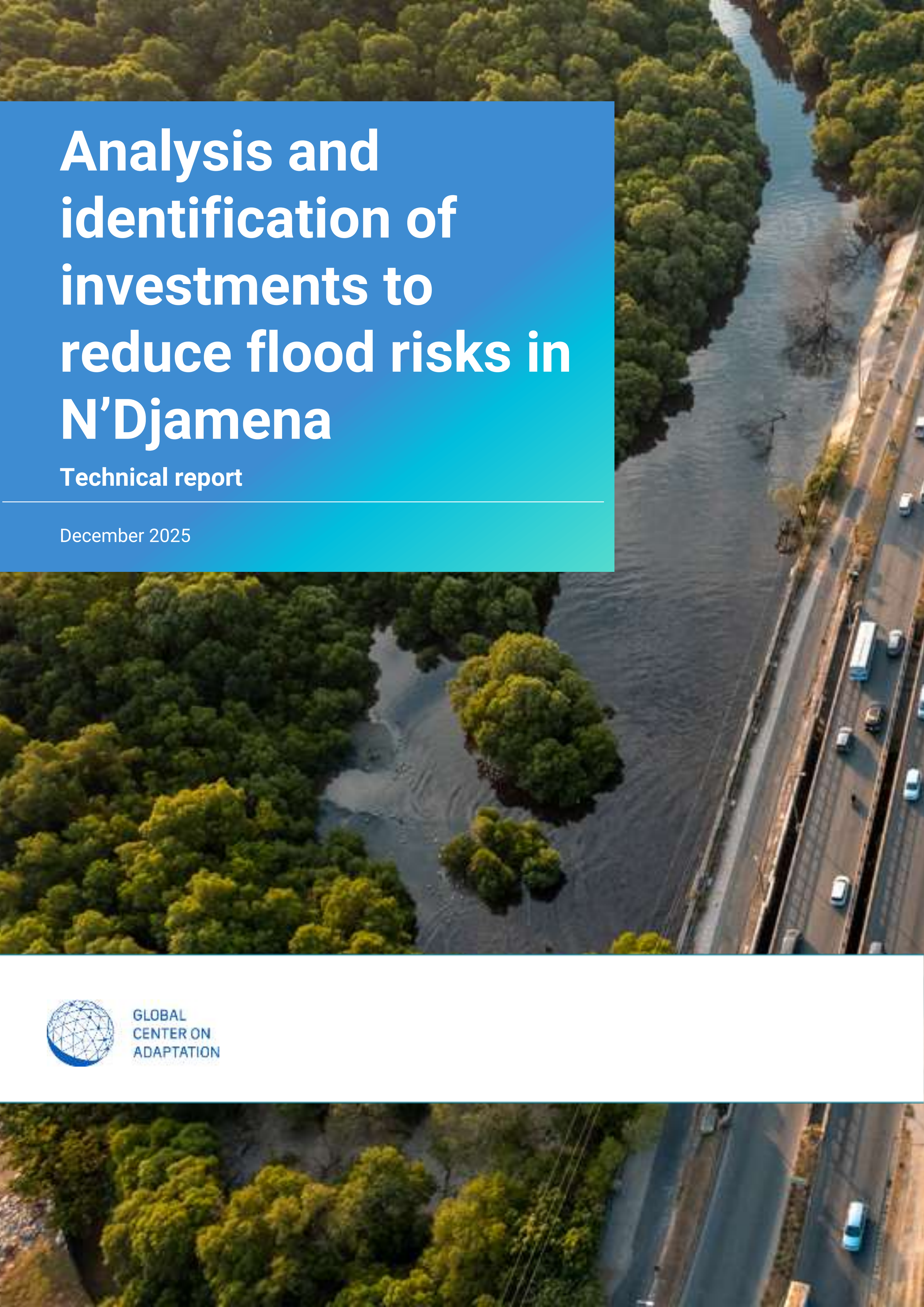

Analysis and identification of investments to reduce flood risks in N'Djamena

Technical report

December 2025

GLOBAL CENTER ON ADAPTATION

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Consultants:
Groupement Groupe Huit – Groupe Huit Côte d'ivoire (and JBA as sub-contractor)

DESCRIPTORS

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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.

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1. ABBREVIATIONS

Acronyms	Definitions
AFD	Agence Française de Développement
BM	Banque Mondiale / World Bank
DRE	Direction des Ressources en Eau / Directorate of Water Resources
GCA	Global Center on Adaptation
MATUH	Ministère de l'Aménagement du Territoire, de l'Urbanisme et de l'Habitat / Ministry of Territorial Planning, Urban Planning and Housing
PAR	Plan d'Action et de Réinstallation / Resettlement Action Plan
PILIER	Projet Intégré de Lutte contre les Inondations et de Résilience Urbaine / Integrated Flood Control and Urban Resilience Project
PMR	Personnes à Mobilité Réduite / Persons with Reduced Mobility
UGP	Unité de Gestion de Projet / Project Management Unit

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3. EXECUTIVE SUMMARY

The city of N'Djamena is located on the right bank of the Chari River and is therefore exposed to flooding from both rainwater and river water. Doubly affected by the risk of flooding, low-lying areas and floodplains are particularly vulnerable. The city experienced numerous floods between 2007 and 2022, causing displacement, death, and disease among millions of people in the country. In 2024, the Chari and Logone rivers once again reached record levels, causing flooding in several districts. Flood vulnerability is exacerbated by factors such as irregular occupation of areas where construction is prohibited and uncontrolled urban densification. The lack of and insufficient investment in drainage infrastructure also contributes to the precariousness of populations living in unplanned and high-risk areas. Although some efforts are underway, the identification and design of investment projects are still not based on a comprehensive understanding of flood risks.

Thanks to funding from the World Bank, the PILIER Project is working hard to secure investments that will improve flood management. To complement the PILIER's actions, the scope of this study has been adjusted to focus on adaptation solutions in the peri-urban areas of N'Djamena, through a more resilient approach along the Logone and Chari river basins. The flood exposure analysis highlights a complex and growing vulnerability due to the convergence of several factors. Water management infrastructure is particularly limited, especially along the Logone and Chari rivers, leaving large areas unprotected. Climate projections, particularly in the pessimistic SSP5-8.5 scenario, predict a significant intensification of precipitation in the short term, thereby increasing exposure to storm flooding in the peri-urban area. Combined with river data, the projections reveal areas of combined risk exposure where heavy precipitation and river flooding are likely to occur simultaneously. Aggravating environmental factors further amplify this risk. These findings underscore the urgency of strategic water management planning. Interventions should prioritize areas where the risks of extreme rainfall and river flooding overlap, particularly along the Chari and Logone river basins.

To achieve the desired level of protection, potentially a 25-year return period, the preferred solution will likely require a combination of measures rather than a single intervention. The main options identified and deemed worthy of further study using hydraulic models are as follows:

- Possible option 1: diversion channel to divert peak river flows from the Chari upstream of N'Djamena
- Possible option 2: Offline water storage in large retention basins located on either side of the main riverbed.
- Possible option 3: improvement of flood defenses in N'Djamena through the construction and rehabilitation of earthen levees
- Possible option 4: nature-based solutions (NbS) according to site projects and opportunities
- Possible option 5: Other flood risk management measures (flood early warning systems (EWS), improvement of evacuation routes for flood victims, dredging of the canal and rivers, and removable/temporary barriers)

After identifying the project objectives, the consultant prioritized the projects and grouped them into components. Consultations carried out during the second mission from November 10 to 16, 2025, enabled the projects to be structured into three components:

- Component 1: construction of storage basins with protective dikes for homes, villages, and agricultural areas
- Component 2: dredging the bed of the El Biher and renaturing the river up to the Chari with protective dikes and public spaces
- Component 3: nature-based solutions: urban park, green corridors, and vegetated irrigation canals.

All three components are developed in project sheets detailing descriptions, phases, related costs, and identification of technical, institutional, environmental, and social risks.

4. CONTEXT AND OBJECTIVES OF THE STUDY

Repeatedly exposed to flooding in recent years, the population of N'Djamena and its surroundings find itself vulnerable and weakened. The short rainy seasons are enough to flood the city due to the absence or dilapidation of drainage infrastructure. Not all outlying neighborhoods have drainage systems to channel rainwater. As a result, water stagnates for longer periods of time, damaging human lives and activities.

When flooding occurs, the city is trapped by a more complex phenomenon. Flooding on the Chari and Logone rivers causes capillary rise and riverbed overflow. As a result, water invades homes, neighborhoods, villages, fields, and farms. Residents are overwhelmed by the fact that these floods occur just after the rainy season The. population has not had time to rebuild, and the river floods compound the rain-induced floods.

Faced with these phenomena, the Chadian government obtained financing from the World Bank in 2023 to fund the Flood Control and Urban Resilience Project (PILIER[1]) to the tune of USD 200,000,000. Part of these funds was used to carry out technical studies that could lead to the construction of water drainage and population protection infrastructure. Despite the efforts made by all stakeholders to resolve the problem, the issue of river flooding remains a major challenge.

Thus, while the flood risk modelling study examines the exposure of populations to risks and the economic damage linked to land use, a more detailed analysis of the socio-economic resilience of the exposed population would improve and clarify the multi-Criteria flood risk Analysis. Indeed, and to give only one example, the current economic assessment of indirect impacts only relies on a ratio approach that would require a deep sectorial analysis as requested in the ToRs.

It is in this context that GCA commissioned a specific feasibility study to identify the resilient infrastructure to be built around N'Djamena in accordance with the hydrological phenomena upstream and downstream of the two rivers. The aim of the study will therefore be to update the prioritization of investments and priority neighborhoods after correcting the qualification of socio-economic vulnerability by considering:

- indirect impacts of service disruptions on populations and key sectors
- links between infrastructures (e.g. water/sanitation/electricity) and cascading impacts (if the Chagoua bridge is impassable due to flooding, all downstream neighborhoods will suffer disruptions to supplies (food, drinking water, etc.) from Cameroon).
- uses (bus routes, daily traffic, O-D, imports, etc.).

This report highlights the results of the two missions based on the data collected and the prioritized projects. Based on the issues identified in the field during the first mission, a list of investments was proposed. Next, prioritization was made to have three integrated components comprising both flood reduction infrastructure and NBS. The component sheets were developed to provide a clear description of the projects as well as the costs and co-benefits in urban, social, hydrological, ecological, environmental, and economic terms.

[1] https://pilier.td (C'est un projet Banque Mondiale financé à hauteur de 200 000 000 USD pour une durée de 6 ans)

5. METHODOLOGY

5.1 Data collection

<u>Documentation</u>

The documentary work is based on reports from previous studies commissioned either by the Chadian government or by IRD or other development partners (Annex 2).

There are also reports and assessments from NGOs and associations responsible for victims of the recent floods. These reports have provided an understanding of the extent of flood risks and the resulting physical and human damage.

The recent EGIS hydraulic study has provided the consultant with technical and cartographic support on which to base the analysis and modeling work.

<u>Field visits</u>

In addition to reviewing documents, the consultant carried out field missions[2] in order to:

- Collect data
- Identify possible types of investment around N'Djamena
- Consult stakeholders to prioritize investments
- Consult communities to identify the benefits of prioritized investments

5.2 **Hydraulic Modelling**

Hydraulic model scenarios have been used to appraise the potential performance, viability and opportunities of the prioritized projects. A cut down model that focuses on the fluvial flood hazard from the Bhar Linia and El Biher watercourses to the north of N'Djamena has been applied. This model is based on the HEC-RAS fluvial model developed by Egis in 2023 with no changes to the model input data (Egis, 2023). Full details of the source model can be found in the Egis report. A summary of the cut-down model inputs are as follows:

- Inflow hydrographs for the Bhar Linia as per the Egis 2023 model.
- Inflow hydrographs for the overland flow pathway from Dijila have been extracted using a profile line along the river bank in four locations where floodwater spills from the Chari River into the floodplain and then flows north towards the Bhar Linia.
- Initial conditions and downstream boundary conditions as set in the Egis 2023 model.
- High-density DTM (LiDAR) produced in 2017 by IGN FI, georeferenced in Chad's general levelling system RGT20.
- Additional FabDEM DTM for areas not covered by IGN FI DTM.
- Bathymetric surveys of the Chari and Logone rivers (DRE, February 2023).
- Altimetric survey of stormwater network outlets in the Chari (DRE, February 2023).
- Survey of crossing structures (DRE, March 2023).

[2] First mission from 5th to 11th May 2025 (for data collection and identification of investments) and second mission from 10th to 16th November 2025 (for data collection and prioritization of investments)

The model scenarios all use the humide set of events to represent the future climate scenarios as determined by Egis (2023)[3]. The cut down version of the model reduces model run times so that efficient testing of potential solutions can be undertaken. To help understand and diagnose flood mechanisms the model is run for two separate individual events: 1) the inflow from the Bhar Linia only, and 2) the overflow from the Chari River only. This allows us to understand how different overland flow pathways and accumulation of floodwater occur. The model schematic showing key features is presented in Figure 1.

It is important to appreciate the limitations of the model input data, which limit the level of detail and precision that can be inferred from the outputs. During development of the model scenarios the project team found that there are inconsistencies in DEM and topographic survey datums in the area of interest. This means that care needs to be taken when using the model to determine levels and depths of proposed flood infrastructure. This is important for offtake and control structures and connecting channels where the level of offtake (or invert level) needs to be set to optimize the attenuation of flood flow in proposed basins and the timing of flow from and into connecting channels is dependent on the timing of the event during the flood hydrograph and the level of different features. The model scenarios are suitable to appraising the potential volume that could be stored and the discharge rate between the proposed basins for sizing of river channels and canals. Updated data and modelling will be required for the Feasibility Study and Detailed Design stages.

Two locations for proposed basins have been tested, as shown in Figure 1. The model outputs have been used to refine the project proposal with local information. It is also important to note that the model domain cannot be extended without further survey and calibration and as such some components of the project may be located outside of this model domain.

It has not been possible to assess the potential storage of urban stormwater runoff that could be provided by the proposed basins because the domain of the pluvial model developed by Egis does not extend to include the northern basin area.

[3] Note on flood probabilities and standard of protection: We commonly use terms such as the 100 year flood. This is a flood with a 1 in 100 chance of occurring in any year. It is also known as having a 1% Annual Exceedance Probability (AEP) and the Q100. This is a flood that 'on average' occurs (or is exceeded) once in a 100 year period, but this is just 'on average'. It may occur many times, or not at all in any given 100 year period. The target design standard of protection for structural measures should relate to the vulnerability or importance of what is being protected or what is practical for that measure. We have to accept that a flood bigger than our target standard of protection can happen. Non-structural measures must therefore be part of flood strategies.

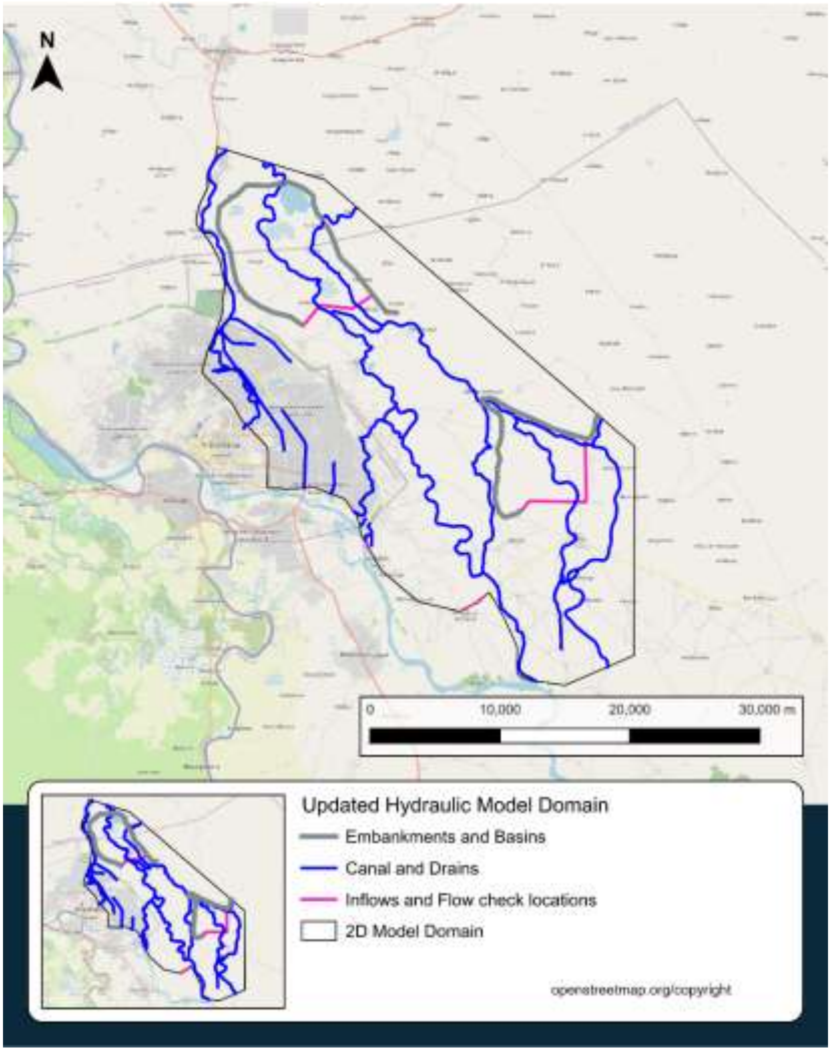


Figure 1. Hydraulic Model Domain used to inform appraisal of prioritized projects.

5.3 Project prioritization

After the first mission, more than five investment options were identified. Each option is evaluated according to the criteria defined in the mission specifications.

Prioritization was based on a multi-criteria matrix, established in accordance with the terms of reference and the local context.

The prioritization method is based on the criteria defined in the terms of reference. These include:

- Flood risk reduction potential: decreased neighborhoods vulnerability; direct risks to vital infrastructure,
- Value for money while considering potential benefits from project implementation
- Political and community support (specific consultation will be done)
- Potential financing from international donors or local government
- Potential environmental and social impacts (to reduce potential risks),
- These include

Each project or action is evaluated according to the above criteria. The question is whether the project or action has high, medium, or low benefits according to the criteria. If the benefit is high, it means that for this criterion, the project is very satisfactory. If the benefit is medium, this simply means that the project is satisfactory for that criterion. And if the benefit is low, this means that the project is unsatisfactory for that criterion. A score out of 3 is assigned according to the degree of satisfaction. The issue of the site and data is also included in the criteria in order to better assess the project.

Very satisfactory	**3**	**Satisfactory**	**2**	**Unsatisfactory**	**1**

5.4 Limitations of data collection

The mapping work is limited to open source data because the team did not have official GIS data to perform modeling or generate relevant maps.

GIS data was used to create hydraulic models that enabled basin development scenarios to be drawn up. The results obtained are approximate but not precise, as the most relevant data is DEM and high-resolution satellite images. To date, some analyses and proposals have also been made based on Google Earth images.

During this study, analytical maps were not produced on social aspects because there is no data available to produce them. However, thanks to fieldwork and discussions with residents, the experts developed maps in line with the expected objectives.

We also note the lack of data from certain public bodies (e.g., the Water Resources Department) that would provide a good history of flood events and enable analysis.

6. LOCAL CONTEXT

6.1 Current water management

This first map shows the water resources present in the Ndjamena surrounding watersheds. The area is crossed by many rivers, of which those on Logone and Chari catchments.

