FLOOD MANAGEMENT FEASIBILITY STUDY FOR THE MSIMBAZI MIDDLE CATCHMENT AREA

Vulnerability Analysis
C40 Cities Finance Facility

FINAL, MARCH 2021
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The C40 Cities Finance Facility (CFF) is a collaboration of the C40 Cities Climate Leadership Group and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The CFF supports cities in developing and emerging economies to develop finance-ready projects to reduce emissions to limit global temperature rise to 1.5°C and strengthen resilience against the impacts of a warming climate. The CFF is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), the Children’s Investment Fund Foundation (CIFF), the Government of the United Kingdom and the United States Agency for International Development (USAID).

ACKNOWLEDGEMENTS
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EXECUTIVE SUMMARY

Introduction

The Msimbazi River Basin (170 km²) is located in the city of Dar es Salaam, Tanzania, and for the last decade this is the city’s worst hit area by serious degrees of flooding nearly every rainy season. The floods are impacting the basin’s inhabitants and environment on different levels, like loss of lives, destroyed homes and assets, traffic interruption, siltation of areas and negative health effects of contaminated flood waters and stagnant ponding after the events. Flooding has become one of the main environmental issues in the basin and it is expected that the situation will get worse if no action will be taken.

The overall objective of this study commissioned by GIZ is to identify and analyze potential flood management and control options in order to reduce risk of flooding to the Msimbazi Middle Basin. The scope consists of i) execution of vulnerability analysis, ii) identification and pre-selection of measures and iii) development of a flood management strategy including preliminary technical and economic feasibility as well as a social, environmental and institutional assessment. The vulnerability analysis report focusses on the scope i) and ii).

This project contributes to a Strategy and Management Framework for the Msimbazi Basin (Msimbazi Opportunity Plan Volume A – Strategy and Management Framework (2019)) developed by President’s Office Regional Administration and Local Government (PO-RALG) and the World Bank.

Study approach

The approach of the vulnerability analysis follows the overall multi-sectoral, participatory and solution driven Study approach, specifically consisting of the following components:

1. Identification of baseline scenarios and flood modelling – Baseline scenarios have been developed to represent i) climate change by a moderate and an extreme scenario with respect to rainfall, ii) socio-economic development by an pessimistic and an optimistic scenario based on an environmental and social baseline, and iii) urbanisation (land use change) based on assumptions for autonomous urban sprawl. Hydrodynamic flood modelling has been conducted separately by Deltares from the Netherlands in association with Openmap Development Tanzania (Modelling Consultant), in close cooperation with GIZ/CFF and CDR International and WEMA Consult (Feasibility Consultant). For the flood modelling above mentioned baselines have formed a basis and have been performed for three projection years (2020, 2050 and 2075) and three return periods (T2yr, T10yr and T50yr) applied to ‘do nothing’ basecases as well as testing the effectiveness of measures;
2. **Hazard risk analysis and impact assessment** – The flood modelling output has formed the main input to a GIS based multi-layered vulnerability and damage model following a commonly used conceptual Hazard Risk equation.

3. **Identification of suitable flood risk mitigation and adaptation measures** – Based on the impact assessment and following common flood management strategies (retreat, adapt or protect) and already developed plans and strategies for the Msimbazi catchment (like the Strategy and Management Framework as part of the Msimbazi Opportunity Plan) suitable flood management measures for the Msimbazi Middle Basin have been identified;

4. **Charrettes and flood management strategy** – The identified measures have been presented to the involved stakeholders and communities during the charrettes of this project. Main objective of the charrettes has been to interactively engage the stakeholders by involving them in the pre-selection process of the measures. The participants of the charrettes have ranked the criteria, scored the identified measures and contributed to develop a spatial strategy for the Msimbazi Middle Basin, for the short and long term.

**Baseline scenarios**

The causes of the flooding of the Msimbazi River Basin are closely related to the rapid unplanned and uncontrolled urbanisation over the last few decades. Urbanisation and deforestation in the project area, and up-stream, result in an increased run-off of precipitation into streams and rivers and consequently reduce the overall retention capacity of the wider basin. Dar es Salaam is one of the fastest growing cities in Africa with an expected average annual population growth of 4.8%. By 2030 Dar es Salaam’s population will have exceeded 10 million inhabitants (United Nations (2018)). Under autonomous development conditions the urbanisation process continues in the future and will put more urban pressure on the Msimbazi catchment.

(Unplanned) urbanization is the main cause of the increasing flood risks in the future. About 70% of the increase of hazards due to flooding for the period 2020-2075 is caused by urbanization, while 30% is caused by climate change (increasing rainfall and more extreme events). The contribution of autonomous urbanization to increased flood risk, represented by an increase of paved areas increasing rainfall run off, is larger than the contribution of climate change. With adequate spatial planning a large share of this expected future flood risk can be avoided. Both a moderate climate change scenario (RCP 4.5) and an extreme climate change scenario (RCP 8.5) will contribute to increased flood risk in the future, where the risk with RCP 8.5 scenario in 2050 is higher compared to RCP 4.5 in 2075;
Hazard risk analysis and impact assessment

The Msimbazi Middle Basin is already seriously vulnerable to pluvial and fluvial flooding in the existing situation; the percentages of flooded areas (flood depths > 0.25m) within the study area are 10% for T2yr, 15% for T10yr and 19% for a T50yr event. During a T50 event about 1,500 ha of the Msimbazi Middle Basin will inundate with flood depths larger than 25cm. The vulnerability to flooding in concerned area will increase considerably in the future (projections 2050 and 2075) under a do-nothing scenario.

Flood impacts on assets (asset damage)

An increasing number of dwellings will be affected by flooding. In the existing situation about 1,800 dwellings will be flooded during a T2yr event and 9,600 dwellings will be flooded during a T50yr event. In 2050, for an extreme climate change scenario (RCP 8.5) and autonomous urbanization, this will increase to 3,800 and 14,300 dwellings for T2yr and T50yr events respectively.

The direct asset damage caused by a flood event can go up to about USD 650 million in 2050 and is much higher than the indirect damage (temporary economic and traffic disruption). In 2050 the bandwidth for expected flood damage with a T10yr event is between USD 360 million and USD 560 million, for a T50yr event in 2050 expected flood event is between USD 550 million and USD 775 million. Main flood damage is
and will be on buildings (>95% out of total damage). From the buildings, residential buildings is the largest share being affected (> 75% out of damage to buildings). Traffic disruption and economic disruption damage can go up to about USD 120 million (T50 in 2050), but are relatively low compared to the direct asset damage.

![Graph showing damage floodings in million USD in case of T2, T10, T50 events, RCP 8.5 high urbanization (2050)]

**Socio-economic and environmental impacts**

Flooding in Dar Es Salaam can result in significant negative socio-economic and environmental impacts for the communities in the area. From historic flood events it is known that 20,000-50,000 persons were affected and that there have been fatalities of 10 to more than 40 people per event. During floods the livelihoods of people (and especially women with informal employment) are significantly disrupted. Problems with solid waste management (70% uncollected waste) cause pollution and adverse health impacts (water borne diseases etc.), especially for women and children. Women and children are especially vulnerable for flooding due to a number of factors as reported in a special gender analysis report (background report of the assignment).

**Flood risk mitigation and adaptation measures**

As a first step prior to the charrettes the Feasibility Consultant has developed an initial flood mitigation strategy by means of analysis on the assessed vulnerability, identification of flood hotspots in the project area and brainstorm sessions with the experts involved.
The hotspots concentrate around infrastructure crossings (bridges) and industrial zones in the project area. Four hotspots have been identified for the middle Msimbazi basin:

i. Kawawa Road Bridge and upstream area affected by back waters;
ii. Kigogo ward;
iii. The Industrial zone at Buguruni;
iv. Railroad Bridge and upstream area affected by back waters.

Generally, flooding in the Msimbazi Middle River Basin is caused by four main factors; i) insufficient hydraulic capacity of the Msimbazi River profile at certain locations, ii) back water effects and piling up of water upstream of structures, e.g. bridges, with an insufficient hydraulic capacity, iii) inadequate urban drainage infrastructure and iv) decrease of ‘green areas’ in the catchment has resulted in reduction of infiltration of precipitation and a direct run off response.

Based on the analysis of main causes of flooding and hotspots Consultants have initially identified five potential flood mitigation measures (see below table).

Initial identified flood mitigation measures for the middle Msimbazi basin.

<table>
<thead>
<tr>
<th>No.</th>
<th>Measure</th>
</tr>
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<tbody>
<tr>
<td>1.</td>
<td>Widening and/or raising bridges crossing the Msimbazi River and her tributaries to increase the hydraulic capacity of the bridge.</td>
</tr>
<tr>
<td>2.</td>
<td>Creating a wider river bed to increase the hydraulic capacity of the river channel.</td>
</tr>
<tr>
<td>3.</td>
<td>Lowered flood plain with emphasised physical edge or raise terraces by reshaping valley profile. This to give room for the river.</td>
</tr>
<tr>
<td>4.</td>
<td>Resettlement at locations with unacceptable residual flood risk after implementation of first three mentioned measures.</td>
</tr>
<tr>
<td>5.</td>
<td>Re-greening of resettled areas as well as reforestation of the upper catchment sections of the Msimbazi River.</td>
</tr>
</tbody>
</table>
Results of charrettes

The charrettes have taken place 13th and 14th of January 2021 at the New Africa Hotel in Dar es Salaam. The main objective was to build consensus of the project together with the stakeholders, update the stakeholders on progress, verify the results of the vulnerability analysis and to interactively rank the design criteria, score the measures and participation in spatial integration of measures in the urban tissue. Due to the COVID-19 pandemic the stakeholder group was divided over two days and the charrettes were held in a hybrid format, viz. a combination of sessions taking place local physically and virtual contributions of experts and project advisors from Europe.

As a summary the following main results have been gained from the charrettes:

- Reduction of flood impact was found to be the most important criterium for a flood mitigation measure. On the second place is Social acceptance, underlining the sensitivity and severeness of the flooding issues in the study area. During the second day, with the community representatives, also Political acceptance scored very high. The general thought is without political acceptance there will not be significant transformation to increased resilience to flooding.
Out of the building blocks (see section 5.3.2) raising and widening of bridges scored highest, followed by interventions which include dredging and excavation activities to provide room for the river. Resettlement scored lowest for all criteria, thereby clearly marking this is a very sensitive topic.

From the spatial design session the following general conclusions can be drawn:

- All groups indicated to widen/raise some of the main bridges, especially Kawawa road bridge and Nelson Mandela road bridge;
- Even though the resettlement scored quite negative in the scoring sessions, all groups indicated that in some locations resettlement might be the best choice, especially in Buguruni;
- Most groups were in favour of several forms of dredging the river channel, with potential increased floodplains and/or terraces;
- Most of the groups proposed nature based solutions, such as rainwater harvesting, reducing paved areas and reforestation/planting more trees as measures for the entire catchment area. Generally re-greening of the study area was considered to be the most sustainable solution in view of flood risk reduction as well as potential (co-) benefits like reduced heatstress, food production and a pleasant and aesthetically attractive living environment.

Based on the Vulnerability Analysis and the charrettes the Feasibility Consultant has developed a hybrid flood mitigation strategy combining long term multi-sectoral integrated sets of measures and short term measures focusing on removal of hydraulic bottlenecks. The results of the break-out sessions have been duly taken into account in the development of this strategy.

Long term components consist of measures with longer implementation schedules with basin wide long term positive effects. This part of the strategy should be managed on a multi-sectoral integrated level with impact on the urban tissue and is expected to require a longer implementation time. The measures of the long term components are focused on increasing infiltration and retention capacity and greening of the Middle Basin by Nature Based Solutions and Spatial Planning including resettlements on the most critical locations. Creating more room for the Msimbazi River and its tributaries also belongs to these measures. Planning and design of such measures and resettlements should be conducted the soonest to prevent further increase of flood impacts due to climate change and further urbanization in the future.

Short term components - Short term implementation measures, mostly on a sectoral level, with immediate positive effects. These are measures that focus on infrastructural works and do not require large scale resettlements. It is expected that both political and social acceptance for these measures will be high, which enables rapid implementation. The short term measures focus on removing hydraulic bottlenecks like raising and widening bridges, localized dredging/excavation activities and small scale resettlements. After implementation of the short term measures a residual flood risk will remain, hence the reason to start planning and implementation of the long term measures simultaneously.
The results presented in the Vulnerability Analysis report form the basis for the development of the Feasibility Stage of this Study. Feasibility stage addresses the technical feasibility, cost estimations and financial and economic feasibility of the various measures as part of the defined Flood Management Strategy for the Msimbazi Middle Basin. The results of the Feasibility Stage are presented in a separate report.
TABLE OF CONTENTS

About the C40 Cities Finance Facility ................................................................. 2
Acknowledgements ............................................................................................... 2
Executive Summary ............................................................................................... 3
List of Abbreviations ............................................................................................. 11
Introduction ........................................................................................................... 12
  Background ........................................................................................................ 12
  Objective of this study ....................................................................................... 13
  Process and Teams ............................................................................................ 14
  Content of this Report ....................................................................................... 15
General Approach and Methodology ................................................................. 16
  Baseline scenarios and flooding modell ............................................................ 16
  Hazard risk analysis and impact assessment ................................................... 18
  Flood risk mitigation options .......................................................................... 19
  Participatory process ......................................................................................... 20
Study Area and Baseline conditions ................................................................. 21
  Study area ......................................................................................................... 21
  Socio-economic context .................................................................................. 26
  Environmental context ..................................................................................... 29
Impact Assessment ............................................................................................... 33
  Hazards ............................................................................................................ 33
    Flood depth and duration ............................................................................... 33
    Flood extent .................................................................................................. 33
    Flow velocities .............................................................................................. 40
    Sedimentation and erosion .......................................................................... 42
  Vulnerability ..................................................................................................... 45
    Impacts on assets ......................................................................................... 46
    Damage to assets ......................................................................................... 52
    Traffic interruption ...................................................................................... 56
    Potential impact on critical assets ............................................................... 61
    Socio-Economic and environmental impacts .............................................. 65
    Total damage ............................................................................................... 70
Main findings and conclusions of Impact assessment .............................................. 71
Identification of hotspots .......................................................................................... 73

Identified measures and strategy ............................................................................... 75
  Introduction .......................................................................................................... 75
  Flood risk management strategies ......................................................................... 75
  Msimbazi Opportunity Plan .................................................................................. 76
  Special Planning Area ............................................................................................ 78

Identification of hotspots ......................................................................................... 73

Identified measures ................................................................................................. 79
  List of measures .................................................................................................... 79
  Initial sketch and building blocks .......................................................................... 85

Charettes ................................................................................................................... 88

Defined flood management strategy ....................................................................... 91

Way forward .............................................................................................................. 92

References ............................................................................................................... 93

Appendix I – Social and Environmental Baseline ...................................................... 95

Appendix II – Socio-economic development and baseline scenarios ......................... 96

Appendix III – Damage Estimation and Damage Model ............................................ 100

Appendix IV – Bridge Overtopping .......................................................................... 107

Appendix V – Memo on Charrettes .......................................................................... 111

Appendix VI – Results Charrettes Miro Board .......................................................... 117
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AED</td>
<td>Annual Expected Damage</td>
</tr>
<tr>
<td>BRT</td>
<td>Bus Rapid Transit</td>
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<tr>
<td>CDR</td>
<td>CDR International BV.</td>
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<tr>
<td>CFF</td>
<td>City Finance Facility</td>
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<tr>
<td>DAWASA</td>
<td>Dar Es Salaam Water and Sewerage Authority</td>
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<tr>
<td>DCC</td>
<td>Dar es Salaam City Consul</td>
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<tr>
<td>DTM</td>
<td>Digital Terrain Model</td>
</tr>
<tr>
<td>EWS</td>
<td>Early Warning System</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>GIZ</td>
<td>Deutsch Gesellschaft für Internationale Zusammenarbeit</td>
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<tr>
<td>MLHHSD</td>
<td>Ministry of Lands Housing and Human Settlement Development</td>
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<tr>
<td>MOP</td>
<td>Msimbazi Opportunity Plan</td>
</tr>
<tr>
<td>OSM</td>
<td>Open Street Map</td>
</tr>
<tr>
<td>PO-RALG</td>
<td>President's Office - Regional Administration and Local Government</td>
</tr>
<tr>
<td>RCP</td>
<td>Representative Concentration Pathway</td>
</tr>
<tr>
<td>TAHMO</td>
<td>Trans-African Hydro-Meteorological Observatory</td>
</tr>
<tr>
<td>TSH</td>
<td>Tanzanian Shilling</td>
</tr>
<tr>
<td>USD</td>
<td>US Dollar</td>
</tr>
<tr>
<td>WEMA</td>
<td>WEMA Consult</td>
</tr>
<tr>
<td>yr</td>
<td>Year</td>
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</table>
INTRODUCTION

Background

The Msimbazi River Basin (170 km²) is located in the city of Dar es Salaam (see Figure 1), Tanzania, and for the last decade this is the city’s worst hit area by serious degrees of flooding nearly every rainy season. The floods are impacting the basin’s inhabitants and environment on different levels, like loss of lives, destroyed homes and assets, traffic interruption, siltation of areas and negative health effects of contaminated flood waters and stagnant ponding after the events. Flooding has become one of the main environmental issues in the basin and it is expected that the situation will get worse if no action will be taken.

Figure 1: Location of the Msimbazi River Basin (after Msimbazi Opportunity Plan Volume A – Strategy and Management Framework (2019)).

The causes of the flooding of the Msimbazi River Basin are closely related to the rapid unplanned and uncontrolled urbanisation over the last few decades. Urbanisation and deforestation in the middle and upper sections on the catchment result in an increased run-off of precipitation into streams and rivers and consequently reduce the overall retention capacity of the wider basin. That also largely explains the rapid river response to heavy downpour with flood peaks in the middle and lower catchment sections within 12 hours after the rainfall event. The urbanisation also creates blockages for natural water discharge, like river crossing infrastructure and solid waste due to improper waste management. The resulting floods are further amplified by...
inadequate storm water and sanitation infrastructure. With the high urbanisation rates in combination with deforestation of the upper basin, the basin has also become more susceptible to unbalanced river erosion and sedimentation processes putting structures at risk to bank erosion and undermining, causing inaccessibility to neighbourhoods and no longer functioning of certain land uses. Dar es Salaam is one of the fastest growing cities in Africa with an expected average annual population growth of 4.8%. By 2030 Dar es Salaam’s population will have exceeded 10 million inhabitants (United Nations, Department of Economic and Social Affairs, Population Division (2018)). With these projections and given the fact that the catchment’s area largely overlaps with the city centre and its densely developed urban functions around, it is very likely the urbanisation process continues in the future and will put more urban pressure on the Msimbazi catchment. In turn this will increase the risk to more frequent and severe flooding.

Besides urbanisation, it is expected that climate change will also be a main contributor to increased, additional flood risk in the Msimbazi catchment in the future. A moderate climate change scenario (RCP4.5) already shows an increase in precipitation of 8.4%, and an extreme climate change scenario (RCP8.5) shows an increase of 23.8% (Deltares (2020)). According to these scenarios flood risk will increase in Dar es Salaam due to climate change. With the ongoing urbanisation and the climate change scenarios for Dar es Salaam, it stands to reason that flooding conditions will worsen in the Msimbazi catchment in the future and thereby increasing the vulnerability of living environments and infrastructure to flooding.

This project contributes to a Strategy and Management Framework for the Msimbazi Basin (Msimbazi Opportunity Plan Volume A – Strategy and Management Framework (2019)) developed by President’s Office Regional Administration and Local Government (PO-RALG) and the World Bank. As part of this Strategy and Management Framework, a Detailed Plan has been developed for the Lower Basin of the Msimbazi River (Msimbazi Opportunity Plan Volume B – Detailed Plan for the Lower Basin (2019)). All the volumes together are referred to as The Msimbazi Opportunity Plan (MOP). Following the principles stipulated in this Strategy and Management Framework, in collaboration with the DCC, the CFF has defined this Flood Management Feasibility Study for the Msimbazi Middle Catchment Area. The outcomes of this Study will be used to define interventions to build flood resilience and the corresponding investments required.

Objective of this study

The overall objective of the Study is to identify and analyze potential flood management and control options in order to reduce risk of flooding for the middle part of the Msimbazi catchment area. The sub-objectives of the Study are to:

1. conduct a vulnerability analysis;
2. identify and pre-select flood mitigation options;
3. develop a flood management strategy including conceptual designs, cost-estimates, determination of cost-effectiveness and advice on institutional
set-up and funding of the implementation.

The Study consists of 3 phases, namely Phase A – Inception, Phase B - Vulnerability Analysis and Phase C – Feasibility Study. This report focusses on sub-objectives 1) and 2) belonging to Phase B – Vulnerability Analysis.

Process and Teams

On 1st November 2019 a Contract for Consultancy Services to undertake the Flood Management Feasibility Study for the Msimbazi Middle Catchment Area was signed between Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and CDR International B.V. (CDR).

