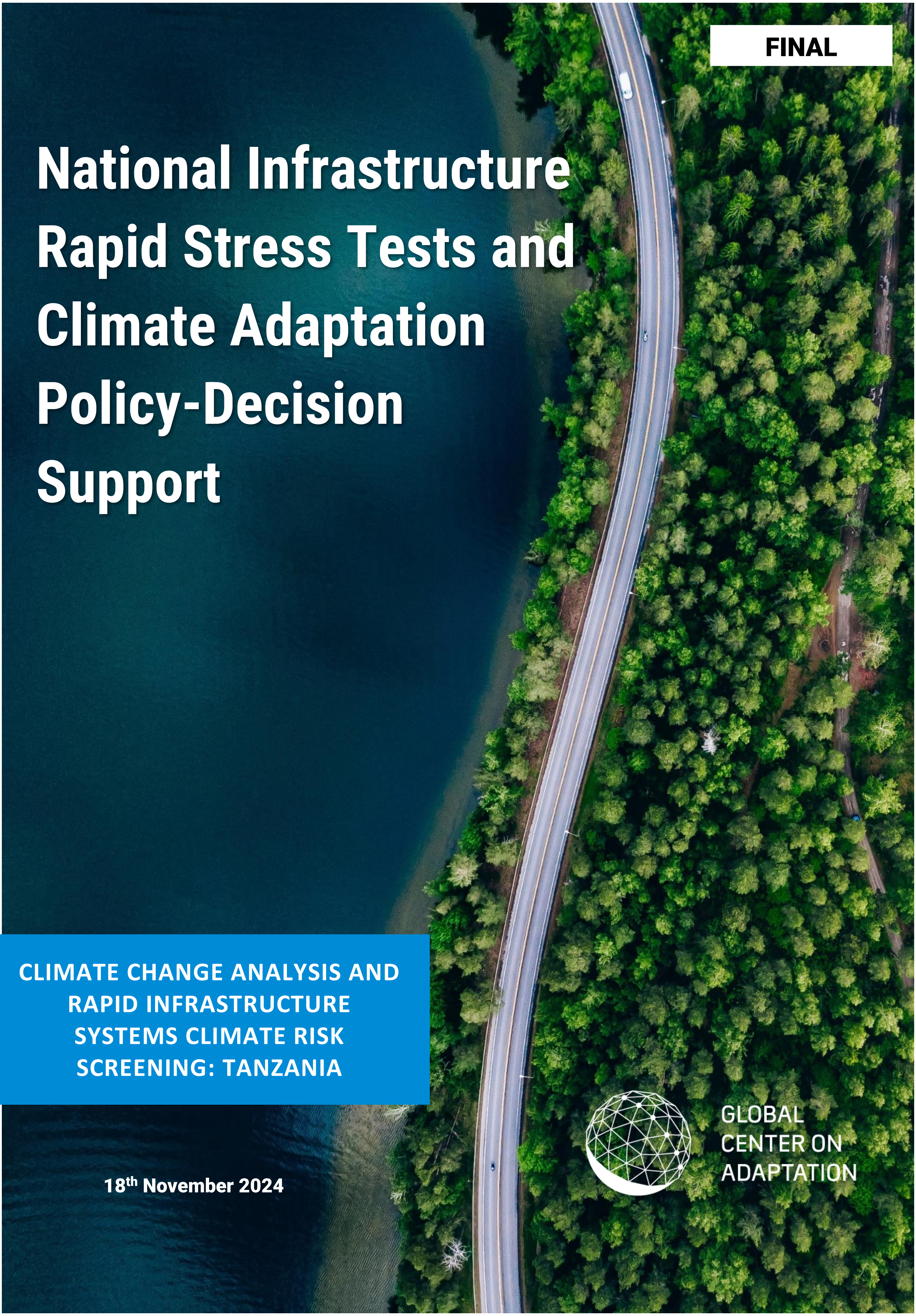

FINAL

National Infrastructure Rapid Stress Tests and Climate Adaptation Policy-Decision Support

CLIMATE CHANGE ANALYSIS AND RAPID INFRASTRUCTURE SYSTEMS CLIMATE RISK SCREENING: TANZANIA

18th November 2024

GLOBAL CENTER ON ADAPTATION

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Sector: Infrastructure
Region: Africa
Keywords: Climate Hazard Assessment, Infrastructure systems rapid risk screening.

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GLOBAL CENTER ON ADAPTATION

ABOUT THE GLOBAL CENTER ON ADAPTATION

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

Consultants:

IISD International Institute for Sustainable Development

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EXECUTIVE SUMMARY

This Report presents the results of the climate hazard assessment and the rapid infrastructure risk and vulnerability assessment undertaken for Tanzania. The results of this analysis are then used in the assessment of socio-economic impacts using a national level Green Economy Model (GEM), which is presented in a separate report, and in the preparation of the national level summaries and policy briefs.

The assessment of the climate-related hazards to critical infrastructure systems was two-fold.

- The standard climate variables of temperature (minimum, mean and maximum), rainfall, aridity, and humidity have been assessed on both an annual and monthly basis to establish the potential new normal for each country. This provides a broader context to the study.
- Analysis of extreme climate parameters that may impact infrastructure. These include changes in the 95th percentile rainfall, peak single day, 5-day rainfall events, and peak prolonged monthly rainfall changes as well as the number of days over 20 mm; For temperature changes, these may include warm spell duration, changes in +35°C days and changes in the historical 99th percentile temperature days. Additional factors considered include sea level rise, extreme storm surge potential, drought conditions (SPEI) and aridity.

The infrastructure systems climate risk and vulnerability assessment undertaken in support of the rapid national climate risk screening study was based on the IPCC definition of climate change related risk as:

RISK = HAZARD x EXPOSURE x VULNERABILITY.

where:

- climate hazard index scores were derived from individual climate parameters for six climate related hazards namely, (1) extreme temperature; (2) heavy rainfall and flooding, (3) drought, (4) Tropical cyclones and wind speed, (5) sea level risk and coastal erosion, and (6) landslides.
- exposure of critical infrastructure was determined in terms of areas subject to different recurrence intervals (RI) for river flooding and landslide susceptibility based on readily available data while all infrastructure was consider exposed to temperature and drought hazard.
- vulnerability to climate impacts was derived from condition assessments, but only for roads.

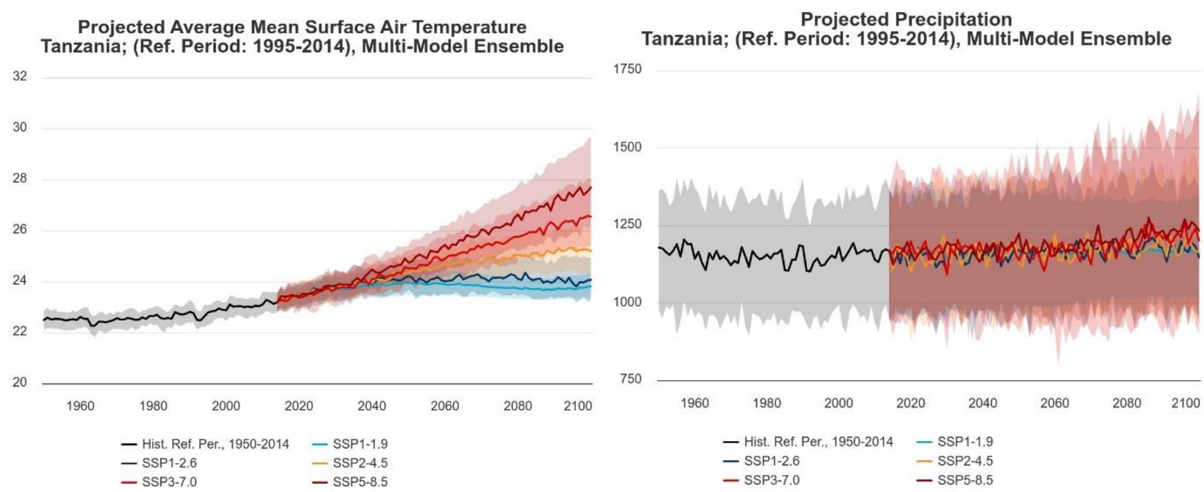

Figure 1: Future climate change projections for Tanzania – Average Temperature and Rainfall (Source: CCKP)

The individual scores for climate hazard, exposure, and vulnerability were combined to result in an overall climate risk score under current and future climate conditions based on the mean value of available climate projections for the SSP2-4.5 and SSP5-8.5 global emission scenarios. The level of risk was the categorised from very low to very high based on the range of values under current and future climate scenarios and across the whole region including all three assessed countries.

The rapid climate infrastructure risk screening included the following critical infrastructure systems:

- Roads (paved and unpaved)
- Railways
- Power stations
- Electricity transmission lines
- Healthcare Facilities
- Education Facilities
- Airports, Bridges and Dams

The results of the climate hazard assessment indicate significant variability across the country and for the individual climate parameters. While there is general constancy in increasing temperatures there is greater variability in terms of the potential impact on both mean annual precipitation and extreme rainfall.

In terms of overall climate risk, critical infrastructure currently exposed to potential high level of river flooding (i.e. within the current 1:25 year flood hazard category) has the highest level of risk, particularly if combined with infrastructure in poor conditions. Overall, there is still a relatively small percentage of critical infrastructure exposed to high levels of river flooding or land slide risk, but these areas still have a significant potential impact on the overall climate risk for critical infrastructure.

The results of the climate hazard and infrastructure risk assessment are used to determine the overall potential economic impact of climate change using the Green Economy Model (GEM) at national scale. The analysis carried out with GEM considers the "High" and "Medium" categories for a realistic representation of climate change adaptation ambition and costs. This is also justified by the fact that the "Medium" category of risk is defined as the assets subject to a 1:100-year RI design flood estimate which is used in most country as an engineering design standard for infrastructure. These results are shown in Table 5-1.

The buildings value is the average of the hazard classification results for health and education facilities.

Table 0-1: Assets at risk considered in the Green Economy Model (GEM)

Assets at Risk		
Asset	**Unit**	**Tanzania**
Roads (km)	%	8.0%
Buildings (Buildings)	%	11.0%
Power Generation Capacity (MW)	%	52%
Transmission Lines (km)	%	16%

In addition to prioritizing these high-risk areas for climate change adaptation, it is also important to consider the potential impact of additional risk amplifiers such as continuing catchment degradation which results in increased levels of soil erosion and sedimentation. The removal of trees on slopes for example will likely increase the risk of landslides particularly when combined with increasing extreme rainfall events. Similarly, increased soil erosion and sedimentation, often resulting from poor land use practices and inadequate sustainable catchment management, can increase flood risks. This occurs both by intensifying surface water runoff and by raising river or lakebed levels, which can lead to elevated water levels during flood events. Erosion and debris from poor catchment management can also block bridges and culverts further increasing the risk of damage to critical infrastructure. Investing in Nature based Solution (NbS) such as improved catchment management and restoration of wetlands, etc. can help in reducing the risks associated with climate change, along with efforts to improve the condition of critical infrastructure to make it more resilient to the increasing climate related threats such as extreme temperatures and floods.

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ABBREVIATIONS

Acronym	Definitions
CCKP	Climate Change Knowledge Portal
CMIP	Coupled Model Intercomparison Project
CRVA	Climate Risk and Vulnerability Assessment
GAR	Global Risk Assessment
GCA	Global Centre for Adaptation
GEF	Green Environment Fund
GEM	Green Economy Model
IMF	International Monetary Fund
ND-GAIN	Notre Dame Global Adaptation Initiative
IPCC	International Panel on Climate Change
RCP	Relative Concentration Pathway
RI	Recurrence Interval
SSA	Sub-Saharan Africa
SSP	Shared Socio-economic Pathway
SPEI	Standard Precipitation and Evaporation Index
UNEP	United Nations Environmental Program

1 BACKGROUND AND INTRODUCTION

1.1 Study Aims and Objectives

The project entails the provision of National Infrastructure Rapid Climate Risk Stress Testing and Climate Adaptation Policy Decision Support in three countries, through the development of on-demand and country-specific rapid analytics and modeling tools aimed to inform country-level strategies and actions to reduce the adverse impacts of climate change on infrastructure systems and hence on communities, ecosystems and economies. The countries initially included are Tanzania, Malawi, and Mozambique.

In support to these objectives the Global Centre for Adaptation (GCA) has undertaken the following:

- Climate hazard assessment for critical infrastructure
- Rapid climate change risk and vulnerability assessment for critical infrastructure
- Assessment of socio-economic impacts of climate change through critical infrastructure sectors
- Policy briefs of climate change risk and vulnerability for critical infrastructure in each country.

The analysis was undertaken by a team led by the International Institute for Sustainable Development (IISD) and supported by Zutari (Pty) Ltd. for the climate hazard and infrastructure risk assessment, and KnowlEdge (KE) who developed the Green Economy Model (GEM) and socio-economic impacts results.

1.2 Purpose of this Report

This Report presents the results of the climate hazard assessment and the rapid infrastructure risk and vulnerability assessment undertaken for Tanzania. The results of this analysis are then used in the assessment of socio-economic impacts using a national level Green Economy Model (GEM), and in the preparation of the national level summaries and policy briefs, both of which are presented in separate reports.

1.3 Definition of Climate Change Risk

The International Panel on Climate Change (IPCC) defines climate change risk as:

> *"The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems" (IPCC, 2020)*

In the context of climate change, risks can arise from potential climate change impacts and their human responses. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making (see also risk management, adaptation, mitigation). This understanding forms the basis for evaluating the climate-change related risks for critical infrastructure in Tanzania as part of the rapid infrastructure risk assessment framework.

The interaction between the climate change hazard, exposure and vulnerability are shown in Figure 2.

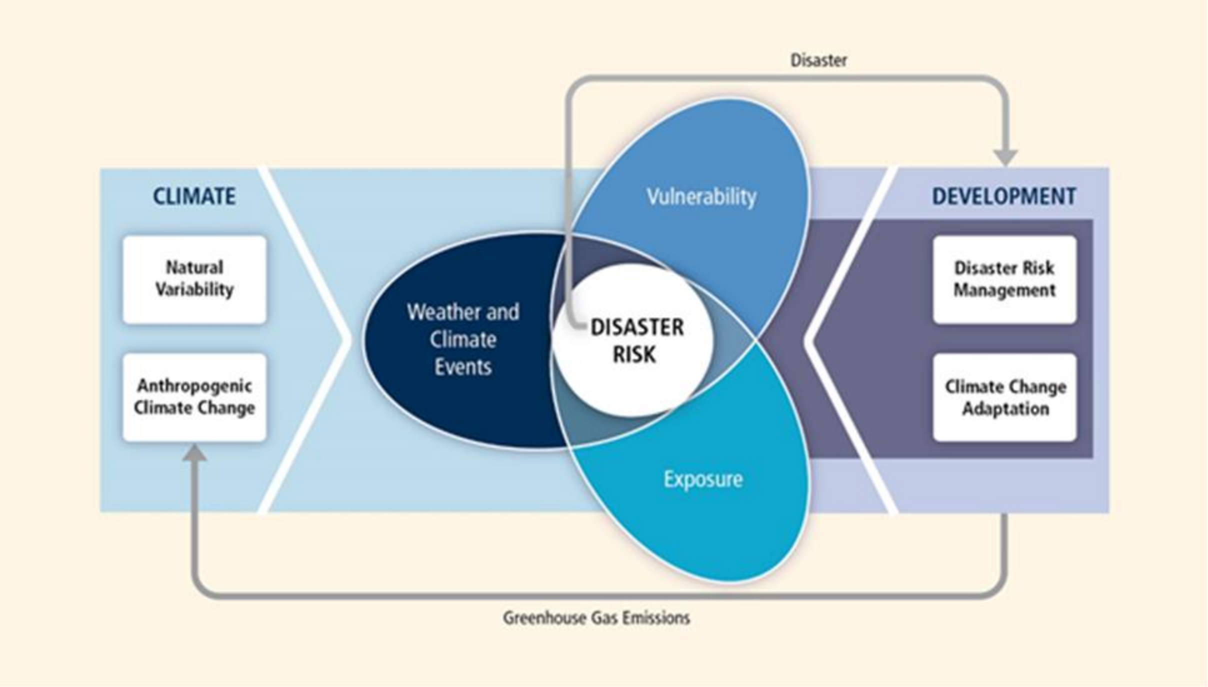

Figure 2: Summary of climate change exposure, risk & vulnerability (Source: IPCC, 2014)

The following definitions for hazard, exposure and vulnerability are from the IPCC online glossary[1].