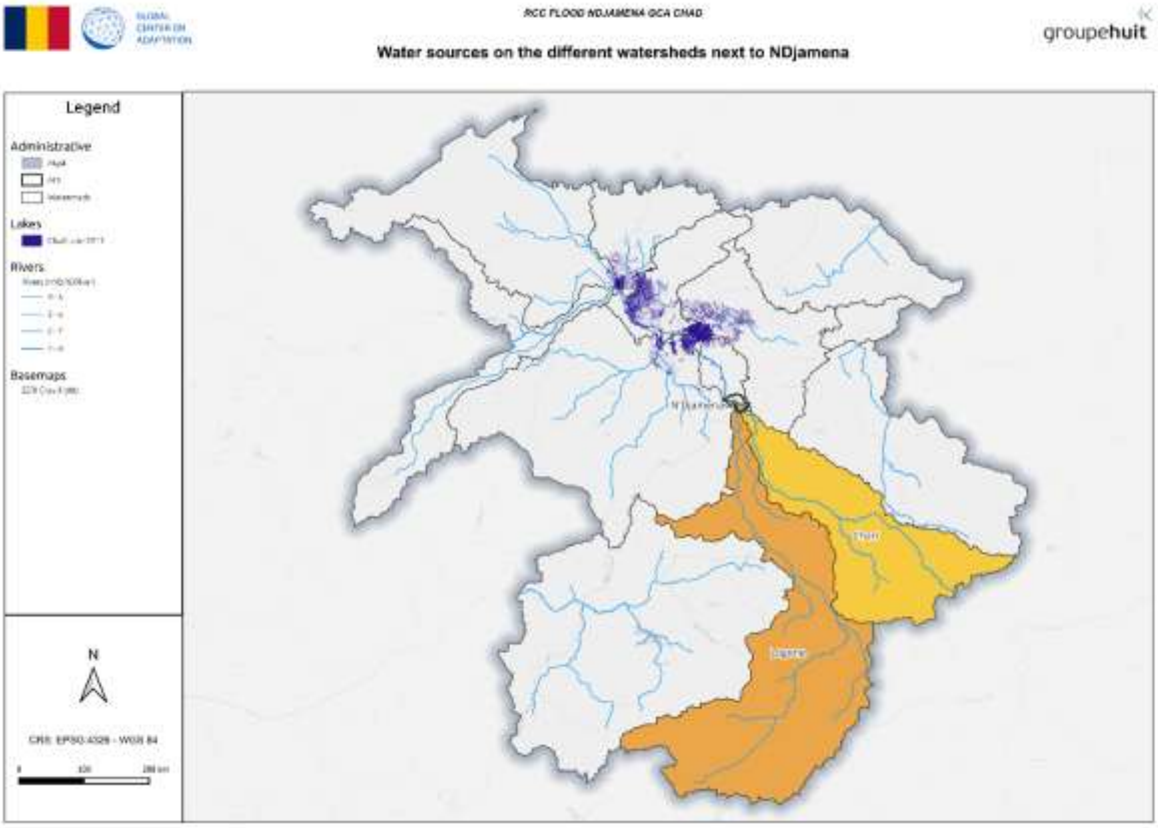


Figure 2: Chad Lake and Rivers crossing Ndjamena region. Source: Conception of Consultant

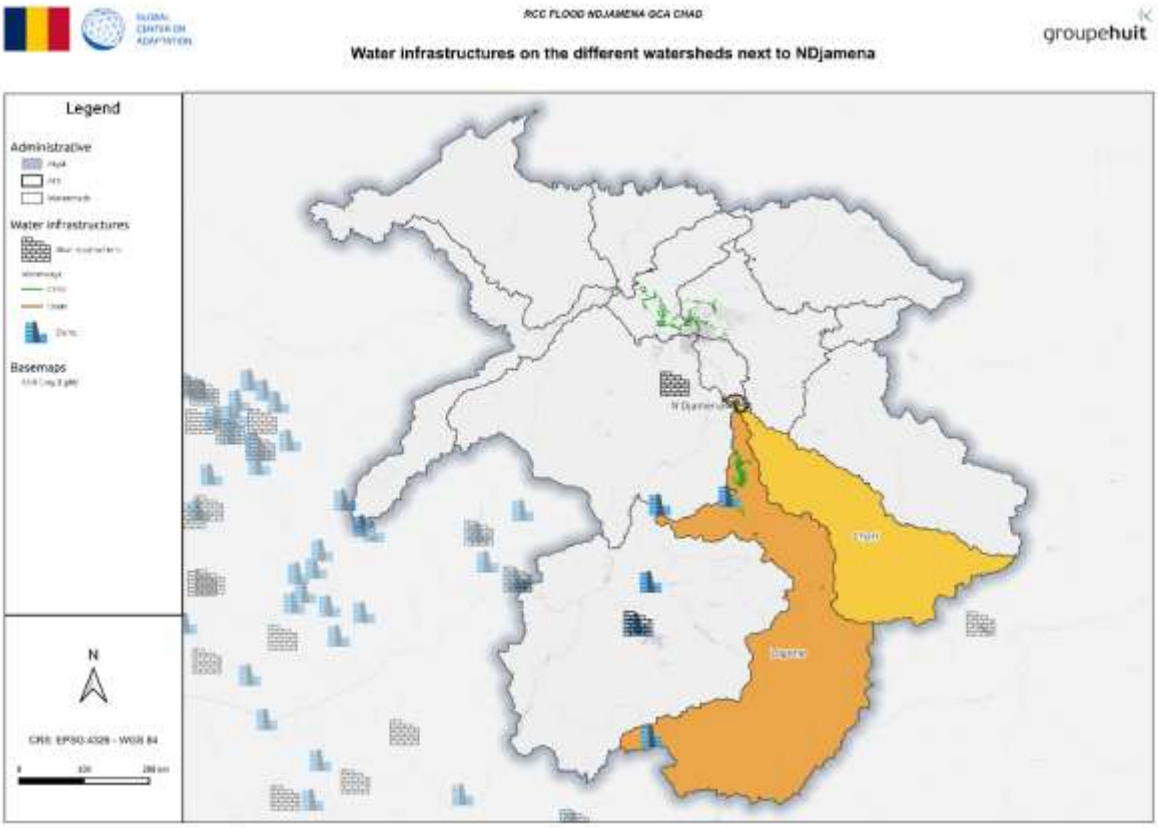


Figure 3: Water management infrastructure in the Ndjamena region. Source: Conception of Consultant

Water management infrastructure is notably limited in the region. The Logone watershed contains only a single dam, which is clearly light to effectively regulate water flow or mitigate flood risks. On the other hand, the Chari River flows without any significant barriers or control structures, which tends to rise the flood exposure.

6.2 Floods Exposure

6.2.1 1-Day Cumulated Precipitation

This indicator shows the annual maximum for a single day of rainfall. The corresponding classes are:

- Low (<30 mm)
- Moderate (30–35 mm)
- High (35–40 mm)
- Extreme (>40 mm)

This indicator is made to see the biggest rain event that can hit the region in one day, so it evaluates the exposure of flash floods, that could be involved by those precipitations.

6.2.2 3-Day Cumulated Precipitation

This indicator reflects the annual maximum amount of rainfall accumulated over three consecutive days. The values have been categorized into the following classes:

- Low (<70 mm)
- Moderate (70–80 mm)
- High (80–90 mm)
- Extreme (>90 mm)

It allows to see quite the same phenomenon but on a longer period, which could cause a lot more damages.

6.2.3 Indicators analysis

To gain a more comprehensive understanding of flood exposure in the N'Djamena region, precipitation-based indicators were combined with river flood exposure data across various return periods (GloFas data). This approach provides a more complete picture of flood risk by capturing both pluvial (rain-related) and fluvial (river-related) flooding dynamics.

6.2.3.1 10 years return period

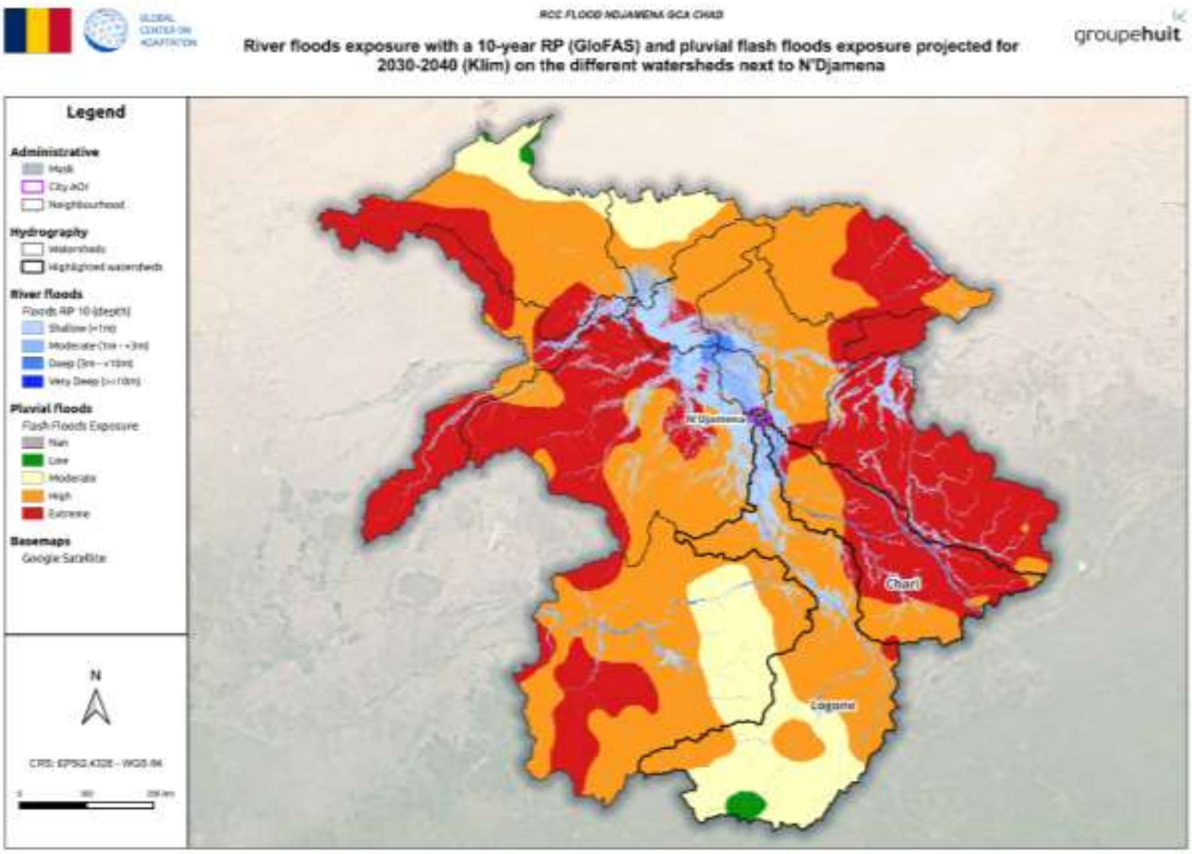
River flood exposure is already widespread around N'Djamena. The indicators further reveal that areas at risk of river flooding also face high to extreme exposure to intense short-term rainfall. This suggests that heavy precipitation events could significantly amplify the impact of river floods, increasing the overall vulnerability of the region. (see *Figure 4: Flood exposure with 10 years return period*)

6.2.3.2 20 years return period

In this case, river flood exposure appears more widespread, indicating that areas previously unaffected by a 10-year return period flood may now be at risk. Similarly, the indicators show a shift toward higher exposure levels — often in the red zone — reflecting an increasing vulnerability to extreme short-term precipitation events. (see *Figure 5: Flood exposure with 20 years return period*)

6.2.3.3 50 years return period

Once again, the situation appears to worsen, with river flood exposure becoming even more extensive. For flash flood risk, the map highlights a notable increase along the Chari catchment, suggesting this area should be prioritized in long-term water management infrastructure planning. Additionally, the 3-day cumulated precipitation indicator shows the entire region in red, signalling a significant intensification of rainfall over short periods. This points to a growing risk of floods not just from intense single-day events, but also from prolonged heavy rainfall. Addressing both types of risks is essential to prevent widespread damage across the territory. (see *Figure 6: Flood exposure with 50 years return period*)



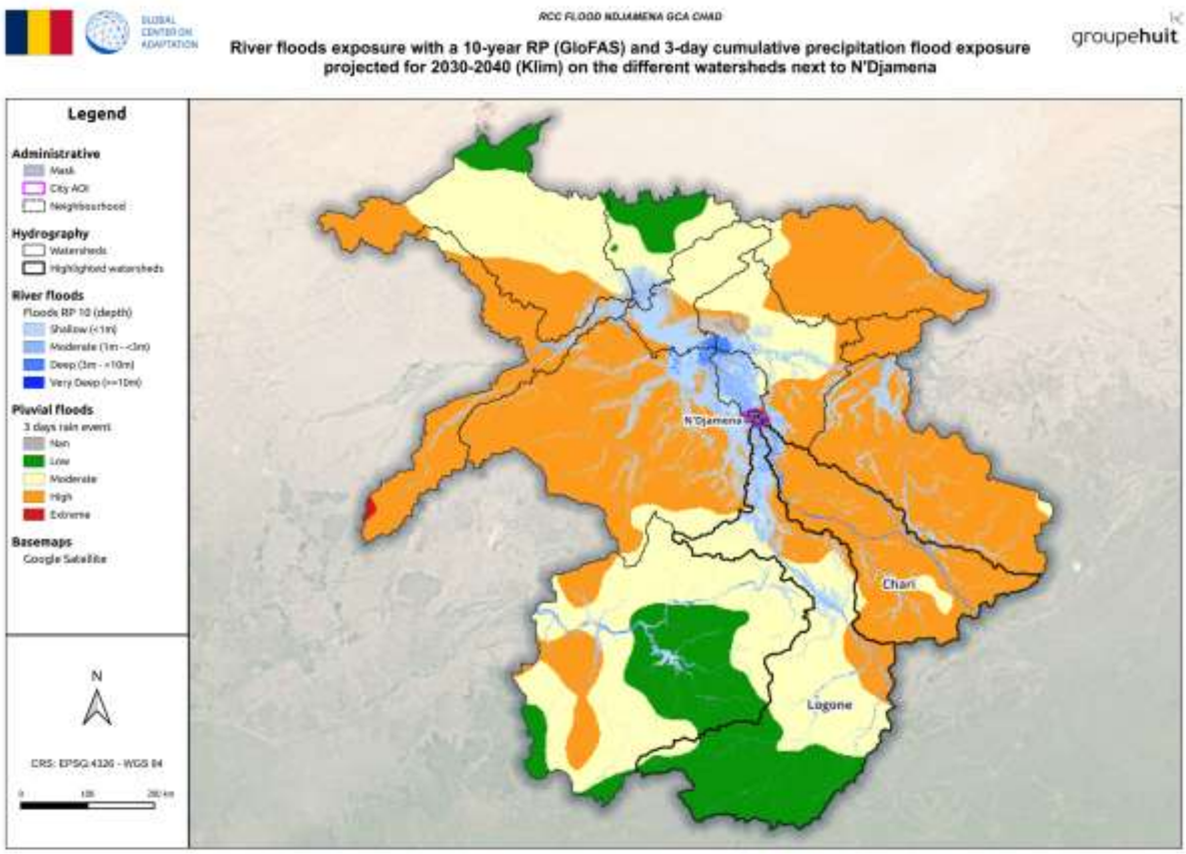


Figure 4: Flood exposure with 10 years return period
Source : Conception of the Consultants, 2025

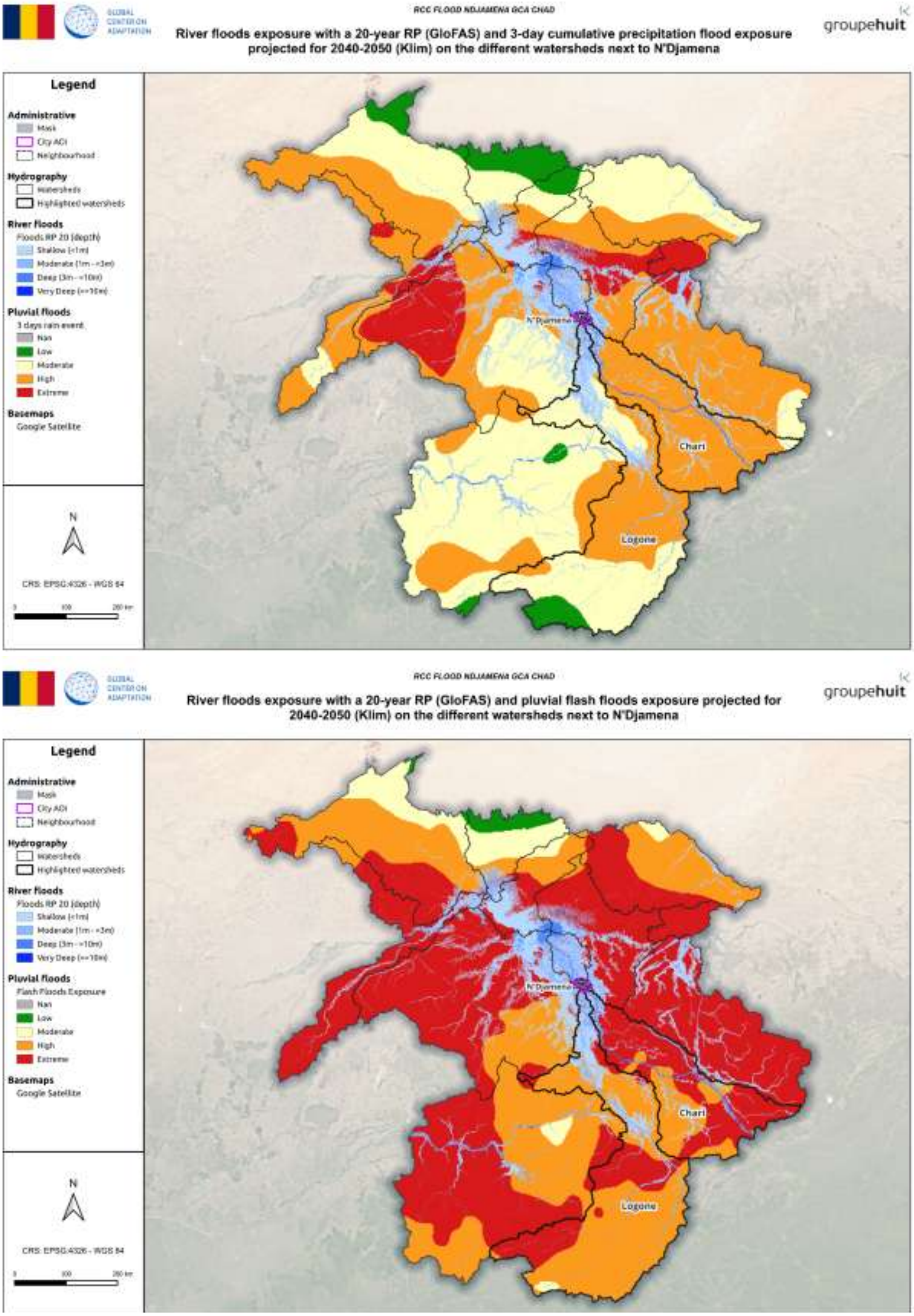
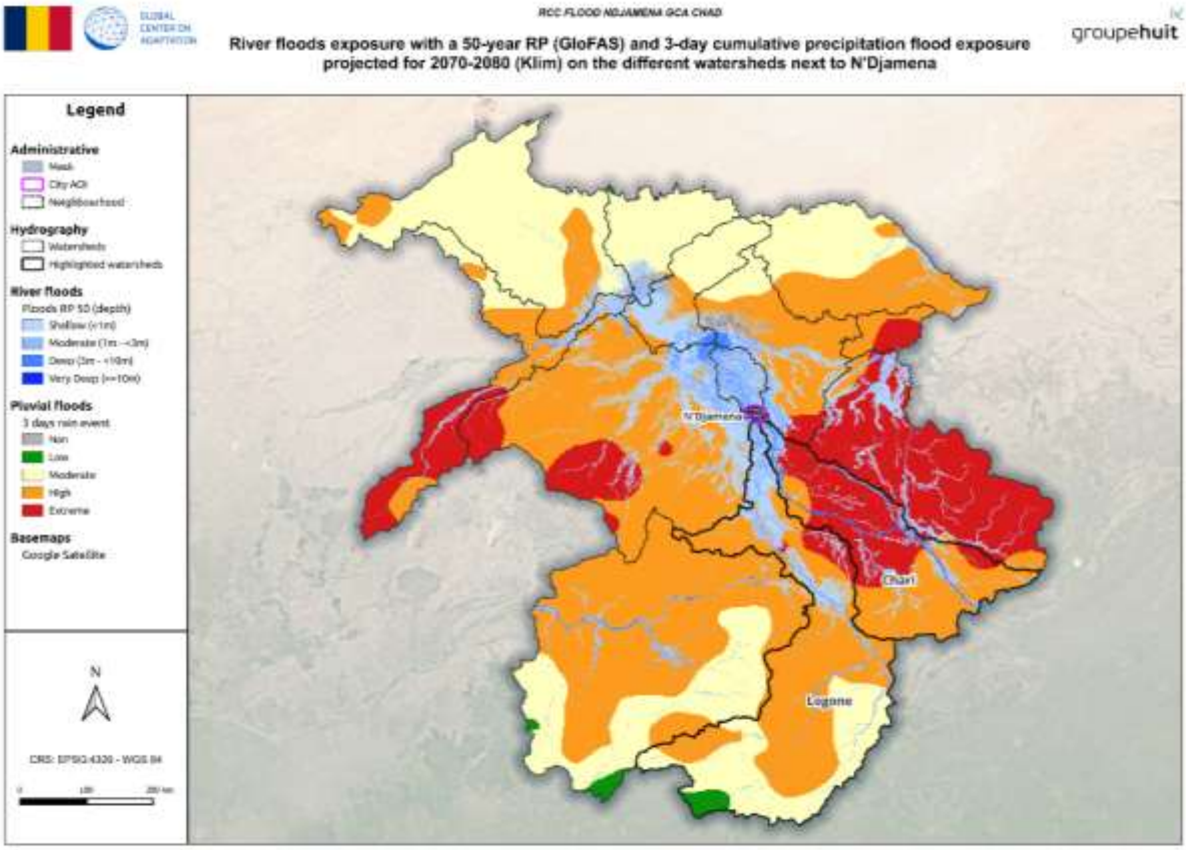


Figure 5: Flood exposure with 20 years return period
Source: Conception of the Consultants, 2025



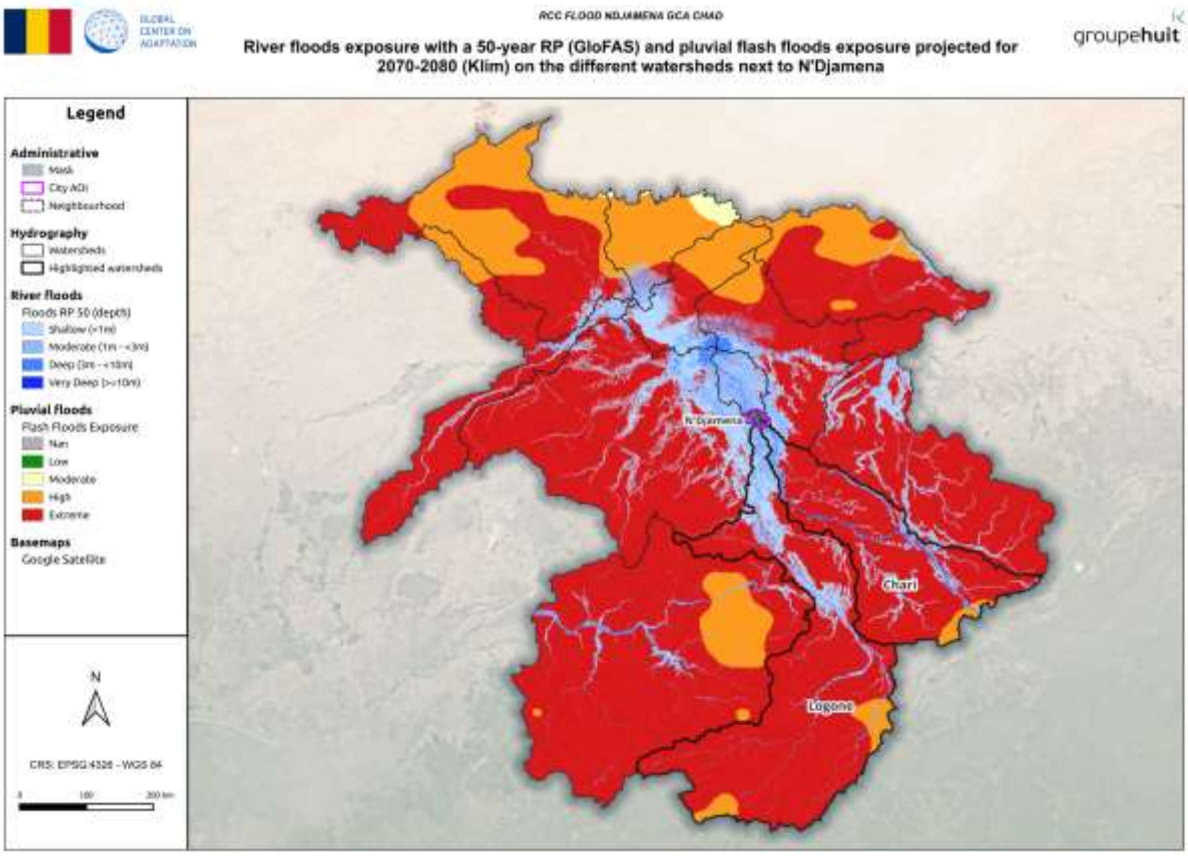


Figure 6: Flood exposure with 50 years return period
Source: Conception of the Consultants, 2025

6.3 Exacerbating factors

In flood analysis, exacerbating factors are elements that intensify or worsen the impact, frequency, or severity of flooding. They don't directly cause floods but make the effects more damaging when floods do occur.