Main beneficiary of this Project is the Dar es Salaam City Council (DCC). The C40 Cities Finance Facility (CFF) is supporting Dar es Salaam to prepare the project on Flood Management in the middle catchment area of the Msimbazi river. The project is implemented through a partnership of the C40 Cities Climate Leadership Group (C40) and the GIZ.

For this Study, CDR has teamed up with WEMA Consult Ltd. (WEMA), a national consultant in the field of water and environment and based in Dar es Salaam, Tanzania.

Table 1: Project partners

<table>
<thead>
<tr>
<th>Partner</th>
<th>Business / Expertise</th>
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<tbody>
<tr>
<td>CDR International B.V.</td>
<td>CDR International provides consulting services in the field of engineering coast, delt</td>
</tr>
<tr>
<td></td>
<td>as, rivers, water resource engineering and ports. Based in The Netherlands</td>
</tr>
<tr>
<td>WEMA Consult Ltd.</td>
<td>Water and Environmental Management Consultancy. Based in Tanzania</td>
</tr>
</tbody>
</table>

For this Study, the above-described consortium will be referred to as the ‘Feasibility Consultant’, whereas the consultant commissioned by GIZ for the flood modelling activities is referred to as the ‘Modelling Consultant’. The Modelling Consultant is represented by Deltares from the Netherlands in association with OpenMap Development Tanzania.

On 28th November 2019 a joint kick-off call between teams of GIZ and the Feasibility Consultant took place. The kick-off meetings in Tanzania were held in the week of 13th to 17th January 2020. The Draft Reporting by the Modelling Consultant was submitted on 20th August 2020, after which the main technical assessments of Feasibility Consultant’s Study could commence.
Content of this Report

This Final Draft Vulnerability Analysis Report includes the following items:

• General Approach and Methodology;
• Project Area;
• Impact Assessment;
• Identification of Measures and Strategy.
GENERAL APPROACH AND METHODOLOGY

The Vulnerability Analysis follows the overall Study approach which includes multi-sectoral integration, a participatory strategy and a solution driven focus. Essential to this is the cooperation between the Feasibility Consultant, Modelling Consultant, and participation of all the stakeholders throughout the process. After establishing a line of communication with the Modelling Consultant in the Inception Phase, regular meetings/calls were planned and are ongoing between GIZ, the Modelling Consultant and the Feasibility Consultant.

Baseline scenarios and flooding model

Baseline scenarios aim to derive a consistent set of drivers for vulnerability (regarding climate change, socio-economic development and urbanization) in order to estimate future hazards and exposed values relevant for the middle Msimbazi River Basin in Dar Es Salaam. Impacts of identified measures need to be assessed for a rather long-time horizon of about 50 years – relevant for the technical lifetime of potential measures – there is quite some uncertainty regarding future developments with respect to climate change, economic growth and urbanization. For this reason, we have developed baseline scenarios for the period 2020-2050-2075: scenarios of flooding and economic development without implementation of flood management measures (sometimes also framed as the “do nothing scenarios”).

Climate change, urbanization and flood modelling

Climate change will affect the future precipitation levels and duration (and thus river flood levels and flows). In order to adequately cover a range of possible future developments regarding flood conditions in the Middle Basin of the Msimabzi River, 3 scenarios have been developed by the Modelling Consultant in consultation with the Feasibility Consultant to represent climate change as follows:

1. Current climate (probability of flood events for the year 2020);
2. A moderate climate change scenario based on RCP4.5;
3. An extreme climate change scenario based on RCP8.5.

In close consultation with the Feasibility Consultant, the Modelling Consultant has specified three typical representative flood events at return periods of once in 2 years (T2yr), once in 10 years (T10yr) and once in 50 years (T50yr). For further information on the developed climate change scenarios reference is made to the Draft Modelling Report (Deltasres (2020)).

Urbanization in terms of land use changes will have an impact on the magnitude and frequency of hazards, because land use changes like deforestation, increase of paved/imperious areas and developments in the flood plains lead to less water infiltration in the soil and more run-off in turn resulting in more flood risk. In order to incorporate urbanization in the flood modelling exercise some sensitivity analyses have been performed. The hydrological model has been changed for the paved/unpaved fractions in the middle and upper basins of the Msimabzi River to check how the river could respond to high future urbanization rates. For projections
2050 and 2075 the situations have been tested for the current land use, referred to as ‘low’ urbanization, and possible future autonomously developed land use, referred to as ‘high’ urbanization. Because (uncontrolled) urbanization is very difficult to predict over long-time horizons, an upper estimation of change into paved areas has been made in close consultation with the Modelling Consultant (Deltares (2020)).

**Socio-economic scenarios**

Next to climate change, socio-economic development will affect the damage of floods in the Msimbazi Basin River to a large extent. Dar es Salaam is developing rapidly and will largely affect the exposure of people and assets to flooding in the next decennia. Firstly, growth of population and the economy can result in additional value in the vulnerable areas such as increase of buildings, commercial assets and production as well as increase of traffic. This is mainly true for those wards where there is still space for extension of the stock of assets (housing, other) or higher densities. In most of the vulnerable wards in the project area, mainly the uncontrolled settlements, there is very small area for expansion. Therefore, no growth of the building stock or densities has been assumed in the project area itself. Secondly, rising incomes will lead to higher qualities of exposed buildings and contents (equipment, furniture etc.) over time in the period 2020-2075.

In order to quantify the effects of population and economic growth and show the uncertainty regarding the future developments of these factors, the Feasibility Consultant has developed two socio-economic scenarios as follows:

- Optimistic socio-economic development scenario (with GDP real growth rates for Tanzania of about on average 5% annually in the period 2020—2075);
- Pessimistic socio-economic development scenario (with GDP volume growth rates of about on average 3% annually in the period 2020—2075).

*Figure 2: Bandwidth impacts floods based upon two key uncertainties: climate change and socio-economic development (including urbanization)*
These two socio-economic scenarios are used as input for the estimation of the asset values in the damage model (damage model is described in the next section). From the combination of the two socio-economic scenarios and the bandwidth of two potential climate change expectations viz. RCP 4.5 and RCP 8.5, there are four possible future cases regarding expected impacts of floods. In order to show a plausible bandwidth of possible scenarios, it has been chosen to generally present the entire band width of cases: the optimistic growth combined with RCP 8.5 scenario (the upper level of impacts), and the lower by combining RCP 4.5 with the more pessimistic growth scenario. In the figure below this is illustrated. Other combinations of scenarios would fall somewhere in this bandwidth. This report focusses on the upper level of impacts.

**Hazard risk analysis and impact assessment**

A commonly used conceptual Hazard Risk equation has been adopted for the impact assessment (see Figure 3). Important drivers of vulnerability of people and assets for flooding in the Msimbazi Middle Basin are climate change and socio-economic development (urbanization). These drivers determine the nature and extent of the key relevant hazards. In this study the main hazards are severe precipitation (rainfall) and the morphological dynamics causing flooding in key areas in Dar Es Salaam (of which inter alia the Middle Msimbazi River Basin). The extent and amount of potential future flooding are derived from the flood modelling conducted by the Modelling Consultant. The exposure to flooding of people and assets – inter alia buildings, infrastructure – and the monetary values of these assets over time are estimated by the Feasibility Consultant. The exposure is based upon the results of the flood modelling and an estimate of number of people and assets in wards (and sub wards) in the middle Msimbazi River Basin area. Openstreetmap\(^1\) data has formed the most important source for the exposure. The overlay of hazards and exposure reveals the vulnerability to flooding and enables to identify hotspots where flood mitigation measures are most needed.

![Figure 3: Conceptual hazard risk equation to identify hotspots](www.openstreetmap.org)

\(^1\) www.openstreetmap.org
The two socio-economic scenarios (optimistic, pessimistic) as mentioned in the previous section, have been combined with the climate change scenarios (hazards) to derive a bandwidth of damage based upon two combined scenarios; high damage (high growth with extreme climate change and urbanization) and moderate damage (low growth, moderate climate change).

For assessing current and expected future physical flood damages to assets a GIS based multi-layered damage model has been developed. In the flood damage model two types of damage are estimated: direct physical damage and indirect damages (economic losses due to e.g. business and traffic interruptions). The resulting calculated risks are presented in the form of flood hazard risk maps and tables to enable quantitative evaluations. In this damage model the derived hazard layers by the Modelling Consultant have been combined with the exposure layers. Information on the asset values and corresponding damage curves (fraction of total damage as a function of inundation depth) have been determined and linked to the exposure layers for calculating current and expected future flood damage for different asset categories and for 2 socio-economic development scenarios. Future asset values are increasing with real income growth based upon the socio-economic scenarios (GDP growth, income growth etc.). More details regarding the damage model, including damage curves, assets and land use and asset values, can be found in Appendix III.

**Flood risk mitigation options**

Based on the impact assessment, flood risk mitigation measures have been identified for the hotspots by following internationally accepted flood risk mitigation strategies (e.g. retreat, adapt and protect). The MOP (Msimbazi Opportunity Plan Volume A – Strategy and Management Framework (2019) and Msimbazi Opportunity Plan Volume B – Detailed Plan for the Lower Basin (2019)) has been adopted as the Strategy Framework for this Study, hence the principles and measures proposed in the MOP are the main guideline for the identification and detailing of measures in the Msimbazi Middle Basin. Structural and non-structural measures have been considered for the short and the long term. Where possible, win-win solutions have been targeted already by ‘mitigation by design’ principles to limit negative social and environmental impacts associated with these solutions.

As the middle catchment area of the Msimbazi river is part of a bigger hydraulic and hydrological system, interfering with the river inevitably will have up- or downstream effects. Therefore, the lower catchment and the upper catchment are also considered in the assessment. The identified appropriate measures are illustrated by explanatory sketches, showing the design principles and indicative dimensions of the respective measures.

The prioritization of the identified measures is based on three main evaluation criteria;

1. **Effectiveness**: to which extent reduction in hazards and risks is achieved;
2. **Sustainability**: how will environmental, social and economic values develop in the short and long term;
3. **Implementability**: is implementation of measures feasible in terms of e.g. costs, financing, institutional arrangements, constructability and maintenance.

Technical measures, which include physical interventions in the riverbed, flood plain or the structures (bridges) have been tested by the Modelling Consultant. Resulting hazard layers (e.g. propagation of flood depth, flood levels) have been processed in the GIS model again to re-generate the risk and damage figures to enable evaluation of the effectiveness of the intervention.

The main criteria are further divided into sub-criteria. The evaluation of the measures will be done in a qualitative manner together with the stakeholders during the Charrette (see next section). Firstly, in order to know which criteria are found more important/relevant per stakeholder (group) the criteria will be ranked and weighed. Secondly, the identified measures will be scored qualitatively by a simple scoring system (e.g. ++, +, 0, -, --) and mentioning the pros and cons. Based on the results of the ranking and, scoring prioritizations can be made. Subsequently, Flood Management Strategies (combination of measures) for the short and the long term will be composed for the Msimbazi Middle Basin. The feasibility of the Strategy will be assessed in the Feasibility Stage of this Study.

**Participatory process**

The commitment of the stakeholders and the support of the Government on a local and national level is of an utmost importance for selection and realization of the proposed measures and flood management strategy. Inter-institutional coordination, together with the communities, will be required to support and align adequate decision making. To this end all the main stakeholders need to communicate with each other already in very early stages of the project development as was done in January 2020 at the start of the Study. Following the MOPs Action Plan the Charrette process is continued in this Study by having a Charrette and discuss the identified measures for the Msimbazi Middle Basin with the stakeholders.

The purpose of the Charrette is not only to present the vulnerability and impact assessment, but also to discuss, by means of creative break-out sessions, how the area could look in the future and what kind of flood risk measures would be most appropriate for each of the different flood risk mitigation strategies.

Due to the COVID-19 pandemic, a hybrid Charrette, combination of physical and virtual sessions, was conducted in January 2021. The Charrette consisted partly of presentations by both the Feasibility and Modelling Consultants and partly of break-out sessions together with the representatives of the various organizations and the communities involved.
STUDY AREA AND BASELINE CONDITIONS

This section describes the study area and the main baseline conditions relevant for this Study. A social and environmental baseline study has been conducted and is reported in Appendix I.

Study area

In this Study the Msimbazi Middle Basin is defined as the area between Kawawa Road Bridge and Kinyerezi Bridge consisting of a total project area size of about 5,000 ha. The Msimbazi River is the main river flowing through the area with two main tributaries, namely the Kibangu River and the Tenge River (see Figure).

Figure 4: Reference map for the Msimbazi Middle Basin and the study area

Names have been given to all the bridges for clear communication between GIZ, involved Consultants and the stakeholders. It is noted that the following bridges fall within the Project area for the Feasibility Consultant (from downstream to upstream as numbered in Figure 4):

1. Kawawa Road Bridge (Msimbazi River);
2. Nelson Mandela Road Bridge;
3. Railway Bridge;
4. Vingunguti Bridge;
5. Kinyerezi Bridge;
6. Kawawa Road Bridge (Kibangu tributary);
7. Kibangu Kigogo Road Bridge (Kibangu tributary).

Funding partners: Implementing agencies:

[Logos and text for funding partners and implementing agencies]
1. Kawawa Road Bridge (Msimbazi)
2. Nelson Mandela Bridge
3. Railroad bridge
4. Vingunguti Bridge
5. Kinerezi Bridge

*Figure 5: Main bridges in the study area*
Main issues and considerations

Based on the MOP and Consultant’s observations during the fieldwork, consultations and their assessments, the main issues and considerations can be summarized as follows:

- Urbanisation: Deforestation of Pugu hills in the upper catchment and the rapid urbanization of the middle catchment area (contributing to Dar es Salaam being the second fastest growing city in Africa) have diminished the natural water retention capacities of the land in the Msimbazi catchment area and this is causing increased storm water runoff. This is also the main reason why the nature of flooding in the Msimbazi River is of a so called flash flood type. Within a couple of hours after heavy downpour the river and her tributaries will flood because of the enormously increased discharges;

- Flooding in relation to erosion and sedimentation: With less vegetation and increased storm water runoff, the bare soils, mainly consisting of sand and silt, the areas exposed to extreme erosion and sedimentation patterns will increase. Main problems of the erosion, are the risks of undermining of structures, loss of land and landslides. Sedimentation, on the other hand can increase flood risk due to raised river and flood plain levels, siltation and clogging of infrastructure barriers also causing increased flooding;

- Infrastructure crossings: Infrastructure crossings by means of bridges, culverts and embankments are causing increased risk of flooding and morphological dynamics of the river because of reduced discharge capacities underneath or alongside the structures. The crossings could also increase risks to upstream of downstream areas, and the structures itself also run the risk to be undermined by scour, erosion and/or sedimentation or washing out of backfilling materials;

- Vulnerable living environments: From the above, it is evident that community environments are very vulnerable to flood related risks. Risks include among others loss of life, inaccessibility/immobility, damage to households, pollution and disease outbreaks (e.g. cholera, malaria and dengue).

The afore mentioned issues have been taken into account in the vulnerability analysis and the feasibility phase of this Study. The results of the latter will allow GIZ defining infrastructural solutions with the aim of preventing or reducing impacts of flooding.

Administrative boundaries

The results of the vulnerability analysis and the impact assessment have been aggregated to different spatial administrative boundaries including the municipalities, wards and sub-wards (see Figure 6).
In this Study only the sub-wards within the project boundary will be included in the statistics and results. The index numbers as shown in the map (Figure 6) are linked to the corresponding sub-wards as indicated in Table 2.

Table 2: Index numbers of the sub-wards within project area

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Funding partners:

Implementing agencies:
Upstream and downstream sections and area characteristics

A division of the study area has been made into a Downstream Section and an Upstream Section. The Nelson Mandela Road is the split between the two Sections as follows:

- the area between Kawawa Road and Nelson Mandela Road is the Downstream Section;
- the area further upstream from Nelson Mandela Road is the Upstream Section.

This location has been chosen to separate the area into two sections because of the river characteristics. Where downstream of the Nelson Mandela road the river characteristics, such as the gentler longitudinal gradient, is more similar to the Lower Msimba basin. Upstream of the Nelson Mandela road, the longitudinal gradient of the river is steeper and the river shows a curved pattern with many bends. The areas are separated by the industrial zone around Nelson Mandela bridge. The downstream section, the industrial section around the bridge and the upstream section can also be characterized as different urban zones, Zone A, B and C.

Figure 7: Project area within Msimba basin separated in a section upstream and downstream of Nelson Mandela road bridge
Zone A in the downstream section, between Kawawa Road and Nelson Mandela Road. Zone which includes so called area Sukita. This area belongs to the Chama cha Mapinduzi (CCM) party and has been used for agricultural purposes including poultry farming. Nowadays it is mainly used as agricultural land. The land is still owned by CCM, and is one of the scarce green locations within Dar es Salaam.

Zone B, the transition between upstream and downstream sections: industrial and logistics area around the Nelson Mandela Road Bridge. Close to the Port of Dar es Salaam and in the vicinity of main infrastructure arteries this location has been planned and developed for this purpose. However, there is very small space for the river to run through as can be seen from the picture at the right.

Zone C, upstream section: large uncontrolled urban residential development areas from rail road bridge further upstream. In this area urban sprawl has taken place all the way down to the river banks making the dwellings very vulnerable to river flooding. In the upper reaches of the upstream section the area is constantly in development increasing the paved area fractions.

**Socio-economic context**

The main sources regarding the social-economic context in the Middle Msimbazi area are from two sub studies undertaken as part of the overall Study; the social and environmental baseline study (Appendix I) and the gender analysis study for the Msimbazi Middle Basin (CDR International and partners (2020)). Moreover, data from Ilala Municipal Council socio-economic profile (Ilala Municipal Council socio-economic profile (2019)) and Population Census (Population and Housing Census (2012)) has been used.

**Demography**

Based on the number of residential and mixed-use houses mapped in the Open Street Map database and the average household size (see Appendix I), the current population size in the Study area is estimated to be some 550,000 people. Details per ward are provided in Appendix I. Vingunguti ward has the largest population exceeding 100,000 people. About 50.5% of the population within the Study area is female. The figures from the Census in 2012 are an underestimation of the current population due...
to continuous influx of people from rural regions elsewhere in Tanzania. Moreover, a substantial amount of people come at daytime to the area to earn some money and stay in other areas during the night. Population in Dar Es Salaam grows significantly mainly due to economically motivated rural urban migration, in the period 2000-2019 the population increased at an average annual growth of about 5.5% (World Bank data). The population has a variety of native ethnic backgrounds, with the main ethnic groups the Zaramo and Ndengereko.

**Economy and livelihoods**
The main economic activities in Ilala municipality are retail (small shops, informal markets), hotels, restaurants, bars, handicraft, transportation services, textile, construction and medical business and agriculture and livestock (see Municipal Council socio-economic profile (2019)). Ilala and Kinondoni municipalities have a number of developed industries, such as food processing, beverage and textiles (see Appendix I). For Dar Es Salaam regional GDP was estimated at USD 8.6 million (20,1 trillion Tsh), about 13% of the national GDP (see Dar Es Salaam Regional Profile, 2016).

Focusing on the middle Msimbazi catchment area, predominant sectors are retail (small shops, and shopping centers), banks, restaurants, bars, hotels, wholesale trade and logistics companies, textile mills, agrofood processing companies and agriculture and livestock activities. Landmarks in this respect are the Benjamin Mkapa Export Processing Zone and the agricultural area along the more upper middle part of the Msimbazi (Zone C). For 2018 it was estimated that still about 5,000 ha of land in Ilala Municipality was used for agricultural crops (such as cassava, sweet potatoes, paddy, maize and cowpeas).

Although a significant number of people work in the industries in the middle catchment area, many of these workers do not live in the area. Most people living in the flood prone areas in Dar Es Salaam (especially women) are depending on small scale business as main source of income. From a survey undertaken as part of the environmental and social baseline study in selected wards, the majority of the population is self-employed (54%), followed by private sector employed (25%). 9% state they do not have specific employment. More than half of the respondents earn less than 30,000 TSH per day, while almost 30% earns between 30,000 and 100,000 TSH per day. See Figure 8.
In D.M. and Luhunga, P.M. (2019) a survey was held among people affected by the flood in December 2011 in Dar Es Salaam. From this survey it becomes clear that many inhabitants affected by the flood were marginalized groups with limited adaptive capacity to respond to flood events. A large part of the people (especially women), work in small businesses (often related to informal manual work related to selling or processing of food, textile and handicraft).

Due to the nature of the activities, flood events can have a significant impact while both transportation of goods and the workers and potential clients are affected. Many of the food sellers use simple means of transportation (handcars, cargo bikes etc.), which are easily affected by inundation of roads or bridges.