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

Exposure: The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Sensitivity: The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Adaptive Capacity: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences.

In the context of the rapid climate change risk assessment for critical infrastructure, risk is considered in terms of the potential for damage to the infrastructure that would have a potentially negative social and economic impact. The risk is determined as a function of the current and future climate related hazards (e.g. temperature, extreme rainfall, wind, sea level rise etc.), exposure which is determined based on the proximity if the infrastructure to areas of high risk mainly in terms of flooding (e.g. being located along a river bank or near below a certain elevation above a river or sea level, or in areas already susceptible to landslides due to the current topography and soil characteristics, and vulnerability which is derived from a measure of the current condition of the infrastructure with the consideration that infrastructure in a poorer condition will be more sensitive to the climate related impacts and therefore more likely to be

[1] https://apps.ipcc.ch/glossary/

damaged by a given level of hazard and exposure than infrastructure that is either new (provided it has been built to suitable standards to be climate resilient) or has been well maintained. At this level of analysis no consideration is given to the potential for adaptive capacity although this could be considered for example based on an estimation of the amount of money spent on road maintenance or on the existence of guidelines and standards for monitoring of the condition of infrastructure and maintenance.

1.4 Overview of Climate Change Risks for Critical Infrastructure

Critical infrastructure is designed to enhance convenience and benefit communities. It is the primary foundation of development (Pudyastuti & Nugraha, 2018), as adequate infrastructure provision and management will enhance economic growth and competitiveness. Infrastructure also plays a crucial role in improving society's quality of life. It is, however, subjected to increasing risks due to climate change.

Infrastructure is inevitably ageing, leading to poor performance due to various technical and non-technical factors (Pudyastuti & Nugraha, 2018; Dawson, et al., 2018). For example, the increasing impact of climate change is expected to intensify the damage to infrastructure due to the rising frequency of extreme weather events, thus weakening it, if not completely destroying it. Further, many urban drainage systems cannot operate effectively due to blockages from waste. These systems cannot handle surface runoff caused by unprecedented heavy rainfall, which can lead to damaged roads and vehicles carrying heavier loads than intended. As a result, the cost of operation and maintenance increases.

For road infrastructure, higher temperatures will increase heat, thus shortening the lifespan of asphalt and intensifying stress on bridge expansion joints (Verschuur, et al., 2024). Table 1 shows an example of potential climate change impacts on transportation infrastructures (Pudyastuti & Nugraha, 2018).

Table 1-1 Example of potential climate change impacts on transportation infrastructures

Climate change	Roads	Railways	Ports and waterways	Airports
Temperature change	Accelerated degradation of asphalt	Expansion and deformation of railway tracks	Thermal expansion of bridge joints and paved surfaces	Runway asphalt degradation
	Damage to substructures			
	Increased Operational and Management costs			
Precipitation change	Increased flooding of roadways	Increase flooding of stations	Channel blockage caused by elevated silt accumulation and flooding	Travel disruptions caused by flooding
	Increase erosion		Navigability reduction	Infrastructure damage at airports caused by flooding
	Damage to construction			
Sea level rise	Permanent flooding of airport, port, and road infrastructure			

Due to altered weather patterns and the increasing vulnerability to climate hazards, built environment infrastructure is prone to the climate change impacts in Africa (Agboola, et al., 2024). The built environment includes critical infrastructure such as urban spaces, social facilities, schools, universities, health infrastructure, food and marketplaces. Such infrastructure is crucial for food security, regional economic stability, and educational and recreational services. Extreme climate hazards and increased intensity and frequency of weather events such as storms, floods, sea level rise and heatwaves pose significant risks to the built environment (Agboola, et al., 2024). For instance, storms can result in the toppling of buildings due to winds and flooding of buildings during storm surges. Flooding of these facilities can result from intense rainfall over a short period of time and from sea level rise, which is a result of permanent inundation of seawater in low-lying areas (Santos, et al., 2024).

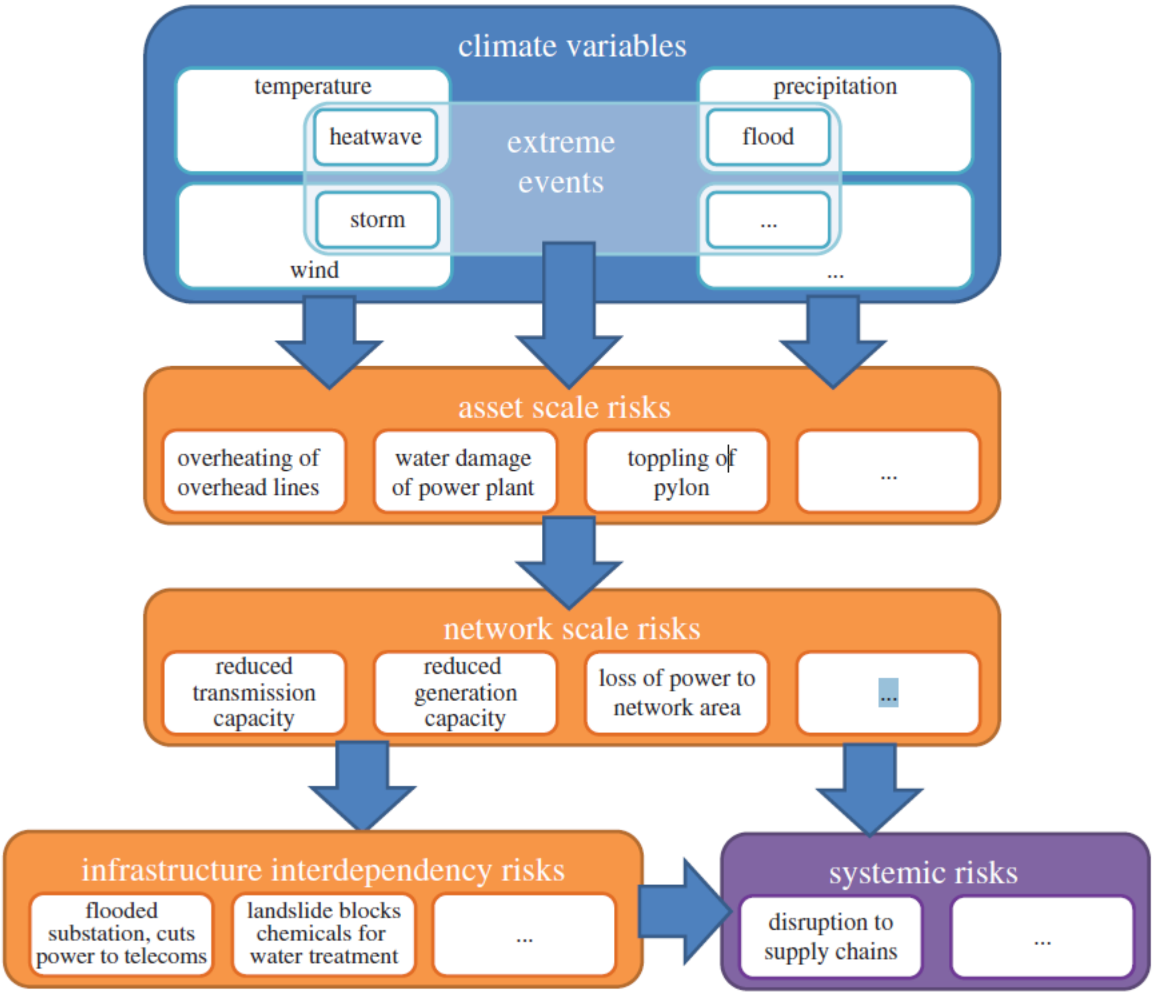

Figure 3: Systems approach to a climate change risk assessment framework for infrastructure (Dawson, et al., 2018)

In the energy sector, it is vital for the proper functioning of energy production and distribution facilities to guarantee the provision of electricity to a specific area (Verschuur, et al., 2024). Climate change has the potential to significantly impact energy infrastructure, particularly in the areas of extraction, generation, and transmission, which can lead to reduced efficiency and disruption. As many human activities depend on energy, the physical damage and service disruptions caused by climate change can result in substantial economic and human losses. Flooding, for example, can degrade energy infrastructure and lead to power outages. Additionally, public facilities such as hospitals, schools, marketplaces, and offices are also susceptible to damage from flooding (Dawson, et al., 2018; Verschuur, et al., 2024).

The paragraph above shows the growing interconnection of infrastructure systems, heightening the associated risks. However, the lack of clearly defined responsibilities is constraining the implementation of adaptation measures (Dawson, et al., 2018). Assessing infrastructure risk involves more than just evaluating the effects on physical components like tracks, pipes, and wires. It's important to also consider the resources these physical components transport and the services they provide, which are relied upon by the public and businesses. The diagram below illustrates some of the considerations for evaluating the climate change risks for critical infrastructure and includes representative variables or risks.

There are several ways interconnections can impact climate-related risks. For instance, the water and sanitation infrastructure, which is crucial for communities is at an increased risk of extreme climate events due to the expected changes brought on by the 1.5°C temperature increase (Howard, et al., 2016).

It is expected that the local hydrology and groundwater will be impacted due to changes in precipitation patterns, affecting water supply as a result of the increased temperature. Water and sanitation infrastructure can be affected by climate events such as flooding, droughts and storms. These conditions can expose water and sanitation infrastructure to increased climate risk as flooding from increased rainfall can damage water infrastructure in place which might have been under-designed to cater for such conditions. Droughts from reduced rainfall can reduce water supply, thus overwhelming the system as it is used to normal conditions and increase the risk of contamination from pathogens and chemicals.

Further, storms can expose underground infrastructure, making it prone to contamination, destroy water treatment plants thus inundating sewage treatment plants and halting water supply services.

Table 1-2 illustrates some interdependencies of infrastructure system and climate related risks.

Table 1-2: Infrastructure dependencies and associated impacts (Dawson, et al., 2018)

Infrastructure Dependencies	Associated Impacts
Dependence on water infrastructure	The majority of the country's energy production mix necessitates large amounts of water for cooling; the most susceptible sector to decreased water availability is inland power generation. The type of energy generated determines how much water is needed for cooling; decarbonization plans with large amounts of carbon capture and storage have the potential to treble freshwater use by the 2050s. This would increase the danger of a drought.
Dependence on power infrastructure	Energy is necessary for some, if not all, of the assets in every infrastructure sector. The water supply, telecommunications, and wastewater treatment infrastructure might all be affected if this power infrastructure collapses.
Dependence on information and communication technology infrastructure	ICT is becoming increasingly vital for modern infrastructure since it allows remote operation, clock synchronization, emergency response coordination during extreme events, and monitoring.
Dependence on transport infrastructure	Transport infrastructure is frequently necessary for infrastructure networks to continue operating, such as providing access to resources like fuel, labor, and emergency response. When vital infrastructure elements fail—like bridges or landslides that obstruct vital transit routes—travel times can rise dramatically due to trips having to be rerouted.

1.5 National Level Climate Change Risk and Vulnerability

Droughts and floods have led to infrastructure damage, causing significant economic expenses in Tanzania (IMF African Dept., 2023). A post-disaster evaluation reveals that the 2019 Tanga flood significantly damaged essential infrastructure, including water supply systems, electricity grids, transportation routes, educational and medical facilities, residential structures, and assorted equipment. The cumulative direct damages and losses amount to $19 million.

Additionally, in Dar es Salaam, infrastructure assets worth $5.3 billion are progressively endangered by the combined threats of flooding and rising sea levels (IMF African Dept., 2023). Intensification of heavy rainfall events is poised to amplify the adverse effects of flooding on infrastructure, potentially leading to heightened disruptions in energy, water, and transportation services (USAID, 2018b).

Tanzania's diverse topography generates four distinct climatic zones (USAID, 2018b). Firstly, the coastal belt, including the Zanzibar archipelago, experiences hot and humid conditions, with temperatures averaging 27–30°C and annual rainfall ranging from 750 to 1,250 mm, although Zanzibar receives 1,400-2,000 mm. Secondly, the central plateau is characterized by hot and arid conditions, with only 500 mm of rainfall annually. Thirdly, the northern and western semi-temperate high lakes region, home to the East African Rift System's lakes and valleys, receives 750–1,250 mm of rainfall yearly. Lastly, the northeast and southwest highlands, such as Kilimanjaro, are the coldest parts of the country, with average temperatures of 20–23°C. The southwest highlands and the Lake Tanganyika basin in the west receive the highest rainfall, exceeding 2,000 mm annually. Rainfall patterns are influenced by the Inter-Tropical Convergence Zone, leading to high seasonal precipitation. The north and east experience two rainy seasons, the primary one from March to May and a secondary one from October to December, while the south, west, and central regions have a single rainy season from October to May (USAID, 2018b).

In Tanzania, there is a persistent pattern of both floods and droughts, with occurrences becoming more frequent and severe over the past few decades (IMF African Dept., 2023). Over the last forty years, floods have constituted approximately 66% of all-natural calamities, demonstrating a notable surge from an average of 0.8 annually between 1980 and 2010 to 1.8 events annually between 2011 and 2022. Following floods, droughts emerged as the second most frequent catastrophe, significantly impacting the populace, with droughts affecting 10% of the population in 2006, marking them as a primary source of disruption (IMF African Dept., 2023). During the period from 2010 to 2020, there was a notable 45% rise in flood occurrences in Tanzania, contrasting with a decline of 14% in Sub-Saharan Africa (SSA) and 15% globally. Additionally, droughts and storms have heightened in Tanzania, aligning with trends observed in neighboring countries and worldwide. A summary of previous extreme events is shown Figure 4.