6.3.1 Topography

The relief can be seen on a Digital Elevation Model (DEM), like the one below. This DEM is not very accurate because it has been taken on Internet open-source database, and not from Lidar measures, but it is enough to illustrate the underlying idea.

Apart from the southern part, the entire region around N'Djamena is extremely flat. This flatness can be problematic during major floods, as it prevents efficient water drainage. As a result, floodwaters may stagnate for longer periods, increasing the risk of prolonged damage to infrastructure, agriculture, and livelihoods.

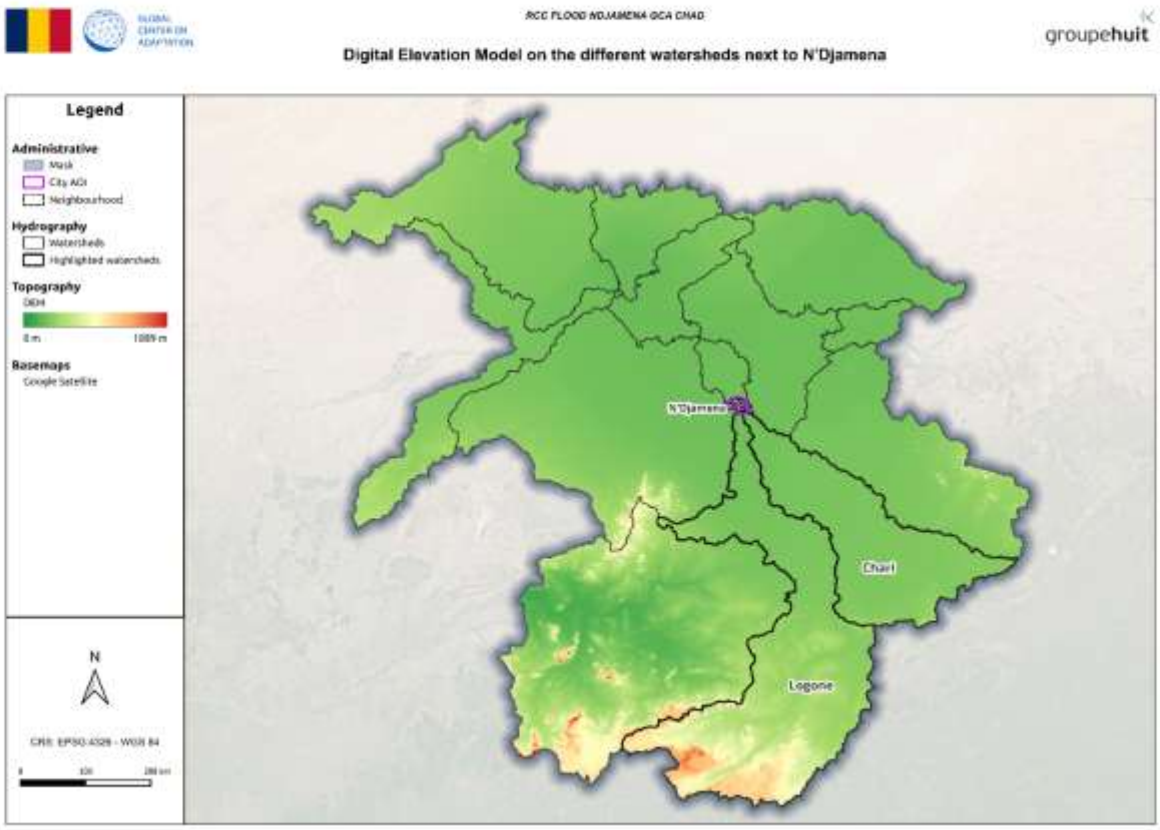


Figure 7: DEM map on the different catchments next to Ndjamena
Source: Conception of the Consultants, 2025

6.3.2 Permeability

Permeability is the capacity of the ground to absorb and transmit water. **Soils with high permeability** (like sand) allow water to infiltrate easily, reducing surface runoff. **Soils with low permeability** (like clay or compacted urban surfaces) resist infiltration, leading to higher runoff and increased flood risk.

Permeability classes were derived from soil texture data provided by ISDASOIL (*https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e09.htm*).

This method relies solely on soil texture, so the results should be seen as indicative rather than definitive. Nonetheless, it provides useful insight into the soil's water infiltration capacity.

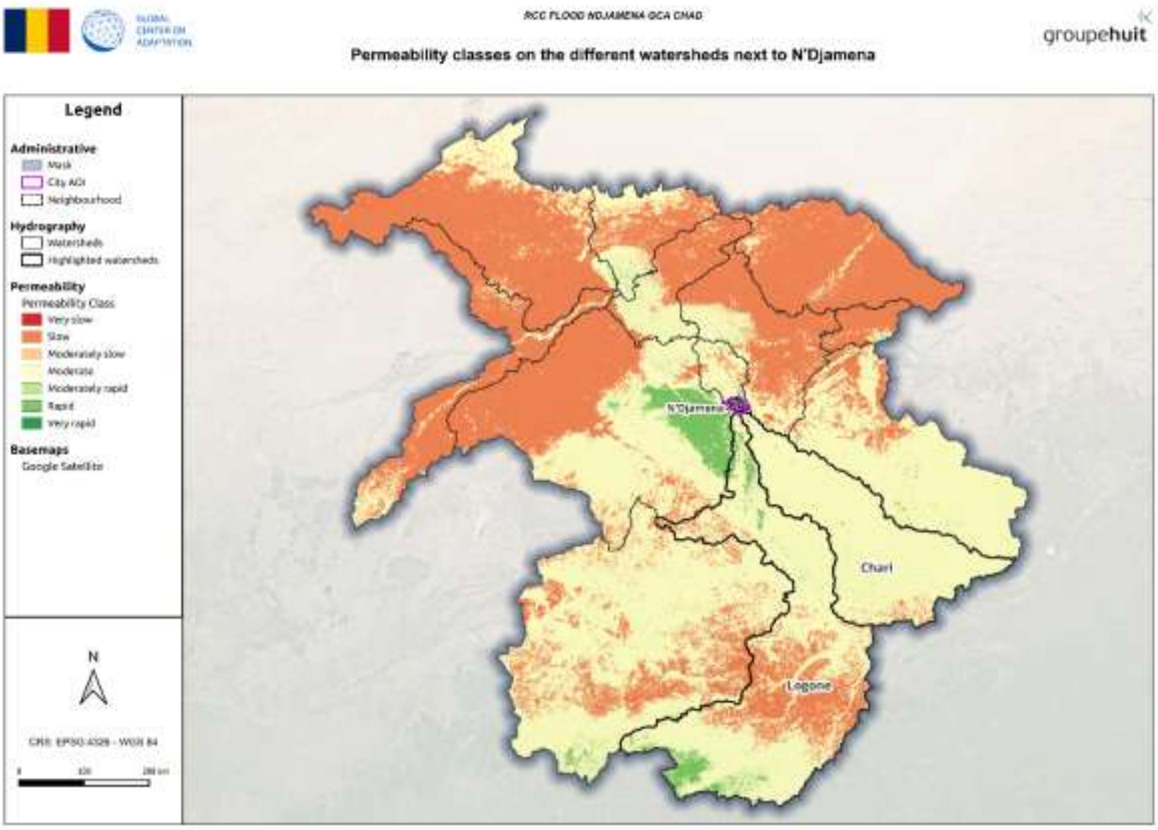


Figure 8: Permeability on different catchments around Ndjamena
Source: Conception of the Consultants, 2025

The classes represent the velocity at which water penetrates the soil. To the west of N'Djamena, there is an area characterized by fast infiltration, which could be worth investigating further as a potential natural factor for flood mitigation in this zone. Apart from this, most flood-prone areas fall within the moderate permeability class (shown in yellow), making it difficult to draw strong conclusions regarding their influence on flooding.

7. IDENTIFIED INVESTMENTS

The consultant has done the first mission to identify all these following investments. During the mission from May 5 to 11, we met with the MATUH teams, the PILIER PMU experts, the Bahr Linia project coordination team, and the DRE to hear their analyses and ideas on projects to be carried out in order to reduce the risk of flooding. During the discussions, several proposals were made by the stakeholders. Based on our experience and the context, we have drawn up a list of investment options to be implemented.

7.1 Bypass

This option could potentially be effective in reducing the volume and peak discharge from the Chari Rivers in N'Djamena during floods. To be effective the bypass would need to divert a significant proportion of the flood flows from the Chari River. There is not sufficient land available or hydraulic conditions for an larger Bhar Linia offtake and channel to reduce flood levels in N'Djamena on the Chari to make this worthwhile. Other potential diversion routes are located more than 100km upstream of N'Djamena.

The further a diversion or offline storage pond is from the area at risk, the more diminished an effect these measures have. Measures would still be required to address flood risk from the Logone river and urban stormwater floods. This option also requires a huge investment that could cause further damage to the ecosystem and communities. The project is too costly to be financed by an international donor, and the cost-benefit ratio in socioeconomic terms could be risky. Finally, in order to make such an investment, preliminary Lidar studies are needed to obtain sufficiently accurate data across a large area of the Chari river catchment. Without this precision, it will be impossible to make this type of investment, even if the financial resources are available. Therefore, given the lack of information, this project cannot be selected to meet current needs.

7.2 Offline flood storage

This type of investment does not completely reduce floodwaters in Ndjamena, but it does allow some of the water to be conserved for various uses. In addition to being costly, these projects require specific sites that will facilitate community and political support. It is also a relevant project, supported by the government, which envisages the creation of retention basins that meet the agricultural and economic needs of the communities concerned. Depending on the number to be built and the capacity of the basins defined by the engineers, this project may be feasible if all the technical conditions are met.

To reduce flood levels in N'Djamena from the Chari and Logone would require a significant number of large retention basins all along the Chari River, many of which will require mechanically operated gates to optimize the timing of spill from the Chari into the retention basin. The scale of such an option requires significant land and excavations for almost the entire Chari River for more than 100km upstream of N'Djamena. The cumulative sizing of retention basins needs to consider the full seasonal volume of flood flows.

Two potential candidate locations were proposed. These are located along the Bhar Linia canal and to the north of N'Djamena. As these are only connected to the Chari River through the Bhar Linia irrigation offtake they will not have any noticeable effect on flood level, flow or duration of flooding from the Chari or Logone Rivers (see note above on viability of increased offtake discharge). These measures proposed could provide flood storage and attenuation for flow in the Bhar Linea system and potentially also act as storage ponds to receive increased urban drainage from N'Djamena.

The two sites are located within the existing HEC-RAS fluvial model domain which can be used to test options. They are located outside of the HEC-RAS pluvial model domain.

7.3 New dikes

Designed to protect residents from floodwaters, levees are a tried-and-tested investment in Ndjamena, but due to the quality of their construction and their specific characteristics, some levees have failed in recent years. Therefore, if dikes are to be built, it is important to redesign them to make them more durable and resistant to flooding or the force of water. Depending on their location, these projects are technically feasible and can be financed by donors. This investment option is therefore feasible and well suited to the context of the city of N'Djamena.

Subject to land availability and community desires the embankments could provide multiple other functions and co-benefits such as erosion bank protection, improved stormwater outlets, urban greening, recreation, trading locations, meeting places, etc.

Feasibility studies need to carefully review land availability for larger embankment footprints, and ground stability. Encroachment into the river should be avoided, and if necessary needs to carefully consider potential impact on pushing water levels elsewhere.

For equitable reasons it is important to consider fair levels of protection are provided to all arrondisements on both sides of the Chari and on the Logone.

NB: The number of dikes depends on several parameters, including the number of basins, the size of the basins, and the development principles of El Biher.

7.4 Nature Based Solutions (NBS)

NBS are more resilient investment solutions tailored to specific sites and vulnerabilities. These are natural solutions that facilitate water infiltration, stabilize soil, slow down water velocity, reduce flood volumes, store water for reuse, etc. There are several types of NBS, including large-scale NBS such as riverbank and channel development, and other NBS that accompany upstream investments. In addition, there are NBS that can be quick wins, easy to implement with small budgets. Politically, nature-based solutions (NBS) do not generally give rise to conflicts or differences of opinion. From a financial point of view, they are inexpensive, even free in some cases. They also offer significant environmental benefits, contributing positively to the preservation of ecosystems.

This should not be seen as a standalone option. NbS components can be incorporated into the specification and design of structural flood management measures.

7.5 Improved egress for flood victims

In the event of flood risks, residents need basic infrastructure for evacuation. This infrastructure must be adapted to the neighborhoods concerned, with controlled costs and technical resources. All of this infrastructure, adapted to the neighborhoods concerned, may already be taken into account in the PILIER project, which covers the urban area of Ndjamena and its immediate surroundings.

Interpretation of the existing HEC-RAS models can identify safe havens, community buildings suitable for safe refuge centers and to identify safe access routes.

7.6 Channel dredging

Channel dredging is not considered a priority measure for reducing flood risk, as it may not be deep enough to effectively reduce water volume. In terms of assessing the relationship between the cost of the project and its benefits, this solution appears to be of little advantage due to its low sustainability, high cost, and environmental risks. Its political and community acceptability remains uncertain, as does its financing, particularly due to its potential effects on aquatic environments. Dredging should therefore be considered with caution and only as a complement to more sustainable and integrated measures.

7.7 Demountable / temporary defences

Temporary defense solutions are often mechanical or precarious and are implemented according to the technical, technological, and financial capabilities of the countries concerned. In the context of Chad, it is quite difficult to build this type of infrastructure, which requires costly maintenance and upkeep. For this reason, this option is not recommended for the city of N'Djamena. These reasons include:

- Demountable defences often require solid foundations. If investment into foundations is made it would not be much extra to raise these with permanent embankments.
- The availability of materials to fill sand bags (in the simplest case of temporary defences) can be a challenge.
- Modular demountable defences require depots and storage facilities.

7.8 Flood early warning

The early warning system for flooding is not a direct solution to the problem of high water levels, particularly in the event of a rapid rise in water levels. It does not physically reduce the volume of water, which limits its hydraulic effectiveness. Flood warning systems can significantly improve community resilience and reduce business disruption. This is only achieved when combined with a broader flood awareness campaign and emergency flood response plans and responsibilities. However, in terms of cost, it presents negligible risks as it requires few financial resources. Politically and socially, it does not generate tension or confusion. On the other hand, its environmental impact is limited, as it does not provide any direct benefits to ecosystems.

8. MAIN COMPONENTS

8.1 Summary and evaluation of Options

The analysis was carried out using a multi-criteria analysis method based on the terms of reference and the realities on the ground. The criteria considered were: (i) flood prevention and reduction, (ii) Availability of site, , (iii) environmental and social impacts, (iv) social and political acceptance, (v) financing opportunities and (vi) the relationship between project costs and benefits.

The following table is the summary of investments to be prioritized.

Table 1: Prioritization regarding criteria without weighting

Projects	Prevention and reduction of flood risks	Availability of site	Environmental and social benefits	Political and community acceptability	Opportunity of financing	Relation between cost of project and its benefits	Total (18 points)
Bypass channel	3	1	1	1	1	1	8
Offline flood storage	3	3	2	3	2	3	16
Flood defence improvements in N'Djaména	1	3	2	3	2	2	13
Nature-based Solutions (NbS)	1	3	3	3	2	3	15
Improved egress for flood victims	1	3	2	3	2	3	14
Channel dredging	2	3	1	2	2	1	11
Demountable / temporary defences	1	1	1	1	1	1	6
River renaturation	2	3	3	3	2	2	15
Flood early warning	1	3	2	3	2	3	14

A weighting ranging from 1 to 6 according to the degree of importance of the criteria allows for more refined prioritization of projects. This step resulted in a series of investments to be organized into components. Of the nine options, two projects (river arm and temporary flood defense and protection system) were not considered due to a lack of data and technology available in this context, not to mention cost considerations. As a result, the seven other projects were considered in the form of three components. This is because certain projects and actions, such as dykes and early warning systems, are cross-cutting and may be found in two or all of the components.

Table 2: Prioritization regarding criteria and weighting

Projects	Prevention and reduction of flood risks	Availability of site	Environmental and social benefits	Political and community acceptability	Opportunity of financing	Relation between cost of project and its benefits	Total (18 points)	Conclusion
	6	5	4	3	2	1		
Bypass channel	18	5	4	3	2	1	33	NO
Offline flood storage	18	15	8	9	4	3	57	Yes
Flood defence improvements in N'Djaména	6	15	8	9	4	2	44	Yes
Nature-based Solutions (NbS)	6	15	12	9	4	3	49	Yes
Improved egress for flood victims	18	15	8	9	4	3	57	Yes
Channel dredging	12	15	4	6	4	1	42	Yes
Demountable / temporary defences	6	5	4	3	2	1	21	No
River renaturation	12	15	12	9	4	2	54	Yes
Flood early warning	6	15	8	9	4	3	45	Yes

Yes	These are projects that are prioritized and selected to create the three components
No	For these two projects, it's impossible to integrate in the feasibility because of the constraint of

8.2 Prioritized components

After analysis, the following options could be selected as investments to implement:

- The offline flood storage with dykes and some NBS as set of component 1
- The dredging of channel and the renaturation of rivers are set of component 2
- NBS as green corridors, green public spaces, vegetables dykes, etc.

There are also some transversal actions like Flood early warning, improved egress for flood victims and some NBS as farming, green corridor and public space

8.2.1 Component 1: Offline flood storage and dykes

Basins and dikes

The existing hydraulic model has been used to assess possible basins and associated storage capacity with new model scenarios. The hydraulic model has datum inconsistencies between the DEM tiles used to define the ground topography and channel form in the model. For this reason, extreme care needs to be taken, and it is not appropriate to use the model to specify levels, excavation and alignment without improvements to the DEM, river channel survey and updated hydraulic modelling. It is possible to determine the scale of storage that may be possible within the basins, the typical height above ground level and length of raised embankments and the potential channel capacity required.

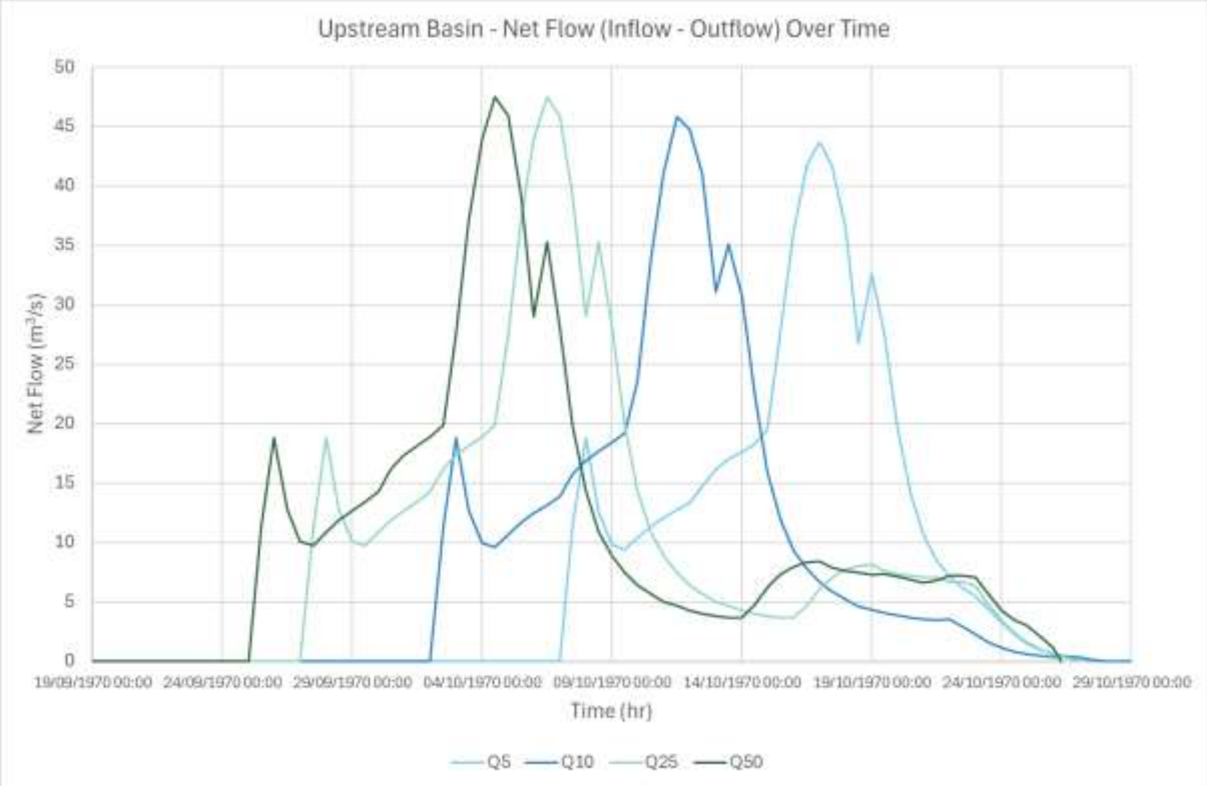
In the development of this component the model was run with two main basins. An upstream basin 1 and a single downstream basin that covers both basin 2 and 3 (Annex 1, map 1). Given these uncertainties it is more appropriate to quote a range of possible storage capacity of each basin is presented in the table below. An explicit measurement of the amount of water volume stored within the basins would be unreliable due to the DEM inconsistencies and so we have used the difference between the inflow and outflow hydrographs to the basins as a measure of potential capacity. These plots are shown below.