**Gender**

According to the 2012 Census 51.3% of the population in Dar Es Salaam are female. The 2012 Census report indicates disparities regarding employment situation and asset ownership: 40% of the female were employed, while 60% of men had some kind of employment (in 2012). This implies that compared to men women have less employment and women are often depending on the income of the men. The gender analysis undertaken as part of this Study shows that a high proportion of women are in informal vulnerable employment situations, such as restaurants, vendors of snacks, hair dresser, fryers of fish and chicken, market vendors, stone quarry processers, tailors, etc. Men are engaged in service delivery related works such as shop sellers, watchman, sellers in market and supermarkets, horticulture, sand mining, repair and maintenance works of motor vehicles, transportation and storage.

Regarding asset ownership the study shows that while men often own the premises, the women own the furniture, kitchen equipment and cook stoves. A recent household survey in Dar es Salaam found that asset losses—including household appliances, other electronics, clothes, and furniture—made up 77 percent of total flood damage, surpassing the value of housing repairs (Erman et al. 2019)

International studies also show the vulnerability of women for disasters like floods. Economically, disasters have different effects for men and women, with women largely disadvantaged because of less favourable employment situation, less access to bank...
accounts and responsibility for the family. Doocey et al (2013), conclude that in developing countries, mortality among women because of floods is higher. The primary cause of the higher flood-related mortality is a lower risk coping ability of women (drowning). Moreover, the assets inside the dwellings of women are more affected at the low inundation levels (< 0.5 m. which happen more frequent at T1 and T2 events compared to damage on the dwelling construction).

In conclusion, the background gender analysis study and international literature show women are particularly vulnerable for flooding in the project area due to lower risk coping abilities, type of informal job situation (in outside areas), being often responsible for (disrupted) drinking water provision to the family and as caretaker for vulnerable children. Finally, during floods most of the families are left with females (men are more often away from the families).

**Environmental context**

**Climatic characteristics**

Dar es Salaam has a tropical type of climate characterized by a bi-modal rainfall regime which is influenced by the Indian Ocean. The two rainy seasons run from October to December and from March up to and including May with an average rainfall of about 1,000 mm per year. More information on rainfall and expected extremes in the future are reported by the Modelling Consultant (Deltares (2020)).

The rainy seasons are also the most humid periods. It is generally hot and humid throughout the year with an average temperature of 29ºC. The hottest season is from October/November to March during which temperatures can raise up to 35ºC. Humidity is around 96% in the mornings and 67% in the afternoons. The project area is less hot between May and August, with a temperature of around 25ºC.

Heat stress in Dar es Salaam is also a growing threat. On a regional scale it is expected average temperatures will rise due to climate change, whereas on a local scale, temperatures will rise due to urbanization by increased fraction of paved and built up areas. According to recent studies, the average maximum duration of heat waves will double by 2050 and the number of events with 5 days of lasting heat could increase from 3 to 24 times in 2050 (CLUVA (2012)).

**Topography, geology and landscape**

The Msimbazi Middle Basin area is slightly hilly with a terrain elevation range from about 8m +MSL in the lowest section bordering the Lower Basin to 140m +MSL in the upper reaches. The abiotic landscape is shaped by the Msimbazi River and its tributaries whereby the main river is located at the right side of the catchment (in direction of river flow) flowing from SW to NE along a ridge. The tributaries are mainly located NW of the main river. Figure 9 shows the topography of the Study area.

Sandstone is the dominant group of rocks that typify the Dar es Salaam region. The upper soil layers of the Msimbazi catchment area, including the Middle Basin section, mainly comprise sands, sandy loam and clay with a dominance of sand (JBA (2018)).

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2 See for example, Erman et al. (2021), Gender Dimensions of Disaster Risk and Resilience, World Bank Group.
In most areas the water content is reduced causing the soils to be loose and susceptible to erosion.

Figure 9: Terrain elevation of Msimbazi catchment area

**Building typologies**

The larger share of the buildings in the Study area has a residential function (more than 90% based on building count), followed by mixed use function (~5%, small shops, retail). According to the survey undertaken as part of the baseline study 68% of the respondents stated they were the owner of the house and 32% reported they were tenants (Appendix I).

Density of residential and mixed use buildings in the Study area is 26 buildings per hectare. The number of industrial buildings is low, however the footprint area of industrial areas is about 5% to the total footprint area of all building types. This is mainly attributed by the logistic zone at Buguruni.

The type of residential houses, range from temporary to semi-permanent to permanent types. Based on the fieldwork conducted for the environmental and social baseline, it appears most of the houses have been built with cement blocks and corrugated iron roofs. The dwellings of a more temporary nature are patched up with pieces of iron steel, corrugated steel and wood. All surveyed buildings were single-storey with a maximum height of about 3 m.
Vegetation
Most of the natural vegetation has been lost due to rapid urbanization in the Study area. Also, in general the density of vegetation is considered to be relatively low to very low in some sub-wards like Kombo (Vingunguti ward). Present vegetation is mostly planted in gardens and along roads. Urban agriculture is located along some sections of the riverbanks. Largest continuous green section is at Sukita, characterized by urban agricultural patches marked by coconut trees. Lowest building densities are in the wards located further upstream, like Kinyerezi and Ukonga. Here vegetation densities are highest with more (urban) agricultural functions and growth of the Indian charcoal-tree (Trema orientalis), for charcoal production.

The catchment area of Msimbazi River has become increasingly flood-prone over the past decade, as a result of progressive deforestation within the upper catchment area.
The deforestation has increased surface runoff from built-up watersheds and clogging of the hydraulic structures due to continual soil erosion. Problems with waste management have worsened this situation.

**Waste management and drainage**

Solid waste collection is organized by the municipality in partnership with private collectors. Most of the solid waste is domestic waste related to high share of dwellings in the project area (90%). According to the gender analysis report (CDR International and partners (2020)) there are a number challenges related to solid waste collection apart from the unplanned nature of the area: poverty, lack of willingness to comply with regulations, availability of the basin as a free resource for dumping solid waste and poor road infrastructure to allow provision of such services. According to this sub-study only 28% of waste is collected in Kigogo ward. The environmental and social baseline (Appendix I) reports a collection rate of about 50-65% of generated waste. Hence, it can be assumed a large fraction of solid waste is dumped in the project area. Solid wastes are scattered along the streets and some are dumped into storm water drainage channels. This practice increase siltation, blockage of channels and eventually causing more flooding within the area.
IMPACT ASSESSMENT
The vulnerability of the Msimbazi Middle Basin to flooding depends on the magnitude of the flood hazards and the different impacts caused by these hazards (consequences). The assessed impact is the result of the overlay analysis of the hazards and the exposure, and is further elaborated in a description of the vulnerability and a quantitative damage assessment. The magnitude and spreading of the flood impacts form the basis for the determination of the hotspots, the direction of possible flood risk mitigation strategies and the cost-benefit analysis for the feasibility stage of this Study.

Hazards
The nature of flooding in the Msimbazi River is, as said, of a flash flood type. Within a couple of hours after heavy downpour the river and her tributaries flood because of the enormously increased discharges. Flood extent, flood depth and flow velocities are the main flood hazard indicators for the Msimbazi Middle Basin. Morphological changes (erosion and sedimentation processes) are also considered a hazard but has not been assessed or modelled quantitatively by the Modelling Consultant and hence has been addressed in this Study only qualitatively.

Flood depth and duration
Flood depth is the height between the flood water level and the terrain level. Flood depth is one of the key hazard indicators which are used as basis to determine the impact; the higher the flood depth the higher the impact or damage. In the Msimbazi Middle Basin, river flooding occurs due to insufficient hydraulic capacity of the river sections and blockages or strictures in the river profile.

In order to analyze the different scenarios for flood depth, a fixed detailed flood depth classification has been applied for the damage assessment (see next section). The flood depth classes also form the main classification used for the flood extent analysis (see next section).

The duration of floods influence the well-being and livelihoods of affected communities and transportation possibilities. The longer the duration of floods, the higher the impacts on these aspects. In the social & environmental baseline study most respondents in the survey report that they see inundation between 1 to 3 days (74% of respondents, Appendix I). Inundation periods of 1-3 days correspond with the flood modelling results of the Modelling Consultant. A smaller percentage states that water stays for about a week (20%).

Flood extent
The flood extent is the area affected by a certain event, occurred or simulated. This indicator is particularly interesting to take into account, when areas which can potentially be flooded by adjacent streams or waterbodies are relatively flat or gently sloped, which is the case in the Msimbazi Middle Basin. In such areas a rise in water level will be reflected as an increase in the flood extent. As indicated in the previous sub-chapter the flood depth is an important indicator for the severity of flooding. For the quantitative flood extent analysis, a simplified flood depth classification has been used, namely 0.03 – 0.25m, 0.25m – 1m and more than 1m flood depth. For the
mappings, the detailed classification has been used; this classification also forms the basis for the flood damage curves.

The flood extent has been analyzed on three scenario components; i) effect of different event frequencies, ii) effect of climate change and iii) effect of urbanization.

**Effect of return periods**

The figure below shows the flood extents for three return periods T2yr, T10yr, T50yr (annual exceedance probability of 50%, 10% and 2% respectively). From this graph, it is clear that the flood extents increase, including its portion with higher flood depths, with less frequent events. The rise in flood depth is relatively higher than the rise in flood extent; the natural flood plain basins fill up further with less frequent events, but increase in flood extent is smaller. So, during a current (2020) T50 event about 19% of the Msimbazi Middle Basin project area will be inundated with flood waters deeper than 0.25m, and almost 10% of the project area, which is about 500 hectares, will have flood waters even deeper than 1m. This is considered a substantial flood risk.

![Figure 12: Flood extent relative to Study area for different return periods and flood depths for current scenario](image-url)
Climate change effect
The effect of climate change on the flood extents has been analyzed by comparing the 2020 situation with the climate change scenarios (RCP4.5 and RCP8.5 for the years 2050 and 2075). The flood extents for a T10yr event for the various scenarios are shown in the figure below (flood extents are relative to the entire project area).

Figure 14: Flood extent relative to project area for T10yr, for different flood depth classes, for current, 2050 and 2075 climate change scenarios (low urbanization)
Figure 15: Flood depth and extent for T10yr, current scenario.

Figure 16: Flood depth and extent for T10yr, for climate change scenario RCP85 (2050), low urbanization.
Figure 14 shows that the flood extent between 2020 and the two climate change scenarios for 2050 will increase, of which RCP8.5 shows a higher increase than RCP4.5. The relative increase in simulated flood extent is higher for the flood depths larger than 1m (over 50% increase between current and 2075 RCP8.5) compared with relative increase of flood extent for all flood depth classes (about 20% increase for the same scenarios). This means that the flood depth will have a relatively larger increase compared to the flood extent during future flood conditions. In other words, currently extreme flood events already fill the basins, so in the future it is mainly the water depths which will rise rather than further spatial spreading of the flood.

Figure 15 and Figure 16 show the flood extents spatially for a T10yr condition for current (2020) and RCP8.5 (2050) respectively. The larger flood depths and flood extents for RCP85 are clearly visible, particularly between Jangwani Bridge and Segerea ward.

**Effect of urbanization**

Increased urbanization in the middle and the upper basin of the Msimbazi catchment has been simulated by changing the paved/unpaved fraction in the hydrological model. The effect of urbanization is visualized in Figure 17, and has been based on the delta for the flood hazard extent areas between the situation with and without urbanization for the respective combinations of climate change scenarios, time horizons and return periods. According to these results the flood extent area will increase 14% to 18% in 2050, as a direct result of urbanization.

![Figure 17](image-url)

*Figure 17: flood extent relative to project area for T10yr, for different flood depth classes, for current scenario, 2050 scenario with RCP 8.5 and 2050 with RCP 8.5 in combination with urbanization*

Considering climate change and urbanization (through changes in paved/unpaved fractions) as main drivers of increased expected future flood hazards in the Msimbazi Middle Basin the table below shows the contributions of both drivers as a percentage of the total increased flood extent for 2050.
Table 3: Contributions of climate change and urbanization to increased flood hazards for 2050

<table>
<thead>
<tr>
<th>Contribution</th>
<th>T2</th>
<th>T10</th>
<th>T50</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2050 RCP45</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urbanization</td>
<td>77%</td>
<td>78%</td>
<td>80%</td>
</tr>
<tr>
<td>Climate Change</td>
<td>23%</td>
<td>22%</td>
<td>20%</td>
</tr>
<tr>
<td><strong>2050 RCP85</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urbanization</td>
<td>61%</td>
<td>58%</td>
<td>59%</td>
</tr>
<tr>
<td>Climate Change</td>
<td>39%</td>
<td>42%</td>
<td>41%</td>
</tr>
</tbody>
</table>

The table above shows that for all simulated situations for 2050 urbanization has a larger contribution to increased flood hazards than climate change. For the moderate climate change scenario (RCP45) more than 75% of the increased hazard is caused by urbanization, for the extreme climate change scenario this has reduced to about 60%. The effect of urbanization is considered substantial and gives insight in the potential to avoid further increase of flood risk by means of adequate, integrated multi sectoral spatial planning.

**Flood extents per administrative units**

Figure 17 and Figure 18 show the (spatial) variability of relative flood extents per ward and subward for a T10yr event for a RCP8.5 (2050) scenario. By looking at the flood extents per ward, large differences can be found. Wards Kigogo (Lower Middle Basin) and Mchickichini (Lower Basin) are clearly the wards with the largest flood extents.

![Figure 18: Relative flood extent per area of ward for T10yr current scenario](image)
Figure 19: Percentage flooded >0.25m per sub-ward

Table 5 shows the percentage of the area flooded per subward, ranked based on the T10 percentage flooded >0.25 m for the current scenario. On the subward spatial aggregation level it is revealed that also subwards from wards in the upstream section, like Tabata and Vingunguti, have relatively large flood extents further expressed by the map presented.

There are some wards, such as Kiwalini and Sandali where the flood extent is negligible. Flooding is substantially less in these areas, but it needs to be mentioned that only a small part of these wards is part of the catchment area of the Msimbazi.

Table 4: Ranked subwards based on relative flood extents

<table>
<thead>
<tr>
<th>#</th>
<th>Subward</th>
<th>Index</th>
<th>Ward</th>
<th>T10 Current</th>
<th>T10 2050 - RCP 4.5</th>
<th>T10 2050 - RCP 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low urbanisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flooded &gt;0.25 m [%]</td>
<td>Flooded &gt;1.0m [%]</td>
<td>Flooded &gt;0.25 m [%]</td>
</tr>
<tr>
<td>1</td>
<td>Msimbazi Bondeni</td>
<td>26</td>
<td>Mchikichini</td>
<td>68.6</td>
<td>70.7</td>
<td>76.9</td>
</tr>
<tr>
<td>2</td>
<td>Mbuyuni</td>
<td>9</td>
<td>Kigogo</td>
<td>50.6</td>
<td>51.9</td>
<td>56.4</td>
</tr>
<tr>
<td>3</td>
<td>Kisiwani</td>
<td>15</td>
<td>Mburohati</td>
<td>45.3</td>
<td>46.8</td>
<td>53.8</td>
</tr>
<tr>
<td>4</td>
<td>Kigogo Mkwauni</td>
<td>7</td>
<td>Kigogo</td>
<td>41.7</td>
<td>46.6</td>
<td>53.8</td>
</tr>
<tr>
<td>5</td>
<td>Kigogo Kati</td>
<td>8</td>
<td>Kigogo</td>
<td>41.3</td>
<td>42.6</td>
<td>46.7</td>
</tr>
<tr>
<td>6</td>
<td>Kombo</td>
<td>30</td>
<td>Vingunguti</td>
<td>37.2</td>
<td>43.2</td>
<td>55.4</td>
</tr>
<tr>
<td>7</td>
<td>Mtambani</td>
<td>6</td>
<td>Mzimuni</td>
<td>28.0</td>
<td>29.1</td>
<td>30.6</td>
</tr>
<tr>
<td>8</td>
<td>Mwiyumkulu</td>
<td>5</td>
<td>Mzimuni</td>
<td>27.0</td>
<td>27.0</td>
<td>30.0</td>
</tr>
<tr>
<td>9</td>
<td>Barafu</td>
<td>14</td>
<td>Mburohati</td>
<td>26.8</td>
<td>28.5</td>
<td>32.9</td>
</tr>
<tr>
<td>10</td>
<td>Matumbi</td>
<td>19</td>
<td>Tabata</td>
<td>26.8</td>
<td>27.3</td>
<td>28.6</td>
</tr>
</tbody>
</table>
Flow velocities

Amongst other factors, changes in variability and gradient of flow velocities could lead to morphologic changes to the river. This could be a risk for bank erosion and/or structural instability due to erosion near infrastructural assets. Also, high flow velocities could significantly increase the risk to loss of life, in particular in combination with larger flood depths. This section addresses the modelled flow conditions for the various return periods and scenarios.

Generally, the maximum flow velocities are highest in the main river branches and in the inundated areas in the order of 1 – 2 m/s. The maximum flow velocity in the mainstream is mainly depending on the capacity of the river stream compared to the discharge and the longitudinal gradient. The capacity of the river is mainly governed by the width and depth of the river stream locally and by bridges or other crossing infrastructure with a relatively small cross-sectional flow area. The longitudinal gradient is mostly depending on the natural terrain slope, which is more or less constant in most of the Msimbazi Middle Basin, but with a slight decrease downstream of Nelson Mandela Bridge (Lower Middle basin).

Figure 19 shows the maximum flow velocities along the mainstream of the Msimbazi for the modelled scenarios, relative to the location of Kawawa road bridge. From this figure the following can be concluded:

- Upstream of most bridges a clear local decrease of the maximum flow velocity is present, followed by a local increase through/downstream of the bridge. This generally indicates that a backwater is present upstream of the bridge, which is caused by an insufficient capacity;

- In case of Nelson Mandela road bridge and Kawawa road bridge, the maximum flow velocity does not increase for the more severe scenarios. This might indicate that the bridges obstruct the flow and are overtopping;

- The areas between Kinyerezi bridge and Vingunguti bridge and downstream of Nelson Mandele bridge show for all scenarios relatively higher flow velocities compared to the other areas. This can be caused by a decrease in flow conveying area of the river, for example due to a narrowed width and/or depth.

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Mnyamani</td>
<td>37</td>
<td>Buguruni</td>
<td>25.9</td>
<td>3.4</td>
<td>29.6</td>
<td>4.0</td>
</tr>
<tr>
<td>12</td>
<td>Mabibo Farasi</td>
<td>12</td>
<td>Mabibo</td>
<td>22.8</td>
<td>9.0</td>
<td>25.5</td>
<td>10.7</td>
</tr>
<tr>
<td>13</td>
<td>Tabata Kisiwani</td>
<td>22</td>
<td>Tabata</td>
<td>22.8</td>
<td>12.9</td>
<td>23.4</td>
<td>14.3</td>
</tr>
<tr>
<td>14</td>
<td>Ilala Kota</td>
<td>27</td>
<td>Mohikichini</td>
<td>22.2</td>
<td>18.6</td>
<td>22.6</td>
<td>19.0</td>
</tr>
<tr>
<td>15</td>
<td>Kisiwani Illala</td>
<td>34</td>
<td>Buguruni</td>
<td>18.9</td>
<td>7.7</td>
<td>21.4</td>
<td>9.3</td>
</tr>
<tr>
<td>16</td>
<td>Msimbazi</td>
<td>20</td>
<td>Tabata</td>
<td>18.8</td>
<td>9.8</td>
<td>20.5</td>
<td>10.4</td>
</tr>
<tr>
<td>17</td>
<td>Amani</td>
<td>40</td>
<td>Segerea</td>
<td>16.4</td>
<td>4.8</td>
<td>16.7</td>
<td>5.2</td>
</tr>
<tr>
<td>18</td>
<td>Mandela</td>
<td>18</td>
<td>Tabata</td>
<td>15.8</td>
<td>12.8</td>
<td>16.2</td>
<td>12.9</td>
</tr>
<tr>
<td>19</td>
<td>Mtakuja</td>
<td>29</td>
<td>Vingunguti</td>
<td>15.2</td>
<td>8.3</td>
<td>19.3</td>
<td>8.8</td>
</tr>
<tr>
<td>20</td>
<td>Malotekeo</td>
<td>10</td>
<td>Mabibo</td>
<td>15.1</td>
<td>8.4</td>
<td>16.1</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Funding partners: Implementing agencies:
Because the banks along the Msimbazi are generally unprotected (besides from local bridge heads), these areas are prone to bank erosion;

- The local peak at rail road bridge indicates a strong and local conveyance of the river flow. This can be observed in the flood inundation maps as well, where the areas both upstream and downstream of the rail road bridge (and embankment of the rail road) are flooded.