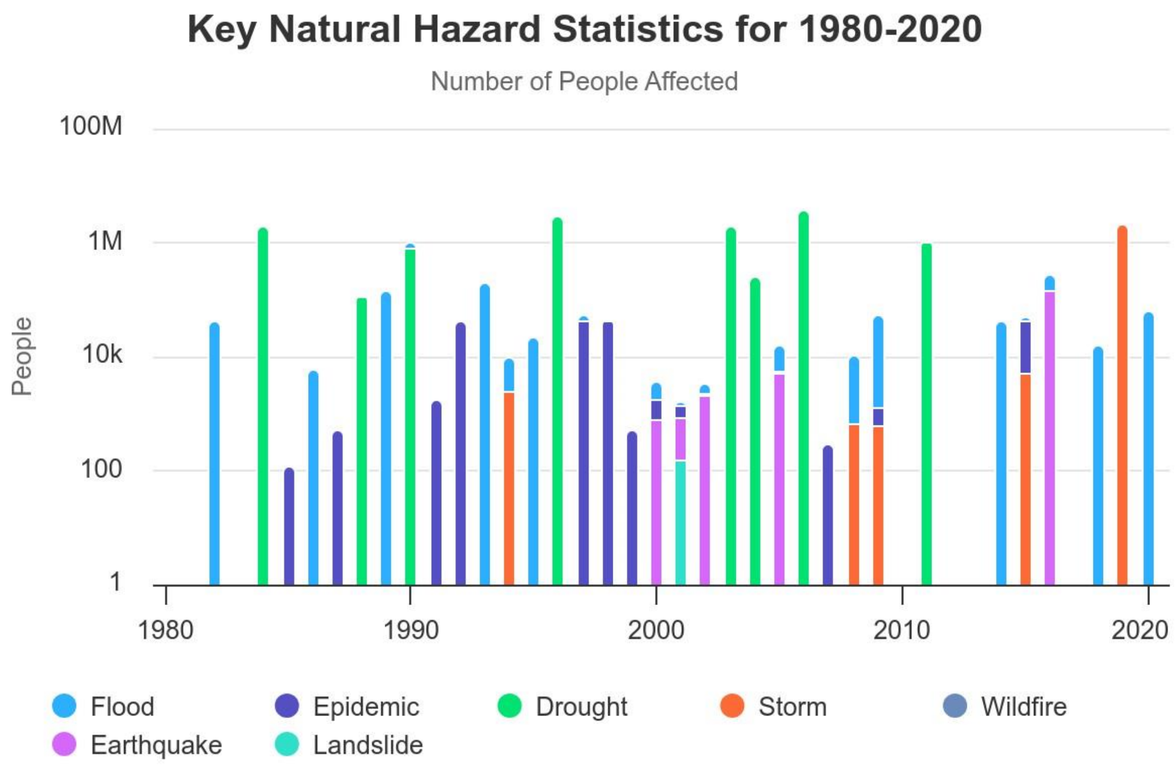

Figure 4: Summary of previous extreme events for Tanzania (Source: CCKP)

The table below provides a summary of the historical climate observations and trends since 1960 and future climate projections to 2050 (USAID, 2018b). The latest climate projections for Tanzania in terms of average and extreme temperature and rainfall under different climate scenarios are shown below.

Table 1-3 Historical and projected climate summary for Tanzania (USAID, 2018b)

Historical Climate	Future Climate (Projected changes by the 2050s)
Average temperatures have increased by 1°C from 1960 to 2006 on average over most of Tanzania.	The average annual temperature rise ranges from 1.4 to 2.3°C, with the most significant warming observed in the western and southwestern regions
	Extended periods of heat waves have lengthened by 7 to 22 days, while dry spells have been prolonged by up to 7 days.
There has been minimal variation in total precipitation levels over time. However, a subtle decline was observed from 1961 to 2013, primarily occurring between March and June, which coincides with the main rain season	Change in the average annual precipitation, ranging from a decrease of 3 percent to an increase of 9 percent, with the most significant increment expected in the northeast region. Conversely, there is a likelihood of decreased rainfall during the period from July to September.
	Heavy rainfall events are expected to increase both in frequency, ranging from 7 to 40 percent, and intensity, with an increase of 2 to 11 percent.
The increase in sea levels averaged between 4 to 20 centimeters per decade from 1955 to 2003 globally, except Zanzibar, where a decline in sea levels was observed from 1984 to 2004	The increase in sea levels ranges from 16 to 42 centimeters
The rapid decline in glacial volume on Mount Kilimanjaro, seen by an 85% decrease in the size of the Kibo Summit Glacier between 1912 and 2009, illustrates an accelerated trend in glacial recession.	Reduced glaciers from Kilimanjaro.

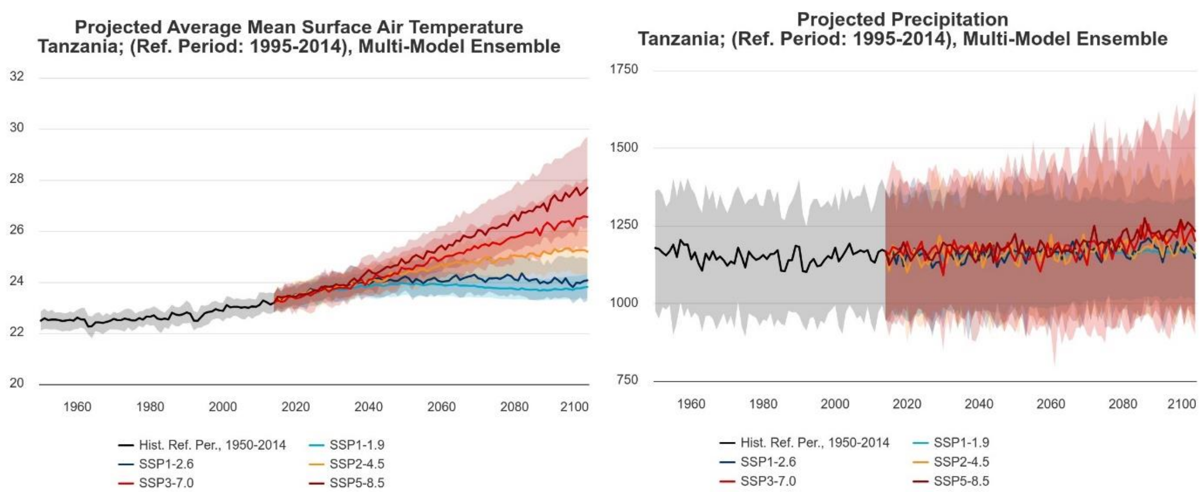

Figure 5: Future climate change projections for Tanzania – Average Temperature and Rainfall (Source: CCKP)

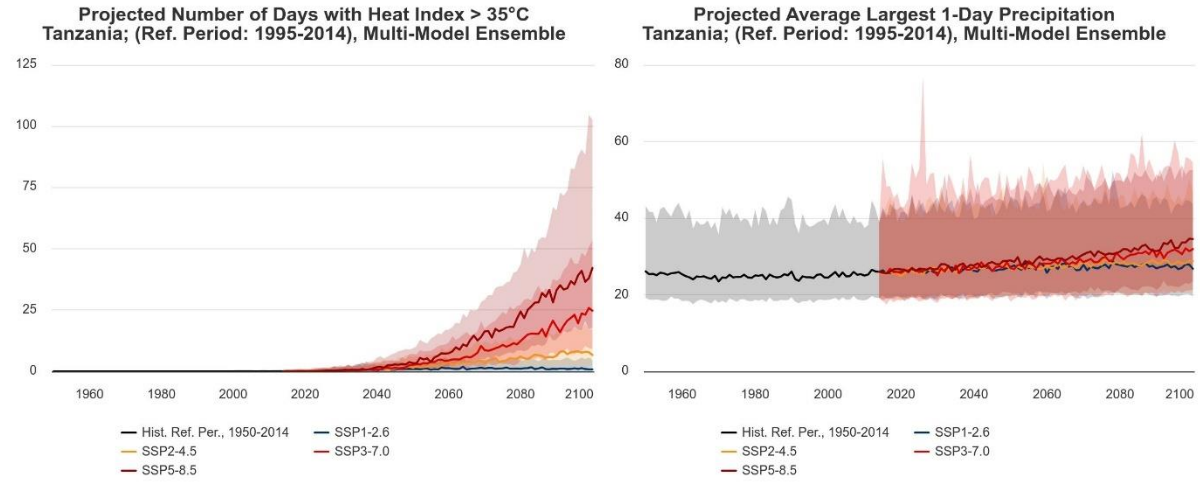

Figure 6: Future climate change projections for Tanzania – Extreme Temperature and Rainfall (Source: CCKP)

The table below provides the ThinkHazard! Tool results for Tanzania in terms of climate change related risks and shows high levels of risk for river, urban and coastal flooding as well as wildfire risks to 2050.

Table 1-4 Summary of critical climate-related hazard assessment for Tanzania using the ThinkHazard! Tool.

Climate Related Hazards									
Country	River flood	Urban flood	Coastal flood	Wildfire	Landslide	Water scarcity	Extreme heat	Cyclone	Tsunami
Tanzania	High	High	High	High	Medium	Medium	Medium	Low	N/A

Source: ***ThinkHazard! Tool***

Tanzania ranks 145th among 182 assessed in the ND-GAIN Country Index most vulnerable country to climate change and the 151st most ready country (ND-GAIN, 2021). Tanzania's positioning in the upper-left quadrant of the ND-GAIN Matrix indicates its high vulnerability score juxtaposed with a low readiness score (Figure 7). This configuration underscores the pressing need for substantial investment and innovative initiatives to bolster its readiness alongside an urgent call for action. Prioritizing investments in climate proofing infrastructure is a critical part of reducing the overall vulnerability of the country.

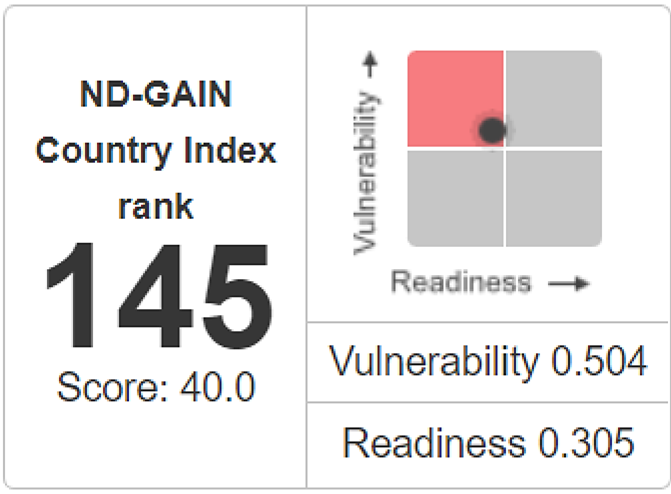

Figure 7: Climate Change Vulnerability and Readiness Score for Tanzania (Source: ND-GAIN)

2 APPROACH AND METHODOLOGY

The climate change risk and vulnerability assessment was undertaken in following three phases:

- Identifying critical infrastructure assets
- Analysis of current and future climate related hazards
- Infrastructure risk assessment based on classification hazard, vulnerability and exposure.

The approach followed for each phase and the data used are described in the following sections.

2.1 Identifying Critical Infrastructure and Climate Change Related Risks

The current critical infrastructure identified for Tanzania are shown in Figure 8 and include primary, secondar and tertiary roads, railways, airport and ports, power stations classified by type, transmission lines, airports and health care facilities. Not shown here, but still relevant are local scale infrastructure including rural roads as well as critical ecological infrastructure such as rivers, wetlands and forests.

The data used for identifying the critical infrastructure in Tanzania was derived primarily from readily available global datasets. This enables comparison between countries but could be improved with access to national level datasets that could also provide additional information such as current condition, value and criticality of the infrastructure that could be used to further develop the risk assessments.

The following sections provide a brief overview of the critical infrastructure and climate related risks.

2.1.1 Transport Infrastructure

The Republic of Tanzania has three primary maritime terminals at Dar es Salaam, Tanga, and Mtwara and smaller ports such as Kilwa, Lindi, Mafia, Pangani, and Bagamoyo which contribute to the country's maritime infrastructure. There are several lake ports on Lake Victoria, Lake Tanganyika, and Lake Nyasa.

The nation's civil aviation industry is expanding, evidenced by its 58 airports and a network of over 20 airlines facilitating both domestic and international travel connections[2].

Road transportation is the predominant mode, facilitating over 90% of passenger movements and 75% of freight activities nationwide. The extensive road infrastructure spans 181,189.77 km, with TANROADS overseeing 36,760 km, encompassing 12,223 km of Trunk roads, 23,846 km of regional roads, and 691 km of Designated District roads. The residual 144,429.77 km comprise rural, urban, and feeder roads.

Tanzania has a railway network spanning 2,706 km in total length.[3].

Tanzania's transport infrastructure faces significant climate risks, particularly from extreme weather events exacerbated by climate change. The country is susceptible to heavy rainfall and flooding, which can damage roads, bridges, and railways, leading to increased maintenance costs and transportation disruptions. Coastal regions, such as Dar es Salaam, are vulnerable to sea-level rise and coastal erosion, threatening port facilities and undermining crucial maritime activities. A study by Mbezi et al. (2024) found that the eastern coast of Ungunja was eroding at 15.560 m/year on average, and it was projected that by 2040 the erosion rate would be 25.648 m/year. Prolonged droughts can also impact the integrity of road networks, causing pavement cracks and reduced load-bearing capacity.

[2] https://dlca.logcluster.org/tanzania-united-republic-22-aviation

[3] https://dlca.logcluster.org/tanzania-united-republic-24-railway-assessment

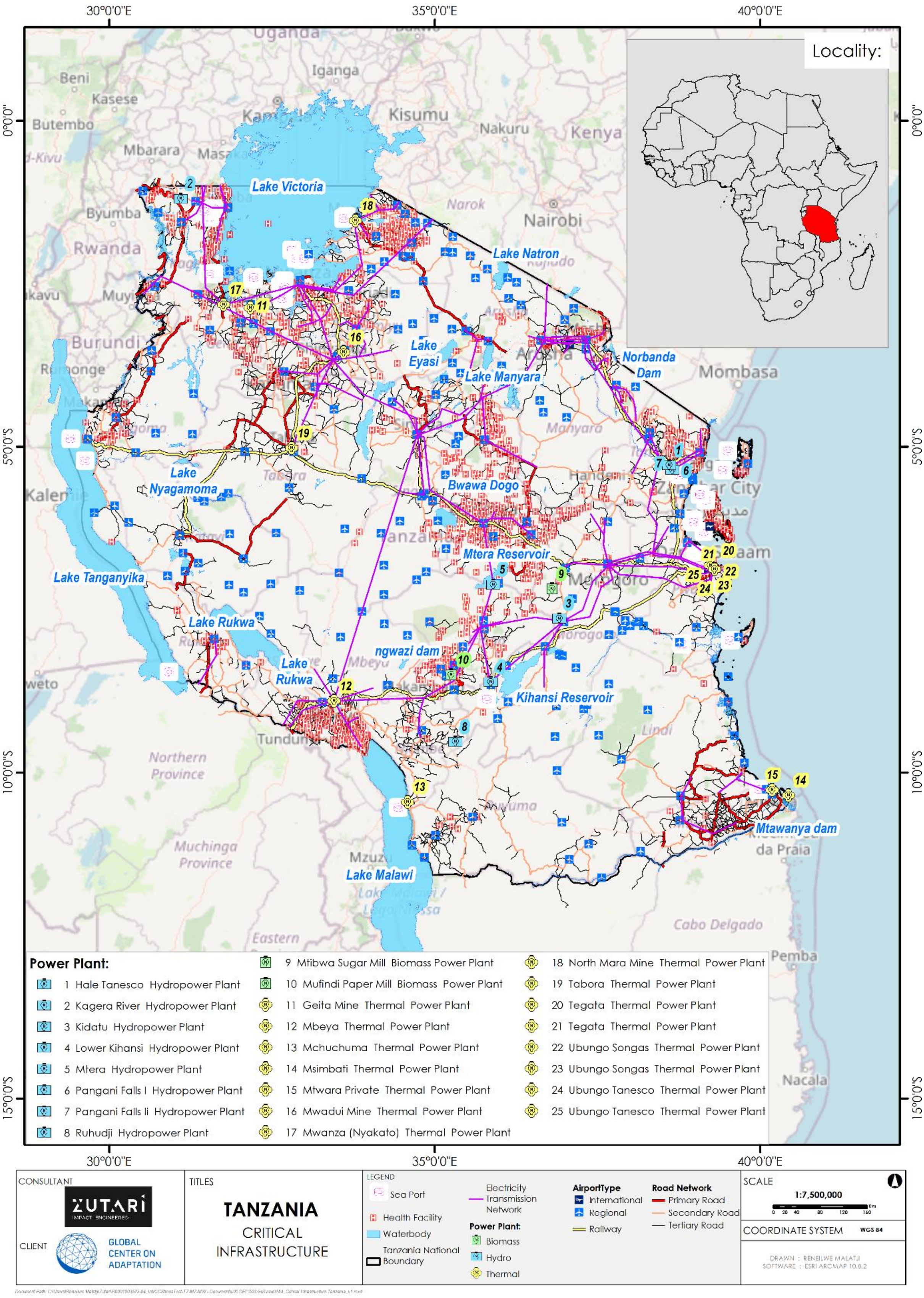

Figure 8: Map of critical infrastructure systems for Tanzania.