- For the upstream basin we see that the net change is consistent for all flood probabilities with only a variation in timing of the flood event and peak. This gives us good confidence in the storage volume based on the model.
- For the downstream basin we can see a big difference between flood events which suggests that the basin is not full in the Q5, Q10 or Q25 events. The reason for this is that there is a significant backwater effect along the Bhar Linia as water flows into this basin. This backwater causes an increase in flood depths upstream of basin 2 and 3 (to the south west of the basins) which without properly designed outflow control structures could increase flood exposure and hazard to land between basins 1 and 2.

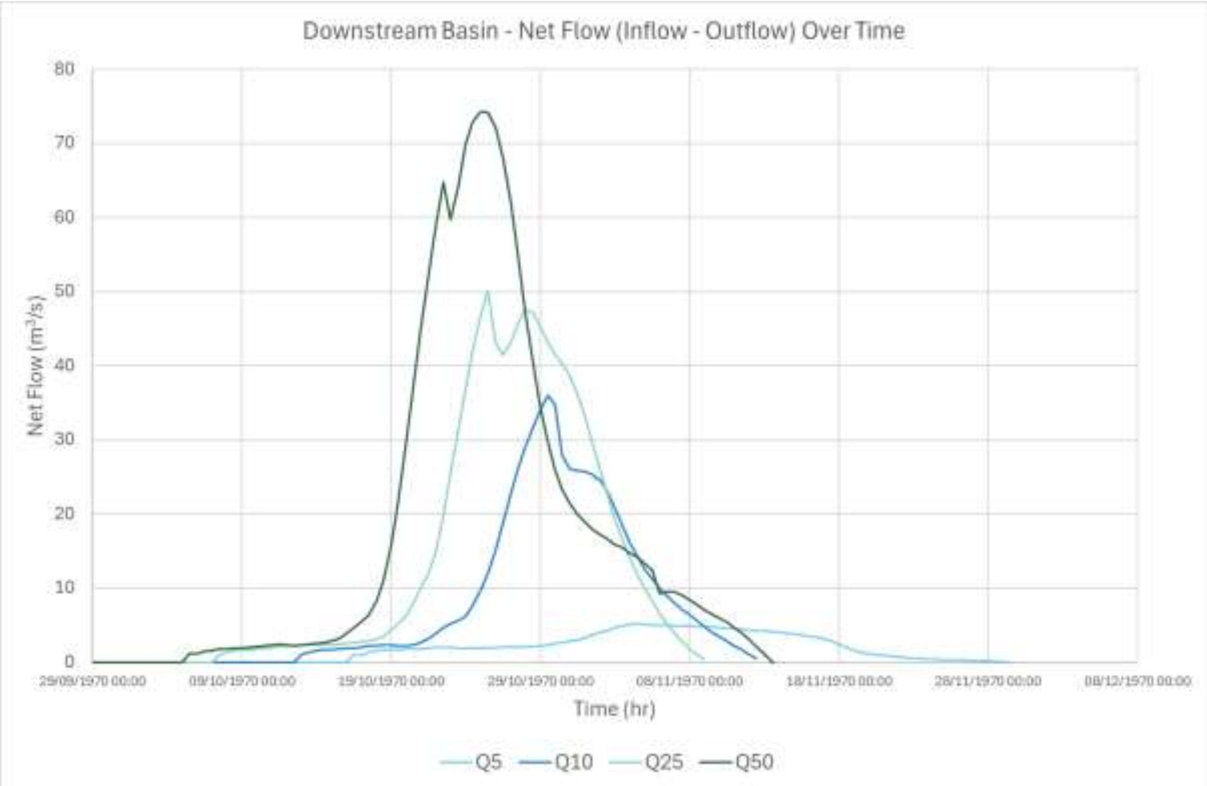
The model does not include any outflow control structures. To represent these needs good quality topographic and channel survey data.

In all cases the humide inflow scenario that represents future climate conditions has been applied (refer to the baseline hydraulic model report).

Modelled Basin	Minimum storage range (million litres)	Maximum storage range (million litres)
Basin 1 (upstream basin)	1,800	2,000
Basin 2 and 3 (downstream basin)	1,000	3,200
Basin 4	Outside of model domain	Outside of model domain



Graph 1: Upstream basin - net flow (inflow - overflow) Over time



Graph 2: Downstream basin - net flow (inflow - overflow) Over time

This component includes three basins, the dimensions of which will be determined based on the suitability of the site. Water collection capacity will vary depending on depth. These three basins are interconnected and connected to the two rivers by irrigation channels, the routes and sections of which will be defined in more detailed technical studies during the project management phase.

- Basins surrounded by dikes to contain flood water
- Control structures to safely manage outflow and in some cases inflow to the basins
- Channels to connect the basins to the river channels in the form of green corridors

The basins are represented through the inclusion of a raised dike around the potential basin area, with the upstream side left as open ground so that overland flow can drain into the basin freely. This ensures that the performance of the basin is not limited by the ability of channels to convey all floodwater and maximizes the benefit through capturing as much floodwater as possible. This is an important consideration because the baseline model outputs confirmed that floodwater is not fully contained within the Bhar Linia canal and can reach the area from overland flows as a result of spills from the Chari River near Dijila.

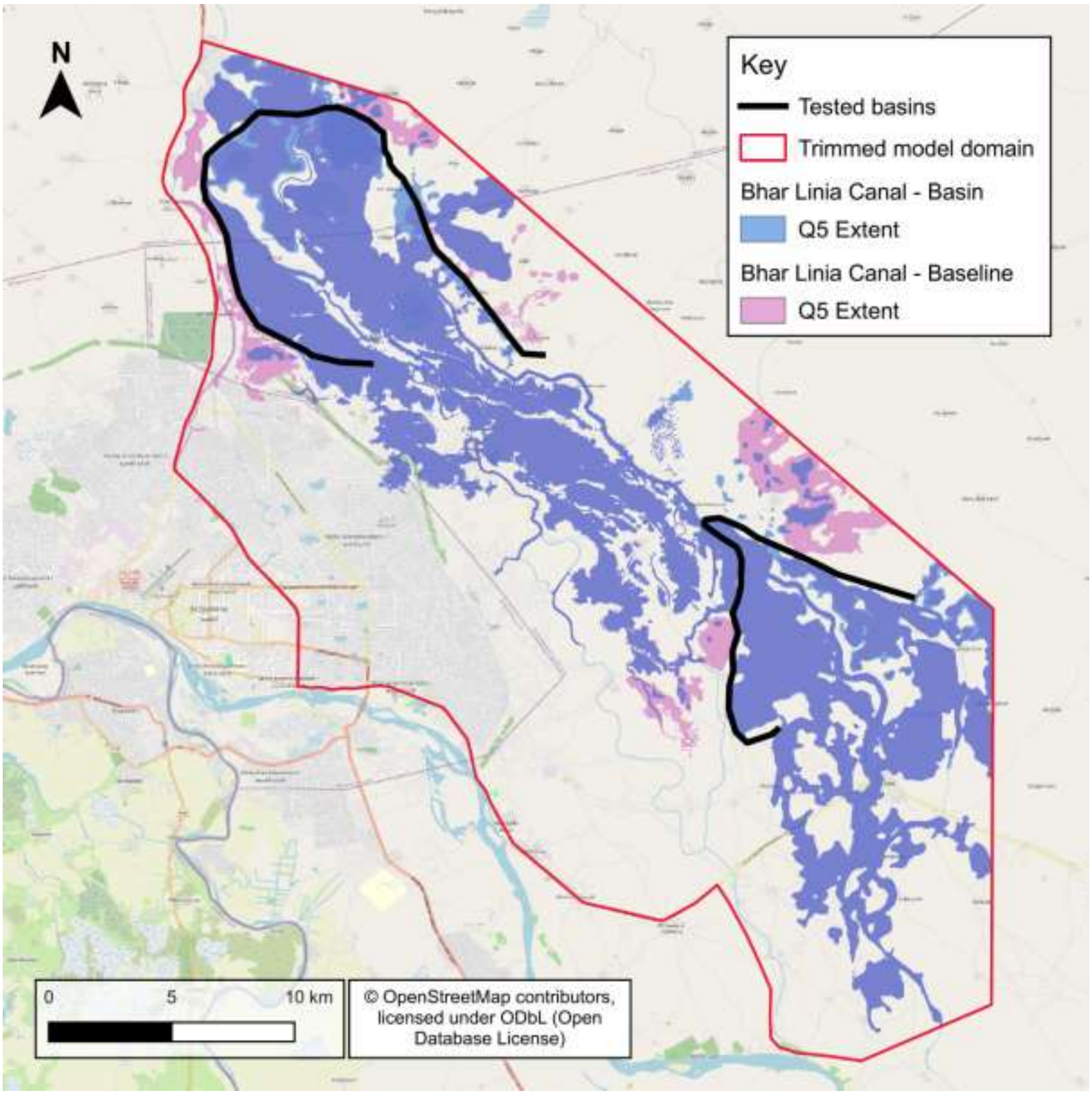
Based on the existing data available it is not possible to specify the size, location, type and capacity of the control structures, dikes and connecting channels cannot with sufficient confidence. These need to be analyzed in more detail during subsequent Feasibility Studies and Detailed Design.

The hydraulic model has been run with two different inflow sources separated so that different flood mechanisms can be considered. One scenario is with the Bhar Linia inflow only, and the second scenario is with only the overflow from the Chari River at Djjali. The maps below show the difference between the baseline and with basin model scenario flood extents for these two scenarios, for the Q5, Q10 and Q50 flood probabilities. It is important to understand these as separate events because depending on how and where floodwater spills from the Chari will determine which basins will fill first and how. We can see there are some localised reductions in flood extent in the Q5 and Q10 but the level of protection is negligible in the Q50 event. The direct flood benefits from these basins will be limited to these areas shown in pink on the maps below, and only provide flood protection in the more frequent flood events. The upper part has been left open because this maximizes the inflow into the basin from runoff. The basin can only capture water that flows and remains in the bed of the Bhar Linia River, which cannot contain the entire flood flow.

to inform appropriate channel sizes. The duration of flooding within the basins will be dependent upon the detailed design and optimisation of control structures. The duration should balance the water stored for agricultural uses such as irrigation and the need to ensure sufficient capacity in the basins for possible further flooding during the season.

There is a backwater effect of greater flood depths upstream of each basin. This needs to be carefully managed and designed so that communities are not exposure to increased risk of flooding as a result of the proposed project.

The proposed basins do not provide any reduction in flood risk from the Chari or Logone Rivers.


N
Key
Tested basins
Trimmed model domain
Bhar Linia Canal - Basin
Q5 Extent
Bhar Linia Canal - Baseline
Q5 Extent
0
5
10 km
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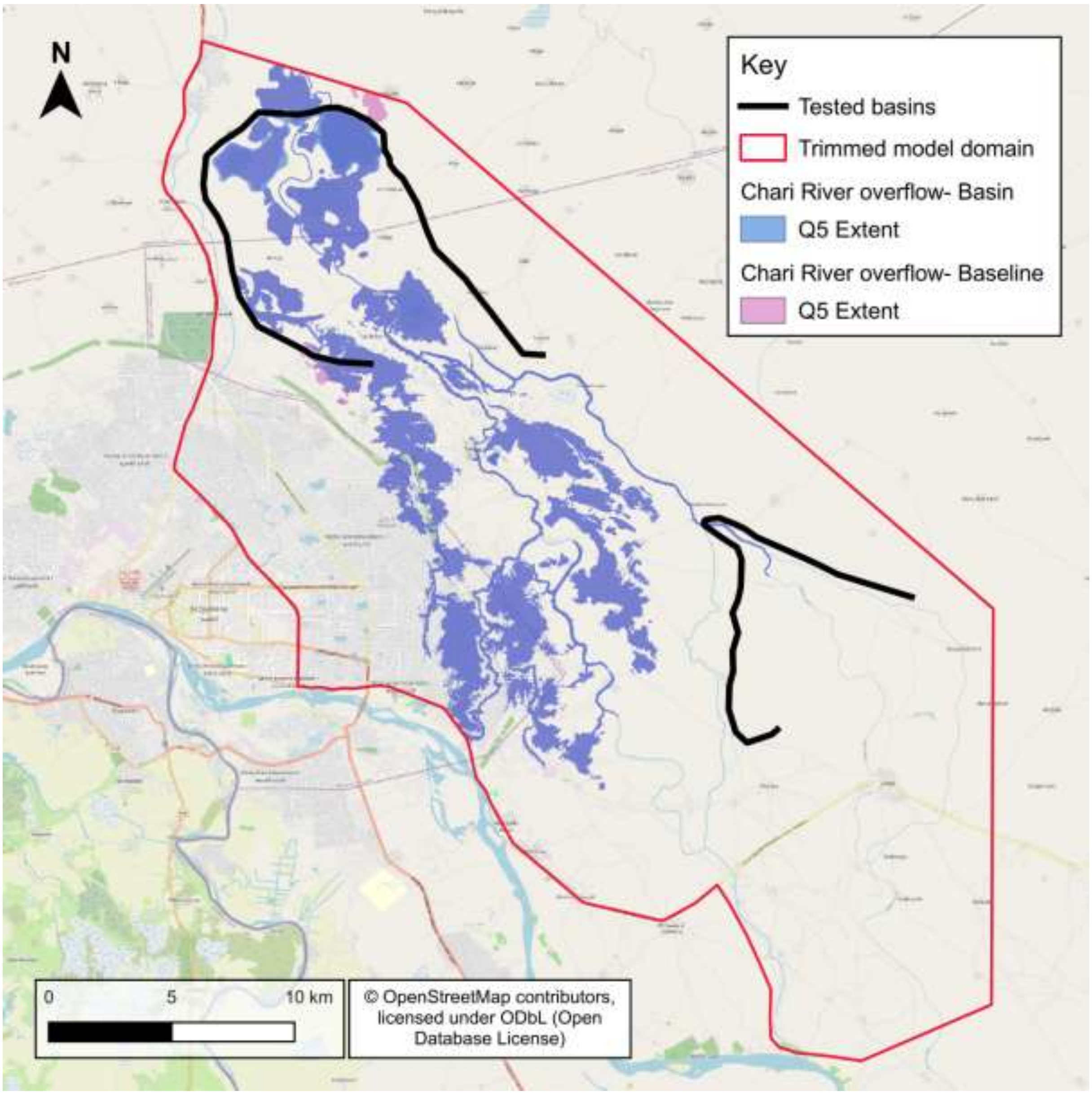
N
Key
Tested basins
Trimmed model domain
Chari River overflow- Basin
Q5 Extent
Chari River overflow- Baseline
Q5 Extent
0
5
10 km
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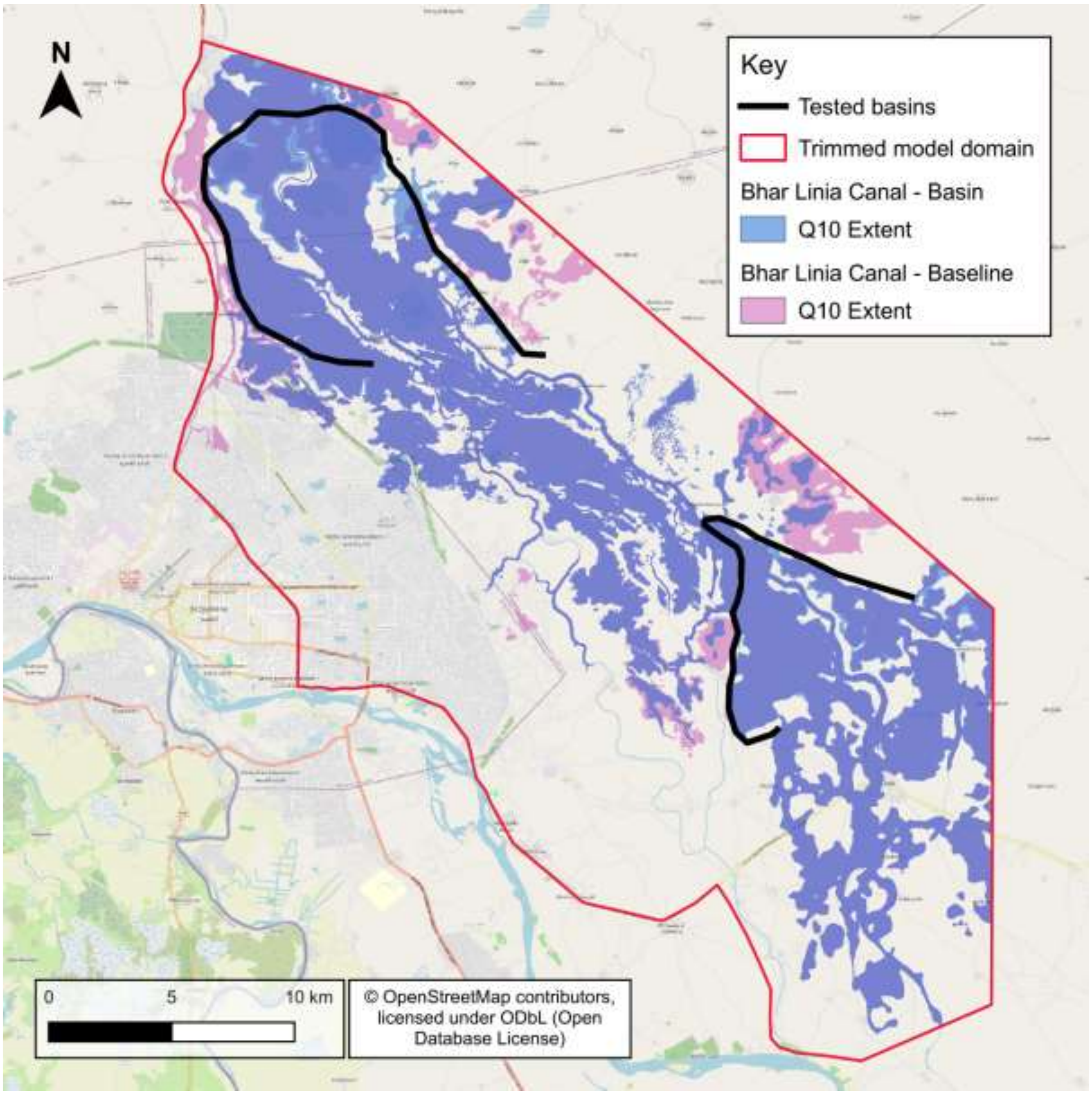