![Figure 20: Maximum flow velocities in the Msimbazi mainstream for the modelling scenarios](image)

Based on the modelling results the following observations are made for the different return periods with respect to flow velocities:

- 2 years - the maximum flow velocities are limited to 0.5 m/s;
- 10 years – the maximum flow velocity increases mainly downstream of Nelson Mandela bridge, up to 1 m/s;
- 50 years – the maximum flow velocity increases also upstream of Nelson Mandela bridge up to 1 m/s, downstream of the bridge, flow velocity could reach 2 m/s locally.
Figure 21: Maximum flow velocities in the project area for T50 with climate change scenario RCP 8.5

Sedimentation and erosion

Sedimentation and erosion are morphologic processes that are driven by the hydrodynamic forcing in the river branches. Erosion occurs in case the local transport capacity (directly related to the flow velocity) is larger than the supply of sediment. There are several potential risks related to these processes not limited to the following:

- Bank erosion and outflanking of the river bends cause a risk of undermining of structures which are constructed close to the river bank;
- Bottom and bank erosion around bridges could cause geotechnical or structural instability of the bridge;
- Land uses, e.g. agriculture, are becoming unsuitable;
- Sedimentation causes in some cases a rise in water levels, which increases the potential flood extent and depth.

Bank erosion

The banks along the Msimbazi River are mostly natural and only protected with vegetation. This could lead to bank erosion in case of high flow velocities. The maximum flow velocities vary significantly along the river chainage. Because bank erosion is also a continuous process that slowly increases over time, it is important not to only look at the most extreme events, but also more often occurring scenarios.
Therefore, sections along the river with a relatively high flow velocity are indicated for the most frequently recurring scenario available, T2 current.

The areas along the Msimbazi, where it is expected that bank erosion could cause potential hazards are indicate in Figure 21. It is expected that banks were the flow velocity is higher than 2.5 m/s for this scenario have a high risk of bank erosion. Between 2.0 and 2.5 m/s, the risk is classified as medium and between 1.5 and 2.0 m/s as low.

![Flow Velocity Map and Indication of Risk for Bank Erosion Along the Main Stream of the Msimbazi for T2 - Current Scenario](image)

This assessment is only indicative and not taken into account other relative important aspects for bank erosion, such as the local soil properties (or areas with unmovable bed/banks due to natural rocks or protection structures). Besides, the potential for bank erosion in sharp bends is even larger. This is because the flow tends to be higher in the outer bend. This is not included in this assessment of areas of risk. However, from satellite images over time it can be observed that there is morpho-dynamic activity in the sharp bends of the Msimbazi stream, mostly in the section upstream of Nelson Mandela bridge.

**Bank and bed erosion around bridges**

A bridge changes the natural flow regime and thus the sedimentation rates, especially in case the hydraulic capacity is too small. In this case, upstream the flow velocity decreases and downstream an increase of flow velocity (and turbulence) is found. The change in flow velocities results in morphologic changes to the river, hence the bed level next to scour near bridge piers and abutments. The Nelson Mandela road bridge is a clear example where these changes in the flow regime lead to a change in bed level. There is a jump present at the location of the bridge (observed during the field
visits at the kick off to be downstream of the bridge) where the bed level drops approximately 3m. The gradient of the bed level directly upstream of the bridge is lower compared to directly downstream of the bridge. This change in gradient is caused due to deposition of material upstream of the bridge and erosion downstream of the bridge. At Kawawa road bridge, the change in bed level gradient is also visible but to a much lesser extent.

Figure 23: Longitudinal profiles of the Msimbazi and Sinza river along the thalweg

The bed level change and riverbank erosion downstream of Nelson Mandela road bridge are clearly visible in photographs from recent site visits and in satellite images of February 2020.

Figure 24: Drop in bed level directly downstream of the concrete foundation of Nelson Mandela bridge

This erosion directly behind the bridge foundation could cause geotechnical instability of the bridge structure. In case of an extreme event when the bridge is overtopping, the forces on the upstream side of the bridge could become very high. Because the erosion is a continuous process, the risk for this kind of geotechnical failure will increase over time in case no extra measures are taken.

Due to the contracting of flow through the bridge, the water becomes very turbulent directly downstream of the bridge. This increases the potential for bed erosion as well as for bank erosion, which can be observed in Figure 23. The buildings are constructed...
very close to the river bank, hence further river bank erosion is likely to damage these assets.

Figure 25: Riverbank erosion downstream of Nelson Mandela bridge due to increased flow velocity and turbulence behind the bridge

**Sedimentation**

Sedimentation is difficult to assess in this Study, because the modelling is limited to hydraulics only and hence is not taking morphology into account. However, information on morphological processes in the Msimbazi catchment has been made available for this Study, among others the Dar es Salaam Geomorphology Assessment study (JBA (2018)). Based on these studies and observations of previous events it is known that during heavy rainfall events, large volumes of sediments, up to 100,000’s of cubic meters annually, are transported by the Msimbazi to the Middle and Lower basin. In areas where the flow velocities decrease, such as upstream of the bridges and in the flood plains, this causes sedimentation. In the flood plain areas, the deposit sediment could cause economical damage to assets and traffic interruption. The effect of these deposits in the riverbed on flooding cannot be evaluated, without including the morphologic processes in the hydrodynamic model.

**Vulnerability**

In this paragraph the results of the vulnerability analysis are shown for the do nothing (baseline) scenarios regarding impacts of relevant flood events. In this paragraph several types of impacts of floods are described as follows:

- Direct (tangible) impacts on assets. The physical (material) impacts of T2, T10 and T50 flood events are presented on various categories of assets in the Middle Msimbazi area. Maps are presented of exposed and vulnerable assets in wards and subwards in the Middle Msimbazi area. Moreover, the total
damage values (current scenario) and for the High-RCP 8.5 and Low-RCP 4.5 scenario are presented;

- Indirect (disruption) impacts: traffic and economic functions will be disrupted during and after some flood events. Due to flooding of key infrastructure (e.g. road bridges) and commercial or industrial areas production can be disturbed during and after the duration of the flood event;
- Socio-economic and environmental impacts: impacts on health and loss of life have occurred in past events in Dar Es Salaam due to flood events. This paragraph will also assess these impacts.

In this chapter we will present all impacts for the minimum and maximum extremes of the bandwidth of scenarios; the upper scenario combines RCP 8.5 with high socio-economic development and high urbanisation, whereas the lower scenario combines RCP 4.5 with low socio-economic development and low urbanisation.

**Impacts on assets**

**Buildings and infrastructure**

For each sub-ward in the middle Msimbazi River Basin area the following categories of assets have been included in the GIS based damage model.

- Residential buildings;
- Commercial buildings (business and offices);
- Industrial buildings;
- Hotels and restaurants;
- Religion & heritage;
- Health and sanitation;
- Government and education;
- Mix use;
- Roads;
- Bridges.

Main source for the exposure data, are the spatial layers obtained from the OpenStreetMap database (www.openstreetmap.org). For the analysis buildings and land use have been further processed on surface/area quantities and infrastructure has been further analyzed on linear/length. Amenities have been addressed separately as point locations.

Figure 25 shows the exposed existing density of the buildings in the Middle Msimbazi basin per sub-ward, and Figure 26 shows this for paved roads including railroads. This gives an indication of concentration and spatial spread of assets, infrastructure and its economic value. Densities and concentrations of assets and infrastructure is more in the east/ north east of the study area.
Figure 26: Exposure: density of buildings Middle Msimbazi area per sub-ward (2020)

Figure 27: Exposure: Density of paved roads and rail road per sub-ward (2020)
Based upon the overlays of the flood hazard layers (for different return periods and scenarios) and exposed asset maps (GIS analysis) the vulnerable assets have been determined. Figure 27 to Figure 29 show an example of the vulnerability of buildings for the Middle Msimbazi area for a T10 flood event in 2050 (High-RCP 8.5 scenario).

Figure 28: Vulnerability for flood event T10 buildings Middle Msimbazi area (RCP 8.5 2050)
Figure 29: Vulnerability of buildings to flood event T10, RCP 8.5 2050, high urbanization, zoomed in to Vingunguti

Figure 30: Vulnerability of buildings to flood event T10, RCP 8.5 2050, high urbanisation, zoomed in to Kawawa Road and Kigogo area

Funding partners: 
Implementing agencies:
As can be seen in the map especially the buildings in the areas surrounding the railroad bridge and Nelson Mandela road bridge are vulnerable for T10yr floods (blue, green and yellow colored assets). The main vulnerable assets are predominantly dwellings and the industrial zone around the river between the Nelson Mandela and Kawawa road bridges. For T50yr events the vulnerable areas are similar, but with a higher inundation level.

In below chart we present the categories of assets prone to floods for a T10 event. As can be seen residential areas are the dominant asset category affected, while the industrial buildings, close to the river in the lower part, are the second important asset category.

In below table we present the number of dwellings affected by various scenarios. As can be seen in Table 6 the number of dwellings with inundation levels over 25cm is expected to be over 27,000 for an event under T50, RCP85, high urbanization conditions in 2050, of which over 14,000 dwellings will experience an even larger flood depth than 1m. Calculations are based on inundated building areas in the OSM building database, divided by the average footprint size of residential buildings (80 m2).

Table 5: Number of dwellings Msimbazi Middle Basin area prone to different flood return periods for 2050, for the Lower and the Upper Scenario

<table>
<thead>
<tr>
<th></th>
<th>T2 Current</th>
<th>T2 2050 Lower Scenario</th>
<th>T2 2050 Upper Scenario</th>
<th>T50 Lower Scenario</th>
<th>T50 2050 Lower Scenario</th>
<th>T50 2050 Upper Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwellings flooded &gt; 0.25 m</td>
<td>9,092</td>
<td>9,712</td>
<td>13,251</td>
<td>23,447</td>
<td>27,054</td>
<td></td>
</tr>
<tr>
<td>Dwellings flooded &gt; 1m</td>
<td>1,840</td>
<td>2,073</td>
<td>3,797</td>
<td>10,831</td>
<td>14,268</td>
<td></td>
</tr>
</tbody>
</table>
Figure 32: Percentage of flooded buildings with flood depth > 0.25m, per ward for T10yr, for current, RCP45 and RCP85 scenarios

Looking at the fraction of flooded buildings per ward it is remarkable that 2 wards, Kigogo and Mchikichini, have flooded fractions exceeding 40%. Further, it can be concluded that from the wards that exceed 10% of flooded buildings for any of the scenarios the larger share is located in the downstream section (7 wards), against 3 wards (Segerea, Tabata and Vingunguti) in the upstream section.

Looking more specifically at the sub-ward level Table 7 and Table 8 show a ranking of flooded building area and percentage of flooded buildings within the sub-ward for the current, lower and upper scenario. From these tables it becomes clear that sub-ward Msimbazi Bondeni (index 26) will experience the largest flooding impact on buildings in the absolute and relative sense. Besides this, both tables show that in the downstream section all the sub-wards of ward Kigogo are severely affected. In the upstream section subwards Kombo (Vingunguti ward), Msimbazi (Tabata ward) and Liwiti and Amani (Segerea ward) are the most vulnerable with respect to flooding of buildings.

Table 6: m2 flooded buildings (footprint) ranked per subward for T10yr, current and two scenarios (RCP 8.5 - high urbanisation and RCP 4.5 – low urbanisation for 2050)

<table>
<thead>
<tr>
<th>#</th>
<th>Subward</th>
<th>Index</th>
<th>Ward</th>
<th>Buildings flooded [m2]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
</tr>
<tr>
<td>1</td>
<td>Msimbazi Bondeni</td>
<td>26</td>
<td>Mchikichini</td>
<td>167,948</td>
</tr>
<tr>
<td>2</td>
<td>Mbuyuni</td>
<td>9</td>
<td>Kigogo</td>
<td>135,063</td>
</tr>
<tr>
<td>3</td>
<td>Kigogo Mkwajuni</td>
<td>7</td>
<td>Kigogo</td>
<td>117,324</td>
</tr>
<tr>
<td>4</td>
<td>Kombo</td>
<td>30</td>
<td>Vingunguti</td>
<td>107,148</td>
</tr>
<tr>
<td>5</td>
<td>Kigogo Kali</td>
<td>8</td>
<td>Kigogo</td>
<td>90,435</td>
</tr>
<tr>
<td>6</td>
<td>Mnyamani</td>
<td>37</td>
<td>Buguruni</td>
<td>55,516</td>
</tr>
<tr>
<td>7</td>
<td>Msimbazi</td>
<td>20</td>
<td>Tabata</td>
<td>57,287</td>
</tr>
<tr>
<td>8</td>
<td>Mabibo Farasi</td>
<td>12</td>
<td>Mabibo</td>
<td>55,516</td>
</tr>
</tbody>
</table>

Funding partners: Implementing agencies:
Damage to assets

Based upon calculations from the damage model the direct physical damage to assets due to flood events has been estimated for the three scenarios (current, Low-RCP 4.5 – high urbanisation and RCP 4.5 – low urbanisation for 2050).

Table 7: Percentage flooded buildings (footprint) ranked per subward for T10yr, current and two scenarios (RCP 8.5 – high urbanisation and RCP 4.5 – low urbanisation for 2050)

<table>
<thead>
<tr>
<th>#</th>
<th>Subward</th>
<th>Index</th>
<th>Ward</th>
<th>Percentage Buildings flooded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Current</td>
</tr>
<tr>
<td>1</td>
<td>Msimbazi Bondeni</td>
<td>26</td>
<td>Mchikichini</td>
<td>56.1</td>
</tr>
<tr>
<td>2</td>
<td>Mbuyuni</td>
<td>9</td>
<td>Kigogo</td>
<td>45.4</td>
</tr>
<tr>
<td>3</td>
<td>Kisiwani</td>
<td>15</td>
<td>Mburahati</td>
<td>39.6</td>
</tr>
<tr>
<td>4</td>
<td>Kigogo Kati</td>
<td>8</td>
<td>Kigogo</td>
<td>39.4</td>
</tr>
<tr>
<td>5</td>
<td>Kigogo Mkwajuni</td>
<td>7</td>
<td>Kigogo</td>
<td>37.3</td>
</tr>
<tr>
<td>6</td>
<td>Kombo</td>
<td>30</td>
<td>Vingunguti</td>
<td>27.5</td>
</tr>
<tr>
<td>7</td>
<td>Mnyamani</td>
<td>37</td>
<td>Buguruni</td>
<td>22.0</td>
</tr>
<tr>
<td>8</td>
<td>Matumbi</td>
<td>19</td>
<td>Tabata</td>
<td>21.7</td>
</tr>
<tr>
<td>9</td>
<td>Barafu</td>
<td>14</td>
<td>Mburahati</td>
<td>20.2</td>
</tr>
<tr>
<td>10</td>
<td>Ilala Kota</td>
<td>27</td>
<td>Mchikichini</td>
<td>19.3</td>
</tr>
<tr>
<td>11</td>
<td>Mabibo Farasi</td>
<td>12</td>
<td>Mabibo</td>
<td>15.7</td>
</tr>
<tr>
<td>12</td>
<td>Msimbazi</td>
<td>20</td>
<td>Tabata</td>
<td>14.6</td>
</tr>
<tr>
<td>13</td>
<td>Amani</td>
<td>40</td>
<td>Segerea</td>
<td>14.5</td>
</tr>
<tr>
<td>14</td>
<td>Mwinyimkuu</td>
<td>5</td>
<td>Mzimuni</td>
<td>13.3</td>
</tr>
<tr>
<td>15</td>
<td>Idrissa</td>
<td>4</td>
<td>Mzimuni</td>
<td>11.3</td>
</tr>
<tr>
<td>16</td>
<td>Tabata Kisiwani</td>
<td>22</td>
<td>Tabata</td>
<td>11.1</td>
</tr>
<tr>
<td>17</td>
<td>Mandela</td>
<td>18</td>
<td>Tabata</td>
<td>10.9</td>
</tr>
<tr>
<td>18</td>
<td>Makumbusho</td>
<td>3</td>
<td>Mzimuni</td>
<td>10.4</td>
</tr>
<tr>
<td>19</td>
<td>Liwiti</td>
<td>41</td>
<td>Segerea</td>
<td>10.4</td>
</tr>
<tr>
<td>20</td>
<td>Matokeo</td>
<td>10</td>
<td>Mabibo</td>
<td>10.3</td>
</tr>
</tbody>
</table>
and High-RCP 8.5) for three flood events (return time T2, T10 and T50) for buildings, roads and land use. For each asset category a damage function was estimated, and the volume and value of assets was projected for 2050 and 2075 for these scenarios. A more detailed description of the developed damage model (including damage curves, asset values, AED approach etc.) is provided in Appendix III.

**Damage to buildings**

From the previous paragraph it became clear that residential and to a lesser extent industrial assets are the most important affected buildings. Most dwellings in the wards are more informal one storey houses for which a value of USD 11,000 per dwelling was assumed based upon information from Ilala Municipal town planning office. For the formal houses data from Zoom³ and Numbeo⁴ has been used which amounts to about USD 25,000 per dwelling. On average this implies about USD 13,000 was used in the model for average price of residential dwellings.

In the chart below the total value of estimated damage per asset category for a T10 flood event in for 2050 situation with RCP8.5.

![Figure 33: Distribution of damage values over asset categories for a T10yr flood event, 2050 situation with RCP8.5 and high socio-economic development](image)

As can be seen the amount of damage for a T10 event in 2050 is significant (exceeding 350 million USD) for the residential areas, which is over 75% of the total building damages. The second largest category is the damage to industrial buildings. Table 9 shows the calculated damage to buildings.

<table>
<thead>
<tr>
<th>Asset Category</th>
<th>t2</th>
<th>t10</th>
<th>t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business &amp; Offices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government &amp; Schools</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health &amp; Sanitation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hotels &amp; Restaurants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed Use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Religion &amp; Heritage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>$1.5 billion</td>
<td>$1.5 billion</td>
<td>$1.5 billion</td>
</tr>
</tbody>
</table>

Table 8: Calculated damage to all buildings for current and 2050 for the lower and the upper scenario, for three return periods, in million USD

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³ [https://www.zoomtanzania.com/](https://www.zoomtanzania.com/)
⁴ [https://www.numbeo.com/property-investment/country_result.jsp?country=Tanzania](https://www.numbeo.com/property-investment/country_result.jsp?country=Tanzania)
Low socio-economic development, low urbanisation upper section and climate scenario RCP45

<table>
<thead>
<tr>
<th></th>
<th>t2</th>
<th>t10</th>
<th>t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>1.7</td>
<td>2.9</td>
<td>4.3</td>
</tr>
<tr>
<td>Low socio-economic development, low urbanisation upper section and climate scenario RCP45</td>
<td>1.8</td>
<td>3.2</td>
<td>4.8</td>
</tr>
<tr>
<td>High socio-economic development, high urbanisation upper section and climate scenario RCP85</td>
<td>2.5</td>
<td>4.3</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Damage to Land Use

Direct damage to land use has been assessed for agriculture (farmland and orchards). From the results presented in Table 11 it is clear that damage levels to agriculture are smaller than for infrastructure.

<table>
<thead>
<tr>
<th></th>
<th>t2</th>
<th>t10</th>
<th>t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Low socio-economic development, low urbanisation upper section and climate scenario RCP45</td>
<td>0.4</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>High socio-economic development, high urbanisation upper section and climate scenario RCP85</td>
<td>0.6</td>
<td>1.0</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Overall direct damages

The damage fractions for the three categories (buildings, infrastructure and land use) are shown in the table below. From this table it becomes clear that buildings contribute
for a very large share to the total direct damages for the Msimbazi Middle Basin. From the buildings over 75% of the damage is related to residential buildings.

**Table 11: Damage fractions of damage of buildings, infrastructure and land use to total direct damage**

<table>
<thead>
<tr>
<th></th>
<th>T10 current</th>
<th>T50 2050 RCP85 high urbanization</th>
</tr>
</thead>
<tbody>
<tr>
<td>buildings</td>
<td>98.6%</td>
<td>98.9%</td>
</tr>
<tr>
<td>infrastructure</td>
<td>1.2%</td>
<td>0.9%</td>
</tr>
<tr>
<td>land use</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

The total direct damage is presented for the lower and the upper scenarios and for three return periods in a bar chart. As can be seen the damage is highest in case of a T50 event in the high RCP 8.5 scenario. Lowest damages are related to T2 current scenario. Socio-economic development (urbanization and income growth) have a major impact on the development of damage over time in the period 2020-2075. This is mainly because of the expected increase in quality of the building stock and content over such a long time period. Moreover, the level of future climate change and autonomous urbanization of the Msimbazi catchment area has a significant impact on the amount of asset damage over time. From Table 13, it can be observed that the damage for a T10 event with high development scenario and high climate change could be larger than the damage of a T50 event in the current situation.