2.1.2 Power Stations and Transmission

Currently, approximately 37% of Tanzania's electricity production capability relies on hydropower, a source vulnerable to fluctuations in precipitation patterns (IMF African Dept., 2023). Intense rainfall events in 2017 and 2020 posed a threat to dam integrity, while periods of drought, notably in 2015, severely curtailed operations at the Mtera dam. These climatic fluctuations have precipitated adverse economic consequences, notably a reduction in hydropower output. Specifically, an extended dry period in October 2015 resulted in a significant decline in hydropower generation nationwide. Despite potential future increases in water flow within critical basins such as Pangani and Rufiji, essential for hydropower generation, challenges such as escalating evaporation rates and silt accumulation, which is impacted by increasing rainfall intensity and land degradation, are anticipated to impede Tanzania's already insufficient electricity supply, which currently only serves 16 to 18 percent of the populace (USAID, 2018b).

Tanzania's energy infrastructure is increasingly vulnerable to climate change related hazards including floods, fire, and wind, significantly challenging its stability and development. The country's reliance on hydropower, accounting for about a third of its electricity generation, makes it particularly susceptible to variations in rainfall patterns. Extended periods of drought, which are becoming more frequent due to climate change, lead to reduced water levels in reservoirs, diminishing hydroelectric output.

Additionally, coastal energy facilities face the threat of rising sea levels and extreme weather events like cyclones, which can damage infrastructure and disrupt fuel supply chains. The literature on long-term sea level trend reconstruction from 1955 to 2003 reveals a 0.4 – 20.0 mm/year rising trend of sea level in Tanzania (Mahongo, 2009). Inland, higher temperatures and shifting weather patterns can affect thermal power plants' cooling processes and increase the risk of wildfires, which can damage transmission lines and other critical infrastructure.

2.1.3 Water and Sanitation

Water plays a crucial role in Tanzania and its economy, as it used for hydropower generation, agricultural purposes, domestic uses and the tourism sector (national parks and protected areas) (Oates, et al., 2014). The hydrological system and water availability are impacted by climate change in Tanzania. In 2011, there was a decline in water supply from 55% to 53%, however, sanitation provision increased. It was reported that, in the past 30 years, Lakes Victoria, Tanganyika, Rukwa and Babati water levels have declined significantly, reducing water availability. This reduction can be due to increased evaporation from increased temperatures, and recurrent droughts (Sindato & Mboera, 2024).

Increased sea level has affected the country's water supply in areas such as Maziwi in Pangani and Fungu la Nyani in Rufiji districts. Tanzania is also prone to flooding (Rugai & Kassenga, 2014), and landslide. All these climate hazards strain and damage water and sanitation infrastructure, which is associated with high costs to restore (Sindato & Mboera, 2024). Further, the unbalanced investment and the aging infrastructure further exacerbate the impacts of climate on the water infrastructure (Sweya, et al., 2018), increasing the risk of waterborne diseases, due to reduced water levels resulting in water contamination.

In areas such as Dar es Salaam, whereby about 75% of the residents live in informal settlement, such risks are increased due to poor or unplanned sewage systems, water drains, and clean & portable water systems (Rugai & Kassenga, 2014). The impacts on water infrastructure can be summed up to water contamination from saltwater intrusion and flooding, whereby suspended materials can damage water supply and sewage systems, resulting in more operation and maintenance cost (Muzuka, et al., 2015; Sweya, et al., 2018; Sindato & Mboera, 2024), and thus reduced water and sanitation services.

2.1.4 Telecommunication

In Tanzania, there has been a notable rise in internet penetration, with half of the population now able to connect to either mobile or fixed broadband networks [4]. In urban areas like Dar es Salaam and Arusha, internet reliability generally remains consistent, albeit subject to variations in speed and dependability

[4] https://dlca.logcluster.org/tanzania-united-republic-34-telecommunications

based on the service provider and infrastructure availability. Additionally, the stability of the national power grid plays a significant role in sustaining internet connectivity. While urban regions in Tanzania typically offer 3G services or better for mobile users, 5G technology has yet to be introduced commercially. Conversely, around twenty percent of the country's populace, predominantly situated in rural areas, still grapple with limited access to basic 2G network coverage. Considering ongoing climate shifts, it is imperative to thoroughly consider climate-related hazards in the planning and development of energy infrastructure. Tanzania's telecommunication infrastructure faces significant climate risks due to its vulnerability to extreme weather events and climate variability. Frequent flooding, particularly in coastal and low-lying areas, can damage underground cables, disrupt signal transmission, and cause prolonged service outages. Heavy rains and storms often lead to power outages, affecting network reliability and accessibility. Additionally, the increasing frequency of droughts can exacerbate power shortages, as the country relies heavily on hydroelectric power, which impacts the operation of telecom networks. Rising temperatures and humidity levels also pose risks by accelerating equipment wear and corrosion, necessitating more frequent maintenance and replacement.

2.1.5 Healthcare Facilities

Climate change poses a significant risk to the health and sanitation sector due to an increased occurrence of heatwaves, floods, and droughts (IMF African Dept., 2023). As temperatures rise and heavy rainfall becomes more frequent, there is a heightened risk of escalating incidences of diarrheal diseases and malaria in Tanzania. This is particularly concerning as previously unaffected regions are now experiencing malaria outbreaks, primarily attributed to elevated temperatures and moisture levels. Additionally, the rising temperatures are expected to lead to more frequent instances of heat-related fatalities, while increased flooding poses a significant threat of waterborne disease outbreaks. Therefore, it is anticipated that both diarrheal diseases and malaria, which are among the primary causes of mortality in Tanzania, will see a notable increase due to these environmental changes (USAID, 2018b).

Tanzania's health infrastructure faces significant climate-related risks that threaten its capacity to provide essential services. Increasing temperatures and more frequent extreme weather events, such as floods and droughts, exacerbate the spread of vector-borne diseases like malaria and dengue fever, straining healthcare facilities. Flooding can damage critical infrastructure, disrupt water and sanitation systems, and hinder access to healthcare, particularly in rural areas. Conversely, drought can lead to water shortages and reduced agricultural productivity, causing malnutrition and impacting overall health.

2.1.6 Education Facilities

Climate change is disrupting the education system (Marin, et al., 2024) by destroying learning facilities and access to such places. These can be seen during an extreme climate event whereby, if not the infrastructure is not destroyed, the buildings are used as temporary shelter. For example, in Rufiji and Kibiti districts, eastern Tanzania, schools were destroyed by flash floods (Xinhua, 2024; reliefweb, 2024). Furthermore, in Dar es Salaam Kisarawe Girlstown and Kiluvya Training Centre & Nursery were physically destroyed by floods, several vehicles were destroyed and access to schools as roads were destroyed.

2.2 Climate Hazard Assessment

The aim of the hazard assessment is to assess possible climate change related impacts on infrastructure including the severity of change and spatial variability that will inform country-level development strategies and intervention actions. This assessment will use the most recent and readily available climate data as inputs for the infrastructure risk assessment and Green Economy Model (GEM).

2.2.1 Data Used

The modeling data used for the assessment will be the Coupled Model Intercomparison Project Phase 6 (CMIP6). CMIP6 is a large-scale climate modeling effort aimed at providing the most up-to-date and reliable projections of future climate change. It is a collaborative project involving climate modeling groups from all over the world, and it is intended to help the Intergovernmental Panel on Climate Change (IPCC) in its assessments of the state of the climate system.[1][2]

CMIP6 simulates the behavior of the Earth's climate system using a variety of modeling methodologies, including atmosphere-only models, ocean-only models, and fully coupled atmosphere-ocean-land models. These models represent the physical, chemical, and biological processes that govern the climate system, and they are used to simulate past and future climate conditions under a variety of greenhouse gas concentrations and other climate drivers.

The variety of modeling methodologies used in CMIP6 enables a comprehensive assessment of the uncertainties and range of future climate change projections, which is critical for informing climate policy and adaptation strategies. The CMIP6 project expands on previous phases of the Coupled Model Intercomparison Project (CMIP), which have provided valuable information on the past and future evolution of the Earth's climate system. This analysis is based on CMIP6 data, which includes 134 models from 53 modeling centers. The publication of CMIP6 data began in 2019, with the majority of the data expected to be published by 2022, with CMIP6 scientific analyses used in the IPCC's 6th Assessment Report (AR6).[5] The CMIP6 models used for this statistical and spatial analysis are given in Table 2-1:

Table 2-1: Climate models available from CMIP6 and used in the climate hazard assessment

ACCESS-CM2 (Australia) ACCESS-ESM1-5 (Australia) AWI-CM-1-1-MR (Germany) AWI-ESM-1-1-LR (Germany) BCC-CSM2-MR (China) BCC-ESM1 (China) CAMS-CSM1-0 (China) CanESM5 (Canada) CanESM5-CanOE (Canada) CESM2 (USA) CESM2-FV2 (USA) CESM2-WACCM (USA) CESM2-WACCM-FV2 (USA) CIESM (China) CMCC-CM2-HR4 (Italy) CMCC-CM2-SR5 (Italy) CMCC-ESM2 (Italy) CNRM-CM6-1 (France) CNRM-CM6-1-HR (France) CNRM-ESM2-1 (France)	E3SM-1-0 (USA) E3SM-1-1 (USA) E3SM-1-1-ECA (USA) EC-Earth3 (Europe) EC-Earth3-AerChem (Europe) EC-Earth3-CC (Europe) EC-Earth3-Veg (Europe) EC-Earth3-Veg-LR (Europe) FGOALS-f3-L (China) FGOALS-g3 (China) FIO-ESM-2-0 (China) GFDL-ESM4 (USA) GISS-E2-1-G (USA) GISS-E2-1-H (USA) HadGEM3-GC31-LL (UK) HadGEM3-GC31-MM (UK) IITM-ESM (India) INM-CM4-8 (Russia) INM-CM5-0 (Russia) IPSL-CM5A2-INCA (France)	IPSL-CM6A-LR (France) KACE-1-0-G (South Korea) KIOST-ESM (South Korea) MCM-UA-1-0 (USA) MIROC6 (Japan) MIROC-ES2H (Japan) MIROC-ES2L (Japan) MPI-ESM-1-2-HAM (Switzerland) MPI-ESM1-2-HR (Germany) MPI-ESM1-2-LR (Germany) MRI-ESM2-0 (Japan) NESM3 (China) NorCPM1 (Norway) NorESM2-LM (Norway) NorESM2-MM (Norway) SAM0-UNICON (South Korea) TaiESM1 (Taiwan) UKESM1-0-LL (UK

Because CMIP6 includes more advanced representations of the physical, chemical, and biological processes that govern the climate system than previous phases, it allows for a more comprehensive understanding of the complex interactions between the atmosphere, oceans, land surface, and cryosphere, and how they are likely to change in response to increasing greenhouse gas concentrations and other climate change drivers. The outputs derived from the CMIP6 data are the following:

- Raw CMIP6 data is projected via Shared Socioeconomic Pathways (SSPs) to provide insight into future climates based on defined emissions, mitigation efforts, and development paths. The data used has a varied downscaled resolution of ~50km and presents a daily temporal output of the climate from 1960-2100.[3]
- WorldClim: WorldClim data is a set of bias-corrected, high-resolution, downscaled climate models that can be used for detailed spatial analysis of an area's climate changes. The data used has a downscaled resolution of ~10km and presents a temporal average of the climate from 2021-2040 representing the near-term projection.[4]
- The Climate Change Knowledge Portal (CCKP): the CCKP is a hub for climate-related information, data, and tools which provides an online platform from which to access and analyse comprehensive data related to climate change and development. The data used has a

[5] ECMWF, CMIP6 climate projections, information.

downscaled resolution of ~50km and presents a temporal average of the climate from 2020-2039 representing the near-term projection.[5]

- Copernicus Climate Change Service (C3S): This dataset provides aridity indicators useful for climate and vegetation interaction assessment.[6]
- Köppen-Geiger climate classification: Maps present global maps of the Köppen-Geiger climate classification at a high resolution for historical and future climate conditions. The data used has a downscaled resolution of 1km and presents a temporal average of the climate from 2041-2070 representing the medium-term projection.[7]

While the global climate model projections available from the CMIP6 are relevant for use in the rapid infrastructure climate risk assessment it is important to undertake additional analysis of current and future climate scenarios when undertaking more detailed level risk assessment and for design purposes. This would include considering which models might be most appropriate for a given location based either on comparison with observed data or on an understanding of the individual model assumptions. It is also important to consider the range of uncertainty for the different projections and to consider outputs either from individual models or from other parts of the distribution such as upper or lower percentiles as opposed to the ensemble mean as used for the rapid risk assessment. For the assessment of critical infrastructure, it is preferable to also consider more extreme results such as the 90th Percentile to be conservative.

2.2.2 Future Climate Scenarios

The IPCC Sixth Assessment Report 2021[8] (AR6) confirms that the world is on the verge of major tipping points and that immediate climate action is critical for our survival. It emphasizes the most recent and sophisticated physical understanding of the climate system and climate change[9]. It combines multiple pieces of evidence from past observations of the ecosystem, scientific and process understanding, and provides data and information to global and regional climate models to formulate advice on climate variables such as weather and climate extremes in a specific situation under various emission criteria. Despite the NDCs, recent global emissions indicate that we are very unlikely to meet the SSP1 scenario milestones. SSP5 is the worst-case scenario and mitigation measures are anticipated to make this an avoided reality. Assessment, therefore, is proposed to be done against the more probable SSP2-4.5 or SSP3-6.5 scenario. Other scenarios (and time periods) can be facilitated as required.

2.2.3 Timeframe

Climate modeling is the assessment of the long-term anticipated changes in the climate system. These are normally done for 30 years at the mid-century (2040-2069) and late-century (2070-2099) time intervals. However, the need for interventions to adapt to climate change requires the development of intervention actions in the short term. The planning and adaptation horizons should match the projected climate analysis timeframes. The 30-year time frame of 2020-2050 with a mid-point of 2035 is therefore proposed for the assessment of the near future climate changes for infrastructure. The baseline of the current climate used is 1990-2020 unless otherwise stipulated. Future anomalies are derived from this baseline.

2.2.4 Reducing Uncertainty

There is often uncertainty associated with these model data. To limit this model validation can be performed in varying locations with different climate drivers and forcing mechanisms to ensure there is a robust simulation of the current, and subsequently future climate scenarios. The best-performing model or ensemble of models will be selected for further analysis. Additionally, these model outcomes will be compared directly to the country's NAP and NDC documents. However, such validation is not possible during the period of this assessment and therefore we propose using the ensemble mean for all projections as inputs to the GEM. An assessment of the range of uncertainty for individual climate variables will be considered in the hazard assessment for critical infrastructure systems across the three countries of interest. The selection of these models, scenarios and timeframes are based on the current status of climate science. Furthermore, these align with international funding agencies (such as the GCF), so this could act as part of the feasibility studies for possible future funding proposals.

2.2.5 Climate Change Hazard Assessment

The assessment of the climate-related hazards to critical infrastructure systems was two-fold.