N
Key
Tested basins
Trimmed model domain
Bhar Linia Canal - Basin
Q10 Extent
Bhar Linia Canal - Baseline
Q10 Extent
0
5
10 km
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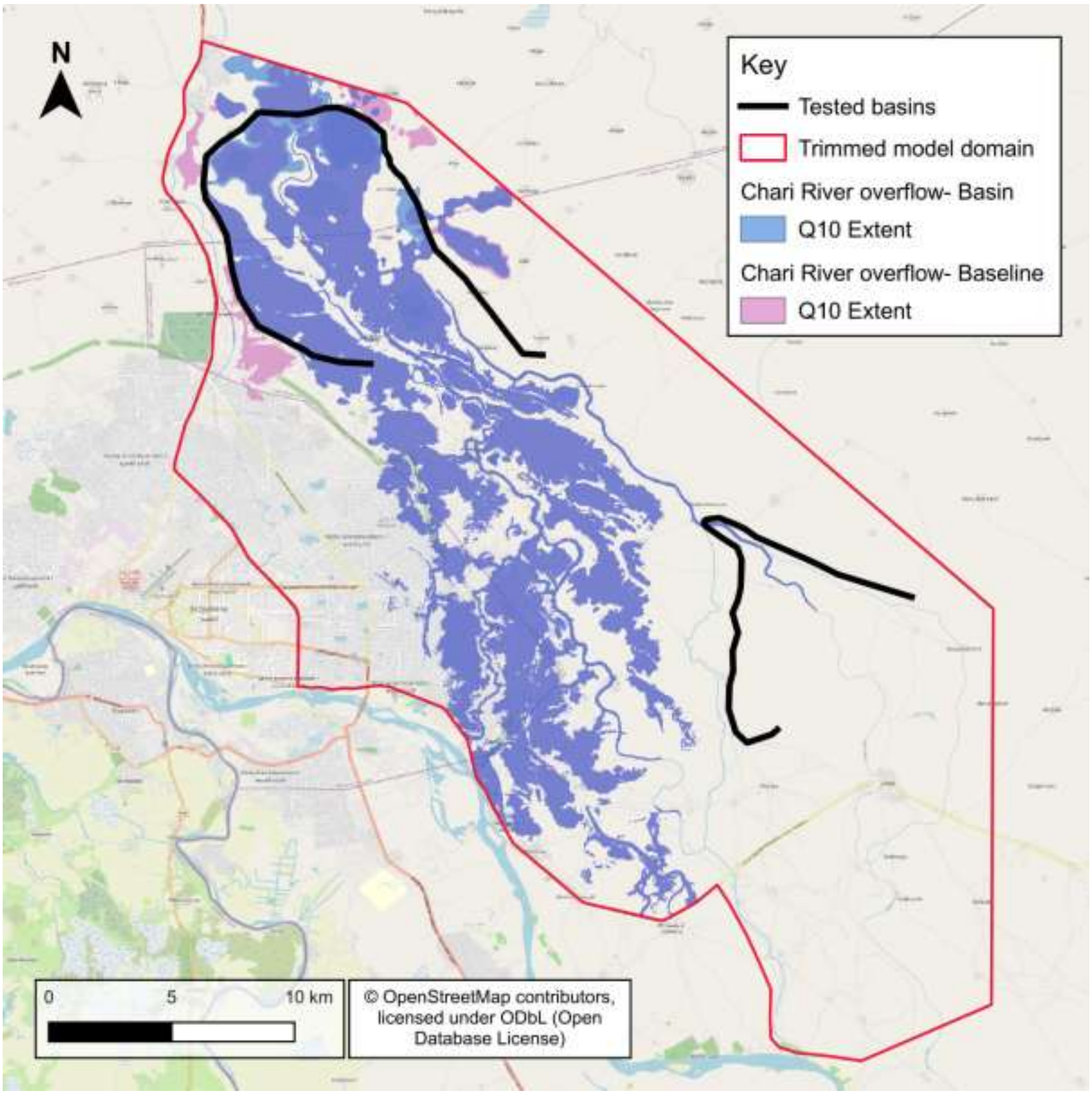
N
Key
Tested basins
Trimmed model domain
Chari River overflow- Basin
Q10 Extent
Chari River overflow- Baseline
Q10 Extent
0
5
10 km
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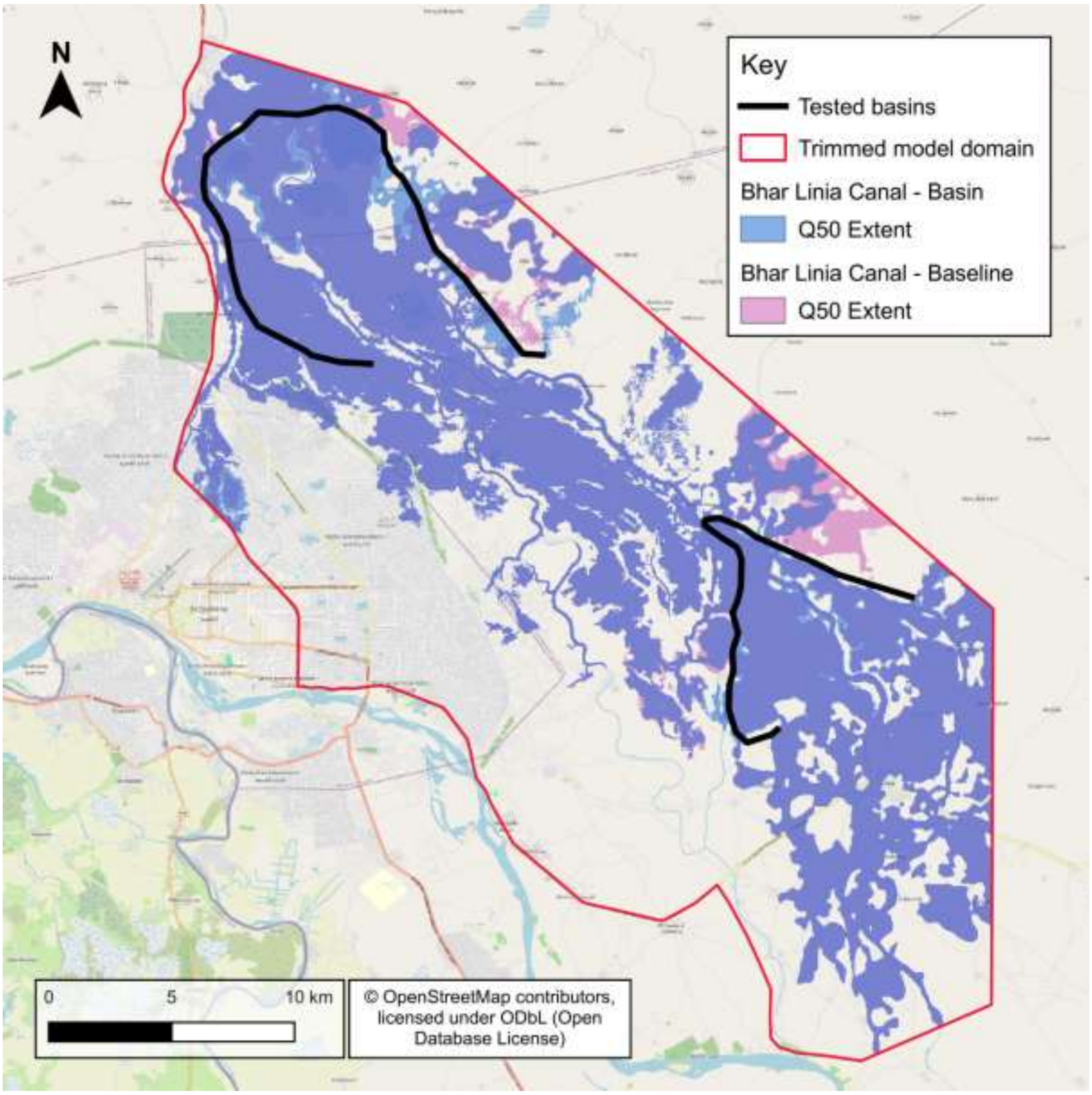
N
Key
Tested basins
Trimmed model domain
Bhar Linia Canal - Basin
Q50 Extent
Bhar Linia Canal - Baseline
Q50 Extent
0
5
10 km
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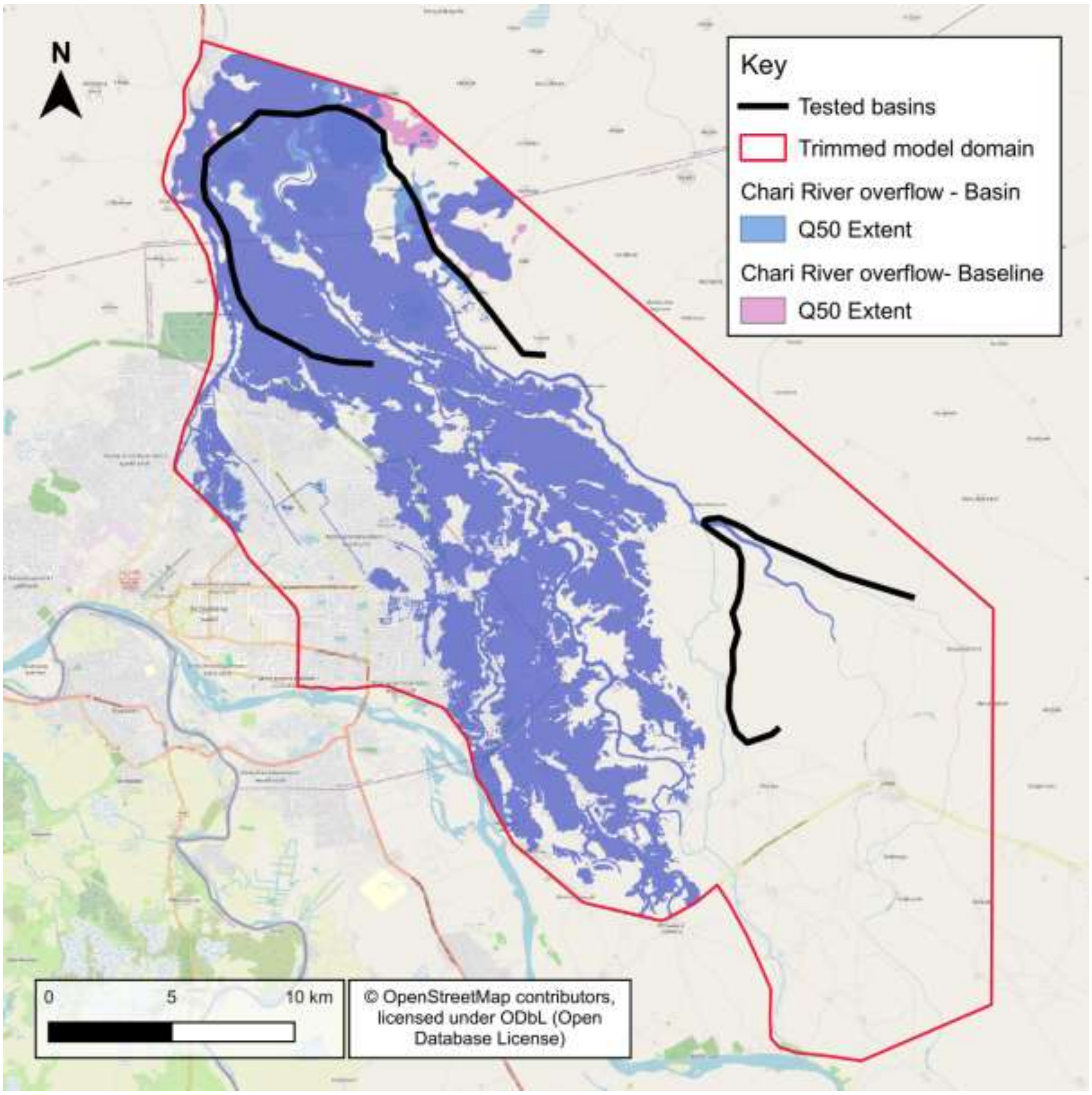

To ensure the protection of homes, farmland, and grazing areas, protective dikes of varying sizes are planned, depending on the actual constraints of the terrain.

The basins are directly bordered by green corridors. These consist of trees and grasses planted to stabilize the protective dikes.

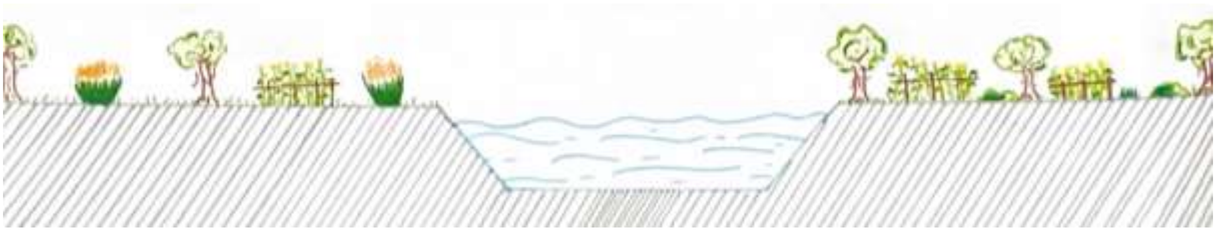

Figure 9: Section of basin with green and farming spaces

8.2.2 Component 2: Riverbed and renaturation

The El Biher development consists of a hydraulic component, an ecological component, and a social/urban component.

- Dredging and re-profiling of the riverbed and development of riverbanks

  From a hydraulic perspective, the riverbed must be dredged and reprofiled to facilitate water flow. This involves either removing or relocating human activities that take place on the riverbed. These include market gardening and brickmaking, as well as dwellings and industrial units (locally known as "endrouilla"). Reprofiling therefore ensures minimal and continuous flow, preventing stagnation and maintaining acceptable water quality until the return of the rainy season. This measure thus helps to preserve the river's hydrological and ecological balance while improving sanitary conditions for riverside populations.

  Rockfill involves placing blocks of stone in a structured manner along the banks to reinforce and stabilize the most vulnerable areas. These protections are only installed in strategic locations, particularly where erosion is particularly active or where the banks have low natural resistance. Rockfill absorbs the energy of the current, limits bank retreat and provides lasting protection against damage caused by water level variations. This type of development thus offers a robust and appropriate solution for securing sensitive sections of the river.

  From an ecological standpoint, the riverbanks are stabilized with vegetation. The creation of vegetated caissons involves installing modular structures filled with soil and vegetation to stabilize the riverbanks and reinforce their resistance to erosion. These caissons provide mechanical support while promoting ecological integration through plant rooting. They also improve the landscape quality of the site and contribute to the restoration of a sustainable natural environment by creating microhabitats that promote biodiversity.

- Construction of levees (dikes)

  The levees are structures designed to protect homes and businesses from the risk of river flooding. To this end, they are built along the El Biher in accordance with current regulations. In this context, river dikes made of embankments, rocks, and vegetation are planned. The aim is to plant species that are ecologically suited to stabilizing the soil. Along El Biher and on either side, the dykes will be built according to the dimensions defined in technical studies. These dimensions will be assessed according to the risk levels of each area.

- Bridges

  Currently, between the Lamadji pumping station and the intersection between El Biher and the national highway, there are a total of five bridges, some of which were built using traditional methods without any real technical studies or standards. There are also around 20 places where people cross El Biher, either during the dry season or when the water level is low. This project involves the construction of four bridges and the rehabilitation of three bridges (Kilmé, Frouk, Karal).

- Public space as an interface between the river and the city

  Between the city-river interface and the riverbed, protective levees are planned to prevent the risk of flooding, which could cause the destruction of lives and activities. The construction of levees along the watercourse aims to contain and control rising water levels during periods of heavy rainfall. During periods of high water, the river level can rise rapidly, leading to overflowing, bank erosion, and flooding of riverside areas. The levees then serve as physical barriers capable of retaining water, stabilizing the banks, and protecting nearby homes, infrastructure, and human activities. They thus play an essential role in reducing the risks associated with bad weather, while ensuring the safety of populations and the resilience of the territory in the face of extreme hydrological events.

- The interfaces between the riverbed and urban areas are landscaped to create living spaces consisting of gardens, fruit trees, and shade, as well as rest areas with a few shops. This type of landscaping offers the opportunity to plant more environmentally friendly species that improve air quality and facilitate carbon absorption.

- The creation of a green pedestrian path along the river aims to improve accessibility and enhance the landscape of the site. This path, landscaped with suitable vegetation, will not only provide a safe walking area for users, but also reinforce the protection of the riverbanks. The windbreak hedge, which is part of this development, will play an ecological and functional role by reducing the impact of prevailing winds, limiting wind erosion, and creating a natural barrier between the river and areas of human activity. This development contributes to the comfort of users, the preservation of the natural environment, and the beautification of the riverside landscape.

- The creation of green spaces involves planting trees, shrubs, and grasses to stabilize the soil and limit erosion caused by wind or runoff. Vegetation also significantly reduces dust by binding particles to the ground. In addition to their environmental functions, these green spaces improve the aesthetics of the site, create a more pleasant environment for users, and promote a more comfortable microclimate.

- The installation of urban equipment such as adapted benches, solar lighting, and rest areas helps to improve the comfort and safety of residents. Benches provide spaces for rest and social interaction, while solar lighting ensures optimal visibility at night while being environmentally friendly and economical. The creation of landscaped rest areas also makes public spaces more attractive and accessible, encouraging people to walk and use the areas in a pleasant and safe manner.

With this development, El Biher plays a central role in the organization of the urban landscape, serving as a link between the city and its natural environment. As a structuring element, it influences the layout of infrastructure (engineering structures), public spaces, and traffic. The presence of riparian forest, dense and varied vegetation along the riverbanks, enriches this space by giving it recreational and aesthetic value: it provides shaded areas, promotes biodiversity, and creates places conducive to walking, leisure, and relaxation for residents. Thus, the river and its riparian forest become a true living heritage, combining ecological, social, and landscape functions.

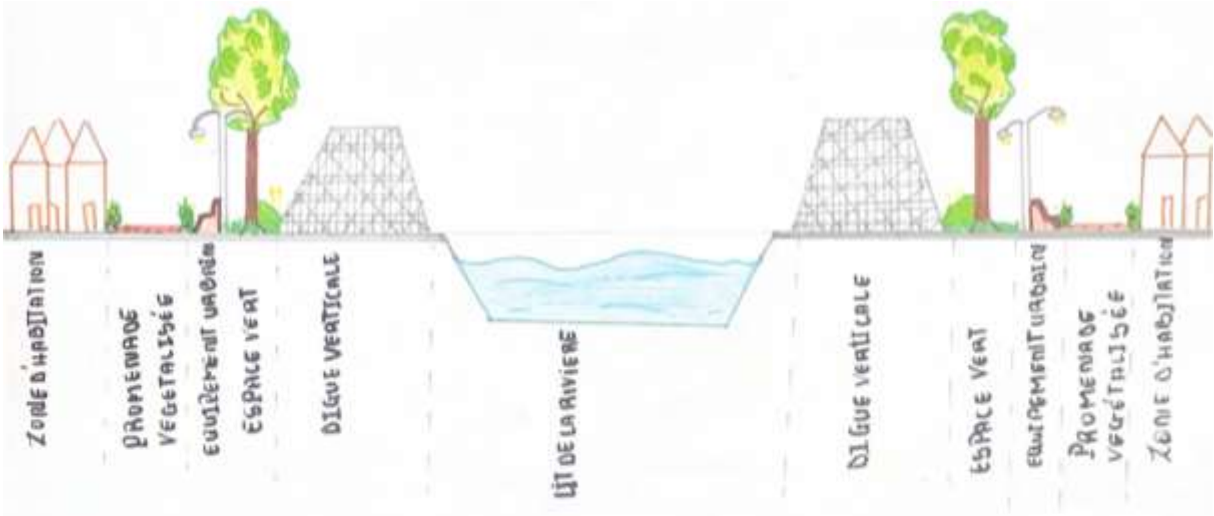

Figure 10: Section of river, dike and green spaces

8.2.3 Component 3: Nature Based Solutions (NBS):

Reforestation, reduce erosion. The NBS could be include in every option according to the nature of project.

- Urban parc at Kilmé and Mabrouka, covers 270 000m² and it should create as integrated urban parc where there are resting places, children playground, gardens, artificial lake, trees for shadow, commercial activities, restaurants, sports. The following trees species may be used for the establishment of these parks: Azadirachta indica (Neem), Khaya senegalensis, Terminalia mantaly, Terminalia catappa, Delonix regia, Eucalyptus spp., and so all.
- Public spaces along El Biher are small urban and green areas for socializing as resting places and some commercial activities. In these areas, there are green corridors for shadow, children playground. For public green spaces, species such as Azadirachta indica (Neem), Khaya senegalensis, Terminalia mantaly, Ficus benjamina, Delonix regia, Eucalyptus spp., and Sorghum arundinaceum, Vetiveria zizanioides (Vétiver) and so all
- Irrigation channels between basin and bahr Linia for agriculture areas. These channels should be made as green spaces with plants which could reduce erosion and flood. Agriculture should be developed around the villages located nearby the rivers (Bahr Linia and EL biher). Species that are essential for creating a favourable microclimate, improving fertility and protecting plots from drought and erosion are offered. These include : Faidherbia albida (Acacia albida), Acacia seyal, Ziziphus mauritiana (Jujubier), Citrus sinensis, C. lemon, Annona squamosa (pomme cannelle), Balanites aegyptiaca.
- Dikes for protection of farming areas in Farouk, marouka, Kilmé, Abdeli Goussour, Medebe Madouan and other villages. The dikes are made infrastructure of defence for the citizen and activities. For the protection of dykes in agricultural areas, herbaceous species such as Vetiveria zizanioides (Vétiver), Andropogon gayanus, Sorghum arundinaceum, and so all.

Part of these 3 options, there are some NBS which could be integrated to each option of investment. NBS for urban farming could be included in the flood storage investment for example. Or the NBS for soil stabilization could be included in the flood defense infrastructures.

And we note that before any investment, it's important to make sur that the flood early warning system should be implemented in Ndjamena and community with the way to enhance the infrastructure for people evacuation during flooding.

8.3 How do the basins function with the two rivers?

The components work together systematically to regulate flood management in N'Djamena.

The basins are directly connected to the Bahr Linia River, while the more urban El Biher river will be connected to the basins by drainage canals. The two rivers have specific functions. El Biher is the preferred route for efficiently draining rainwater to the Chari River in the north (Annex 1, map 2) and to the basins via canals. The Bahr Linia, connected to the Chari River in the south, is the preferred means of discharging water from the Chari River to the basins.

This operation demonstrates that the usefulness of these investments lies in the hydrological regulation between the water collection capacities of the basins and the roles of the two rivers. If all these infrastructures are completed as planned, rainwater flood management will be more or less under control until the flood season. The only constraint is the construction and proper functioning of the gutters and drainage infrastructures.

During floods, the basins and rivers may overflow if the designed and estimated capacities are reached. The management of this type of infrastructure requires technical prerequisites. It is therefore essential to provide training to strengthen the capacities of the technical services in charge of management. In addition, adequate equipment is needed to effectively monitor the hydrological, ecological, and socioeconomic benefits.

8.4 Analysis of the benefits of prioritized components

The proposed investments are part of a comprehensive approach to reducing flood risks in the northern neighborhoods of N'Djamena and its surrounding areas along the Bhar Linia and El Biher corridors. They involve three complementary approaches: the creation of basins and dykes, the dredging (river reprofiling) and renaturation of the El Biher riverbed, and the development of nature-based solutions. A detailed analysis of the benefits highlights both the direct effects of these investments on flood reduction and the socio-economic and environmental co-benefits that reinforce their impact. Consultations with rural and urban communities. confirm the relevance of these interventions and illustrate how they respond to the expectations expressed on the ground

8.4.1 Global benefits of investments

8.4.1.1 Direct benefits

Several direct benefits are common to the various investments. First, all three interventions will help reduce flooding by acting on the storage, flow, or dissipation of floodwaters. Whether through the creation of large-capacity basins, improved drainage along the El Biher River, or natural stabilization of riverbanks using nature-based solutions, the investments will strengthen the region's capacity to absorb or evacuate excess water volumes. This convergence of hydraulic effects provides a common basis for reducing the exposure of residential and agricultural areas to flood risks in N'Djamena.

8.4.1.2 Co-benefits

The investments also share a set of co-benefits. They will all contribute to improving the living environment, whether through the creation of public spaces, recreational areas, or green spaces. They will also help protect riverbanks and combat erosion, either through structural work (dredging) or green infrastructure (nature-based solutions). In addition, the three components will generate economic opportunities, whether through market gardening and fish farming around the basins, businesses in public spaces, or enhanced rural activities. Finally, these investments will fuel positive momentum in terms of mobility and connectivity, particularly thanks to the crossing structures along the El Biher mentioned during the community consultations in Kilmé.