**Table 12: Calculated direct damage for buildings, infrastructure and land use in 2050 for current and the lower and the upper scenario, for three return periods, in million USD**

<table>
<thead>
<tr>
<th></th>
<th>t2</th>
<th>t10</th>
<th>t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>128</td>
<td>239</td>
<td>368</td>
</tr>
<tr>
<td>Low socio-economic development, low urbanisation upper section and climate scenario RCP45</td>
<td>158</td>
<td>307</td>
<td>464</td>
</tr>
<tr>
<td>High socio-economic development, high urbanisation upper section and climate scenario RCP85</td>
<td>257</td>
<td>475</td>
<td>650</td>
</tr>
</tbody>
</table>

The spatial distribution of the direct damage (USD/ha) over the project area is presented in Figure 33 for 2050 upper scenario. The distribution pattern is comparable for the other assessed scenarios. Higher levels of damage are observable in the downstream section around the Kawawa Road bridges, particularly in wards Mchikichini and Kigogo. In the upstream section highest damage is observed around the Nelson Mandela Bridge and the Railroad Bridge in wards Buguruni and Vingunguti. In aforementioned areas the damage levels exceed USD 300,000 per ha, which are considered to be very high losses.
Traffic interruption

The transport system in Dar Es Salaam is affected by floods several times per year. Roads, the BRT system and rail services are inundated a few times annually. According to the results of the flood model, five bridges in the main stream of the middle Msimbazi area are affected by floods. These are: Kawawa road bridge, Nelson Mandela road bridge, railroad bridge, Vingunguti road bridge and Kinyerezi road bridge. A map of these bridges is shown below.
Due to flood events parts of these roads and these three bridges are inundated (for durations between 2 and about 5 hours depending on the event and scenario), which in turn causes severe traffic disruptions when inundation is above 30-40 cm above bridge road level. In recent events such as in January 2020, we have seen serious blockage of some bridges and severe traffic disruptions for a day until several days (also related to the removal of debris from the bridge deck after a flood event). Simulations have been done in the model of the Modelling Consultant for T2, T10 and T50 events in different scenarios. Results for Nelson Mandela bridge are shown in below figure. In Appendix IV results for the other bridges in all scenarios are shown.
In the table below the inundation levels, inundation period and out of order period is shown for the five bridges for the RCP 8.5 scenario (high). For the other scenarios, see Appendix IV.

**Table 13: Inundation of core bridges (above deck level) for different flood events (RCP 8.5 scenario in 2050)**

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Inundation deck level t10</th>
<th>Inundation deck level t50</th>
<th>Inundation period t10</th>
<th>Inundation period t50</th>
<th>Out of order period t10</th>
<th>Out of order period t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kawawa</td>
<td>22</td>
<td>100</td>
<td>2.25</td>
<td>5.3</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>Nelson Mandela</td>
<td>-</td>
<td>72</td>
<td>-</td>
<td>3.0</td>
<td>-</td>
<td>39</td>
</tr>
<tr>
<td>Railroad</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vingunguti</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kinyerezi</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

According to the hydraulic model results, both Kawawa and Nelson Mandela bridges are overtopped in case of rain events with return times t50. At t10 events, only Kawawa bridge is overtopped. The railroad bridge is not overtopped, but the flooding of the embankments of the rail can prevent trains from running in t10 and t50 events. For t2 events, the model outcomes do not result in overtopping of the bridge decks. For t10 and t50 events, Kawawa and Nelson Mandela bridges are inundated for more than 20 cm for about 3-5 hours. The assumption is that car traffic is blocked with more than 20 cm inundation above bridge road level. The overall period that bridges are blocked is usually longer than the inundation period due to cleaning or repair works. We have assumed that these works generally take 36 hours on top of the inundation period.
In case of Nelson Mandela road bridge and Kawawa road bridge, the maximum flow velocity does not increase for the more severe scenarios. This is probably mainly due to the overtopping effect.

The flood modelling results show no overtopping of the other bridges (rail road, Vingunguti, Kinyerezi). For 2020 (current scenario) Kawawa bridge and to a lesser extent Nelson Mandela bridge inundate above bridge road level for t50 events. Given the experience with floods in recent years, the model could underestimate inundation of the bridges due to absence of sedimentation effects in the hydraulic model (see more on this in text box in next sub section).

**Traffic disruption impacts**

Due to the flood events t10 and t50 traffic will be disrupted at Kawawa and Nelson Mandela bridges. Traffic disruption implies i) increased travel time due to congestion and rerouting (people have to take routes with larger distances) and ii) disruption of economic activities when workers, clients or visitors cannot reach the trip destination. The disruption of economic activities is most serious when several bridges are blocked at the same time and traffic to either side of the Msimbazi is impossible. This scenario is likely in t50 events when also Jangwani bridge (downstream) is blocked.

In order to calculate the traffic disruption impacts we have estimated the increased travel times and valued the travel time based on results of other studies (see for example World Bank, 2019)]. Traffic intensities are based upon traffic count data and the World Bank (2019) study. A traffic growth has been assumed of on average 4% annually based upon a GDP elasticity of the volume of traffic of 0.9. This is in line with the annual growth assumptions in the Dar Es Salaam Transport Masterplan. Based upon the World Bank 2019 study a value of time was used of 2017 of $0.85 per hour (adjusted to $0.95 in 2020). In the table below the impacts of travel time increases are shown.

*Table 14: Travel time impacts of blockage of core bridges middle Msimbazi for different flood events (RCP 8.5 high socio-economic growth scenario)*

<table>
<thead>
<tr>
<th>Impact</th>
<th>2020</th>
<th>2050</th>
<th>2075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average travel time increase due to rerouting (per event)</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Traffic intensity (affected no. vehicles per event)</td>
<td>4</td>
<td>218</td>
<td>470</td>
</tr>
<tr>
<td>Traffic time welfare loss (in case of the event in a year)</td>
<td>0.01</td>
<td>0.827</td>
<td>2.952</td>
</tr>
</tbody>
</table>

Note: The traffic intensity is based upon source DSM Traffic Counts 2017 for the relevant roads (12 hour count 6AM-6PM).

Estimations of traffic disruption losses have been made for the combined two climate change socio-economic growth scenarios. In above table assumptions are shown for the RCP 8.5 climate change scenario combined with high economic growth. High economic growth in this scenario results in growth of traffic intensities of around 3-4%
annually in the period 2020-2075 (in line with the high growth traffic growth in the Dar Es Salaam Transport Masterplan).

In the high climate change and economic – traffic growth scenario, the travel time loss for a T10 flooding can go up to about 3 -12 million USD for such an event. A T50 event can even result in a welfare loss of about 8 – 33 million USD (2050 resp. 2075) in the year of occurrence.

In the low climate change and development scenario, the Kawawa and Nelson Mandela bridges are only overtopped in the T50 flood event. In below table traffic disruption impacts are summarized for the two scenarios.

**Table 15: Traffic disruption costs for 2050 lower and upper scenario for all return periods in million USD (in current prices)**

<table>
<thead>
<tr>
<th></th>
<th>t10</th>
<th>t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP 4.5 - Low (low socio-economic development, low urbanisation)</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>RCP 8.5- high (high socio-economic development, high urbanisation)</td>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

**Sensitivity for higher bridge deck overtopping**
The hydraulic model does not contain sedimentation effects. Because sedimentation is likely to take place around the structures of the bridges, this implies that the above bridge deck overtopping figures might be too low, which results in an underestimation of traffic disruption damage in the scenarios. For this reason, a sensitivity analysis has been done for an additional 50 centimeter water depth at the bridge deck with longer durations of blocking of Kawawa and Nelson Mandela bridges (on average about 2-3 hours longer). This would result to USD 6 million damage for a T10 event and about USD 8.5 million damage for T50 event in 2050 (RCP 8.5-high scenario). For the RCP 4.5-low scenario this results in damage of traffic disruption of about 2.7 (T10) and 3.8 million USD (for a T50 event). Due to lack of specific hydraulic model runs these figures are indicative and are probably an underestimation, due to lack of flood model result effects on the other bridges.

**Economic disruption impacts**
Disruption of economic activities might happen when workers, clients or visitors have serious delays or cannot reach the trip destinations. The disruption of economic activities is most serious when several bridges are blocked at the same time and traffic to either side of the Msimbazi river is impossible. In that case the production is reduced in those economic activities which are sensitive to transport of workers, clients or products. This impact is very difficult to assess without further study (enterprise surveys). Therefore, in this study we have built upon the ratio’s used in the literature for indirect damages. In a number of other studies ratios are used with an average of indirect damage as % of direct damage of 18%. See for example: Briene et al (2002); Yangtze River Flood Control and Management Project (2003), HKV (2018).
Table 16: Economic disruption costs for 2050 lower and upper scenario for all return periods in million USD

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>t2</th>
<th>t10</th>
<th>t50</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP 4.5 - Low (low socio-economic development, low urbanisation)</td>
<td>28</td>
<td>55</td>
<td>84</td>
</tr>
<tr>
<td>RCP 8.5 - high (high socio-economic development, high urbanisation)</td>
<td>46</td>
<td>86</td>
<td>117</td>
</tr>
</tbody>
</table>

**Potential impact on critical assets**

**Bridges**

Apart from traffic disruption and damage to the pavement of the bridge caused by overtopping, another potential impact is structural damage to the mostly affected bridges (Kawawa road bridge, Nelson Mandela road bridge and Vingunguti bridge). The structures of these bridges might not withstand extreme (future) flow velocities, water inundation depths, erosion and scour. Particularly undermining of bridge abutments and box culverts due to scour and erosion could result in overturning (geotechnical instability) causing complete damage/collapse of the structure making the connection inaccessible with long term traffic disruption and large economic consequences. Just upstream of the Middle Basin a number of bridges have been totally damaged due to the river dynamics, indicating this risk is considerable (see Figure 36).

At Nelson Mandela road bridge and Kawawa road bridge, the insufficient hydraulic capacity of the bridge causes morphologic changes to the river bed. Downstream of these bridges erosion occurs due to the increase of flow velocity and turbulence. This, in combination with the expected increase in upstream forcing could result in risks regarding the structural integrity of the bridges.

It is also observed that some bridge heads do have little protection, as can be seen in Figure 36 at the railroad bridge. The protection is applied very locally, which causes erosion of the bank both upstream and downstream. Eventually, this could lead to geotechnical and/or structural failure of the bridge head.
Based on four other bridges in Tanzania an estimation was made of bridge reconstruction costs (about USD 100,000 per meter bridge length, see Appendix III). For the three mostly affected bridges in the Msimbazi Middle Basin this would compass total bridge reconstruction costs in the order of 5-20 million USD per bridge. Indirect damages could be much higher as this includes the potential economic disruption impacts, which could easily be in the order of hundreds of millions USD per bridge assuming reconstruction will take considerable time. For adequate estimation of the probability of complete bridge failure/damage in depth analysis of the structural integrity of existing structures is required. The latter would go beyond the scope of this Study.

Electricity supply
Electricity infrastructure is considered to be a critical asset, because power cuts have a large social and economic impact. Therefore, it could be of importance to protect these critical assets or reduce potential impacts of flooding to the asset.

In the project area there are no power stations and or sub-stations present. There is a high voltage power line that crosses the Msimbazi river between Vingunguti and Kinyerezi bridge through Segerea and Kipawa wards, as can be seen in Figure 37 the powerline connects Ubungo Power Station with a power substation close to the International Airport, to be determined if the line provides power to the airport. The line is supported by pylons, hence flood damage will occur only in case the pylon is washed away by the water or the foundation is undermined due to erosion. Only in severe events (T10 or T50), one of the pylons is located in an area with limited flood depth. However, the flow velocities can be in the order of 0.5-1.0 m/s, hence the foundation of the pylon should be stable against these flow velocities. However, with current information available it is difficult to assess any potential damage of flooding. This requires additional study (including interviews with the electricity company).
Fuel stations

Several fuel stations are located within the project area. These are mostly constructed along the main roads (secondary and primary). As can be observed in Figure 38 there are nine fuel stations which are prone to flooding in case of a T10 event. These fuel stations should take measures to prevent potential spills during flood events and prevent environmental damage.
Drinking water locations
The water supply system in the project area is dominated by boreholes (49%) followed by the official DAWASA supply system (35%) and private water vendors supply about 3% (Appendix I). Most of the informal settlements along the river -mainly dwellings - are not connected to the DAWASA water supply system. This finding implies that it is very likely that during floods the informal water supply systems are impacted due the unavailability of water or cope with pollution due to runoff during a flood. Flooding and related contamination of the drinking water supply has a large social impact (including negative impacts on health). Especially in the ward Tabata, according to the inundation maps most of the available drinking water points near the river will be exposed to flooding.

![Figure 40: Drinking water locations and flooded drinking water locations in case of a T10 - RCP 8.5 event](image)

Healthcare
The GIS analysis of the project area concluded that no hospitals were located in the vulnerable areas. Only one small private clinic is located in the area. Therefore, no hospitals are at risk for flooding in the project area. However, due to traffic disruption (mainly regarding Kawawa and nelson Mandela bridges in T10 and T50 events) ambulances transporting people could be affected resulting in potential loss of life during this type of flood events.
Socio-Economic and environmental impacts

In the paragraph a number of socio-economic and environmental impacts of flooding in Dar Es Salaam are discussed. Important socio-economic impacts of floods are loss of life, health impacts, and negative impacts on livelihoods of communities and disruption of social affairs. Environmental degradation can take place in case of flooding of waste disposition facilities and the urban drainage system.

As was shown in the section “Study Area and Baseline Conditions” about 550,000 people are living in the Middle Msimba catchment area. According to the overlay of flood maps and current dwellings about 45,000 (T2) to 125,000 (T50) people could be affected in 2050 by floods (>0.25 m) in the project area. Many of these people are to some extent affected by floods: fatalities or waterborne diseases in some families, loss or damage of properties (dwellings, commercial assets), disruption of economic and social activities (reduced incomes) and disruption of transportation.

In below figure we show the number of affected dwellings and people by flooding in the project area at different return periods.

![Figure 41: Number of dwellings and persons affected by floods for current, lower and upper scenario at different return periods and inundation levels](image)

Loss of life and health impacts

A significant social impact of flooding is loss of life. After previous flooding events casualties were reported due to flooding. In below table an overview is given of fatalities reported in recent flood events in Dar Es Salaam. As can be seen in below table the number of fatalities was between 12 and more than 40 people in recent flood events. Due to loss of lives, a number of children lose parents and become orphans.

<table>
<thead>
<tr>
<th>Flood event</th>
<th>People, health or assets affected</th>
<th>No. fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Oct 2020</td>
<td>10.000-20.000 people affected</td>
<td>12</td>
</tr>
<tr>
<td>18 April 2018</td>
<td>342 houses damaged, BRT disrupted</td>
<td>15</td>
</tr>
</tbody>
</table>
April 2014

20,000 people affected, 13 houses washed away, 600 houses inundated. 283 people were treated for waterborne diseases such as cholera.

Dec 2011

Over 50,000 people affected, 200 people were injured, with approximately 2,500 people missing, mostly children. About 10,000 people (approximately 2,000 families) were displaced. The flood event damaged a median value of properties per representative of 7.5 million Tsh (USD 3,200 in 2011).

Nov-Dec 2006

10,758 people affected


Apart from fatalities, flooding can cause waterborne diseases, such as cholera. In the April 2014 event, e.g., 283 people were treated for waterborne diseases. The reason is that often water quality is affected due to overflow of the urban drainage systems and waste and pollutants affect the water quality in the inundated areas.

**Risk of loss of life**

Loss of life causes a risk in case persons are in an area where the flooding causes persons to not be able to stand/swim or find a refugee on a higher building. Whether persons are in an area where the flooding could cause loss of life depends amongst others on:

- Time available to evacuate to a safe area;
- Distance to a safe area to evacuate;
- Willingness to evacuate.

In the Msimbazi basin, the flooding can be classified as flash flooding which implies that the flooding occurs within a very short period and the water rises rapidly. The time available for evacuation is therefore quite short in case there is no warning before the water starts rising. More time for evacuation can be created with a flood early warning system.

Whether people are at risk for drowning in case they remain in the area of flooding is depending on whether a person can stand stable in the water and the ability to swim of the person. For example children and elderly people are in general more affected by floods. The stability of persons in flowing water has been investigated by Jonkman and Penning-Rowsell (S.N.Jonkman, E. Penning Rowsell (2008)) and is one of the main parameters in estimating whether people in flooded areas risk drowning. This is expressed as a function between the water depth and the flow velocity (hv). This showed that depth-velocity products between 0.6 – 2 m2/s results in instability of the persons. Abt et al (1989)), determined the average value of human stability as 1.35 m2/s.
For this assessment, the risk for loss of life is evaluated only by critical depth-velocity product. In Figure 41, the risk for loss of life was indicated as the depth-velocity product for return period of T10 and a current scenario and 2050 with RCP 8.5 scenario. The risk was classified as follows:

- Low in case $hv < 0.6 \text{ m}^2/\text{s}$;
- Medium in case $0.6 \text{ m}^2/\text{s} \leq hv \leq 1.35 \text{ m}^2/\text{s}$;
- High in case $hv > 1.35 \text{ m}^2/\text{s}$.

Only the relevant area (downstream of Kinyerezi bridge) is shown, because more upstream the area with more risk is limited to the river flow area. The area with a high risk is for T10 – current scenario mostly limited to the flow conveying area of the river.

It can be observed that the area with the highest risk for loss of life is further downstream. This can be attributed to the relative higher flood depths here. The areas correspond to the back waters that are caused due to flow obstruction at the bridges. Upstream of the Nelson Mandela bridge, areas with potential for loss of life are located close to the river.
Figure 42: Indication of risk for life for T10 scenario Current (top) and 2050 with RCP 8.5 (bottom) for the most relevant part of the project area

Funding partners:  Implementing agencies:
The following can be concluded based on these results:

- Due to climate change (scenario RCP 8.5) the areas where a risk for loss of life due to flood events is present increases by approximately 20% to 2050;
- A more severe event (T50 instead of T10) shows an increase in areas for risk of approximately 25% (medium risk) to 50% (high risk);
- The increase of area with a high risk above T10 – Current is only attributed to areas in the flood plain.

Figure 43: Area size for different risk levels of loss of life for different scenarios

Impacts on livelihoods of communities

From the section “study Area and Baseline Conditions” it can be concluded that a large part of the people living in the area are poor and depend for their livelihood on small business (mainly food, textile and handicraft and small industries like textile, construction materials, wholesale, logistics), see also Anande and Luhunga (2019). Most of the empirical flood impact studies highlight that floods disproportionately affect lower-socioeconomic status households (see for example Rufat et. al, 2015). Apart from this growth of agricultural crops adjacent to the river is still an important source for food and income of many families.

Due to the nature of these activities, flood events can have a significant impact on the activity itself during and after a flood event. The economic activities are disrupted because of two reasons. Firstly, inundation above 1m results in serious damage to the commercial buildings or equipment used. This impact can destroy the economic activity and it can take serious time to rebuild the activity (semi-permanent impact). This impact is addressed as part of the direct asset damages. Secondly, flooding implies certain locations are inundated where the functioning of the activity itself (retail
selling, restaurants serving their clients etc.) for some time is disrupted during and just after the inundation period (a temporary impact). Thirdly, transportation is disrupted due to blockage of bridges and roads during and after the flooding. Both transportation of goods and the workers and accessibility of the services for potential clients are affected. For example, many of the food sellers use simple means of transportation (handcars, cargo bikes etc.), which are easily blocked by inundation of roads or bridges. Overall this implies that flood events have significant impacts on the livelihoods of people, ranging from permanent loss of assets and income, and temporary loss of income for a day or several days, depending on the flood event (inundation level and inundation duration).

In order to quantify the temporary economic disruption impacts, a survey among formal and informal businesses in the area would be needed. However, this was not possible within the scope of this study. Therefore, in the feasibility study a less sophisticated approach will be used (whereby assumptions will be made for these indirect economic impacts based on some factors from literature).

**Gender**

Women are particulary vulnerable for impacts of floods due to several factors: women are more involved in informal labor (at outside locations) affected by floods, women often own the dwelling furniture and cookware affected at more frequent (T1, T2) flood events with low inundation levels, women are affected by the exposure of water supply points and the resulting pollution (and waterborne diseases) affect children and women more heavily. Finally, many families are without men during flood events.

**Environmental impact**

The environmental impacts of flooding mainly relate to the problems regarding solid waste collection. Firstly, due to the increasing runoff (also due to deforestation) during heavy rainfall in upper areas of the basin, solid waste flows from the upstream parts to the middle and downstream basin area. Next to this – as reported above - a large fraction (about 70%) of solid waste generated is uncollected (often dumped in the project area). In times of flooding this solid waste mixes with the water and causes pollution and can impact the health of the population (water borne diseases etc.). This is especially affecting women and children in the project area in case of more severe floods (see gender analysis study, CDR International and Partners (2020)). Moreover, the solid waste blocks drainage channels and worsens the flooding.

**Total damage**

In this report various types of flood damage impacts have been estimated for the project area in for two future possible scenarios. These two scenarios show the bandwidth of potential impacts of flood events at different return times. The range of outcomes shows the uncertainty in possible future developments regarding climate change, socio-economic development and urbanization. The damages have been estimated based on the results of the hydraulic flood model of the Modelling
Consultant and damage modelling by the Feasibility Consultant. As is shown in table below direct asset damage (buildings, roads) can range from about USD 160 million (T2 event) to 650 million (T50 event) in 2050. Traffic disruption damages (travel time losses) could vary from USD 0 (T2) to 8 million for a T50 event, while economic disruption damages are ranging from 28 (T2 event) to 117 million (T50 event) USD in 2050. Traffic disruption damages could be underestimated due to absence of sedimentation effects in the flood model.