- The standard climate variables of temperature (minimum, mean and maximum), rainfall, aridity, and humidity have been assessed on both an annual and monthly basis to establish the likely new normal for each country. This provides a broader context to the study.
- The detailed analysis of derived extreme climate parameters that may impact infrastructure. These include changes in the change in the 95th percentile rainfall, peak single day, 5-day rainfall events, and peak prolonged monthly rainfall changes as well as the number of days over 20 mm; For temperature changes, these may include warm spell duration, changes in +35°C days and changes in the historical 99th percentile temperature days. Additional factors considered include sea level rise, extreme storm surge potential and, drought conditions (SPEI) and aridity.

The changes in standard and extreme climate parameters were then overlayed with the national infrastructure datasets to initially infer basic risk. Further detailed analysis link to critical infrastructure will be informed based on the initial risk findings. Where possible information on condition and the criticality of infrastructure will be used to provide additional context for identifying hot spots of climate change related risk as well inputs to the Green Economy Model (GEM) for determining overall impact.

The specific climate parameters used to define each of the different climate hazards considered relevant for the rapid climate change risk assessment for critical infrastructure are listed in Table 2-2 below.

2.3 Infrastructure Risk Assessment

2.3.1 Overview of the Approach

The infrastructure systems climate risk assessment undertaken in support of the rapid climate risk screening study was based on the IPCC definition of climate change related risk as:

RISK = HAZARD x EXPOSURE x VULNERABILITY.

The impact on infrastructure is often caused by extreme weather events. These can be floods, heat waves, drought, tropical cyclones, etc. Assessment of the impact of these events in the historical context is measurable but when considering the projected future, assessment requires analysis of projected future climate models as considering the principle of stationarity in that climate mechanisms that drive impacts noted in the historical period will be consistent in the future but just under different climate conditions.

This assessment considers two future timeframes of near term (2020-2039) and mid-term (2040-2059) for SSP2-45 and SSP5-85 as the most likely and the extreme scenarios in line with IPCC AR6 standards and as the international funding agency's preference. The climate parameters assessed are aligned with hazards likely to impact infrastructure function or resilience. The hazards considered are heat hazards that may cause softening of asphalt or warping of surfaces; heavy rainfall and flooding which may physically damage infrastructure; drought hazards which may result in drying of soils and compromising grounds on which infrastructure is located; Tropical Cyclones and wind speed which may damage exposed infrastructure; Sea Level Rise and Coastal Erosion which will compromise coastal infrastructure; and Rainfall triggered Landslides which will cause damages in areas where these occur.

2.3.2 Determinig the Curent and Future Climate Related Risk

The overall climate risk to critical infrastructure for roads for example is calculated by combining the standardized hazard indexes and the road condition index. This results in a rational number risk score of between 1 (very low risk) and 5 (very high risk). Each of extreme temperature, Heavy Rainfall and Flooding, Drought, Tropical Cyclones and wind speed, Sea Level Rise and Coastal Erosion, and Rainfall triggered Landslides risks are assessed separately to allow for a hazard-focused assessment at the road level and allow for targeted climate hazard intervention. For other infrastructure classes that do not have condition, the overall risk is determine based on the climate hazard only at the spatial location of the infrastructure.

Cumulative risk is presented by combining all the hazard types to show the overall road risks to current and future climate change. The resulting length of road in each risk category can then be aggregated up to a district and provincial level as well as national and if necessary, can be distinguished by road type.

For each section of road or railway, or for each individual power station, hospital or school, identified the location is intersected with the various climate hazard layers to determine the climate hazard score (from 1 to 9) under current and future climate conditions. The rating is derived from the full range of values for the specific climate hazard across all three countries and both current and future timeframes. This enables a comparison between countries and also between current and future climate scenarios.

The overall climate hazard risk score is derived from the individual climate hazard score (classified from 1 to 9) multiplied by the exposure score for river flooding (1 to 4) and landslide risk (1 to 3) only, and then by the road condition score (1 to 5) but for road infrastructure only. The final climate hazard risk score is then reclassified into five classes from very low to very high. The final climate risk score can then be compared for the current and future climate scenarios as an indication of the climate change related risk.

The approach used to determine each of the climate hazard, exposure and vulnerability scores used in the overall climate risk assessment for critical infrastructure are described in the following sections.

2.3.3 Climate Hazard Index

The climate hazard index is a combination of climate variables. This is done because there are often several chronic and acute factors that will contribute to the degradation of an asset. For instance, an assessment of the peak extreme temperature days will consider only a short-term impact of temperature on a road, whereas considering the number of days above 35°C will assess the frequency of events that will degrade road surfaces over several days. In addition, considering the peak monthly temperatures will take into account the degradation over a long period. When combined, these account for a potential single day, several days and monthly high-temperature degradation on roads. Similarly selected extreme rainfall variables such as peak single day maximum rainfall or number of days above 20mm are used to determine both the potential for direct impacts on the infrastructure and local flooding and drainage risks, but also contribute to the evaluation of river flooding and landslide risk by combining it with the exposure index which is based on the current topographic details such as slope and soil type or proximity to the river channel.

The climate hazards used to assess the current and future likelihood of these impacts are in Table 2-2.

Table 2-2: Climate variables used to define climate hazard index for critical infrastructure

Hazard Index	Climate variable	Motivation and thresholds (based on consideration for roads)
Extreme temperature	• Peak daily Maximum temperature • Number of days over 35°C • Maximum temperature monthly peak	Asphalt pavements are particularly vulnerable to high temperatures. The bitumen binder in asphalt softens under prolonged heating leading to Deformation of the surface and bitumen seeping to the surface. This can occur at ambient temperatures reaching 35°C to 40°C.[6] It's also noted that thermal expansion issues and potential buckling at ambient temperatures above 35°C.[7]

[6] Yang, H. (2018). "Effects of High Temperature on Asphalt Pavement Performance." Journal of Transportation Engineering, Part B: Pavements, 144(2), 04018021. Available at: https://doi.org/10.1061/JPEODX.0000093

[7] Kim, Y.R., & Little, D.N. (2020). "Evaluation of High-Temperature Properties of Asphalt Binders and Mixtures." Transportation Research Record, 2674(10), 593-602. Available at: https://doi.org/10.1177/0361198120913343

Heavy Rainfall and Flooding[8]	• Peak single-day rainfall • Number of days above 20mm • Simple daily rainfall intensity index • Areas of noted floods	High volumes of rainfall and flooding can lead to Water Infiltration and Subgrade Weakening through erosion and support losses. Additionally, Water can infiltrate and expand existing cracks and can cause potholes.[9] Erosion and weakening of the subgrade can occur with rainfall events exceeding 50mm in 24 hours. Persistent rainfall exceeding 20 mm per day over several days can lead to significant water infiltration, which can exacerbate existing cracks and lead to pothole formation.[10]
Drought	• SPEI (Standardized Precipitation-Evapotranspiration Index) • Aridity index	Drought and subsequent drying of soils can lead to shrinkage of the subgrade soils and possible soil movement. Additionally, the top surface of concrete pavements dries out and shrinks faster than the bottom, leading to curling.[11] [12] Threshold qualification is challenging so drought severity and aridity are used.
Tropical Cyclones and wind speed	• Peak wind speeds • Tropical cyclone frequency	In addition to the noted impacts of extreme rainfall and erosion on infrastructure, tropical cyclones will also result in very high wind speeds that themselves can cause physical damage from debris falling onto road surfaces and surface abrasion of moving debris driven by floodwaters and winds. Wind speeds above 74 km/h (the threshold for a Category 1 tropical cyclone) can cause physical damage from debris impact.[13]
Sea Level Rise and Coastal Erosion	• Sea level rise • Storm surge height	Roads at low elevations may become permanently submerged or be subject to more frequent and severe flooding due to sea level rise, making them permanently or occasionally impassable. Additionally, saltwater can accelerate the corrosion of steel reinforcements in concrete and degrade other materials used in infrastructure. Storm surges will also have these negative effects but at a much more acute scale. Storm surges of 2 meters or more can cause severe flooding and erosion while sea level rise projections of 0.5 to 1 meter by 2100 pose significant threats to such low-lying infrastructure.[14] [15]
Rainfall triggered Landslides	• Rainfall-triggered landslides hazard • Cumulative 5-day rainfall volume • Peak monthly rainfall volumes	Landslides can completely block roads and infrastructure with debris, making them impassable until cleared. Additionally, the force of the landslide can damage or destroy the road surface, bridges, and other infrastructure. Landslides can also remove support from underneath the road, causing sections of the pavement to collapse or slump. Thresholds vary by soil type but range from 50mm to 200 mm of cumulative rainfall over a short period depending on soil saturation.[16] [17]

[8] Heavy rainfall and flooding hazard is calculated over the local catchment. All other hazards are based on the location of the climate impact

[9] Al-Qadi, I. L., & Elseifi, M. A. (2018). "Pavement Sustainability." In Climate Change, Energy, Sustainability and Pavements (pp. 317-342). Springer, Dordrecht. Available at: https://doi.org/10.1007/978-94-007-6222-3_11

[10] Federal Highway Administration (FHWA). (2019). "Hydraulic Performance of Permeable Pavement Under Extreme Rainfall Conditions." Available at: https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/17043/17043.pdf

[11] Dawson, A. R., et al. (2020). "Impact of Climate Change on Road Infrastructure." In: Climate Change Adaptation for Transportation Systems. Elsevier. Available at: https://doi.org/10.1016/B978-0-12-819138-8.00009-7

[12] Puppala, A. J., et al. (2017). "Drought-Induced Soil Shrinkage in Expansive Soils and Its Impacts on Road Infrastructure." Journal of Geotechnical and Geoenvironmental Engineering, 143(5), 04017008. Available at: https://doi.org/10.1061/(ASCE)GT.1943-5606.0001677

[13] Turner, A., & Zhang, L. (2011). "The Impact of Hurricane Katrina on Road Infrastructure and Transportation." Natural Hazards Review, 12(3), 133-139. Available at: https://doi.org/10.1061/(ASCE)NH.1527-6996.0000030

[14] Intergovernmental Panel on Climate Change (IPCC). (2021). "Sixth Assessment Report: Climate Change 2021: The Physical Science Basis." Available at: https://www.ipcc.ch/report/ar6/wg1/

[15] National Oceanic and Atmospheric Administration (NOAA). (2018). "Hurricane Storm Surge and Coastal Inundation." Available at: https://www.noaa.gov/hurricane-storm-surge-coastal-inundation

[16] Crozier, M. J. (2010). "Deciphering the Effect of Climate Change on Landslide Activity: A Review." Geomorphology, 124(3-4), 260-267. Available at: https://doi.org/10.1016/j.geomorph.2010.04.009

[17] Dahal, R. K., & Hasegawa, S. (2008). "Representative Rainfall Thresholds for Landslides in the Nepal Himalaya." Geomorphology, 100(3-4), 429-443. Available at: https://doi.org/10.1016/j.geomorph.2008.01.014

Each of the individual climate indicators is standardized and classified over the full study area to allow comparisons between countries. The scoring for these hazard ranges from 1 (very low magnitude) to 5 (very high magnitude). The individual hazard indicators are created by combining the standardized and classified individual climate indicator index values with equal weighting over the complete area (I.e. the based on the range of values for Malawi, Mozambique and Tanzania and not just the individual country).

There was a total of 9 classes used to provide greater analysis resolution. These are arranged as follows:

Table 2-3. Hazard index range classification

Hazard Rating	Score Range	Proportion of range	Deterioration Range Motivation
Very Low	1-2	12.5%	Infrastructure will likely experience zero to little deterioration from this current and projected climate hazard.
Low	2-4	25.0%	Infrastructure will likely experience Little to moderate deterioration from this current and projected climate hazard.
Medium	4-6	25.0%	Infrastructure will likely experience moderate deterioration from this current and projected climate hazard.
High	6-8	25.0%	Infrastructure will likely experience moderate to high deterioration from this current and projected climate hazard.
Very High	8-9	12.5%	Infrastructure will likely experience significant deterioration from this current and projected climate hazard.

Each extreme event index uses these scores based on the Jenks classification[18] of the individual climate variable values. This was done using the range of the complete study area to ensure inter-country comparison as well as using both the current and the future climate scenario ranges. Below are the climatic ranges used to classify each of the climate variables into the Very low to Very high hazard score.

Table 2-4. Climate hazard range classification

Deterioration Range		Very Low	Low	Medium	High	Very High
Extreme Temperature Index	Peak single-day temperature (°C)	<29	29-32	32-35	35-40	>40
	Number of days over 35°C	<3	3-25	25-40	40-56	>56
	Peak monthly maximum temperature (°C)	<21	21-27	27-30	30-35	>35
Flooding Index	Peak single-day rainfall (mm)	<15	15-25	25-36	36-54	>54
	Number of days above 20mm	<2	2-6	6-10	10-18	>18
	Average rainfall intensity (mm/day)	<3	3-5	5-6	6-9	>9
Drought Index	Aridity Index	<0.2	0.2-0.4	0.4-0.5	0.5-0.6	>0.6
	Standardized precipitation evaporation index (SPEI)	> +0.06	+0.03 - +0.06	-0.15 - +0.03	-0.2 - -0.15	< -0.2
Tropical cyclone and wind Index	Tropical cyclone Wind speed (km/h)	<10	10-50	50-100	100-130	>130
Sea Level Rise and Coastal Flooding	Sea level rise (cm)	<0.8	0.8-1.0	1.0-15.0	15.0-25.0	>25.0
	Inundation depth (m)	<0.15	0.15-1.00	1.00-2.00	2.00-2.90	>2.90
	Storm Surge risk	<0.3	0.3-0.4	0.4-0.5	0.5-0.6	>0.6
Landslide Index	Peak 5-day rainfall (mm)	<45	45-70	70-100	100-160	>160
	Peak monthly rainfall (mm)	<130	130-200	200-260	260-350	>350

[18] The Jenks classification technique is a data clustering method commonly used in GIS for dividing a dataset into distinct classes. It is specifically designed to minimize the variance within classes and maximize the variance between classes clustering data with natural groupings.

2.3.4 Exposure – River Flooding and Landslides

Exposure of critical infrastructure to potential increased river flooding and landslide risks due to climate change is determined using global flood hazard and landslide susceptibility maps available from the United Nations Environmental Program (UNEP) global risk assessment (GAR) portal[19] . The river flooding hazard map and landslide susceptibility map for Tanzania are shown in Figure 9 and Figure 10 respectively.

The GAR Atlas global flood hazard assessment uses a probabilistic approach for modeling riverine flood major river basins around the globe. This has been possible after compiling a global database of stream-flow data, merging different sources and gathering more than 8000 stations over the globe in order to calculate the range of possible discharges from very low to the maximum possible scales at different locations along the rivers. The calculated discharges were introduced in the river sections to model water levels downstream. This procedure allowed for the determination of stochastic event-sets of riverine floods from which hazard maps for several return periods (25, 50, 100, 200, 500, 1000 years) were obtained.

The hazard maps are developed at 1 km x 1 km resolution and have been validated against satellite flood footprints from different sources (DFO archive, UNOSAT flood portal) performing well especially for big events. For smaller events (lower return periods), the GAR Atlas flood hazard maps tend to overestimate with respect to similar maps produced locally (hazard maps where available for some countries and were used as benchmark). The main issue being that, due to the resolution, the GAR Atlas flood hazard maps do not take into account flood defenses that are normally present to preserve the value exposed to floods.

More information about the flood hazard assessment method used can be found in Rudari *et al.* (2015).