8.4.2 **Specific benefits**

8.4.2.1 Component 1 – Basins and dikes

- Direct benefits

The creation of retention basins at the Linia, Mabrouka, and Kilmé sites will enable large-scale storage of floodwater, reducing the flow entering the city of N'Djamena. Depending on the depth chosen, storage volumes will vary from 48.5 million m³ to 242.5 million m³, illustrating their crucial role in reducing flood risks. Associated levees will reinforce this protection by limiting overflow into residential and agricultural areas.

- Co-benefits

The basins will offer several major co-benefits. The first advantage is that they will protect homes, crops, livestock, and local industrial activities. Secondly, these infrastructures will ensure increased water availability during the dry season, well beyond the natural cycle of existing basins. While natural basins retain water until December, basins built to the planned dimensions could store water until February, March, or April. This water will support irrigation, market gardening, and livestock farming, paving the way for agricultural development, fish farming, and activities generated along irrigation canals.

8.4.2.2 Component 2 – Dredging and reprofiling EL Biher river

- Direct benefits

Dredging and reprofiling the bed of the El Biher will significantly improve floodwater drainage, facilitating its evacuation towards the northern exit of N'Djamena. This intervention will reduce flooding and require studies for the stabilization of the banks, thus contributing to the protection of riverside homes.

- Co-benefits

The renaturation of the watercourse will offer several co-benefits, including an improvement in the living environment thanks to the revegetation of the banks and bed of the El Biher River. The development of public spaces, play areas, and recreational areas along the river will create new opportunities for residents to relax, while enhancing the appeal of the riverside neighborhoods.

8.4.2.3 Component 3 – Development of NBS

- Direct benefits

Nature-based solutions will contribute directly to erosion protection. Vegetated levees will increase infrastructure durability and protect homes and agro-pastoral activities from erosion risks. In addition, the creation of vegetated banks will stabilize riverbanks, thereby reducing damage related to river erosion.

- Co-benefits

SFNs will generate several co-benefits in terms of urban and social development. The creation of gardens, public spaces, and shaded areas near investment sites will improve the living environment of urban communities. These spaces will provide places for socializing, relaxation, and recreation, while contributing to the growth of small businesses.

8.4.3 **Contributions from community consultations**

Consultations conducted in rural and urban areas confirmed the relevance of the proposed investments and guided their design in line with local expectations. They revealed a clear divergence between the needs of rural communities, which are mainly focused on access to water and agro-pastoral development, and those of urban populations, which are more focused on rapid drainage, improvement of living conditions, and urban services.

In rural areas, particularly in Abdeli Goussour and Kilmé (annex 3 and 4), agro-pastoral communities expressed strong support for the creation of the reservoir on the Bahr Linia. They see this infrastructure as a sustainable solution to ensure water availability during the dry season, enabling the cultivation of okra, squash, tomatoes, watermelons, and other vegetables. The inhabitants believe that the presence of stored water will promote agriculture, livestock farming, and fish farming, while generating significant economic benefits for household incomes. This feedback confirms that Component 1 directly responds to their needs for water security and the enhancement of agricultural production.

In urban areas, particularly in Lamadji and Mabrouka, (annex 3 and 4) perceptions are significantly different. Residents express reluctance towards water conservation in basins, favoring rapid drainage of water after rainfall. Their priorities are flood reduction, the absence of stagnant water, and the creation of public, social, and commercial spaces. These factors reinforce the relevance of the urban developments planned in nature-based solutions, which allow for the integration of playgrounds, shaded areas, and meeting places in the immediate environment of the neighborhoods.

Finally, consultations in Kilmé (annex 3 and 4), along the El Biher, revealed strong expectations regarding mobility and internal connectivity. Eight crossing structures have been identified as essential to facilitate travel and trade between villages on either side of the river. Although this need is distinct from the main objective of dredging for drainage, it constitutes a structuring co-benefit associated with component 2, as it strengthens the socio-economic integration of the localities concerned.

9. INTEGRATED PROJECTS SHEETS

After analysis, these following components (Annex 1) could be selected as investments to implement.

9.1 Component 1: Offline flood storage

Table 3: Project sheet - component 1

Title	Development of 4 reservoirs to the north and east of N'Djamena
Description	There three flood storage with dikes should be implemented in the North and East of N'Djamena. Basin 1 is located north of Linia. This flood storage covers an area of 5 695 338 m². Basin 2 is located at the northern end of Bahr Linia. This basin covers of 3 867 633 m². Basin 3 is located east of the villages of Kilmé and Mabrouka. It covers an area of 34 724 440 m². The sites are basins that act as natural water retention areas until November and December after the rainy season. (See Appendix 6) Around each basin, dykes are built in order to protect citizen and farming areas. From these basins to the rivers, there irrigation channels for the agriculture and farming market. The alignment and height of the dikes are to be proposed in the Feasibility Study and Detailed Design stages. Control structures to manage inflow and outflow to the basins and connecting channels will also be required. These are to be proposed during the Feasibility Study.
Phasing	Studies : 12 months • Hydraulic and civil engineering studies • Preparation of consultation files for project management stakeholders and contractors. Procurement : 6 months This involves selecting design offices for specific technical studies and recruiting companies to carry out the work. Recruitment concerns local and international consulting firms, local construction companies, and NGOs/associations for mobilization of citizens. International consulting firms for technical studies on the basins. National engineering firms for skills available at the national level (drainage, dykes, irrigation canals, etc.). The work can be carried out by national companies with international project management to ensure the quality of implementation. To encourage high labor intensity, it is advisable to recruit local companies. Works : 24 months This is the implementation phase of the project. All work must be carried out under the supervision and control of an experienced and approved engineering firm. Monitoring and evaluation : 12 months The phase may last one year, during which time the following will be assessed: (i) the effectiveness of the infrastructure in reducing flood waters and (ii) the social, economic, human, and environmental impacts of the project.
Costs	448 020 000 € without studies, monitoring of works and O&M • 3% for technical studies

	• 10% for the monitoring of works • ~~And~~ 1% for O&M
Methodology of cost evaluation	Estimation of the quantities of dredging river and dikes. After these quantities, the calculations have done by the unit cost regarding the local context.
Financing	Donors (World Bank, FFEM, AFD, BAD) and the Government of Chad. Because these lenders have guidelines on climate change adaptation and resilience.
Project management	Ministère de l'Aménagement du Territoire et de l'Urbanisme City Hall
Stakeholders' engagement	Government: MATUH, City Hall, District City Hall Hadjer Lamis District Linia Sub-Prefecture Local and Community Authorities Civil Society Bahr Linia Project
Advantages or opportunities	• Agricultural development • Protection of biodiversity and the natural ecosystem • Reduction of flood risks • Reduction of the risk of overflowing basins • Employment (HIMO approach)
Risks	• Risk of overflowing basins • Technical risk if maintenance is not properly understood by operators • Land acquisition linked to the expansion of pond areas • Conflicts of use in rural areas dedicated to agro-pastoralism • Perceived inequality in the distribution of investments, which are mainly located in the east and north • Without proper awareness and engagement, community use of the basins could expose people to flood hazards during flooding

Figure 11: Location of the basin 1's site

Figure 12: Location of the basin 2's site

Figure 13: Location of basin 3's site

9.2 Component 2: riverbed dredging and renaturation

Table 4: Project sheet - component 2

Title	Dredging and renaturation of the El Biher River with riverbank improvements
Description	The river starts from Lamadji to north of Ndjamena until Chari river. It is planned for dredging and re-profiling of the riverbed. This works depends of topographic surveys. For the protection of the citizen and agriculture areas, along the river, the dikes are planned to be implemented. And in each part of the riverbed after the dikes, green public spaces are developed for the citizen. It is composed of children playground, resting places, commercial activities There are also some bridges which. 3 Bridges must be rehabilitated, and it planned to build 2 new bridges. Below the geographical coordinates of bridges to be built: *En face de pont bellilé vers le site du grand Bassin* — *504 450,219* — *1 356 393,274* *Pont pour accéder à Karal* — *504 691,441* — *1 359 183,269* Below the geographical coordinates of bridges to be rehabilitated: *Pont sous la route nationale* — *504 756,808* — *1 367 112,548* *Pont de Kilmé* — *506 116,869* — *1 363 166,875* *Pont conduisant Afrouk* — *5057 54,856* — *1 354 042,060*
Phasing	Studies :12 months • Technical studies • Preparation of consultation files for project management stakeholders and contractors. Procurement : 6 months This involves selecting design offices for specific technical studies and recruiting companies to carry out the work. Recruitment concerns local and international consulting firms, local construction companies, and NGOs/associations for mobilization of citizens. International consulting firms for technical studies on the dredging and renaturation of El Biher. National engineering firms for skills available at the national level (public spaces, drainage, dykes, irrigation canals, etc.). The work can be carried out by national companies with international project management to ensure the quality of implementation. To encourage high labor intensity, it is advisable to recruit local companies. Works : 42 months This is the implementation phase of the project. All work must be carried out under the supervision and control of an experienced and approved engineering firm. Monitoring and evaluation : 12 months The phase may last one year, during which time the following will be assessed: (i) the effectiveness of the infrastructure in reducing flood waters and (ii) the social, economic, human, and environmental impacts of the project.
Costs	175 810 000 € without studies, monitoring of works and O&M • 3% for technical studies • 10% for the monitoring of works • ~~And~~ 1% for O&M
Methodology of cost evaluation	Estimation of the quantities of dredging river, the area for renaturation and the area for public green spaces. After these quantities, the calculations has done by the unit cost regarding the local context.

Financing	Donors and the Government of Chad
Project management	Ministère de l'Aménagement du Territoire et de l'Urbanisme City Hall
Stakeholders engagement	Government: MATUH, City Hall, District City Hall Hadjer Lamis District Linia Sub-Prefecture Local and Community Authorities Civil Society Bahr Linia Project
Advantage or opportunities	• Agricultural development • Protection of biodiversity and the natural ecosystem • Reduction of flood risks • Employment (HIMO approach)
Risks	• Risk of overflowing river • Technical risk if maintenance is not properly understood by operators • Risk of community dissatisfaction if the crossing structures are not built • Disruption of inter-village mobility in the event of prolonged works without alternatives • Risk of relocation of brickmaking activities

Figure 14: Drawing of river, dike and green spaces

9.3 Component 3: Nature Based Solutions (NBS): reforestation, reduce erosion.

The new NBSs concern public spaces to be created along El Biher, the Mabrouka–Kilmé urban park, protective dykes, irrigation canals, and urban agriculture.

Table 5: Project sheet - component 3

Title	Development of public spaces, sustainable protective dikes and agricultural areas
Description	NBS concerned includes urban green public space, urban agriculture, irrigation channels and dikes of protection. • Urban parc at Kilmé and Mabrouka, covers 270 000 m² and it should create as integrated urban parc where there are resting places, children playground, gardens, • Urban agriculture along the Bahr Linia are activities of agriculture developed around the villages located nearby the rivers (Bahr Linia and EL biher. • Irrigation channels between basin and bahr Linia and agriculture areas. These channels should be made as green spaces with plants which could reduce erosion and flood. • Dikes for protection of farming areas in Afrouk, marouka, Kilmé, Abdeli Goussour, Medebe Madouan and other villages. The dikes are made infrastructure of defence for the citizen and activities. Below, the geographical coordinates of urban green parc: *1 505 948,198 1 362 116,984* *2 506 178,160 1 362 253,140* *3 506 387,162 1 362 188,220* *4 506 626,801 1 361 739,168* *5 506 303,281 1 361 582,332* *6 506 069,957 1 361 729,160* *7 505 928,254 1 362 027,123*
Phasing	Studies : 6 months • Technical studies : APS and APD • Preparation of consultation files for project management stakeholders and contractors. Procurement : 6 months This involves selecting design offices for specific technical studies and recruiting companies to carry out the work. Works : 24 months This is the implementation phase of the project. All work must be carried out under the supervision and control of an experienced and approved engineering firm. Monitoring and evaluation : 12 months The phase may last one year, during which time the following will be assessed: (i) the effectiveness of the infrastructure in reducing flood waters and (ii) the social, economic, human, and environmental impacts of the project.
Costs	48 200 000 € without studies, monitoring of works and O&M • 3% for technical studies • 10% for the monitoring of works • ~~And~~ 1% for O&M
Methodology of cost evaluation	Estimation of the quantities of dikes, channels and the area for public green spaces. After these quantities, the calculations have done by the unit cost regarding the local context.
Financing	Donors and the Government of Chad

Project management	Ministère de l'Aménagement du Territoire et de l'Urbanisme City Hall
Stakeholders engagement	Government: MATUH, City Hall, District City Hall Hadjer Lamis District Linia Sub-Prefecture Local and Community Authorities Civil Society Bahr Linia Project
Advantage or opportunities	• Agricultural development • Protection of biodiversity and the natural ecosystem • Reduction of pollutions • Employment (HIMO approach)
Risks	• Risk of overflowing river • Technical risk if maintenance is not properly understood by operators • Performance depends on plantation maintenance and vegetation cover • Low erosion control effectiveness if vegetation does not establish properly • Risk of unequal appropriation if public spaces are not co-managed by communities • Potential conflicts of use for urban spaces (commerce, recreation, traffic)

Figure 15: Schematic diagram of an urban park

9.4 High Labor Intensity (HIMO) Approach

In order to provide more job opportunities for local residents, we are proposing a HIMO approach. During the operational phase of the project, the project owner will rely on representatives from villages in the study area and from the northern and eastern districts of N'Djamena to recruit local labor.

10. ACTION PLAN

10.1 Summary of costs

This following shows the details of the costs of all components.

10.1.1 Evaluation of quantities

This table shows the details of quantities estimated:

Table 6- Measures for quantities estimations

Basins	Basins	Areas: 34724440m²+3867633m²+5695338m² Depth proposed : 1.5m Perimeters : 10400m+8080m+24270m
	Dikes	Length: 24600m+12700m Width: 3m Height: 1,5m Expansion coefficient : 1,3m
El Biher dredging and renaturation	Dredging and renaturation	Length: 70 200 m Width: 95m Width of public space: 6m
	Bridges/ crossing structures	3 bridges to rehabilitate 2 bridges to build Details of drainage channel regarding existing infrastructure under the national road; L=7m L=6m H=1.5 Ep:30cm
Nature Based Solutions (NBS)	Public space	Area:27 Ha
	Sustainable dikes	Length: 15100m+35300m Width: 3m Height: 1.5m Expansion coefficient : 1,3m
	Channels	Length: = 15100m+35300m+13500m Width: 15m Depth: 3m

10.1.2 Evaluation of costs

Unit cost of basin, dredging river and channels

Work on the basins and dredging of the riverbed requires excavation and backfilling with compaction. Excavation work in Chad costs between 2,000 and 3,000 CFA francs per square meter. Given the need to stabilize the walls, we propose a unit price of 5,000 CFA francs.

Unit cost of development of stabilized riverbanks

Masonry work in Chad is estimated to cost an average of 7,000 CFA francs. Landscaping is estimated at 10,000 XAF per square meter. The average is 8,500 XOF per square meter. Since stones are not readily available nearby, we propose an estimate of 10,000 XAF per square meter. This is because the walls of the ponds will be constructed using a combination of vegetation and stone or brick blocks.

Unit cost of Dikes

For dikes, the cost of excavated material is estimated at 3,000 xaf (around 5€) francs per square meter. Due to dike stabilization and the use of machinery and equipment, the cost has increased to a unit price of 7,000 xaf (around 10€) per square meter. For vegetated dikes, the unit cost has increased to 10,000 xaf (around 15€) per square meter.

Unit cost of green public space:

In Chad's construction industry, the cost of landscaping varies depending on the earthworks and the type of landscaping. Unit costs are in square meters and start at 10,000 xaf (around 15€).

- For public spaces along El Biher, 15,000 xaf (around 20€) is planned due to the earthworks required.
- For the urban park in Mabrouka and Kilmé, 40,000 xaf (around 50€) is planned because it is a large park that requires heavy earthworks with a wide variety of landscaping and significant urban furniture.

Cost of Bridge building :

The cost of constructing a crossing structure is calculated empirically based on the cost of constructing one under the national highway. The bridges will be constructed using culverts with a cross-section of L: 2 m, l = 1.5 m, and ep = 30 cm. Based on these observations and the unit cost of this type of precast concrete, the construction of three culverts with walls and road slabs will cost around 15,000,000 xaf. Taking into account the earthworks and surfacing, we estimate the total construction cost at 30,000,000 xaf. Taking into account specific studies, contingencies, and site constraints, we estimate the construction of a bridge at 50,000,000 xaf. We choose 60% for renovations, or 30,000,000 xaf.

Unit cost of river renaturation

Renaturation work requires soil preparation, planting of plants according to their ecology, and maintenance. Given that this is a more natural development than a green space designed for leisure and relaxation, we estimate the unit cost at 5,000 xaf (around 5€), or half the average rate of 10,000 xaf (around 15€) per square meter for public spaces.

Technical studies

3% of works is used for all hydraulic, hydrological, civil engineering, topography, and bathymetry studies. In most projects in Chad, technical studies are estimated at around 2% or 3%. Given that this is a special project outside the urban center, we propose to keep 3%.

10.1.3 Estimation of investment beneficiaries

According to the website https://www.worldometers.info/fr/population-mondiale/tchad-population/#google_vignette, the population density of N'Djamena is 4,400 inhabitants per km² according to Wikipedia. According to a SWEDD country profile, the population density for the country as a whole is 14 inhabitants per km². Given the peri-urban nature of the project area, we propose using the average of the two densities for villages and maintaining the urban density for urban areas along El Biher up to the intersection with the national road. The tables below provide an estimate of the number of inhabitants who will directly benefit from the investments.

- Around the reservoirs, there are approximately 11 villages whose calculations (see Appendix 5) indicate a direct beneficiary population of 7,000 inhabitants. Indirectly, the entire rest of the population of N'Djamena (and the southern localities) benefits from these basins. Therefore, we can indirectly estimate a beneficiary population of more than 1 million inhabitants. Thus, for component 1, there will be approximately 7,000 direct beneficiaries.

- Along El Biher, from the city to the intersection with the national highway, it is estimated that more than 100,000 inhabitants will ultimately benefit directly. Indirectly, the entire city of N'Djamena will benefit, as the city's entire drainage system is designed to drain floodwaters into El Biher.

For the El Biher branch from the intersection with the national road to the Chari River, there are approximately 15 villages with an estimated population of over 14,000 inhabitants. Thus, for Component 2, the investments will directly benefit at least 114,000 inhabitants and indirectly benefit more than 1 million inhabitants.

- Component 3 on NBS concerns specific and cross-cutting interventions on other projects. The urban park project in Mabrouka is a large-scale urban park project whose impact extends to all urban areas along El Biher and also to the rest of the population of N'Djamena. The number of beneficiaries of this component is therefore approximately the same as that of Component 2.

NB: At this stage, these estimates do not take into account the benefits linked to the economic activities that will result from these investments, as we do not have the basic data to evaluate them.

Table 7: projects costs' evaluation

Components	Projects	Unity	Quantities	Unit Costs in XAF	Total Cost in EURO
Offline flood storage with dikes of protections	Offline flood storage	m^3	44300000	10 €	443 000 000 €
	Development of stabilized riverbanks	m^2	86000	20 €	1 720 000 €
	Dikes of protection	m^3	220000	15 €	3 300 000 €
	Cost of works				448 020 000 €
	Technical studies and topographic surveys	FF	3%		13 440 600 €
	Monitoring of works	FF	10%		44 802 000 €
	Operation and management		1%		4 480 200 €
Dredging and renaturation of the El Biher River with riverbank improvements	Dredging river	m^3	10010000	10 €	100 100 000 €
	Renaturation of the El Biher River	m^2	6700000	10 €	67 000 000 €
	Bridges to be built	U	2	80 000 €	160 000 €
	Bridges to be rehabilitated	U	3	50 000 €	150 000 €
	Public spaces	m^2	420000	20 €	8 400 000 €
	Cost of works				175 810 000 €
	Technical studies and topographic surveys	FF	3%		5 274 300 €
	Monitoring of works	FF	10%		17 581 000 €

	Operation and management		1%		1 758 100 €
Nature-based Solutions (NbS)	Urban green parc	m²	270000	50,00 €	13 500 000 €
	Sustainable dikes	m³	295000	20,00 €	5 900 000 €
	Channels	m³	2880000	10,00 €	28 800 000 €
	Cost of works				48 200 000 €
	Technical studies and topographic surveys	FF	3%		1 446 000 €
	Monitoring of works	FF	10%		4 820 000 €
	Operation and management		1%		482 000 €
	TOTAL COST				**672 030 000 €**

10.2 Risks analysis

In the table below, component analyses are performed based on several criteria.

Table 8: Analysis of the projects risks

Components	Stakeholders	Impacted frames / Volume	Land	Disbursement risks	Environmental risks	Social risks	Economic risks	Technical risks	Institutional risks	Legal risks	O&M risks	Cost risks
Offline flood storage with dikes of protections	Moderate	Low	Moderate	Significant	Moderate	Low	Low	Moderate	Significant	Moderate	Significant	Very significant
Dredging and renaturation of the El Biher River with riverbank improvements	Moderate	Low	Low	Moderate	Low	Low	Low	Low	Significant	Low	Significant	Very significant
Nature-based Solutions (NbS)	Low	Low	Low	Low	Low	Low	Moderate	Low	Significant	Significant	Moderate	Very significant

Low and negligible risks — Moderate and mitigable risks

Significant risks — Very significant risks

10.3 Project phasing

The three components are major projects whose implementation will depend on multilateral partnerships and financing memoranda of understanding.