Apart from the monetized damages, flooding in Dar Es Salaam can result in significant negative socio-economic and environmental impacts. Generally women and children are affected hardest. From historic flood events it is known that 20,000-50,000 persons were affected and that there have been fatalities of 10 to more than 40 people per event. Socially, children have lost their parents and after the 2014 event almost 300 people were treated for waterborne diseases. According to the GIS analysis of critical assets, especially bridges, roads and electricity lines are at risk. Flooding also causes negative environmental and health impacts due to high amount of solid waste dumped (70% of solid waste is uncollected and waste is flowing from upper basin to lower areas).

In the table below a summary is provided of the potential damages in the project area in case of various flood events (for the year 2050).

<table>
<thead>
<tr>
<th></th>
<th>RCP 4.5 – Lower Scenario (low climate change, low socio-economic development, low urbanization)</th>
<th>RCP 8.5– Upper Scenario (high climate change, high socio-economic development, high urbanization)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T2</td>
<td>T10</td>
</tr>
<tr>
<td>Direct asset damage</td>
<td>158</td>
<td>307</td>
</tr>
<tr>
<td>Indirect damage - traffic disruption</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Indirect damage - economic disruption</td>
<td>28</td>
<td>55</td>
</tr>
<tr>
<td>Total monetized damage</td>
<td>186</td>
<td>362</td>
</tr>
</tbody>
</table>

**Main findings and conclusions of Impact assessment**

The following main findings and conclusions can be drawn based on the conducted impact assessment for the Msimbazi Middle Basin:

1. **The Msimbazi Middle Basin is already seriously vulnerable to pluvial and fluvial flooding in the existing situation**: the percentages of flooded areas (flood depths > 0.25m) within the study area are 10% for T2yr, 15% for T10yr and 19% for a T50yr event. During a T50 event about 1,500ha of the Msimbazi Middle Basin will inundate with flood depths larger than 25cm. The vulnerability to flooding in concerned area will increase considerably in the future (projections 2050 and 2075) under a do-nothing scenario;
2. **(Unplanned) urbanization is the main cause of the increasing flood risks in the future.** About 70% of the increase of hazards due to flooding for the period 2020-2075 is caused by autonomous urbanization (increase of paved areas), while 30% is caused by climate change (increasing rainfall and more extreme events). With adequate spatial planning a large share of this expected future flood risk can be avoided. Both a moderate climate change scenario (RCP 4.5) and an extreme climate change scenario (RCP 8.5) will contribute to increased flood risk in the future, where the risk with RCP 8.5 scenario in 2050 is higher compared to RCP 4.5 in 2075;

3. **An increasing number of dwellings will be affected by flooding.** In the existing situation about 1,800 dwellings will be flooded during a T2yr event and 9,600 dwellings will be flooded during a T50yr event. In 2050, for an extreme climate change scenario (RCP 8.5) and autonomous urbanization, this will increase to 3,800 and 14,300 dwellings for T2yr and T50yr events respectively. Volume growth of the building stock has not been taken into account in this calculation;

4. **The direct asset damage caused by a flood event can go up to about USD 650 million in 2050 and is much higher than the indirect damage** (temporary economic and traffic disruption). In 2050 the bandwidth for expected flood damage (direct and indirect) with a T10yr event is between USD 362 million and USD 564 million, for a T50yr event in 2050 expected flood event is between USD 552 million and USD 775 million. Main flood damage is and will be on buildings (>95% out of total damage). From the buildings, residential buildings is the largest share being affected (> 75% out of damage to buildings);

5. **Traffic disruption and economic disruption damage can go up to about USD 120 million (T50 in 2050), but are relatively low compared to the direct asset damage.** However, it is expected the estimated numbers are an underestimation, because sedimentation processes have not been included in the hydro-dynamic modelling runs. Sedimentation around bridges can be significant (reference is made to Jangwani Bridge in the Lower Basin) and could become the main cause of overtopping in the future. Finally, some of the bridges are in poor condition and in case of structural damage due to an extreme event, the repair works increase significantly as well as traffic and economic disruption;

6. **Flooding in Dar Es Salaam will result in significant negative socio-economic and environmental impacts for the communities in the area.** From historic flood events it is known that 20,000-50,000 persons were affected and that there have been fatalities of 10 to more than 40 people per event. During floods the livelihoods of people (and especially women with informal employment) are significantly disrupted. Problems
with improper or inadequate solid waste management (70% uncollected waste) causes pollution and adverse health impacts (water borne diseases etc.), especially for women and children. **Women and children are more vulnerable for flooding compared to men due to a number of factors reported in the gender analysis report** (background report of this assignment).

7. The hotspots concentrate around infrastructure crossings (bridges) and industrial zones in the project area. In the next section these hotspots will be discussed in more detail.

**Identification of hotspots**

Based on the vulnerability analysis so called hotspots have been determined where intensity and impact of flooding is relatively largest. By choosing the hotspots, possible effects downstream and upstream of bottlenecks, obstructions and (limited) flood plain area have been taken into account. On a catchment wide scale level it is observed that the vulnerability to flooding increases from upstream to downstream; most vulnerable is the Lower Basin, followed consecutively by the downstream section and the upstream section of the Msimbazi Middle Basin. For the Msimbazi Middle Basin the following four hotspots are determined (from downstream to upstream):

1. Kawawa Road Bridge and upstream area affected by back waters;
2. Kigogo ward;
3. The Industrial zone (referred to ‘Zone B’ in section “Study Area amd Baseline Conditions”);
4. Railroad Bridge and upstream area affected by back waters.
Generally, flooding in the Msimbazi Middle River Basin is caused by four main factors; i) insufficient hydraulic capacity of the Msimbazi River profile at certain locations, ii) back water effects and piling up of water upstream of structures, e.g. bridges, with an insufficient hydraulic capacity, iii) inadequate urban drainage infrastructure and inadequate solid waste management and iv) decrease of ‘green areas’ in the catchment has resulted in reduction of infiltration of precipitation and a direct run off response. For most of the river stretches and tributaries in the project area the hydraulic capacity is too small, so with events with a high frequency, the river can already overflow over the riverbanks and embankments. During these events the flood depth increases upstream of the bridges mainly because of the backwater curves. Also, gradients in flow velocity are observed at these locations because of the limited hydraulic capacity thereby also triggering erosion and sedimentation processes. By addressing the hotspots, a large share of the flood risk could be potentially mitigated. Urban drainage infrastructure has been taken into account, however in this Study focus is on riverine flooding and flood mitigation strategies have been framed as such.
IDENTIFIED MEASURES AND STRATEGY

Introduction

The identification of measures and development of a suitable flood mitigation strategy for the Msimbazi Middle Basin consist of the following:

1. Identification of measures while taking into account existing flood mitigation strategies and plans;
2. Develop an initial flood mitigation strategy;
3. Testing of effectiveness of measures in the model of the Modelling Consultant;
4. Charrette on the results of the previous steps together with the stakeholders and communities with the purpose to prioritise the measures and refine the identified strategy together.

This section addresses step 1, 2 and 4 from above list. Step 3 has been partly undertaken during the process of identifying measures and the strategy, but has been completed and reported in the Feasibility Report of this Study.

Flood risk management strategies

Flood risk management is an approach to identify, analyse, evaluate and control/manage the flood risks in a given system. A general scheme for flood risk management is presented in Figure 44. The following steps are identified:

1. Definition of the system, the analysed hazards and the scale and scope of the analysis;
2. A quantitative analysis where the probabilities and consequences are assessed and combined into a flood risk or vulnerability map;
3. Risk evaluation: With the results of the former analyses the risk is evaluated. In this phase the decision is made whether the risk is acceptable or not;
4. Risk reduction and control: Dependent on the outcome of the risk evaluation measures can be taken to reduce the risk. Measures could concern structural and non-structural measures. It should also be determined how the risks can be controlled, for example by monitoring, inspection or maintenance.

Figure 45: Flood risk management approach
For this Study step 1, 2 and 3 of the flood risk management approach are performed in the Vulnerability Analysis. Step 4 is partly addressed in this chapter and to be further elaborated in the Feasibility Report. Generally, for risk reduction and control commonly used flood mitigation strategies, viz. adapt, protect and retreat are followed (see Figure 45).

| Figure 46: schematic representation of flood mitigation strategies |

Time is an important consideration in the flood risk mitigation strategy. Start/moment of implementation, implementation time, the time it takes for a measure to become effective and its design life are key time parameters for planning of the measures. This can differ significantly for structural and non-structural measures. Usually measures with a direct effect after implementation with a short design time (< 10 years) are referred to as temporary measures, whereas measures with a much longer design life can be considered permanent implementations. Combinations of temporary and permanent measures could ensure that the overall scheme (strategy) caters for acceptable flood risk levels in the short and long term.

A number of previous studies have addressed flood risk mitigation strategies for the Msimbazi catchment area and as such already form a basis for the identification of measures for the Msimbazi Middle Basin and development of area specific flood management strategies. In the following two sub-sections two main previous studies are elaborated.

**Msimbazi Opportunity Plan**

The overall long-term strategy of the Msimbazi Opportunity Plan (MOP) to redesign the entire Msimbazi River catchment area and provide sustainable and integrated solutions to prevent people and assets from flooding comprise 4 strategies as follows: **Mitigate, Protect, Transform and Govern:**

- The Mitigate strategy aims to limit the severity of flood hazard in the long and short-term including restoration of the natural ecosystem and make room for the river, increase the water retention and harvest rainwater, control erosion and sedimentation and enhance the water conveyance capacity;
- The Protect strategy aims to establish location-specific protection of people, livelihoods and assets from flood exposure, and comprises interventions to protect against flooding and resettle people and business assets;

- The Transform strategy aims to convert the most flood-prone areas of the river valley into a multipurpose City Park which can serve as a buffer during extreme flood events and redevelop flood safe surrounding neighborhoods and comprises interventions to improve the Msimbazi river water quality, improve solid waste management.

- The Govern strategy seeks to put in place a planned and coordinated process of integrated governance and thus stop the current uncontrolled urbanization process that is making the river valleys and basin unsafe and unhealthy for human activity. The Govern strategy comprises good governance for coordination, cooperation, communication and finances.

Stage 1 of the MOP is the implementation of the Detailed Plan for the Lower Basin. The two following stages specifically address the Msimbazi Middle Basin; stage 2 covering the area between Kawawa Road Bridge and Nelson Mandela Road Bridge and stage 3 covering from Nelson Mandela Road Bridge upstream. A key principle adopted is that (hydraulic) river interventions with direct effect on the hydraulic regime should be implemented sequentially from down to upstream. By doing so, river flooding related issues can be tackled structurally without leaving behind bottlenecks that hamper the conveyance downstream. Working upwards from Selander Bridge through the stages 1, 2 and 3, the drainage capacity can be increased by structural engineering works. For the three stages the following interventions are proposed:

- Sediment removal;
- Deepening and widening the main river channel;
- Re-use the dredged materials for terrace building;
- Remove obstacles from the river plains, and;
- Widening bridge openings and raising bridge deck levels.

Hydrological, non-structural type of interventions to change the catchment’s water balance and river response have been proposed for the wider catchment. Reforestation of Pugu-Kazimzumbwi Forest Reserves is a good example as proposed measure in the upper basin. Usually it takes a long time before positive effects can be gained after implementation of such measures. Hence, its development and implementation should happen soon.

The Strategy and Management Framework (Msimbazi Opportunity Plan Volume A – Strategy and Management Framework (2019)) and the Detailed Plan for the Lower Basin (Msimbazi Opportunity Plan Volume B – Detailed Plan for the Lower Basin (2019)), the two main documents of the MOP, provide a proper basis for this study given its multi-sectoral, multi-scale and integrative and inclusive approach. The
proposed strategies and corresponding interventions have been further applied and tested in this Study.

**Special Planning Area**

In response to the identified needs and requirements for flood mitigation planning during the process of developing the MOP a review of the Msimbazi Planning Area (gazetted in 2011 by the Ministry of Lands Housing and Human Settlement Development - MLHHSD) has been executed in 2018. Main purpose of the Msimbazi Planning Area in 2011 was to enable the development of a City Park in the Msimbazi Valley and to enhance human safety (Government Notice No. 227 published on 05/08/2011). However, over the years it became evident flooding is a real issue in the valley. Gradually the principle of the demarcation of the valley shifted more to a human safety focus; the valley should be developed in such a way the living environment is safe and living conditions can improve. Also it was needed to extend the area of demarcation to include the tributaries and the Msimbazi River up to Pugu Hills. The development of a City Park will play a major role in this. The boundary that was set in 2011 is very coarse and has an insufficient accuracy to align the boundary to physical features. Besides this an update was required because Dar es Salaam develops with a rapid pace. The review resulted in an adjusted, accurate and practically implementable boundary for the Msimbazi River Valley Planning Area, taking into account latest flood risk studies (COWI (2018) and Deltares (2018)) the development of the MOP. In the figure below the boundary is shown.

![Figure 47: Refined Special Planning Area boundary 2018](image-url)
The Refined Special Planning Area boundary is to guide the development of a detailed low flood risk planning scheme for the Msimbazi River including some tributaries. The boundary has no legal implementation status yet. However, with more feasible planning schemes and flood mitigation measures being developed within this boundary also more substance is created to get the boundary approved and in turn enable implementation of the plans.

For this Study the Refined Special Planning Area boundary is considered an important anchor for justification of measures which will affect the areas adjacent to the river courses.

**Identified measures**

As a first step, based on the vulnerability analysis and previous studies conducted and by taking into account the general flood risk management strategies, the following potential measures have been identified for the Msimbazi Middle Basin.

**List of measures**

a) **Hazard forecasting, early warning systems and emergency plans** - Flooding in the Msimbazi Basin is characterized by a very short response time between the rainfall event and the subsequent floods, giving affected communities and businesses little response time. Some actions have proven effective to reduce community vulnerability. With support from TURP the existing Early Warning System is being improved and capacity building has started for disaster risk management, disaster response plans and emergency evacuation plans, with coordination at Mtaa level. The system is largely based on TAHMO\(^5\) weather stations distributed over Greater Dar es Salaam Region. The existing Early Warning System can be further developed and focussed on the Msimbazi Middle Basin area to address specific vulnerabilities revealed in this Study, specifically to prevent loss of life.

\(^5\) Trans-African Hydro-Meteorological Observatory (TAHMO); [www.tahmo.org](http://www.tahmo.org)
b) **Dredging deeper and/or wider river channels** – The idea is to increase the hydraulic capacity of the existing river channel courses in order to reduce the flood hazards of areas adjacent to concerned river stretches. By doing so the river banks will overflow less frequently, hence the river will start to overflow with higher return periods compared to a river profile which is not deepened and/or widened. It can also be considered to lower or widen floodplain areas where deemed necessary. In the Msimbazi Middle Basin dredging should be executed in the dry seasons. Excavators will be needed for removal of the soil from the channels and plains, and trucks will be needed for disposal of the material.

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**Figure 48:** At least 4 TAHMO weather stations are located in Msimbazi Middle Basin or further upstream, forming a data source for a further applied and specified EWS for the Msimbazi Middle Basin

**Figure 49:** Options for dredging a deeper and/or wider river channel and flood plain

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**Dredging deeper channels**

**Dredging deeper and wider channels, including remoulding flood plains (after Msimbazi Opportunity Plan Volume B – Detailed Plan for the Lower Basin (2019))**
c) Existing bridges which seem to have a limited hydraulic capacity can be rebuilt by increasing the bridge span and/or raising the bridge deck. This will increase the area of cross-sectional flow below the bridge. With this measure interruption of traffic on the bridge by flood overtopping can be avoided or reduced. Also, the flood risk to upstream areas can be reduced because of smaller backwater effects, especially by increasing the span of the bridge. Given the high morphological dynamics of the Msimbazi River and in case it is not possible to have one span for the bridge between two abutments, it is strongly recommended to plan for piled bridges (beam bridges) instead of box culverts.

![Figure 51: Increasing bridge spans and/or raising the bridge deck. Beam bridges are preferred.](image)

d) River training works – Generally, river training works can serve two purposes; i) realising a project, such as construction of a bridge across a river or allowing inland waterway transport to take place, and ii) solving an problem, such a river bank erosion or reducing flood risk. Both purposes might be applicable to the Msimbazi River. River training works, apart from various types of earthwork and dredging, consist of typical fixed hard structures like flow guiding structures and bank
protection. For the Msimbazi Middle Basin the following two applications are foreseen:

i) Flow guiding structures for existing bridges which need to be adapted or new bridges to be developed. Turbulence up- and downstream the bridge and eddy currents can be limited and back water effects upstream can be reduced. Flow guiding structures can be bank reinforcements, groynes, sheetpiles, concrete walls etc. (Detailed information on some of the above-mentioned structures can be found on the CFF’s website – Ecological Infrastructure Toolkit\(^6\).

ii) Reinforcement of critical banks can be proposed for sections where it is desired to fix the river bank to a certain alignment and prevent it from erosion. Main function is to prevent further land loss and prevent undermining and washing away of structures located behind the river bank. Reinforced banks can also serve to reduce flood risk to the land behind the protection. Main materials could be rubble rock, gabions or (concrete) mattresses.

\[\text{Figure 52: Gabion wall revetment (left) and typical armour stone revetment (right; after CIRA (2007))}\]

e) Levees and embankments can be proposed as protection measures to increase the safety level of critical assets in the project area by making it watertight. Typical critical assets are power substations, hospitals, water or sewer treatment plants, (chemical) industries and storage etc., for which (local) flooding could have substantial impact for a much larger area. For example, power cuts for city districts and spread of pollutants that could lead to diseases. Full protection of large flood prone areas by means of this measure is not advisable for the Msimbazi catchment area. Large scale protection not only concerns the implementation of the embankments but also often requires an upgrade of drainage systems in the protected subbasins, including e.g. controllable outlet structures in the embankment or potentially a pumping system to operate during the flood events. In turn this requires more operations and maintenance and makes the whole scheme rather complex and costly (CAPEX and OPEX). However, embankments could form a measure to reduce residual flood risk for larger areas.

in combination with other measures. By doing so the dimensions of the embankment can be kept relatively small which also better facilitates local technical and spatial integration.

![Figure 53: Principle of a dike or levee and typical composition without armour protection](image)

f) **Resettlement** is an intervention that can be proposed if other location-specific protection or mitigation measures are not feasible or do not result in acceptable flood risk levels. If this is the case, affected people and businesses can be relocated supported by Resettlement Action Plans and Livelihood Restoration Programs in line with international best practices. Resettlement of communities can have different compensation options: i) replacement housing within the Msimbazi Special Planning Area, ii) cash, iii) in-kind compensation of land outside the Msimbazi catchment area that includes shared community services such as water points and public services, and iv) voluntary relocation with associated negotiations. After resettlement the remaining structures should be removed from the flood prone areas to reduce obstruction of water flow.

g) **Terrace building with dredged materials** is a way to reuse the sediment yield from capital and maintenance dredging/ excavation works as material required for the construction of terraces along with river training measures such as reinforced banks/ terrace edges. Different terrace levels can be created having different flood safety levels to accommodate different urban functions. Initial findings from associated studies on sediment characteristics indicate that the quality of the soils in the river bed and the flood plains is sufficient to serve as fill material for stable terrace formation.
h) **Reforestation** – Preserve and grow the natural forests in the upper basin through reforestation of the Pugu and Kazimzumbwi Forest Reserves and rehabilitation and stabilization of its slopes. With this measure the infiltration and evaporation will be increased, thereby reducing the run off. Despite the upper basin being is not part of the Middle Msimbazi Middle Basin, this measure is mentioned as it could positively impact the Study area with reduced peak flows and corresponding lower flood risk levels.

i) **Local rainwater harvesting and local infiltration and zoning** - Install rainwater collector barrels in the houses and other buildings in the Msimbazi catchment area. Such barrels/water tanks are locally available and could be manufactured from...
recycled plastic waste material, collected from the river corridor (a small business case option). The provision of barrels in exchange for waste plastic collection if organized at community level could provide a needed incentive for clean-up. This approach would allow households/buildings to use collected water when needed (short-term storage), and to contribute to reducing peak flows. Besides this, promote local infiltration technologies in the building sector. For example, replacing hard or otherwise impervious surfaces with water permeable surfaces and providing small ponds in the flood plain could provide water for irrigation during the dry season.

j) **Storm water retention ponds** – Rain water retention structures can vary from a low dam or weir which overflows when it has been filled up to reservoirs with regulating structures for the in and/or outflow. Because of the large sediment load during peak flows such measures can be combined as sediment trap for controlled sand mining.

k) **Flood proofing** consists of measures to protect individual buildings or structures from flooding. Reinforced houses that will survive flooding, raised buildings (e.g. on piles), barriers, raised tube wells are examples of structural flood proofing measures. A more simple approach is to move properties and belongings to a higher point in the building, like a second floor or tall shelves, or tie them up to the ceiling. Removable doors and placing electrical sockets higher on the walls are also flood proofing measures.