The river flooding exposure index (Table 2-5) is derived from the total inundated area for the different recurrence interval (RI) floods derived from the GAR Atlas and classified as follows: High (<1:25 year RI), Medium (< 1:100 year RI), Low (< 1:1000 year RI), very low (> 1:1000 RI year). Again, it is important to note that the GAR Atlas provides a relatively course scale flood hazard map which, while sufficient for an initial climate risk assessment and screening, would need to be improved with targeted flood risk modeling and analysis for priority infrastructure investments and/or analysis of potential adaptation options.

Table 2-5: Classification of exposure to river flooding

Exposure Score	Exposure	Recurrence Interval (year)
1	High	< 1 : 25 years
2	Medium	< 1: 100 years
3	Low	< 1:1000 years
4	Very Low	> 1: 1000 years

This dataset includes an estimate of the annual frequency of landslide triggered by precipitations. It depends on the combination of trigger and susceptibility defined by six parameters: slope factor, lithological (or geological) conditions, soil moisture condition, vegetation cover, precipitation and seismic conditions. Unit is expected annual probability and percentage of pixel of occurrence of a potentially destructive landslide event x 1000000. This product was designed by International Centre for Geohazards (NGI) for the Global Assessment Report on Risk Reduction (GAR). It was modeled using global data.

[19] Home (unepgrid.ch)

2.3.5 Infrastructure Vulnerability – Road Condition Index

The road condition index is used as an indicator of the vulnerability of the road infrastructure to climate related hazards. The assumption being that a road that is in poorer condition, mainly due to a lack of maintenance is more likely to be damaged by an extreme event such as a flood or higher temperatures than a road in good condition. It is made from the noted current infrastructure condition as given by the GIS attribute table. As a proof of concept, the current road network provides only the major roads in Tanzania[20]. This data set covers 9939 km of road with the following surface and condition characteristics:

Table 2-6: Current condition for paved and unpaved roads in Tanzania

		Condition category	Paved (km)	Unpaved (km)	Total (km)
Condition	Very Good	1	714.06	315.14	1 029.20
	Good	2	2 198.98	1 269.90	3 468.88
	Fair	3	844.49	2 109.99	2 954.48
	Poor	4	91.27	501.48	592.75
	Very Poor	5	97.05	24.78	121.83
	Unknown	5	169.72	1 601.92	1 771.64
		Total (km)	4 115.56	5 823.21	

The condition of the roads is categorized as integers between 1 (very good) and 5 (very bad or unknown). The data used is obtained from the World Bank database[21] and covers only the major national roads. Most countries have their own asset management system for monitoring road condition across the country which could be used to provide more local level data and also updated information at the national level if available. An effort was made to obtain this data for Tanzania, but it could not easily be sourced. It could however be used to further prioritization areas of climate risk at a local/national level.

Unfortunately, no information on condition of the other infrastructure classes could be sourced and as a result the risk assessment for the other infrastructure classes did not include a vulnerability indicator and was therefore based only on the hazard and exposure in terms of flooding and susceptibility to landslides.

Collecting data on the current condition of other critical infrastructure including bridges, transmission lines, power stations, buildings, etc. as a national level would enable further prioritization based on vulnerability to the potential impacts of climate change. This information would also be useful in determining the costs for rehabilitation and refurbishment of infrastructure to be more climate resilient.

2.3.6 Infrastructure Criticality

In order to further assist with prioritizing investments for climate proofing critical infrastructure a first order metric of infrastructure criticality is used. This is derived at the provincial or district level and is based on the estimated total population in each district and the number or length of critical infrastructure assets located within that district. For example, the length of road per 1000 people or the number of people for each power station or power plant in the region. If local data on the actual asset value or the dependency on the individual infrastructure assets was available then this could also be used, particularly for prioritizing critical infrastructure assets at a national or even a regional scale such as road corridors.

Similar metrics for criticality could be developed for other infrastructure assets such as power stations (based on the percentage contribution to the national grid) or education or health care facilities or water and wastewater treatment infrastructure in terms of the population served. The criticality of key transport links such as roads, railways, ports, etc. could also be determine in terms of the value of goods transiting

[20] World Bank Group, Data catalog. Accessed 2024/07/05. https://datacatalog.worldbank.org/search/dataset/0041099/Tanzania-Roads

[21] Tanzania Roads | Data Catalog (worldbank.org)

the specific infrastructure asset. This type of analysis would be done in terms of determining the value of an individual infrastructure asset as part of a more focused asset level risk and vulnerability assessment.

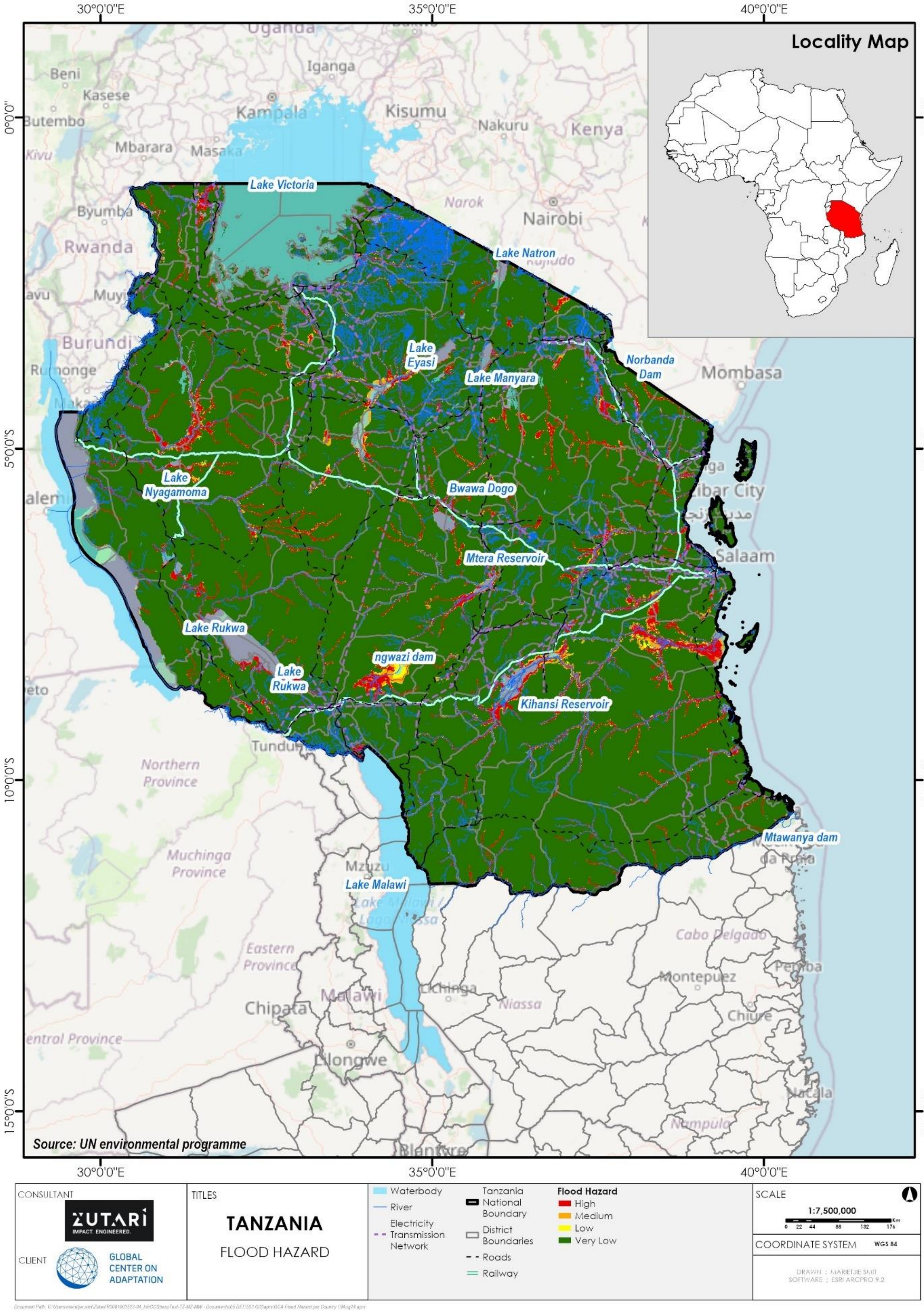

Figure 9: Flood hazard map for Tanzania (Data Source: UNEP GAR Atlas)

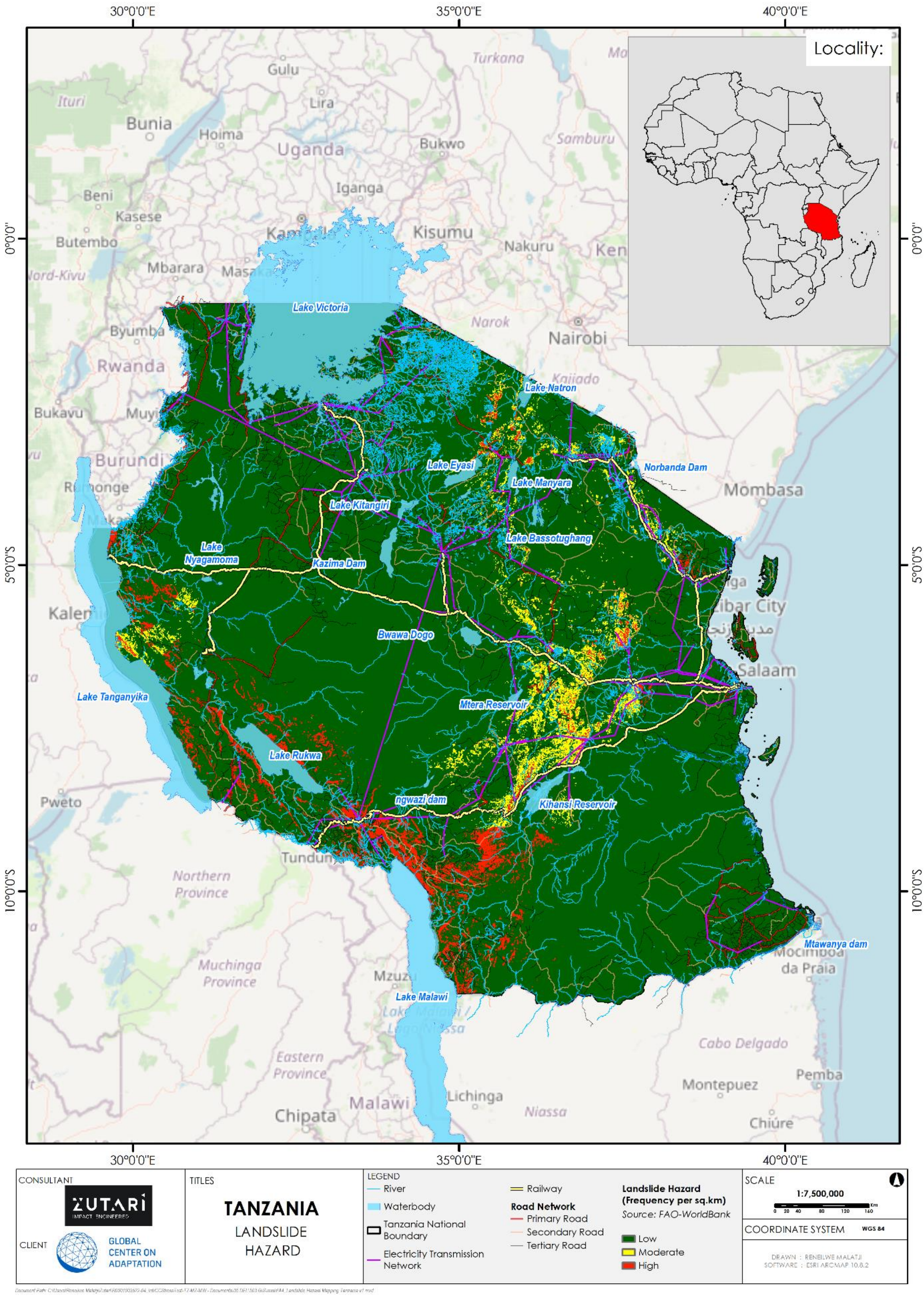

Figure 10: Landslide susceptibility map for Tanzania (Data Source: UNEP GAR Atlas)

3 CLIMATE HAZARD ASSESSMENT RESULTS

The results of the climate hazard assessment for Tanzania are presented below including:

- Climate classification
- Temperature
- Precipitation
- Heatwaves
- Flooding and Landslides
- Sea Surface Temperature and Tropical Cyclones
- Wind, Fire and Cloud Cover

3.1 Climate Classification

Expected changes in the Koppen climate classifications are shown in Figure 11. Future climate changes are anticipated to expand the hot steppe climate and contract the temperate areas of southern Tanzania.

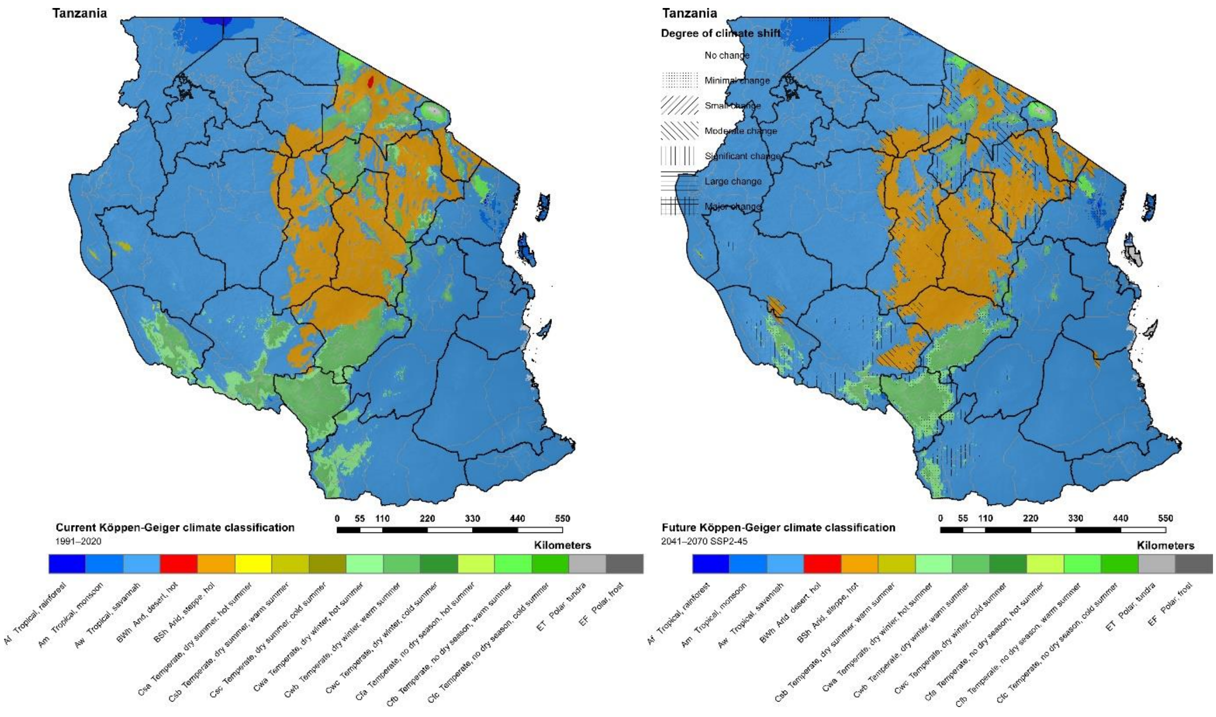

Figure 11. Koppen climate classification. Current (left) and projected future (right)

3.2 Temperature

Currently maximum temperatures are highest along the coastal areas and in some central eastern areas of the country (Figure 12). The peak temperatures are noted from October to January partially in the southeastern part of the country. The projected future suggests an increase in average maximum temperatures over the whole area, with the largest increases noted in the southern part of the country.