- International agreement for financing
  Given the estimated costs of these investments, the Chadian government will have to mobilize either its own resources or donors such as the World Bank, which is working on PILIER, or public-private partnerships.
- Procurements
  Recruitment of a project management assistant: The Chadian government will recruit a project management assistant to help define the terms of reference for recruiting consulting firms and companies.
  Recruitment of consulting firms: Consulting firms are companies that, based on their experience, will carry out technical studies and monitor the execution of works. For example, one design office is needed for the topography team, another for hydraulic studies, and another for urban park development studies.
  Recruitment of contractors: Based on the terms of reference and the call for tenders relating to technical studies, contractors will be recruited according to their trade and the phases of the project.
- Technical studies
  These are studies that provide sufficient technical details to assist in the construction of the infrastructure planned in the components. Examples include geotechnical studies, hydraulic studies, reinforced concrete structural design studies, topographical and bathymetric studies, environmental and social studies, and development studies.
- Topographic surveys
  The topographic brigade is a topographic survey conducted in the field by a team of topographers and surveyors whose mission is to collect the necessary data for a detailed analysis of the site and hydraulic conditions. Given the size of the areas involved, this operation may require the use of drones.
- Works
  The work consists of the construction of basins, dykes, canals, developments, crossing structures, plantations, etc. These works must be carried out in accordance with best practice under the supervision of the inspection agencies.
- Monitoring and evaluation
  The project will be monitored by a dedicated design office, which will mobilize technicians and engineers to ensure the quality of the work to be carried out. They will perform this work in accordance with the technical specifications clearly described in the design and build specifications provided to the companies.

Table 9: projects phasing

Project	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Finding donors agreements							
Procurement: recruitment of firms and companies for works							
Technical studies							
Topographic surveys							
Works and monitoring of component 1: basins and dikes							
Works and monitoring of component 2: River dredging and renaturation							
Works and monitoring of component 3: NBS							
Monitoring and evaluation							

10.4 Implementation constraints

All of these investments require significant funding to complete. This involves both government funding and funding from development partners.

Community acceptance is essential for these infrastructures to be properly operated and maintained. The creation of reservoirs will require the use of land in some areas, including agricultural land on which households depend. Communities whose land is directly linked to the reservoirs or areas of influence must be consulted and involved in the implementation of this type of infrastructure. The participation of women in project activities remains a sensitive issue given the sociocultural context. Women are not allowed to speak to men other than their husbands.

10.5 Data collection needs

10.6.1. Data collecting framework

10.6.1.1. Data for hydraulic models

The next stage of the project must update and extend the hydraulic model with higher resolution topographic and river cross section and structure survey. This is critical to design optimal channel slopes, cross section, plan form and levels, as well as the proposed dikes to contain the basins and control structures. The need for operational or passive control structures to optimize operation can then be determined at this stage with confidence. The model should be developed so that it can inform project development in the following aspects:

- A refined and more detailed understanding of the baseline flood hazard.
- Representation of the proposed project to understand the flood hazard reduction, and the need for any additional measures should flood hazard increase in some locations outside of the basins.
- Ability to optimize the design of any fixed or moveable control structures.
- An assessment of baseline and with-project flow velocities and potential sediment and geomorphological concerns that may require additional scour or erosion protection measures. This can also help to inform appropriate channel sizing to minimize erosion and sediment deposition in channels.

- More locally specific flood hazard risk and damage assessment, and benefits of the proposed project. This would refine the economic justification for the project investment.

The following data should be collected so that models can be developed to address the points listed above:

- All survey must be aligned to the same vertical datum. Care needs to be taken when stitching together DEM, DTM and topographic survey datasets to ensure consistent alignment and elevation.
- Collection during the dry season will capture more of the river channel.
- River cross section and structure survey of the Bahr Linia and El Biher channels. This should be at regular intervals and to capture all changes in cross section profile, width, depth and slope.
- Bank crest alignment and level survey for the full length of the Bhar Linia and El Biher channels.
- Bank crest survey of the Chari river overflow locations to confirm these overflows are correctly represented in the hydraulic model.
- River bed, bank and general soil type and conditions for the Bahr Linea and El Biher channels, and representative locations in the study area to determine the potential for erosion and scour of channels and deposition in basins.

- DTM survey to cover the area of the model domain in Figure 1. Detailed DTM collection with a spatial resolution of 0.5 meters if budget allows. If budget is insufficient a 5m resolution would be considered acceptable. This should focus on the channel and banks to validate the location of natural low spots on the banks for suitable locations for storage and diversion offtakes. It also needs to cover overland flow paths. Additional detailed DTM may need to be collected at key road crossing locations and along the full route of any proposed diversion channel or within any proposed flood storage area. Refer to Figure 16 for further details on potential DTM data sources.

The objectives of this study were to identify relevant projects to reduce flood risks in N'Djamena while also providing environmental, social, and economic benefits. Following analyses and field visits, projects organized into three components were selected to reduce rainwater and river flooding in N'Djamena and its surroundings.

- Component 1- offline flood storage and dykes: this involves the construction of three basins with dykes to protect populations and agricultural activities. Although very large, the basins can collect a significant volume of rainwater and river water. According to estimates based on hydrographs, the final capacity will be more than 5 million m². This volume may be even greater given the total surface area (more than 40,000,000 m²) of the identified sites. These investments will enable the basins to serve as valuable water reserves during the dry season, when water is scarce and agricultural activities are suspended. Farmers, market gardeners, livestock breeders, and fishermen will have access to a source of water from October to February or March, while waiting for the rains to begin in April and May.

- Component 2 - riverbed dredging and renaturation of El Biher: it includes the riverbed, the dykes and the green corridors. The dredging and renaturation of El Biher will allow this river to drain rainwater smoothly to the Chari. The entire development involves the construction of dikes and public spaces along the river. It is an integrated project that will serve as a green and vital lung in urban and rural areas.

- Component 3 – NBS: channels for agriculture, dykes for the protection rural areas and inhabitants and a public green spaces with green corridors.

The realization of these investments will depend on funding opportunities and capacities, as well as the quality of the technical studies. The lack of DEM data during this study has led to approximate estimates. These recently completed DEM studies will serve as a solid basis for future technical studies covering topography, geotechnics, the environment, hydraulics, civil engineering, and urban planning. A detailed hydraulic model should be developed from additional DEM, channel and structure surveys to inform the design of the proposed project. This should seek to ensure that channel, basin and structure sizing is appropriate, and any additional bank protection and channel form features are incorporated into a design that will be resilient to future change and require minimal maintenance. More refined models will also help to validate and refine the benefits of the proposed project for use in the economic justification for investment.

Regardless of financing conditions, the involvement of all stakeholders is essential for the proper execution and success of these investments. The roles of MATUH, other technical ministries, the city council, district municipalities, and the communities concerned must be clearly defined.

The PILIER project involves major investments, but their effectiveness will depend on these proposed components. Without the redevelopment of El Biher, there will always be rainwater backflow at the Lamadji outlet. Without the basins, there will be no possibility of diverting and discharging water from the Chari River in order to reduce the flow of water entering N'Djamena during floods. This interdependence of projects highlights the complexity of the flood crisis in N'Djamena and requires, above all, good synchronization between the actors involved in financing, implementation, and management.

DTM Product	Spatial Resolution	Vertical Accuracy	Data Source	Editing Level	Minimum Order Requirement
WorldDEM™ Neo 5m Level 1	5 m	Absolute: < 1.4 m (90% linear error) Relative: < 2 m (slope ≤ 20%); < 4 m (slope > 20%)	Derived from TanDEM-X mission data acquired between 2017 and 2021	Automated removal of surface structures (e.g., buildings, vegetation) to approximate bare Earth elevation.	1,000 km^2
WorldDEM™ Neo 5m Level 2	5 m	Absolute: < 1.4 m (90% linear error) Relative: < 2 m (slope ≤ 20%); < 4 m (slope > 20%)	Derived from TanDEM-X mission data acquired between 2017 and 2021	Enhanced manual editing, including refinement of land cover boundaries, detailed modelling of transport structures, and precise representation of hydrographic features.	100 km^2
AW3D Enhanced 0.5m	0.5 m	With Ground Control Points (GCP): Absolute: 1 m RMSE / 1.5 m LE90 Without GCP: Absolute: 2 m RMSE / 3 m LE90	Generated from Maxar's satellite imagery (e.g., WorldView)	High-precision processing to create detailed bare Earth models suitable for applications requiring fine-scale accuracy.	25 km^2
AW3D Standard 2.5m	2.5 m	Absolute: 5 m RMSE / 7 m LE90	Based on JAXA's ALOS satellite imagery acquired between 2006 and 2011	Standard processing to generate bare Earth models suitable for various applications.	100 km^2
AW3D Standard 5m	5 m	Absolute: 5 m RMSE / 7 m LE90	Based on JAXA's ALOS satellite imagery acquired between 2006 and 2011	Standard processing to generate bare Earth models suitable for various applications.	Minimum order requirements are not publicly specified; direct inquiry with the provider is recommended.

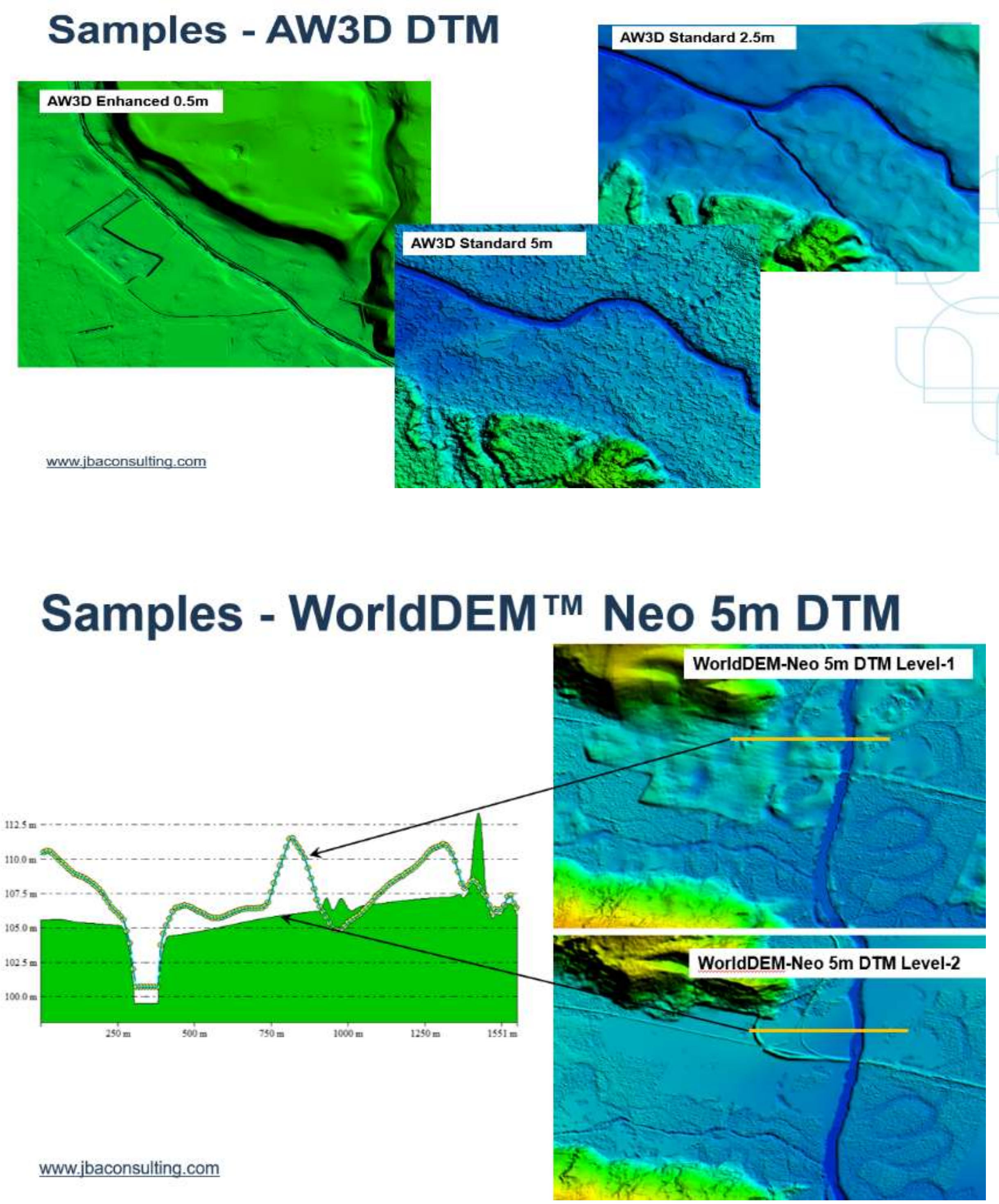

Figure 16. Analysis of possible DTM products and sample images

10.5.1.1. Data for technical, social and environmental

The collection of technical, social, and environmental data will take place in two phases. The first phase will be dedicated to collecting secondary data, in other words, data from existing sources such as public administration documentation, scientific articles, and officially open databases. This data will serve as a reference base and will provide an understanding of the historical and regulatory context. The second phase involves the collection of primary data. This follows on from the previous phase and involves the collection of raw data in the field by experts. This data will fill in any gaps in the information and, above all, enable better targeting of field research.

The data concerned in this project are:

- Technical and GIS data

Technical and GIS data include all geospatial data necessary for characterizing the various sites hosting storage basins and for spatial analysis of the environmental and social issues related to the construction of these basins. They include :

- Topographic maps: Topographic maps will be used to analyze relief, slopes, altitudes, and terrain features. They play a key role in identifying areas suitable for the installation of basins, analyzing surface runoff, and assessing natural hazards, particularly the risks of flooding, erosion, and runoff. This information is crucial for the stability of structures and the control of hydrological impacts during construction and operation.
- Soil maps: Consulting soil maps will help characterize the nature and physical properties of the soil (texture, permeability, bearing capacity). They are essential for assessing the suitability of soils to support planned structures, preventing the risk of leakage, subsidence, or groundwater contamination, and defining the appropriate technical measures for waterproofing and managing excavated soil. The associated issues concern infrastructure safety, water resource protection, and preservation of surrounding land.
- Data collection from open source databases (DEM, temperature, rainfall, wind directions, satellite images): This data includes Digital Elevation Models (DEM), climate data (temperature, rainfall), wind directions, and satellite images, which can be used to supplement and spatialize field information at the scale of the project's area of influence. This data is essential for analyzing environmental dynamics, modeling flows, assessing the site's exposure to climate hazards, and taking climate change into account in the design of basins. The main challenge lies in improving the resilience of structures in the face of extreme weather events.
- Altimetric surveys and topographic brigade (recording of geographic coordinates and altitudes): these cover the recording of geographic coordinates and altitudes, providing accurate and up-to-date data on the actual configuration of the terrain. This information is essential for refining design studies, defining the exact boundaries of the basins, and ensuring consistency between cartographic data and the reality of the terrain. It helps reduce technical risks and optimize project implementation costs.
- Parcel delimitations with GPS receivers: This data will enable the precise demarcation of property boundaries and the project footprint. It is strategic for preventing land disputes, securing usage and property rights, and facilitating the implementation of any compensation or indemnification measures. The major challenge associated with this data is the social acceptability of the project and the reduction of social risks related to land occupation.

a) Environmental and physical data

This category of data will enable analysis of the initial state of the natural environment and assessment of the potential risks and impacts of the project on biophysical components. They include, in particular:

- Hydrological reports containing hydrometric data, particularly flow rates, will enable the hydrological functioning of the watercourses and watersheds affected by the project to be characterized. This information is crucial for analyzing flood risks, assessing the project's impact on flow regimes, and designing storage basins. The associated challenges concern the protection of downstream populations and infrastructure, the preservation of aquatic ecosystems, and the sustainable management of water resources.
- Historical meteorological series: this data includes rainfall and temperature data. This data will be used to analyze climate trends and interannual variability, thus providing an essential basis for integrating the effects of climate change into the design and sizing of structures. The main challenge is to strengthen the project's resilience to extreme weather events, such as heavy rainfall or prolonged periods of drought.
- Collection of data on protected areas (plant and animal species): The identification of plant and animal species, specifically those that are protected, makes it possible to identify ecologically sensitive areas and species with special status. This data is essential for assessing the potential

impacts of the project on biodiversity and for defining measures for protection, restoration, or ecological compensation, in accordance with national regulatory requirements and international environmental standards. The associated challenges concern ecosystem conservation, the maintenance of ecosystem services, and the project's regulatory compliance.

- Agricultural expertise (census of different crops): including the census and characterization of the different crops present in the project's area of influence, enables the analysis of agricultural land use and the interactions between the project and agro-pastoral activities. This data is essential for assessing the risks and impacts of the project on the livelihoods of local populations and for defining appropriate support measures. The main challenge is to preserve food security and limit income losses for affected farmers.

b) Socio economic data

Socio-economic and land data refer to information that is useful for analyzing the human, social, and economic context of the project, as well as for assessing its potential social impacts.

- Collection of documents (scientific articles, institutional reports, official documents, legal texts): This data includes scientific articles, institutional reports, official documents, and legislative and regulatory texts, enabling the project to be placed within its institutional, legal, and strategic framework. These documents ensure that the project complies with current regulations and applicable sectoral policies, while incorporating national and international best practices. The main challenge is to guarantee the legality of the project and the consistency of the ESIA with the requirements of the competent authorities.
- Socio-demographic data: This data will be collected from the technical departments of the relevant ministries and administrative structures. It will be used to characterize the populations in the project's area of influence (size, structure, spatial distribution, vulnerable groups). This information is essential for identifying potentially affected populations and adapting mitigation and social support measures. The associated challenge is to take into account the needs of different social categories in an equitable manner.
- Socio-economic and land surveys (household income, water needs, economic activities, current uses of the site, perception of flood risk): These surveys will focus on household income, water needs, economic activities, current uses of the site, and perception of risks, particularly flood risk, which are central to the analysis of social impacts. They will make it possible to assess the project's effects on people's livelihoods, living conditions, and safety. This data is crucial for designing measures to compensate, restore livelihoods, and reduce the vulnerability of affected households.
- Land survey: The land survey aims to identify the occupancy and ownership status of land, whether formal or customary. The purpose of this survey is to prevent land conflicts, secure the project's right of way, and ensure fair and transparent management of any compensation. The associated challenges are significant, particularly in terms of social stability, respect for land rights, and compliance with social safeguard standards.
- Public consultations and focus group interviews by gender and generation: taking into account gender and generation criteria, these ensure the effective participation of local communities in the decision-making process. They enable the collection of people's concerns, expectations, and recommendations, improving the design of the project and strengthening its social acceptability. Gender is a sensitive and crucial issue that will require special attention during consultations by gender and generation. To this end, socio-cultural and religious factors that could hinder the fluidity of exchanges will be taken into account. The target populations for the consultations are farmers, herders, fishermen, fish farmers, local residents and neighborhood leaders, land chiefs, brickmakers, processing units, traders, and other populations impacted by the project. The main challenge is to ensure that the communities take ownership of the project and to reduce the risk of social unrest
- Consultations with institutional stakeholders: (public administrations, local authorities, technical services, local authorities). It is essential to take institutional stakeholders into account, as this will ensure inter-institutional coordination and the integration of regulatory guidelines and constraints into the project. They contribute to the consistency of the project with existing public policies and reinforce the legitimacy of the ESIA process. The associated challenge is the good governance of the project and the smoothness of its implementation.

10.6 Technical Recommendations

The followings points are important for the success of these projects.

- The existing model is sufficient to make strategic decisions on which investments to proceed with and the general locations and form of these. An updated hydraulic model must be developed during the Feasibility Study. This should be based on detailed topographic data that can be used to determine the alignment, location and geometry of the basins, dikes, channel reprofiling and connecting structures: The required data includes:
  - River channel cross section and structure survey of the Bahr Linia and El Biher channels.
  - DEM and DTM topographic survey of the area north of N'Djamena.
  - It is critical that the survey and DEM have consistent datums
- Deploy a topographic survey team along El Biher, Bahr Linia, and at all project sites. It is important to carry out all topographic surveys to enable the Consultant to perform the necessary hydraulic design work.
- Conduct advanced public consultations, including gender-related aspects, to strongly involve women. For each investment, it is recommended to carry out ESIA and PAR/PRMS with advanced consultations to better understand the expectations, impacts, and risks of the planned investments.
- Carry out appropriate technical studies for all infrastructures planned to be built.

10.7 Next Steps

Step 1 : Data collection

These three components are mega projects on the scale of the city of N'Djamena, and this requires good coordination and significant involvement from public, private, community, and international stakeholders. But technically, the success of these projects will require an excellent database. As far as what is available is concerned, it will be necessary to transmit reliable and up-to-date data. For what is missing, the consultants in charge of feasibility and technical studies will have to go into the field to find it, collect it, and model it according to their area of expertise and sector of intervention.

Step 2 : Conduct feasibility studies incorporating environmental and social safeguard instruments

For each component, it is recommended that a specific feasibility study be carried out. For the basins, this study will provide a clear understanding, based on available data and hydraulic modeling, of the technical characteristics as well as their advantages and associated social and environmental risks and impacts. The same applies to the reprofiling and renaturation of the El Biher riverbed and the urban park. These feasibility studies will be conducted within the overarching environmental and social framework defined by the project-wide Environmental and Social Management Framework (ESMF) and Resettlement Policy Framework (RPF). However, if the project components are financed or/and managed separately, each component will require the preparation of its own Environmental and Social Management Framework (ESMF) and Resettlement Policy Framework (RPF).

Step 3 : Carry out technical studies

The technical studies will depend on feasibility studies that will outline the institutional structure and approximate budget. This study will result in the preparation and compilation of preliminary design and detailed design documents, with design and tender documents and technical specifications for the works. It will be supplemented by environmental and social studies in accordance with World Bank standards or the E&S operational policies in place in Chad. In addition, project management assistance (PMA) will help the project owner prepare the EOI, RFP, and bidding documents to recruit design offices and contractors. In addition to the PMA, a project supervision unit will be needed to manage and carry out all consultations and supervise the HIMO approach during the work.