**Initial sketch and building blocks**

As a second step prior to the charrettes the Feasibility Consultant has developed an initial flood mitigation strategy by means of desktop analysis on the assessed vulnerability, the identified measures and brainstorm sessions with the experts involved. Different disciplines (like hydraulic engineering, urban/landscape planning and environmental and social expertise) were brought together in multiple physical and virtual sessions to ensure a balanced design process encouraging out-of-the box thinking while already taking into account main criteria like effectiveness, sustainability and suitability. Figure 55 shows a map with a sketched plan for mitigation measures in the Msimbazi Middle Basin.
Key identified features shown in the brainstorm map are:

- Suggestion to extend proposed terraces in the Detailed Plan for the Lower Basin (MOP) further upstream into the downstream section of the Msimbazi Middle Basin (Zone A as presented in section “Study Area and Baseline Conditions”);
- the logistic zone (Zone B) functioning as a bottleneck for the Msimbazi River by leaving very small room for the river;
- Combination of adapting the river and small scaled protection measures while minimizing need for resettlement in the upstream section (Zone C).

Further to the brainstorm sessions the following measures with a large potential to become part of a flood risk reduction strategy for the Msimbazi Middle Basin have been selected for testing its effectiveness in the model of the Modelling Consultant and for further elaboration and evaluation during the charrettes. Table 19 shows the 5 selected measures and its principles.
<table>
<thead>
<tr>
<th>Measure 1: Widening and/or raising bridges</th>
<th>Measure 2: Creating wider or deeper river channels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overview</strong></td>
<td><strong>Overview</strong></td>
</tr>
<tr>
<td>Table 19: Overview selected measures</td>
<td>Table 19: Overview selected measures</td>
</tr>
</tbody>
</table>

**Measure 1: Widening and/or raising bridges**

Widen and raise Kawawa bridges crossing Msimbazi and Kibangu and Nelson Mandela and Railroad bridge to prevent traffic and economic disruption and reduce flood risk to upstream areas by minimizing back water curves. Indicative cost level USD 5 – 20 million per bridge.

**Measure 2: Creating wider or deeper river channels**

Dredge deeper and wider channels for Msimbazi River and Kibangu tributary to increase the hydraulic capacity of the river and reduce flood risk to adjacent present buildings, assets, land use and living areas. Indicative cost level USD 5 – 20 million for main river stretches.

**Measure 3a: Lowered flood plain with emphasised physical edge**

Small embankments, largely formed by reusable soil material which becomes available by river bed and flood plain excavation to further reduce residual flood risk of areas located behind the embankment line.

**Measure 3b: Lowered flood plain with raised terraces at the edge**

Raised sections of land for flood safe development of certain (urban) landuses. Fill material consisting of reusable soil material from river bed and flood plain excavation.
Measure 4: Resettlement

Make room for wider river bed and floodplains with emphasized edge to protect remaining settlements. Indicative cost levels could be in USD 10’s to 100’s million for Msimbazi Middle Basin.

Measure 5: Re-greening

Replanting of physical edge and flood plains with trees and vegetation as well as in the urban tissue in the higher reaches. Reforestation of Pugu hills and other sections in the upper catchment is also proposed.

The sequence of measures 1 to 5 could form the basis for an implementation schedule. The strategy is to prioritize adaptation measures (e.g. adjusting bridges, room for the river), protect where flood risk is still unacceptable after implementation of the adaptation measures, and consider retreat (resettlement) as the last resort if adapting and protecting is not sufficiently mitigating flood risk. Re-greening of the catchment area is considered an important measure which can be applied as an adaptation measure in combination with resettlement. Re-greening should be adopted in Dar es Salaam spatial and urban planning practices.

Charettes

The Charrettes have been a key activity in the Study process and took place on 13\textsuperscript{th} and 14\textsuperscript{th} of January 2021 at the New Africa Hotel in Dar es Salaam. The objectives of the charrettes were as follows:

- To build consensus on the project, the impact and the implementation;
- To update the stakeholders on the progress of the modelling and vulnerability analysis;
- To verify the results of the vulnerability analysis and the identified hotspots with the stakeholders;
- To let the stakeholders interactively participate in the design process by ranking the design criteria and scoring the measures;
To let the stakeholders participate in the spatial integration of measures in the urban tissue;
To gain local information on the project area and important aspects to consider.

Because COVID-19 imposed a restriction on the number of participants per day, the stakeholder group was split over the two days with each day the same programme. On the first day (13th January), the participants were stakeholders from governmental and scientific institutions. The second day (14th January), the participants were community representatives, e.g. ward leaders and representatives. On the second day a few participants were present that were not able to participate on the first day of the workshops.

Due to the COVID-19 restrictions from European countries, not all experts were able to travel to Tanzania. In order to cover all aspects of the project and have the input from all experts, the workshops were conducted in a hybrid form. Two international experts and two local experts of the Feasibility Consultant were present in Tanzania to organize and moderate the charrettes, whereas the other experts, including experts from the Modelling Consultant and representatives from GIZ, joined and contributed online via a video call. Most of the presentations were given by the experts via interactive video call and the experts could follow the break-out sessions and participate in the Spatial Design session via an online collaboration board (Miro). A memo on the charrettes is provided in Appendix V.

*Figure 57: Group photo of the participants of the charrettes on 13th January 2021*
All the results of the break out session, both virtually and physically, have been consolidated in overview sheets for both charrettes days (see Appendix VI). As a summary the following main results have been gained from the charrettes:

- Reduction of flood impact was found to be the most important criterium for a flood mitigation measure. On the second place is Social acceptance,
underlying the sensitivity and severeness of the flooding issues in the study area. During the second day, with the community representatives, also political acceptance scored very high. The general thought is without political acceptance there will not be significant transformation to increased resilience to flooding.

- Out of the building blocks (see section Vulnerability Analysis) raising and widening of bridges scored highest, followed by interventions which include dredging and excavation activities to provide room for the river. Resettlement scored lowest for all criteria, thereby clearly marking this is a very sensitive topic.

- From the spatial design session the following general conclusions can be drawn:
  - All groups indicated to widen/raise some of the main bridges, especially Kawawa road bridge and Nelson Mandela road bridge;
  - Even though the resettlement scored quite negative in the scoring sessions, all groups indicated that in some locations resettlement might be the best choice, especially in Buguruni;
  - Most groups were in favour of several forms of dredging the river channel, with potential increased floodplains and/or terraces;
  - Most of the groups proposed nature-based solutions, such as rainwater harvesting, reducing paved areas and reforestation/planting more trees as measures for the entire catchment area. Generally re-greening of the study area was considered to be the most sustainable solution in view of flood risk reduction as well as potential (co-) benefits like reduced heat stress, food production and a pleasant and aesthetically attractive living environment.

**Defined flood management strategy**

Based on the Vulnerability Analysis and the charrettes the Feasibility Consultant is developing a hybrid flood mitigation strategy combining long term multi-sectoral integrated sets of measures and short term measures focusing on removal of hydraulic bottlenecks. The results of the break-out sessions are duly taken into account in the development of this strategy.

**Long term components** consist of measures with longer implementation schedules with basin wide long-term positive effects. This part of the strategy should be managed on a multi-sectoral integrated level with impact on the urban tissue and is expected to require a longer implementation time. The measures of the long-term components are focused on increasing infiltration and retention capacity and greening of the Middle Basin by Nature Based Solutions and Spatial Planning including...
resettlements on the most critical locations. Creating more room for the Msimbazi River and its tributaries also belongs to these measures. Planning and design of such measures and resettlements should be conducted the soonest to prevent further increase of flood impacts due to climate change and further urbanization in the future.

**Short term components** - Short term implementation measures, mostly on a sectoral level, with immediate positive effects. These are measures that focus on infrastructural works and do not require large scale resettlements. It is expected that both political and social acceptance for these measures will be high, which enables rapid implementation. The short-term measures focus on removing hydraulic bottlenecks like raising and widening bridges, localized dredging/excavation activities and small-scale resettlements. After implementation of the short term measures a residual flood risk will remain, hence the reason to start planning and implementation of the long-term measures simultaneously.

**Way forward**

The next step in this Study is the development of the Feasibility Stage (Phase C of this Study), which will include the technical feasibility, cost estimations and financial and economic feasibility aspects for the various measures as part of the defined Flood Management Strategy for the Msimbazi Middle Basin
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APPENDIX I – SOCIAL AND ENVIRONMENTAL BASELINE

Provided as Annex to this document
APPENDIX II – SOCIO-ECONOMIC DEVELOPMENT AND BASELINE SCENARIOS

In this Appendix the baseline scenarios for the vulnerability analysis are presented in more detail. Both socio-economic development (including future urbanization) and future climate change are affecting the vulnerability of the middle Msimbazi basin for floods. The future development of urbanization and climate change is uncertain and will be discussed in this Appendix.

Socio-economic development

Tanzania is growing fast for a number of years. The average volume growth of GDP between 1990 and 2020 was about 5,1% annually. Population of Tanzania increased from 5,4 million inhabitants in 1990 till about 58 million in 2019. Dar Es Salaam is Tanzania primary city and is growing fast. Population increased in this megacity from 1,47 million to 6,7 million people in 2019 (Source World Bank open data). Most of the urbanization in Dar Es Salaam is informal and unplanned (due to lack of formal spatial plans).

In table below some historical growth rates of key indicators are presented.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP growth (constant prices)</td>
<td>5,14%</td>
<td>3,15%</td>
<td>6,21%</td>
<td>5,79%</td>
</tr>
<tr>
<td>Population growth % (national)</td>
<td>6,50%</td>
<td>3,10%</td>
<td>3,20%</td>
<td>3,00%</td>
</tr>
<tr>
<td>Population growth % (Dar Es Salam)</td>
<td>5,30%</td>
<td>5,45%</td>
<td>5,56%</td>
<td>5,55%</td>
</tr>
<tr>
<td>Gross National Income (GNI) growth</td>
<td>22,00%</td>
<td>5,00%</td>
<td>2,00%</td>
<td>5,90%</td>
</tr>
<tr>
<td>GDP gper capita growth</td>
<td>-1,36%</td>
<td>0,05%</td>
<td>3,01%</td>
<td>2,79%</td>
</tr>
<tr>
<td>Inflation (CPI change)</td>
<td>11,97%</td>
<td>3,60%</td>
<td>4,61%</td>
<td>3,46%</td>
</tr>
</tbody>
</table>

Source: World Bank open data

Socio-economic development, especially urbanization (spatial expansion of the city) caused by population growth and economic development, is affecting the vulnerability and exposure of people, assets and economic activities from flood hazards in several ways.

- **Increasing vulnerability**: future population growth in Dar Es Salaam is likely to result in increasing (unplanned) urbanisation and construction of housing and roads in especially the Upper and to some extent the Middle Msimbazi basin. Especially, construction in the Upper hill areas will cause loss of vegetation (erosion) and more and faster run-off on the hills into the Msimbazi river in rainy periods. This will cause higher water levels in the Msimbazi and a higher flow velocity in the river. In turn this will result over time in increasing sizes of vulnerable areas and more inundation depth. This phenomenon is included as part of the flood projections of the hydraulic model. Compared to a scenario
without urbanization the urbanization scenarios resulted in the flood model in about 10% more vulnerability in the project area.

- **Exposure of a higher volume of assets over time.** Growth of population and the economy can result in additional dwellings, commercial assets and other in the vulnerable areas in the middle basin. This is mainly true for those wards where there is still space for extension of the stock of assets (housing, other) or higher densities. This is normally modelled in the damage model (in the baseline or do-nothing scenarios). Most vulnerable wards are already highly urbanized with mainly informal dwellings. Many of the wards did not have space for expansion of the building stock. Therefore, no growth of the number of buildings has been assumed in the project area.

- **Exposure of a higher quality (and real value) of assets over time.** The quality of assets (housing and other buildings, content of buildings etc.) normally increases over time due to development of per capita income and economic growth. By earning more real income over time due to economic development people can afford better houses, improve existing houses and buy higher quality contents (furniture etc.). This is modelled in the damage model by increasing the real value of assets over time. In the model an elasticity was assumed of quality increase with GDP per capita growth of 0.33 in the scenarios.

- **Disruption of a growing size of economic activities (commercial activities, traffic etc.) over time.** Demographic and economic growth affect the size of economic activities and traffic in the vulnerable areas and on vulnerable infrastructure. Due to flood events temporary (and in some cases even permanent) disruption of economic activities takes place during and just after these events (depending also on the duration of floods and inundation levels). Markets, restaurants, hotels etc. stop functioning because clients cannot reach these or because staff is not able to reach or work at the premises. Traffic on inundated roads and bridges is disrupted and halted or rerouted. These (indirect) flood damages can increase in the future due to expected increases of economic activities and traffic in the vulnerable areas. This type of damage is normally modelled in the damage model (in the baseline or do-nothing scenarios). This is included in the damage model by modelling traffic disruption impacts. Due to absence of sound economic survey data for the project area for other indirect economic disruption impacts a simple factor direct-indirect damage based on the literature has been used.

**Socio-economic scenarios 2020-2075**

The population and economy will continue to develop in Tanzania and Dar Es Salaam in the future. In this study a rather long time horizon will be applicable. As the lifetime of flood protection measures will be at least between 30-60 years we regard a life time of 50 years applicable, this is often also used as the period relevant for the technical design of measures. This implies that we will need at least to assess a time horizon...
until 2070 or 2075 (depending on the expected timing of implementation of the interventions). However, over such long time, there is a large uncertainty regarding the magnitude of socio-economic developments: expected future demographic and economic growth. In order to show a plausible potential bandwidth of (uncertain) future damages due to flooding, we have developed two socio-economic scenarios in this study. We will develop a pessimistic socio-economic scenario and an optimistic socio-economic scenario.

In below table the key assumptions for population and GDP growth are summarized for the optimistic scenario. The assumed average growth rates are more in line with the recent favorable growth figures (2015-2019) and are higher compared to the rates in the period 2000-2020. Growth rates weaken over time due to saturation effects.

<table>
<thead>
<tr>
<th>Optimistic socio-economic scenario for damage baseline model and Cost-Benefit Analysis (CBA)</th>
<th>2020-2030</th>
<th>2030-2050</th>
<th>2050-2075</th>
<th>2075-2100</th>
<th>Average 2020-2075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic growth (GDP)</td>
<td>6,0%</td>
<td>5,0%</td>
<td>4,0%</td>
<td>3,0%</td>
<td>4,8%</td>
</tr>
<tr>
<td>Income per capita growth</td>
<td>3,0%</td>
<td>2,5%</td>
<td>2,0%</td>
<td>1,0%</td>
<td>2,4%</td>
</tr>
<tr>
<td>Growth of labour productivity</td>
<td>2,0%</td>
<td>1,7%</td>
<td>1,7%</td>
<td>1,7%</td>
<td>1,8%</td>
</tr>
<tr>
<td>Employment growth</td>
<td>4,0%</td>
<td>3,3%</td>
<td>2,3%</td>
<td>1,3%</td>
<td>3,0%</td>
</tr>
<tr>
<td>Population growth Tanzania</td>
<td>3,0%</td>
<td>2,5%</td>
<td>2,0%</td>
<td>2,0%</td>
<td>2,4%</td>
</tr>
<tr>
<td>Population growth Dar Es Salaam</td>
<td>5,0%</td>
<td>4,5%</td>
<td>4,0%</td>
<td>3,0%</td>
<td>4,4%</td>
</tr>
<tr>
<td>Growth of dwellings Dar Es Salaam middle Msimbasi</td>
<td>2,5%</td>
<td>2,3%</td>
<td>2,0%</td>
<td>1,5%</td>
<td>2,2%</td>
</tr>
<tr>
<td>Growth of commercial buildings</td>
<td>3,6%</td>
<td>3,0%</td>
<td>2,1%</td>
<td>1,2%</td>
<td>2,7%</td>
</tr>
<tr>
<td>Quality increase of building stock &amp; contents</td>
<td>1,0%</td>
<td>0,8%</td>
<td>0,7%</td>
<td>0,3%</td>
<td>0,8%</td>
</tr>
<tr>
<td>Traffic growth</td>
<td>5,4%</td>
<td>4,5%</td>
<td>3,6%</td>
<td>2,7%</td>
<td>4,3%</td>
</tr>
</tbody>
</table>

The assumptions regarding a more pessimistic scenario are shown below. As can be seen the pessimistic scenario is still somewhat higher compared to the average growth rates of the last 20 years, but significantly lower than recent growth figures. Growth rates weaken over time due to saturation effects.

<table>
<thead>
<tr>
<th>Pessimistic socio-economic scenario for damage baseline model and Cost-Benefit Analysis (CBA)</th>
<th>2020-2030</th>
<th>2030-2050</th>
<th>2050-2075</th>
<th>2075-2100</th>
<th>Average 2020-2075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic growth (GDP)</td>
<td>4,5%</td>
<td>3,5%</td>
<td>2,5%</td>
<td>2,0%</td>
<td>3,3%</td>
</tr>
<tr>
<td>Income per capita growth</td>
<td>1,8%</td>
<td>1,2%</td>
<td>0,8%</td>
<td>0,3%</td>
<td>1,1%</td>
</tr>
<tr>
<td>Growth of labour productivity</td>
<td>1,5%</td>
<td>1,2%</td>
<td>1,2%</td>
<td>1,2%</td>
<td>1,3%</td>
</tr>
<tr>
<td>Employment growth</td>
<td>3,0%</td>
<td>2,3%</td>
<td>1,3%</td>
<td>0,8%</td>
<td>2,0%</td>
</tr>
<tr>
<td>Population growth Tanzania</td>
<td>2,7%</td>
<td>2,3%</td>
<td>1,8%</td>
<td>1,8%</td>
<td>2,2%</td>
</tr>
<tr>
<td>Population growth Dar Es Salaam</td>
<td>3,5%</td>
<td>3,0%</td>
<td>2,5%</td>
<td>1,5%</td>
<td>2,9%</td>
</tr>
<tr>
<td>Growth of dwellings Dar Es Salaam middle Msimbasi</td>
<td>1,8%</td>
<td>1,5%</td>
<td>1,3%</td>
<td>0,8%</td>
<td>1,5%</td>
</tr>
<tr>
<td>Growth of commercial buildings</td>
<td>2,7%</td>
<td>2,1%</td>
<td>1,2%</td>
<td>0,7%</td>
<td>1,8%</td>
</tr>
<tr>
<td>Quality increase of building stock &amp; contents</td>
<td>0,6%</td>
<td>0,4%</td>
<td>0,2%</td>
<td>0,1%</td>
<td>0,4%</td>
</tr>
<tr>
<td>Traffic growth</td>
<td>4,1%</td>
<td>3,2%</td>
<td>2,3%</td>
<td>1,8%</td>
<td>3,0%</td>
</tr>
</tbody>
</table>
These rates are proposed as inputs for the damage and Cost-benefit models (regarding exposure developments and damage reduction benefits of interventions).

**Climate change scenarios**

Next to socio-economic developments, the extent of future climate change is uncertain, but will affect the damage of floods in the Msimbazi basins to a large extent. Climate change will affect the future precipitation levels and duration (and thus river levels and flows), but also sea level rise (and therefore potential downstream effects). So we have two key uncertainties regarding the future extent of flood impacts: climate change and socio-economic developments. In the figure below it is shown that this gives rise to potentially four cases (future situations or developments).

![Diagram showing four possible future cases based on two key uncertainties regarding flood impacts](image)

From the combination of two socio-economic scenarios and the bandwidth of two potential climate change expectations (modest and more extreme climate change), there are four possible future cases regarding expected impacts of floods. The bandwidth of (potential range) of impacts of floods is best illustrated by presenting outcomes of damage modelling for case 2 (the most severe future flood damages) and case 3 (the most moderate future flood damages).
APPENDIX III – DAMAGE ESTIMATION AND DAMAGE MODEL

Damage estimation in the baseline (do-nothing) scenario

In the do-nothing scenario (or baseline scenario), damage due to the identified hazards – rain and erosion induced flooding - will increase over time. Direct physical damage will occur to the assets in the Middle Msimbazi area due to inundation levels above threshold levels during the inundation period at each flood event (T2, T10, T50...). The damage will increase over time due to two determinants:

- **Climate change**: climate change will result in sea level rise. Sea level rise increases the effects or erosion and storm erosion in the sense that more meters of land will be lost to the ocean. The extent depends on the climate change scenario. Two scenarios have been used in the damage and CBA model: the RCP 4.5 moderate climate change and RCP 8.5 high climate change IPPC scenarios. In the Chapter Vulnerability Analysis, maps with the areas of vulnerable (sub)wards and assets were presented.