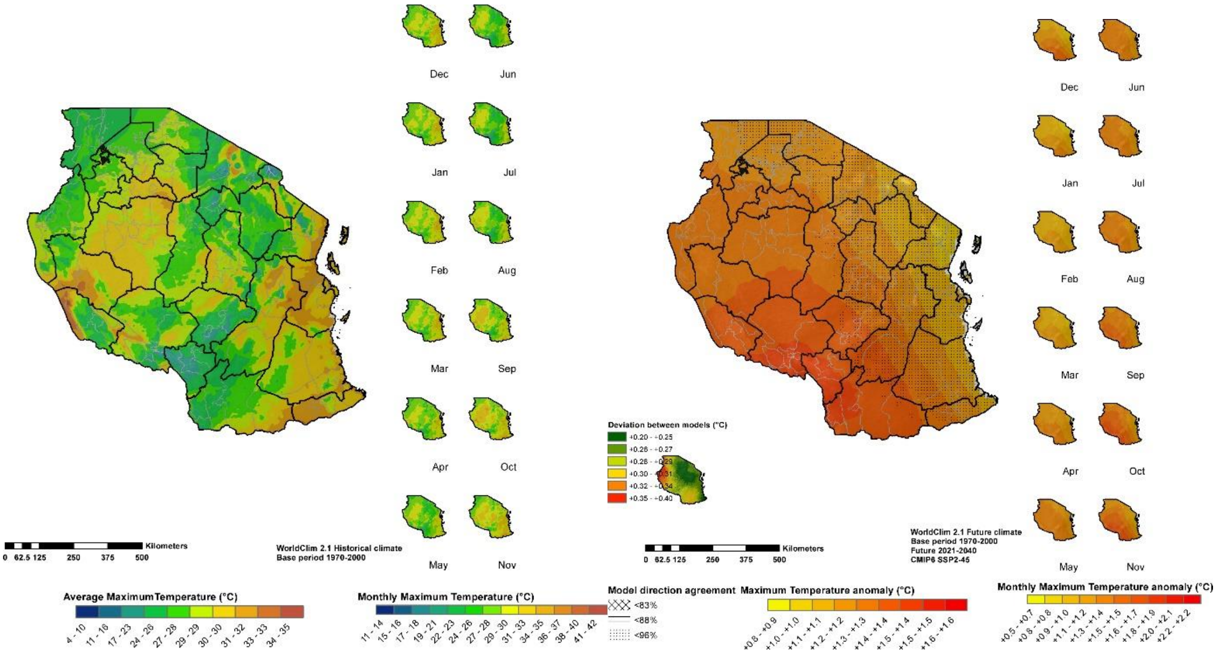

Figure 12. Annual and monthly maximum temperature distribution. Current (left), future anomaly (right)

3.3 Precipitation

Currently, the peak rainfall is noted in the far northern and southeastern areas of the country (Figure 13). The monthly peaks are noted from November to April each year. The projected rainfall suggests a likely overall increase in annual volume over most of the country. There is however greater model disparity in the southern parts of the country. The timing of these changes notes most of the increases will occur from December to March. There are, however, some months showing a small decreased volume, these are November, particularly in the south and May and October.

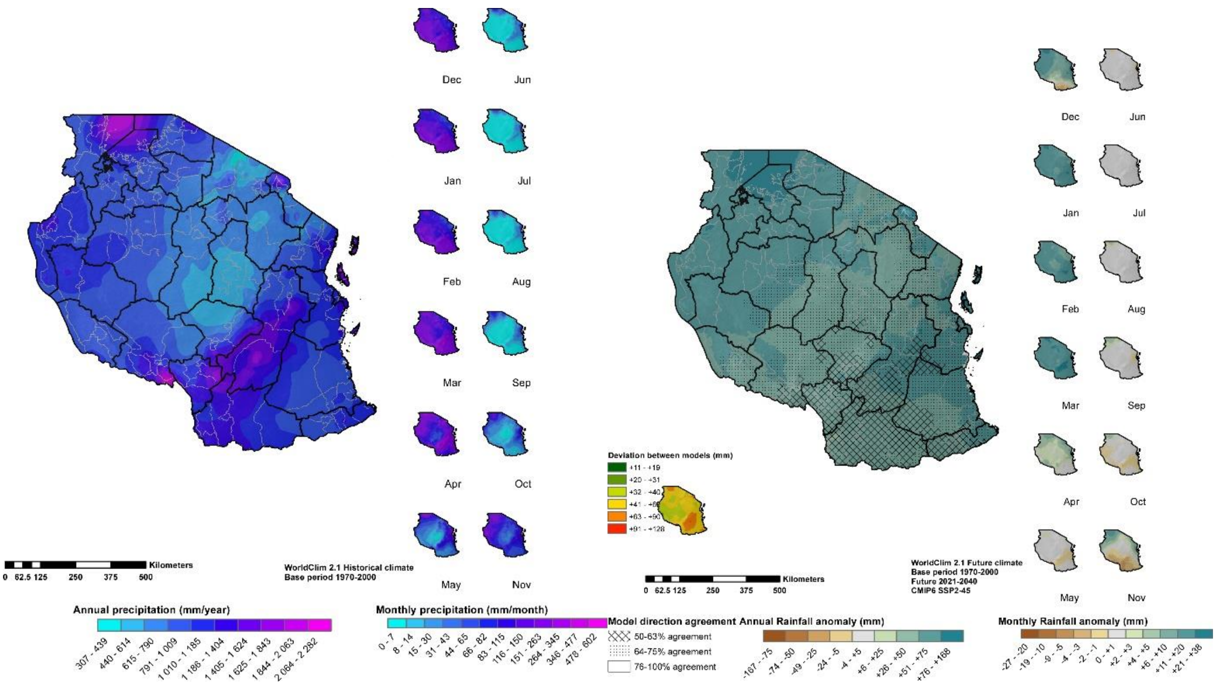

Figure 13. Annual and monthly rainfall distribution. Current (left), future anomaly (right)

3.1 Heatwaves

An increase in maximum temperatures will also lead to heat waves and other severe events. The peak monthly temperatures are noted to the south and coastal areas and in some inland areas. There are higher warm spell durations noted along the coastal and northern edge of the country. The number of days above 35°C is highest in the southern areas as is the peak maximum temperature (Figure 14, left).

The projected temperature increases will result in increased severity of heatwaves. The peak monthly temperatures are projected to increase significantly to the southwest of the country. The warm spell duration is likely to increase mostly uniformly over most of the country with the number of days over 35 °C showing significant focus in the southern areas. The peak maximum temperatures are anticipated to increase further in the southern and central areas of the country (Figure 14, right).

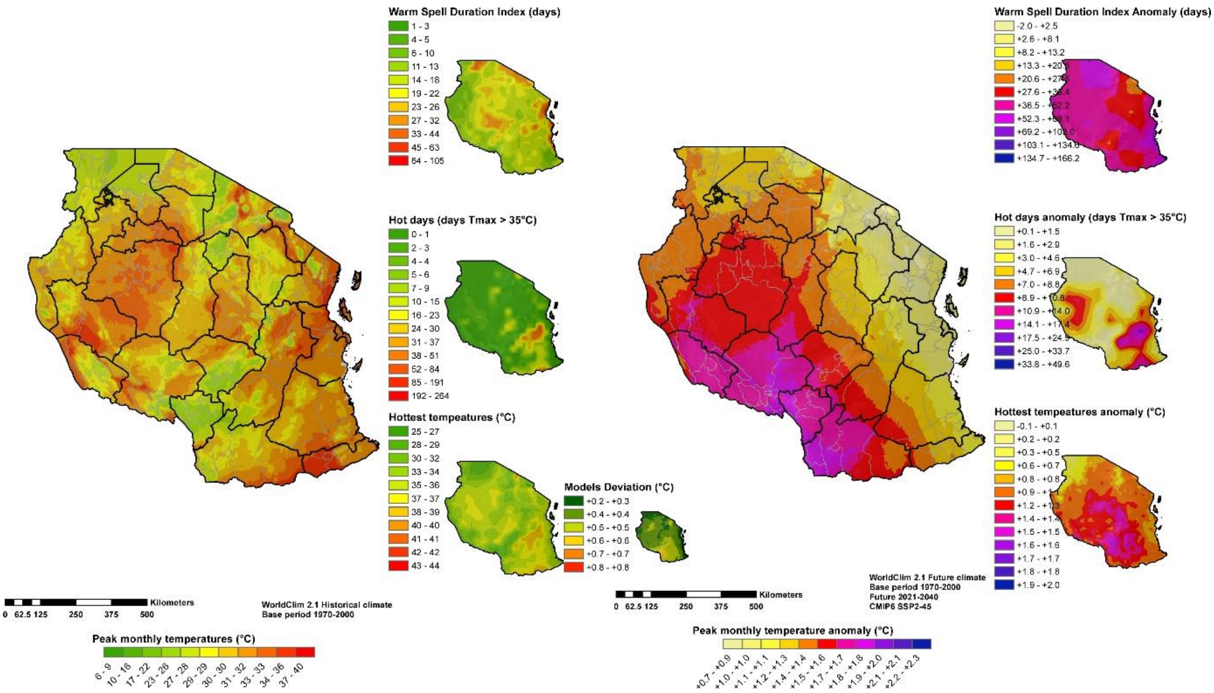

Figure 14. Heatwave and extreme temperature parameter distributions. Current (left), future anomaly (right)

3.2 Flooding and Landslides

The peak monthly rainfall and other extreme rainfall characteristics will give an indication of the potential increase in the risk of both flooding and landslides. The peak monthly rainfall is noted in the southern areas of the country (Figure 15). Many of the extreme parameters show higher isolated focus areas. For instance, the 1-day and 5-day maximum rainfall events are noted in smaller clusters around the country, as are the 95th percentile event magnitude, the average intensity index and the days over 20mm.

The projected changes in severe rainfall events will alter the flood magnitudes that threaten critical infrastructure. The peak monthly rainfall sees an increase over most of the country, particularly the central and southern areas (Figure 16). The 1 and 5-day maximum events see an increase in the central areas and decreased volumes in the northern and southern areas. The intensity index sees an increase in the northern and eastern areas but decreases in the southwestern areas as does the 95th percentile events. The change in the days over 20mm is highly varied over the country.

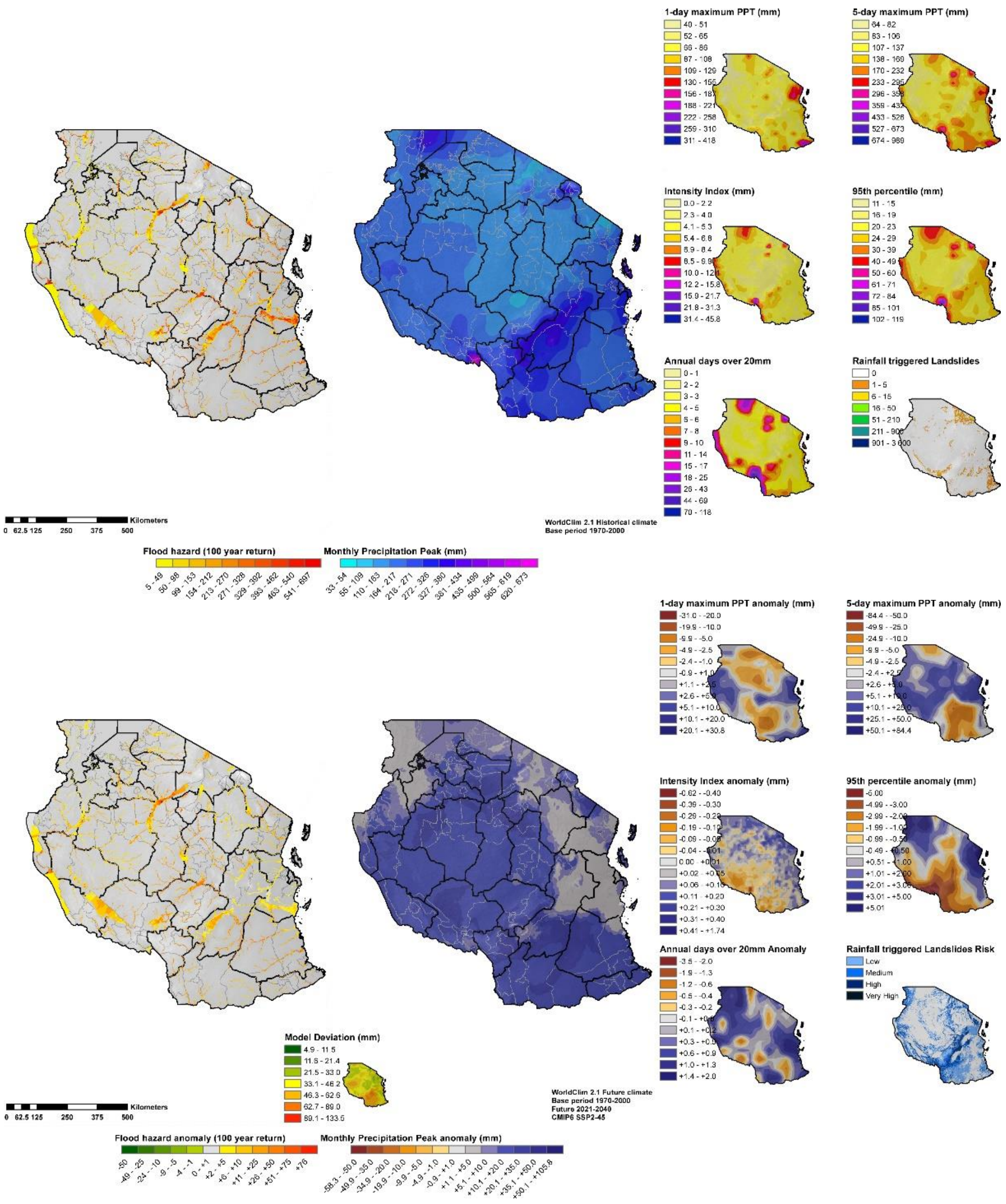

Figure 15. Flood and extreme rainfall parameter distributions. Current (top), future anomaly (bottom)

3.3 Drought

The current drought indices see its peak in the central and southern areas. There is also higher rainfall seasonality in these areas which makes year-on-year reliability troubling. There are also noted increased dry spell duration, consecutive dry days and aridity in the central and southern areas of the country. The consecutive wet days and the evaporation show smaller focus areas to the north and western areas.

The projected future suggests a mild decrease in drought severity due to the increase in annual rainfall volumes. There is however an increase in precipitation seasonality making seasonal planning more challenging. The majority of the country will also see an increase in dry spell duration, consecutive dry days and aridity. The consecutive wet days are simulated to decrease over most of the country. The evaporation is projected to increase in the northwestern parts of the country and decrease in the southeast. The number of consecutive dry days will impact on subsistence agriculture across Tanzania.

