Description
1. Capacity to reduce people's and ecosystem's vulnerability to urban flooding and gully erosion	Does the practice deliver the intended main benefit of reducing people's and ecosystem's vulnerability to urban flooding and gully erosion?
2. Importance of delivering additional socio-economic and environmental benefits.	Does the practice deliver additional socio-economic and environmental benefits besides the main benefit of reducing urban flooding and gully erosion?
3. Technical practicality	Is the implementation, operation and maintenance of this practice functional, practical, and easy to perform using locally available resources, techniques and expertise?
4. Social acceptance	Is this practice acceptable (or even demanded) by local communities?
5. Political alignment	Is this practice likely to receive support from government? Is the practice aligned with the existing policies, laws and regulations?