- **Socio-economic developments**. Increasing population and economic activities will result in higher exposure of people and assets in the different wards over time. However, due to the fact that there is lack of space for expansion on the building stock in the vulnerable areas in the project area we have not included a growth of the number of buildings over time for the project area. However, income growth in the scenarios will result in quality increase of the existing building stock and contents over time. This was included in the real value of assets used in the damage model over time (2020-2050-2075).

Basically, in a first step an overlay is made of the outputs of the hydrologic model (flood modelling results such as flood maps) and the land use (categories of assets in the area or exposed damage classes). In the second step the vulnerable types of land use are related to the inundation levels at different periods by using damage curves. In the final step the amount of damaged types of land areas (assets) are monetary valued by using prices or reconstruction costs of the asset type (the damage values which are translated to prices or cost per m2 of land). In below figure this process is shown.
The approach used for damage estimation due to flooding

In this study we have identified the following vulnerable asset categories based upon the land use as processed from data in google earth, open street maps and other GIS information and the vulnerability analysis. The categories (damage classes) are:

- Residential buildings;
- Commercial buildings (business and offices);
- Industrial buildings;
- Hotels and restaurants;
- Religion & heritage;
- Health and sanitation;
- Government and education;
- Mix use;
- Roads (paved, unpaved);
- Bridges.

Damage curves

Damage curves show the relationship between the flood induced inundation level (in cm or m height) and the % of physical damage to the asset. In general the level and slope of the damage curve depends on the type of asset, the height of the building (number of floor levels) and quality of the construction materials. According to our visits to the areas and overviews from Google earth most of the buildings in the Middle Mzimbas area are small one floor dwellings (informal and formal houses). Apart from residential areas, the other dominant categories assets are industrial and commercial buildings and infrastructure (roads and bridges). For these reasons we present
damage curves for these main asset categories in this Appendix. Most damage curves are derived from the literature and slightly adjusted for the situation in Dar Es Salaam.

**Buildings**

Most damage curves for the different types of buildings are based upon HKV (2018) and Huizinga (2017). HKV used in the study a range of empirical damage functions from a number of countries (Bangladesh, Indonesia, Ghana etc.). We have applied for housing the curve for one storey housing (cement/stone). As can be seen in the curve at inundation levels above 1 meter, more than 80% of the dwelling is damaged. This might lead to a light underestimation of damage to the informal tin type of dwellings.

As can be seen in the figure the damage curves of the other types of buildings show less damage at inundation levels, because of the higher quality constructions of commercial, industrial buildings etc.

**Infrastructure and agriculture**

In below picture the damage curves for paved roads and agricultural land are shown. These are also based on HKV (2017 and Huizinga 2017). Inundation results in damage to paved roads especially at levels above 1 m. As there is still some agriculture land adjacent to the Msimbazi river in the project area, damage to agricultural land is also included in the analysis.

The percentage of land used for agriculture is quite small and land values are with about USD 3 per m2 also small. The land is mainly used for city agriculture (fruits,
vegetables and cattle). However, regarding future land use the development of agriculture is very uncertain. Although the productivity of the existing agriculture might increase over time, often agricultural land is the first to be sold in case of further urbanisation. Due to the uncertainty and low significance of the agricultural land in overall damage, we have kept the agricultural land use constant (at a constant productivity and land price).

Damage curves of roads and agriculture

Asset and land values or costs

Data regarding asset or land prices are scarce for Dar Es Salaam. A complicating factor is that for the most important vulnerable asset category (housing), most dwellings are informal dwellings. Nevertheless, some data search has resulted in estimations of prices of dwellings relevant for the area. These are shown in below table.

Asset values residential buildings (2020)
As can be seen in the table the range in potential construction costs and asset prices of relevant dwellings according to different sources is quite high (from 10.000 USD per dwelling to max. USD 50.000). From the sources used an average formal house has a value of about 25.000 USD per unit, while an informal dwelling amounts to about USD 10.000 in value. On this basis we have derived an average house value of about USD 13.000 in the area (price per m2 land of USD 201).

As the quality of buildings (and contents) is expected to increase over time due to income growth, we have estimated future asset values for the two scenarios. These are presented below. A correlation of real price growth with GDP per capita growth has been assumed of 0.25.

### Asset values (price per m2 land) per land use category (high growth- RCP 8.5 scenario, 2020 - 2075)

<table>
<thead>
<tr>
<th>Values per m2 land</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
<th>2075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>201</td>
<td>221</td>
<td>261</td>
<td>308</td>
</tr>
<tr>
<td>Mixed Use</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Business &amp; Offices</td>
<td>459</td>
<td>507</td>
<td>597</td>
<td>704</td>
</tr>
<tr>
<td>Government &amp; Schools</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Industrial</td>
<td>344</td>
<td>380</td>
<td>448</td>
<td>528</td>
</tr>
<tr>
<td>Infrastructural assets</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Religion &amp; Heritage</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Health &amp; Sanitation</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Hotels &amp; Restaurants</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Agriculture</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Roads paved (constr cost per m lane)</td>
<td>195</td>
<td>195</td>
<td>195</td>
<td>195</td>
</tr>
<tr>
<td>Bridges (constr costs per m bridge)</td>
<td>100.142</td>
<td>100.142</td>
<td>100.142</td>
<td>100.142</td>
</tr>
</tbody>
</table>

### Asset values (price per m2 land) per land use category (low growth- RCP 4.5 scenario, 2020 - 2075)

<table>
<thead>
<tr>
<th>Values per m2 land</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
<th>2075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>201</td>
<td>221</td>
<td>261</td>
<td>308</td>
</tr>
<tr>
<td>Mixed Use</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Business &amp; Offices</td>
<td>459</td>
<td>507</td>
<td>597</td>
<td>704</td>
</tr>
<tr>
<td>Government &amp; Schools</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Industrial</td>
<td>344</td>
<td>380</td>
<td>448</td>
<td>528</td>
</tr>
<tr>
<td>Infrastructural assets</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Religion &amp; Heritage</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Health &amp; Sanitation</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Hotels &amp; Restaurants</td>
<td>220</td>
<td>243</td>
<td>286</td>
<td>337</td>
</tr>
<tr>
<td>Agriculture</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Roads paved (constr cost per m lane)</td>
<td>195</td>
<td>195</td>
<td>195</td>
<td>195</td>
</tr>
<tr>
<td>Bridges (constr costs per m bridge)</td>
<td>100.142</td>
<td>100.142</td>
<td>100.142</td>
<td>100.142</td>
</tr>
</tbody>
</table>

Note Source CHAF: Centre for Affordable Housing in Africa (CHAF, 2020), Tanzania’s housing construction and housing rental activities, housing economic value chain and housing cost benchmarking analysis, June 2020.
<table>
<thead>
<tr>
<th>Values per m² land</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
<th>2075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>201</td>
<td>213</td>
<td>230</td>
<td>245</td>
</tr>
<tr>
<td>Mixed Use</td>
<td>220</td>
<td>233</td>
<td>253</td>
<td>269</td>
</tr>
<tr>
<td>Business &amp; Offices</td>
<td>459</td>
<td>487</td>
<td>527</td>
<td>561</td>
</tr>
<tr>
<td>Government &amp; Schools</td>
<td>220</td>
<td>233</td>
<td>253</td>
<td>269</td>
</tr>
<tr>
<td>Industrial</td>
<td>344</td>
<td>365</td>
<td>395</td>
<td>421</td>
</tr>
<tr>
<td>Infrastructural assets</td>
<td>220</td>
<td>233</td>
<td>253</td>
<td>269</td>
</tr>
<tr>
<td>Religion &amp; Heritage</td>
<td>220</td>
<td>233</td>
<td>253</td>
<td>269</td>
</tr>
<tr>
<td>Health &amp; Sanitation</td>
<td>220</td>
<td>233</td>
<td>253</td>
<td>269</td>
</tr>
<tr>
<td>Hotels &amp; Restaurants</td>
<td>220</td>
<td>233</td>
<td>253</td>
<td>269</td>
</tr>
<tr>
<td>Agriculture</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Roads paved (constr cost per m lane)</td>
<td>195</td>
<td>195</td>
<td>195</td>
<td>195</td>
</tr>
<tr>
<td>Bridges (constr costs per m bridge length)</td>
<td>100.142</td>
<td>100.142</td>
<td>100.142</td>
<td>100.142</td>
</tr>
</tbody>
</table>
Roads and bridges

Regarding the unit costs of roads we have looked into various sources, such as World Bank (2015) and AFDB (2014).

Unit costs roads

<table>
<thead>
<tr>
<th>Transport infrastructure</th>
<th>km lane</th>
<th>m lane</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction costs Tanzania roads per lane</td>
<td>111,700</td>
<td>111,7</td>
<td>Source WB study 2015 data 1996</td>
</tr>
<tr>
<td>AFDB study costs mean Africa per lane</td>
<td>227,800</td>
<td>227,8</td>
<td>AFDB study</td>
</tr>
<tr>
<td>AFDB study Tanzania project costs per lane</td>
<td>195,486</td>
<td>195,5</td>
<td>AFDB study</td>
</tr>
</tbody>
</table>

Regarding asset prices for the inundated bridges (Nelson Mandela, Kawawa, Vingunguti bridges) we have collected data from construction costs of other bridges in Tanzania. Based on four bridges an average construction costs estimation is USD 100.142 per m bridge length.

Unit costs bridges

<table>
<thead>
<tr>
<th>Bridges (costs in Tanzania in USD)</th>
<th>Total USD costs</th>
<th>Per km</th>
<th>per m</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Selander Bridge Dar Es Salam (3 km)</td>
<td>126.260.000</td>
<td>42.086.667</td>
<td>42.087</td>
</tr>
<tr>
<td>Wami bridge (0.513 km)</td>
<td>30.000.000</td>
<td>58.479.532</td>
<td>58.480</td>
</tr>
<tr>
<td>Kigamboni bridge Dar Es Salam (680 m) (2012)</td>
<td>136.000.000</td>
<td>200.000.000</td>
<td>200.000</td>
</tr>
<tr>
<td>New Jangwani bridge 300 m (least cost option)</td>
<td>30.000.000</td>
<td>100.000</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Average costs per m bridge: 100.142

Content damage

Apart from structural damage, also the contents of buildings (furniture, equipment etc.) can be damaged or completely lost due to flooding. We have adjusted the content factors of HKV (2017) downwards for residential buildings due to the informal nature of most houses. For industrial assets HKV factors are used. For commercial assets the factors are somewhat lower compared to HKV. These factors are applied to the total structural asset damage value for below asset categories.

Content factors for damage in buildings

<table>
<thead>
<tr>
<th>Asset category</th>
<th>Content Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>1,25</td>
</tr>
<tr>
<td>Mixed Use</td>
<td>1,25</td>
</tr>
<tr>
<td>Business &amp; Offices</td>
<td>1,5</td>
</tr>
<tr>
<td>Government &amp; Schools</td>
<td>1,5</td>
</tr>
<tr>
<td>Industrial</td>
<td>2</td>
</tr>
<tr>
<td>Infrastructural assets</td>
<td>0</td>
</tr>
<tr>
<td>Religion &amp; Heritage</td>
<td>1,25</td>
</tr>
<tr>
<td>Health &amp; Sanitation</td>
<td>1,75</td>
</tr>
<tr>
<td>Hotels &amp; Restaurants</td>
<td>1,5</td>
</tr>
</tbody>
</table>
Damage to buildings (million USD) at different return period flooding events for two scenarios

As can be seen in the figure the amount of damage to buildings in the project area for 2050 varies between USD 160 million to 225 million for a T2 event. For a T10 flood the bandwidth of damage from the model is from USD 300—470 million. For T50 the bandwidth is from USD 510 – 640 million. In order to verify the damage to dwellings for 2020 we have compared the damage per dwelling from the model with the findings of the survey from the 2011 flood event. The average damage per dwelling from the damage model is estimated at USD 4884 for a T10 event (2020 current scenario). According to Anande, D.M. and Luhunga, P.M. (2019) the 2011 flood event damaged a median value of properties per representative of USD 3.200. Corrected for inflation in the period 2011-2020 this would amount to a very similar damage per dwelling to the model estimation.

Risk values: Annual Expected Damage (AED) approximation

As seen above damage has been estimated for three types of flood events (T2, T10 and T50) for the two scenarios. In order to estimate the total annual risk probabilities (P) of potential flood events should be multiplied with the impact (damage = D ) of each hazard (P* D). The annual risk value is in the literature also called the Annual Expected Damage (AED). However, due to the hydraulic modelling constrains we only have damages of three points (T2, T10, T50) regarding all potential relevant flood events (different return times such as T1, T25 or T100). Therefore we will estimate a Damage curve at other likely return periods in order to calculate the Annual Expected (asset) Damage (AED).
APPENDIX IV – BRIDGE OVERTOPPING

These graphs show the water level directly upstream of the bridges over the time for different flood events. In case the water level is higher than the bridge deck level, this means that the bridge is overtopping.

Only the graphs are presented of bridges, located in the mainstream of the Msimbazi within the defined project area between Kawawa road bridge and Kinyerezi bridge and where there is potential for overtopping for one of the modelled scenarios, these are:

- Kawawa road bridge;
- Nelson Mandela bridge;
- Vingunguti bridge.
In order to address the severe flooding conditions in the Msimbazi Middle Basin a Feasibility Study is being undertaken for Flood Management in the Msimbazi Middle catchment area. The objectives of this Study are in accordance with the Strategy and Management Framework (Msimbazi Opportunity Plan) of the Msimbazi catchment area. Main beneficiary of this Study is the Dar es Salaam City Council (DCC). The C40 Cities Finance Facility (CFF) is supporting Dar es Salaam to prepare the Study and is implemented through a partnership of the C40 Cities Climate Leadership Group (C40) and the GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit).

The Study started in January 2020 and the main objectives are to i) conduct vulnerability analysis, ii) identify and pre-select flood mitigation options and iii) to develop a flood management strategy for the Msimbazi Middle Basin. As part of the overall process stakeholder participation and engagement is essential for the success of this Study. Instrumental to this are the charrettes which were held on the 13th and 14th of January 2021 at the Four Point Hotel Africa in Dar es Salaam. The purpose of this memo is to report on the event which has taken place, the results gained and the way forward in the remainder of this Study.
Charrettes

Because COVID-19 imposed a restriction on the number of participants per day, the stakeholder group was split over the two days with each day the same programme. On the first day (13th January) the participants were stakeholders from governmental and scientific institutions. The second day (14th January), the participants were community representatives, e.g. ward leaders and representatives. On the second day a few participants were present that were not able to participate on the first day of the workshops.

The objectives of the charrettes were as follows:

- To build consensus on the project, the impact and the implementation;

Group photos of the workshops on 13th January (top) and 14th of January (bottom)
- To update the stakeholders on the progress of the modelling and vulnerability analysis;
- To verify the results of the vulnerability analysis and the identified hotspots with the stakeholders;
- To let the stakeholders interactively participate in the design process by ranking the design criteria and scoring the measures;
- To let the stakeholders participate in the spatial integration of measures in the urban tissue;
- To gain local information on the project area and important aspects to consider;

Due to the COVID-19 restrictions from European countries, not all experts were able to travel to Tanzania. In order to cover all aspects of the project and have the input from all experts, the workshops were done in a hybrid form. Therefore 2 CDR experts and 2 local experts from WEMA were present in Tanzania and other experts from CDR and Deltares as well as Client representative from GIZ joined online via a video call (via MS Teams). Most of the presentations were given by the experts via interactive video call and the experts could follow the break out sessions and participate in the Spatial Design session via an online collaboration board (Miro). The programme of both days was as follows:

<table>
<thead>
<tr>
<th>Day part</th>
<th>Time</th>
<th>What</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>09:00 - 09:30</td>
<td>Registration</td>
</tr>
<tr>
<td></td>
<td>09:30 - 10:00</td>
<td>Official Start and Introductions</td>
</tr>
<tr>
<td></td>
<td>10:00 - 10:30</td>
<td>Opening words by DCC, GIZ and CDR</td>
</tr>
<tr>
<td></td>
<td>10:30 - 10:50</td>
<td>Group Photo + Tea break</td>
</tr>
<tr>
<td></td>
<td>10:50 - 11:20</td>
<td>Presentation Hydrodynamic Modelling by Modelling Consultant</td>
</tr>
<tr>
<td></td>
<td>11:20 - 12:30</td>
<td>Presentation Vulnerability Analysis, identification of Measures and Definition of Strategy by Feasibility Consultant</td>
</tr>
<tr>
<td></td>
<td>12:30 - 13:30</td>
<td>Lunch</td>
</tr>
<tr>
<td>Afternoon</td>
<td>13:30 - 14:10</td>
<td>Break out session Ranking of Evaluation Criteria and Scoring of Mitigation Measures</td>
</tr>
<tr>
<td></td>
<td>14:10 - 15:10</td>
<td>Break out session Spatial Design</td>
</tr>
<tr>
<td></td>
<td>15:10 - 15:30</td>
<td>Closing by DCC, GIZ and CDR</td>
</tr>
<tr>
<td></td>
<td>15:30 - ....</td>
<td>Tea, Coffee and Departure</td>
</tr>
</tbody>
</table>
Break out sessions

**Ranking of evaluation criteria**

Participants were asked to individually prioritize the following 7 criteria for evaluation of flood mitigation measures:

- Flood impact reduction
- Economic impact
- Costs
- Sustainability
- Environmental impact
- Political acceptance
- Social acceptance

By ranking criteria for measures, participants can indicate what aspects of measures were important. The ranking session showed for example that besides from the reduction of flood impact, social and political acceptance were found to be important. Participants indicated that political acceptance is very important for the (rapid) implementation of measures.
Scoring of mitigation measures

For this break out session, the participants were divided into three different groups. In the scoring session, participants were asked to give scores (positive/high, neutral, negative/high) for the following measures against a selection of criteria:

1. Widening and/or raising bridges
2. Dredging river channels, lowering flood plains with physical edge and/or creation of terraces
3. Resettlement

Measure 1, widening and/or raising bridges scored positive on all criteria. Measure 2, dredging of the river channel was generally scored positive as well, though the participants questioned the sustainability of this measure regarding the rapid sedimentation that occurs at the moment. Measure 3 scored negative on political and social acceptance for all groups. Some groups indicated sustainability negative as well because they expect new uncontrolled settlements after people are resettled.

Spatial design sessions

In the spatial design sessions, participants were asked to integrate measures within the urban tissue of the Msimbazi catchment area. For this, the measures from the scoring sessions were allowed to be used as well as ideas for measures of their own. In three groups they were able to place measures and notes on a map of the project area. Parallel, the experts joined in an online spatial design session on the Miro board. All the maps are found on the Miro board results, shown in the Appendix. Some general conclusions can be drawn based on these maps of the spatial design session:

- All groups indicated to widen/raise some of the main bridges, especially Kawawa road bridge and Nelson Mandela road bridge;
- Even though the resettlement scored quite negative in the scoring sessions, all groups indicated that in some locations resettlement might be the best choice, especially in Buguruni;
- Most groups were in favour of several forms of dredging the river channel, with potential floodplains and/or terraces;
- Several groups proposed nature based solutions, such as rainwater harvesting, reducing paved areas and reforestation/planting more trees as measures for the entire catchment area.

For both charrette days the results of the three sessions are summarised as Appendix to this memo.

Way forward

Based on the Vulnerability Analysis and the charrettes the Feasibility Consultant is developing a hybrid flood mitigation strategy combining long term multi-sectoral integrated sets of measures and short term measures focusing on removal of hydraulic bottlenecks. The results of the break-out sessions are duly taken into account in the development of this strategy.
**Long term components** - Longer implementation schedules with basin wide long term positive effects. This part of the strategy be done on fully multi-sectoral integrated level with impact on urban tissue and is expected to require a longer implementation time. However, planning and design of such measures and resettlements can already start/should have started already in order to be implemented and preventing further increase of flood impacts due to climate change and further urbanisation. The long term components are focussed on infiltration, retention and greening of the Middle Basin by Nature Based Solutions and Spatial Planning including resettlements on the most critical locations.

**Short term components** - Short term implementation measures, mostly on a sectoral level, with immediate positive effects. These are measures that focus on infrastructural works and do not require large scale resettlements. It is expected that both political and social acceptance for these measures will be high, which enables rapid implementation. The short term measures focus on removing hydraulic bottlenecks like raising and widening bridges, localised dredging/excavation activities and small scale resettlements. After implementation of the short term measures a residual flood risk will remain, hence the reason to start planning and implementation of the long term measures simultaneously.

The Study will be finalised in February 2021, and resulting final reports will be disseminated amongst the stakeholders involved.
APPENDIX VI – RESULTS CHARRETTE MIRO BOARD

Download link Day 1:
https://cdr-international.box.com/s/d3viui6lvg3krb619bjhy0d54r711medb

Download link Day 2:
https://cdr-international.box.com/s/20hnjk7cyp1zccarqxx142alz2wktmkt