Step 4: Engage stakeholders and secure a steering committee

Given the scale and complexity of large flood-reduction infrastructure in N'Djamena, strong institutional governance will be essential to ensure effective coordination, timely decision-making, and long-term sustainability. From the outset, all relevant governmental and institutional stakeholders must be identified and formally engaged. Establishing a steering committee will provide a structured mechanism for strategic oversight, inter-institutional coordination, and alignment of the project with national policies, regulatory frameworks, and urban development priorities.

Each participating institution should designate one or two officially mandated focal points to represent its technical and institutional interests within the steering committee. These focal points will facilitate information flow, contribute technical data and expertise, and support the resolution of institutional or operational challenges. It will also allow us to reduce times to access data and approvals and will reinforce the project's ownership.

It would be relevant to capitalize on PILIER's experience and use the existing organization and management for further responsibilities if possible.

Step 5: Move forward

The technical refinement and detailed engineering studies will constitute a decisive milestone, as they will allow the Government to clearly define investment needs, establish realistic priorities, and estimate the overall budget of the flood-reduction program. Given the scale of the required infrastructure, a substantial public investment by the State will be unavoidable. However, to remain realistic and to ensure long-term sustainability, the project should be designed as a phased program. Phasing will make it possible to progressively mobilize resources, limit upfront financial pressure, and adjust interventions over time based on evolving climatic, hydrological, and urban dynamics.

In parallel, dedicated financing studies should be undertaken to identify, secure, and structure the necessary funding. This includes early engagement with technical and financial partners (TFPs), clarification of the State's financial commitments, and exploration of appropriate financial arrangements such as co-financing, concessional loans, grants, or, where relevant, public–private partnership (PPP) models. Given the long-term nature of flood-risk reduction investments, particular attention must be paid to risk-sharing mechanisms that can secure public and private actors, ensure predictability of funding flows, and support transparent procurement and partnership frameworks. In this context, the project should be clearly carried and led by the State, while strategic partners—such as the World Bank—can play a key role in supporting project preparation, strengthening fiduciary and procurement systems, and contributing to financing and implementation oversight.

11. CONCLUSION

The objectives of this study were to identify relevant projects to reduce flood risks in N'Djamena while also providing environmental, social, and economic benefits.

Following analyses and field visits, projects organized into three components were selected to reduce rainwater and river flooding in N'Djamena and its surroundings.

Component 1- offline flood storage and dykes: this involves the construction of three basins with dykes to protect populations and agricultural activities. Although very large, the basins can collect a significant volume of rainwater and river water. According to estimates based on hydrographs, the final capacity will be more than 5 million m². This volume may be even greater given the total surface area (more than 40,000,000 m²) of the identified sites. These investments will enable the basins to serve as valuable water reserves during the dry season, when water is scarce and agricultural activities are suspended. Farmers, market gardeners, livestock breeders, and fishermen will have access to a source of water from October to February or March, while waiting for the rains to begin in April and May.

Component 2 - riverbed dredging and renaturation of El Biher: it includes the riverbed, the dykes and the green corridors. The dredging and renaturation of El Biher will allow this river to drain rainwater smoothly to the Chari. The entire development involves the construction of dikes and public spaces along the river. It is an integrated project that will serve as a green and vital lung in urban and rural areas.

Component 3 – NBS: channels for agriculture, dykes for the protection rural areas and inhabitants and a public green spaces with green corridors.

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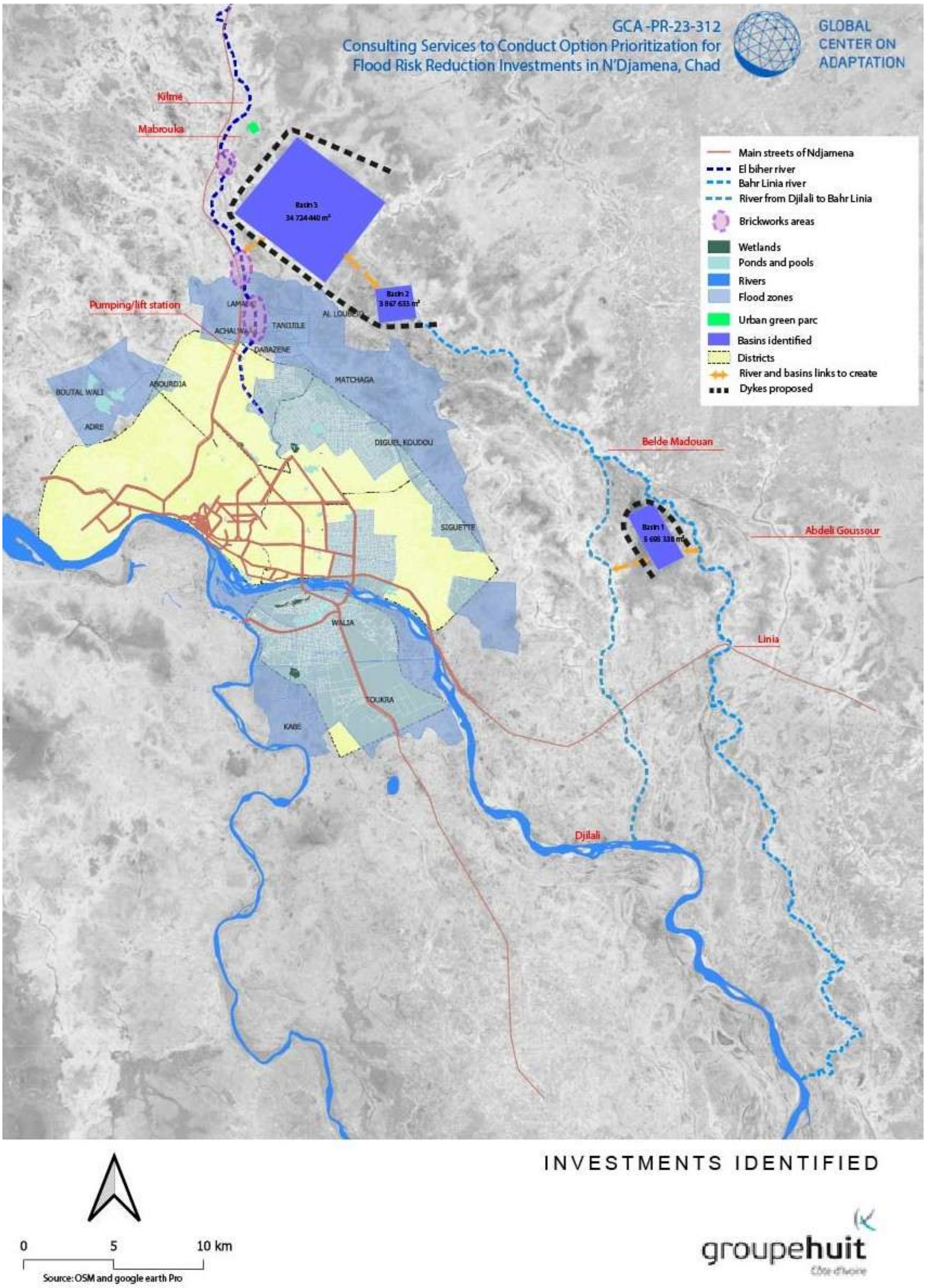
This is a feasibility study, so the realization of these investments will depend on funding opportunities and capacities, as well as the quality of the technical studies. The lack of DEM data during this study has led to approximate estimates. These recently completed DEM studies will serve as a solid basis for future technical studies covering topography, geotechnics, the environment, hydraulics, civil engineering, and urban planning.

Whatever the financing conditions, the involvement of all stakeholders is essential for the proper execution and success of these investments. The roles of MATUH, other technical ministries, the city council, district municipalities, and the communities concerned must be clearly defined.

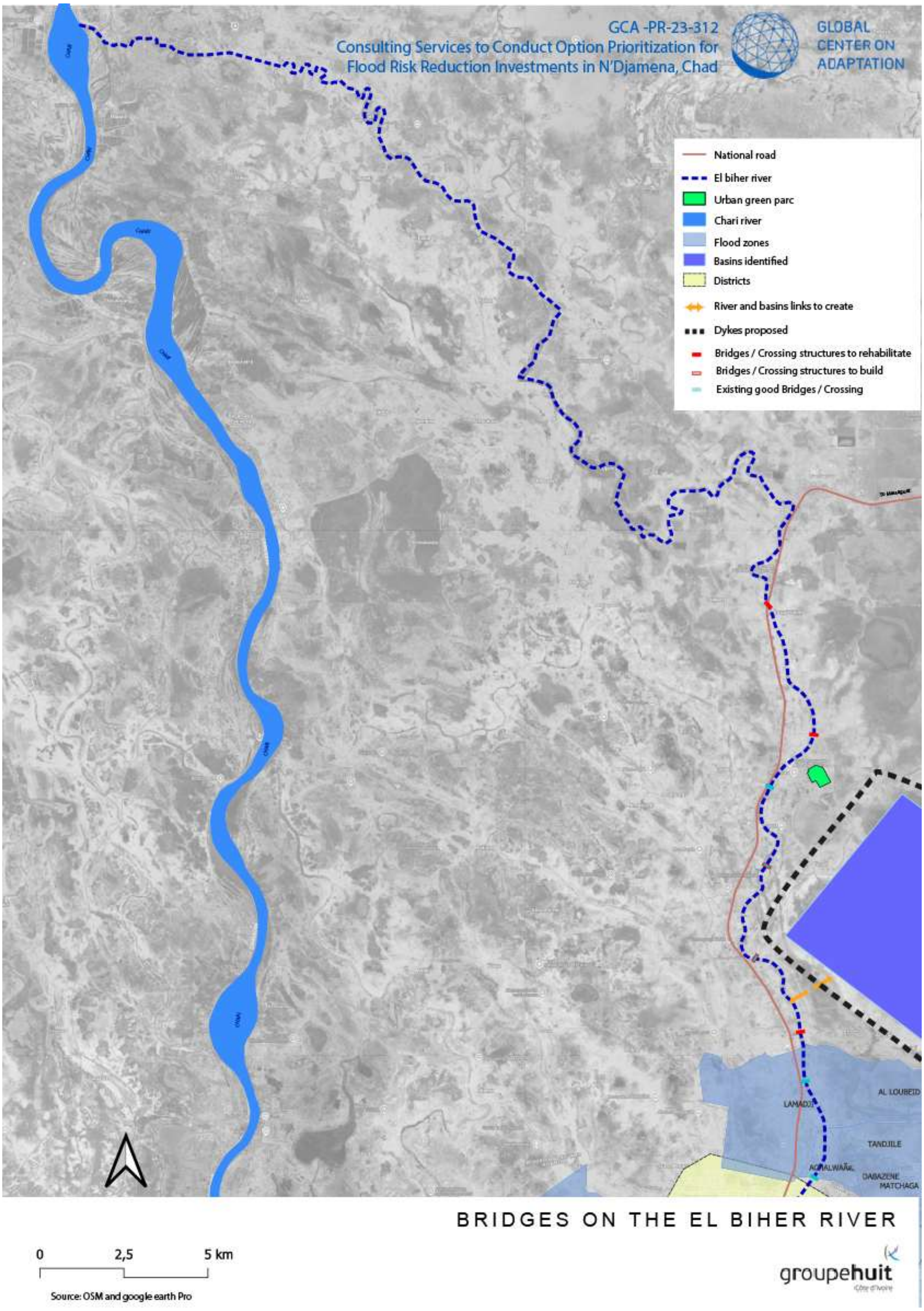
The PILIER project involves major investments, but their effectiveness will depend on these proposed components. Without the redevelopment of El Biher, there will always be rainwater backflow at the Lamadji outlet. Without the basins, there will be no possibility of diverting and discharging water from the Chari River in order to reduce the flow of water entering N'Djamena during floods. This interdependence of projects highlights the complexity of the flood crisis in N'Djamena and requires, above all, good synchronization between the actors involved in financing, implementation, and management.

12. APPENDICES

ANNEX 1. MAPS



Map 1 - Localisation of investments



Map 2: Bridges on the El Biher river, connected to Chari river

ANNEX 2. Bibliography

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ANNEX 3. Photos of meetings and visits

<u>Mission 1 - 05th – 11th May 2025</u>

Private fish farm on the El Biher riverbed

Deteriorating crossing structure

Brickworks on the El Biher riverbed

Stagnant water at the junction between El Biher and Bahr Linia (Mabrouka)

Fish farming on the El Biher riverbed

Fish farming on the Linia riverbed

Fishing activity on the Chari

Vane installed on the El Biher River

Protective device built by communities

Defense trench around N'Djamena

Meeting with MATUH teams

Checking the scale installed on the Chari

Mission 2 – 10th – 16th November 2025

Presentation session at MATUH

Presentation session at MATUH

Consultation with residents living near the pumping station

Consultation in Kilmé

Interview with brick manufacturers

Consultation in Abdeli Goussour

Irrigation carried out using the branches of the Linia River

Brickmaking activities

Agricultural activities around Linia

El Biher Bridge, below the national highway

A manual pump in the village of Abdeli Goussour

View of the village of Abdeli Goussour

ANNEX 4. Attendance List

ANNEX 5. Method for calculating the number of beneficiaries

Bassin (Ha)			
Villages	Surface en Ha	Densité (hbts/Ha)	Population (hnts)
Village 1	1,345	22	30
Village 2	4,948	22	109
Village 3	22,735	22	500
Village 4	16,984	22	374
Village 5	27,31	22	601
Village 6	19,46	22	428
Village 7	18,715	22	412
Village 8	14,48	22	319
Village 9	44,382	22	976
Village 10	118,799	22	2 614
Village 11	47,764	22	1 051
Total	**336,922**		**7 412**

El Biher -Chari (Ha)			
Villages	Surface en Ha	Densité (hbts/Ha)	Population (hnts)
Village 1	322,361	22	7 092
Village 2	54,998	22	1 210
Village 3	41,188	22	906
Village 4	8,244	22	181
Village 5	19,103	22	420
Village 6	8,415	22	185
Village 7	29,733	22	654
Village 8	35,766	22	787
Village 9	58,692	22	1 291
Village 10	32,274	22	710
Village 11	8,444	22	186
Village 12	3,093	22	68
Village 13	21,847	22	481
Village 14	3,476	22	76
Village 15	5,972	22	131
Total	**653,606**		**14 379**

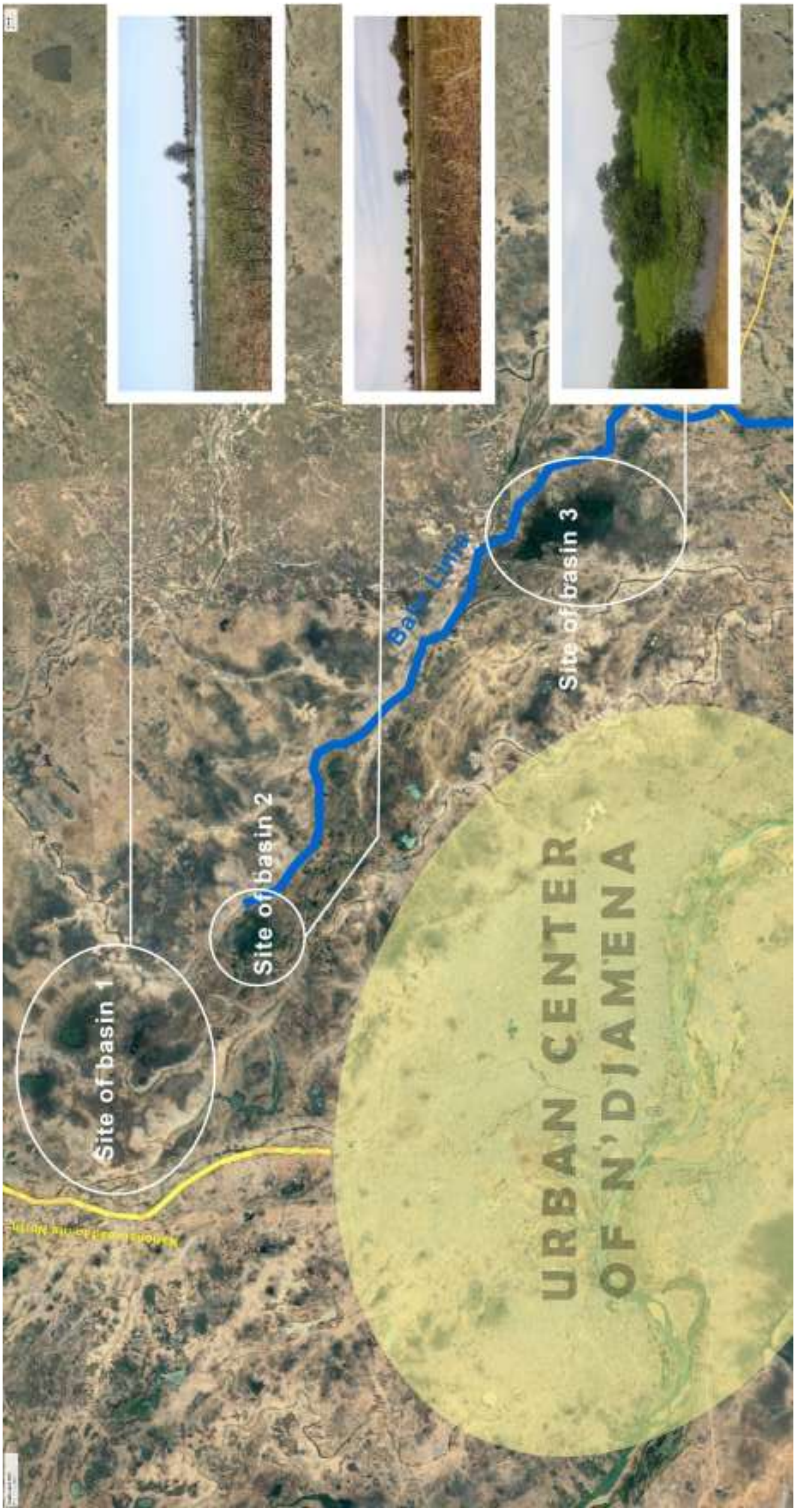
El Biher (Zone tampon Ha)			
Zone urbaine	Surface en Ha	Densité (hbts/Ha)	Population (hnts)
Périmètre inondable	**2737,347**	**44**	**120 443**

ANNEX 6. List of plants and species

Species	Ecological function	Climate adaptation (Chad - N'Djamena)	Priority NBS role	Morphological type
DIKES				
Acacia nilotica	Excellent for riverbanks, stabilising wet soil	Very high	Dikes	Shrub
Vetiveria zizanioides	Anti-erosion	Very high	dikes	Herbaceous
Typha domingensis	Riverbank stabilisation	Very high	dikes	Herbaceous
Cyperus papyrus	Soil stabilisation, filtration and aesthetics	Very high	dikes	Herbaceous
Vetiveria zizanioides (Vétiver)	Global benchmark for erosion control	Very high	dikes	Herbaceous
Andropogon gayanus	Robust, excellent rooting	Very high	dikes	Herbaceous
Sorghum arundinaceum	Fixation of clay-sandy soils	Very high	dikes	Herbaceous
Cenchrus ciliaris	Fodder and stabilisation	Very high	dikes	Herbaceous
Panicum maximum	Soil stabilisation and permeability	Very high	dikes	Herbaceous
Prosopis juliflora	Powerful erosion control, highly invasive	Very high	Dikes	Shrub
Oxytenanthera abyssinica (Bambou africain)	Soil stabilisation, erosion control, wetlands	High	Dikes	Shrub
Ziziphus mauritiana	Highly resistant, fruit-bearing, erosion control	Very high	Dikes	Shrub
Balanites aegyptiaca	Highly resilient, erosion control, local fruit-bearing	Very high	Dikes	Tree
Urban agriculture				
Acacia seyal	Soil fertilisation	Very high	Urban Agriculture	Shrub
Mangifera indica	Fruit tree, shade tree, agroforestry	Good, moderate water requirement	Urban Agriculture	Tree
Psidium guajava	Fruit tree, fast growing	Moderate	Urban Agriculture	Tree
Carica papaya	Productive fruit tree	Moderate	Urban Agriculture	Shrub
Citrus sinensis	Fruit tree, agroforestry	Moderate	Urban Agriculture	Shrub
Musa sp.	High productivity, water requirement	Low without irrigation	Urban Agriculture	Shrub
Acacia albida (Faidherbia albida)	Improves soils, fertilises agroforestry, prevents erosion	Very high	Urban Agriculture	Shrub
Annona squamosa	Fruit tree suited to semi-arid climate	Very high	Urban Agriculture	Shrub
Balanites aegyptiaca	Highly resilient, prevents erosion, local fruit tree	Very high	Urban Agriculture	Shrub

Ziziphus mauritiana (Jujubier)	Fruit tree suited to semi-arid climate, soil stabilisation	Very high	Urban Agriculture	Shrub
Borassus aethiopum	Sahelian palm grove, soil stabilisation	Very high	Urban Agriculture	Palm tree
Green space and urban park				
Ficus Benjamina	Dense shade, good stabilising capacity	Good	Green espaces	Shrub
Terminalia catappa	Wide shade, soil stabilisation	High	Green espaces	Tree
Delonix regia	Flowering, shade, aesthetics	Good	Green espaces	Shrub (palm tree)
Terminalia mantaly	Aesthetic alignment, structured shade	High	Green espaces	Tree
Thevetia neriifolia	Ornamental, undemanding	High	Green space	Shrub
Bougainvillea spectabilis	Ornamental, highly drought-resistant	Very high	Green space	Herbaceous plant
Azadirachta indica	Shade, islands of coolness, pollution control, extreme resistance	Very high	Urban parc	Tree
Khaya senegalensis	Robust urban tree, shade, deep rooting	High	Urban parc	Tree
Eucalyptus spp.	Aesthetic alignment, structured shade	High	Urban parc	Tree

ANNEX 7. Sites of basins



GLOBAL
CENTER ON
ADAPTATION

ANTOINE PLATEKADE 1006
3072 ME ROTTERDAM
THE NETHERLANDS
+31(0)88-088-6800
WWW.GCA.ORG