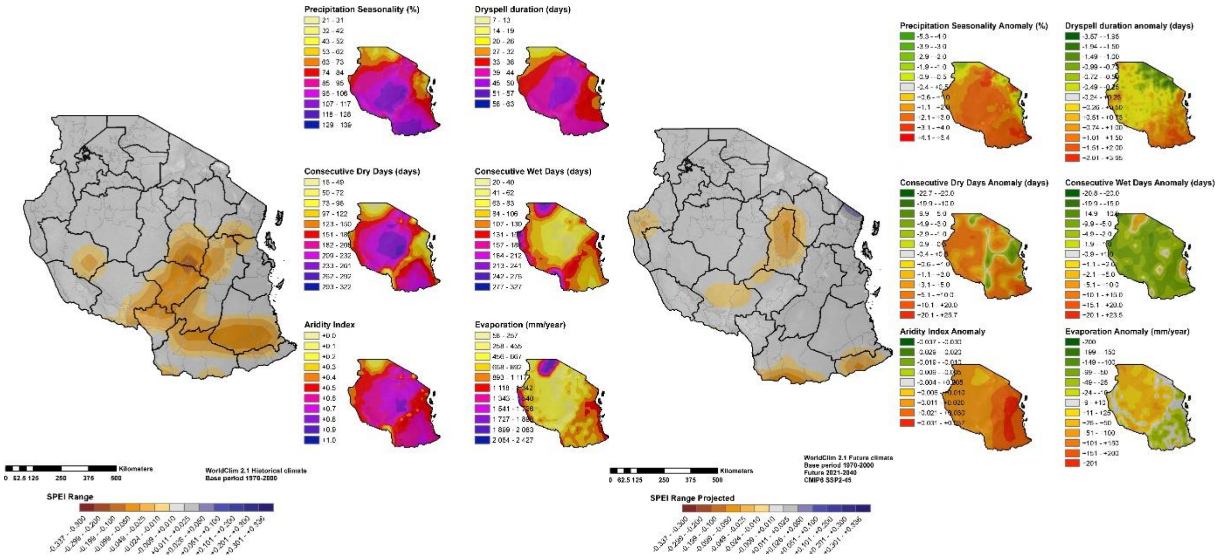

Figure 16. Drought and rainfall variability parameter distributions. Current (left), future anomaly (right)

3.4 Sea Surface Temperature and Tropical Cyclones

Future sea surface temperatures suggest an increase mostly along the eastern coastal areas (Figure 17).

Furthermore, there are decreases in salinity, calcite, aragonite and pH, also along the northern coastal areas. These decreases will result in an increase in ocean acidification in these areas.

The coastal areas are also exposed to higher numbers of tropical cyclones mostly in the southern areas. The peak cyclonic wind speeds are all high in the southern coastal areas. Additionally, there is a possible uniform increase in the storm surge along the coast. The future baseline sea level is projected to increase.

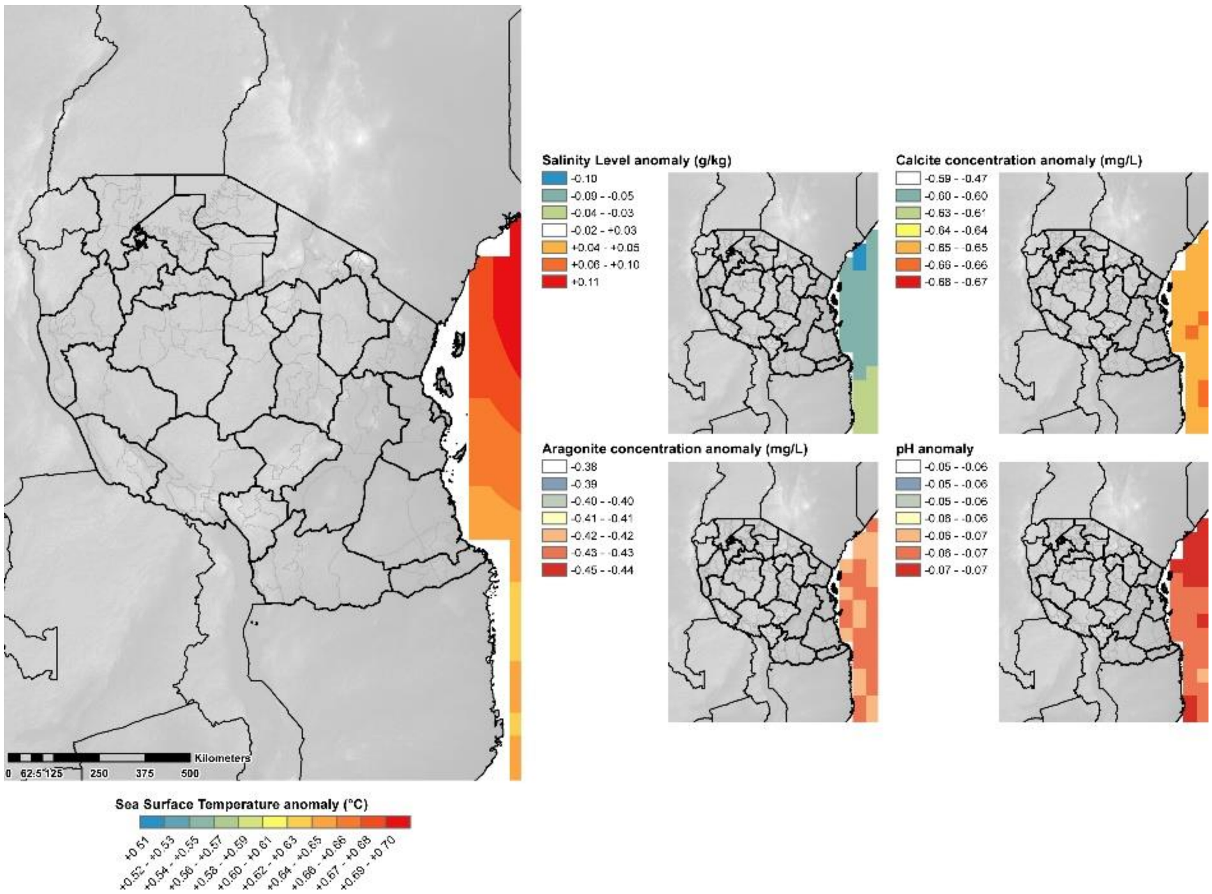

Figure 17. Sea surface temperatures and factors impacting ocean acidification. Future anomaly (bottom)

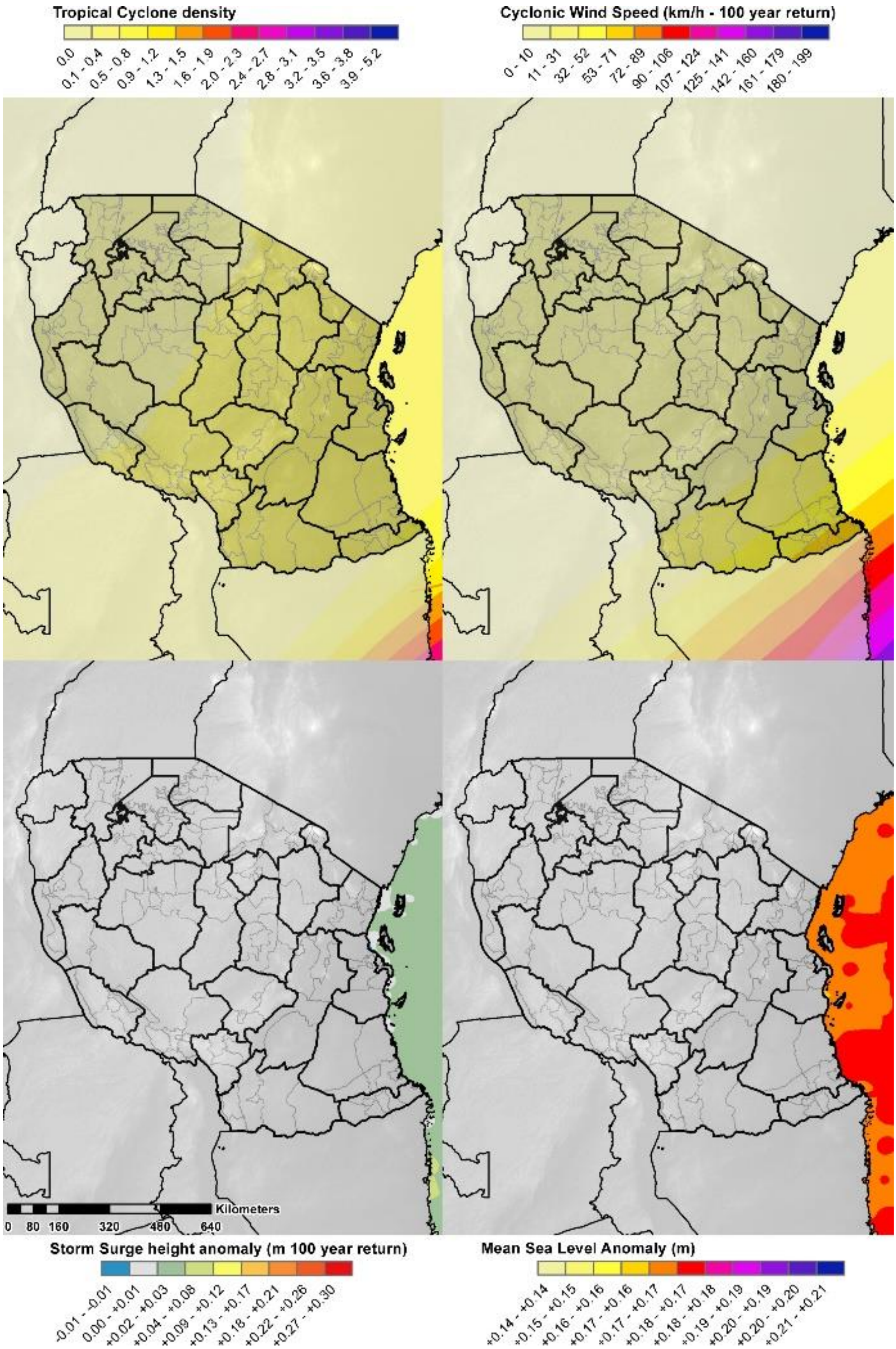

Figure 18. Current tropical cyclone density and maximum windspeeds (top), future storm surge eight and mean sea level anomaly (bottom)

3.5 Wind and Fire and Cloud Cover

The average wind speed sees the highest magnitudes in the central and western areas of the country and lower speeds in the southern areas (Figure 19). The highest fire densities are noted in the western parts of the country. The cloud cover is highest along the eastern parts of the country along the coast. There are also higher cloud cover areas present to the northwest. The projected cloud cover suggests an increase in the far northern areas and a decrease elsewhere over the country affective solar capacity.

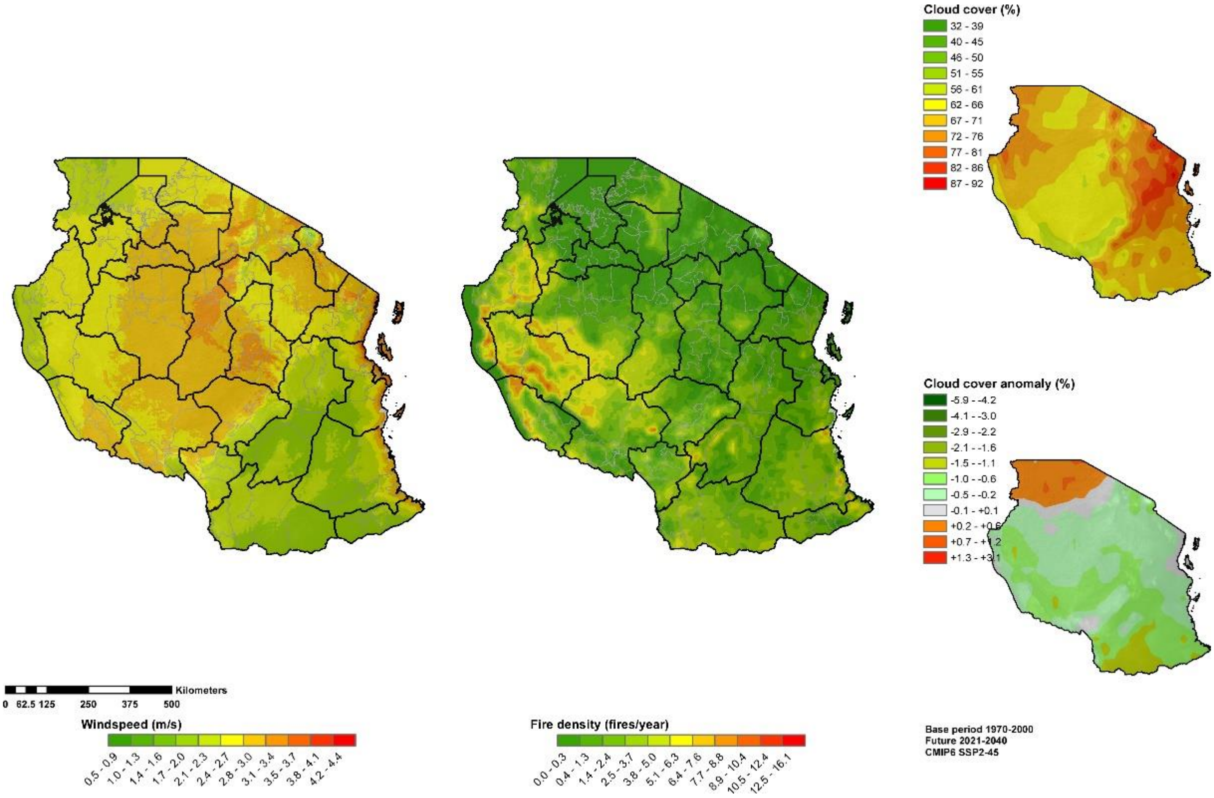

Figure 19. Other climate parameters. Average windspeed, fire density and current and projected cloud cover.

4 INFRASTRUCTURE RISK ASSESSMENT RESULTS

The infrastructure climate risk and vulnerability assessment is based on the risk equation given below:

RISK = HAZARD x EXPOSURE x VULNERABILITY.

The hazard is determined for six main climate related hazards describe in the previous section, exposure is derived using the location of the critical infrastructure assets, and the vulnerability is determined based on the conditions of the infrastructure asset where this data is available. As described in the methodology section the overall climate risk score is derived by multiplying the individual climate hazard scores for both current and future climate scenarios (for all climate hazards) with the exposure score (for river flooding and landslides only) and with the vulnerability score based on current conditions, but for roads only.

Currently condition data is only readily available for the main roads in Tanzania, but it is known that national data on road condition (and potentially other infrastructure) is, or should be, captured and could be used to further fine tune the climate change risk assessment done for individual countries or districts.

It is important to note that the risk being considered is the risk to the infrastructure asset itself in terms of the potential damage and/or deterioration of the asset and not necessarily the risk of climate change to individual communities or the national economy. The impact of the change in the physical risk to the infrastructure assets is interpreted in terms of the potential social and economic impacts at the national level by way of the Green Economy Model (GEM) which is presented in Component 2 of this study. The results of the climate risk and vulnerability assessment can be used to prioritise adaptation investments.

4.1 Roads

The result of the climate risk assessment for extreme temperature is shown in the figures below while the results of the climate risk assessment for all six climate related hazards are shown in Figure 30.

The extreme temperature hazard considers the peak daily maximum temperature as the acute impact, the number of days over 35°C as the moderate impact, and the maximum temperature monthly peak as the chronic impact on infrastructure. Extreme temperatures will cause warping, softening and buckling of the road surfaces. Where these roads are already in poor condition, there will be accelerated deterioration due to more extreme temperatures, they are also more likely to be damaged during to climate events.

The current extreme temperature climate variables are presented below. These have been categorized from 1 (green - very low hazard) to 5 (red - very high hazard). When equally combined they present the combined extreme temperature hazard index again from very low hazard to very high hazard. Overlaying the road conditions gives an indication of where the very good to very poor roads are located. These have been categorized from 1 (blue - very good) and 5 (purple - very bad or unknown).

The projected 2020-2040 SSP2-4.5 climate scenario is also presented. Here there are noted increases in the categorization of the individual climate variables. This in turn results in a higher combined extreme temperature climate hazard index. There is however still quite significant variation across the country with the greatest impact seeming to be towards the south of the country and the highest overall risk for a portion of the road in the southern region that is also currently considered to be in poor condition.

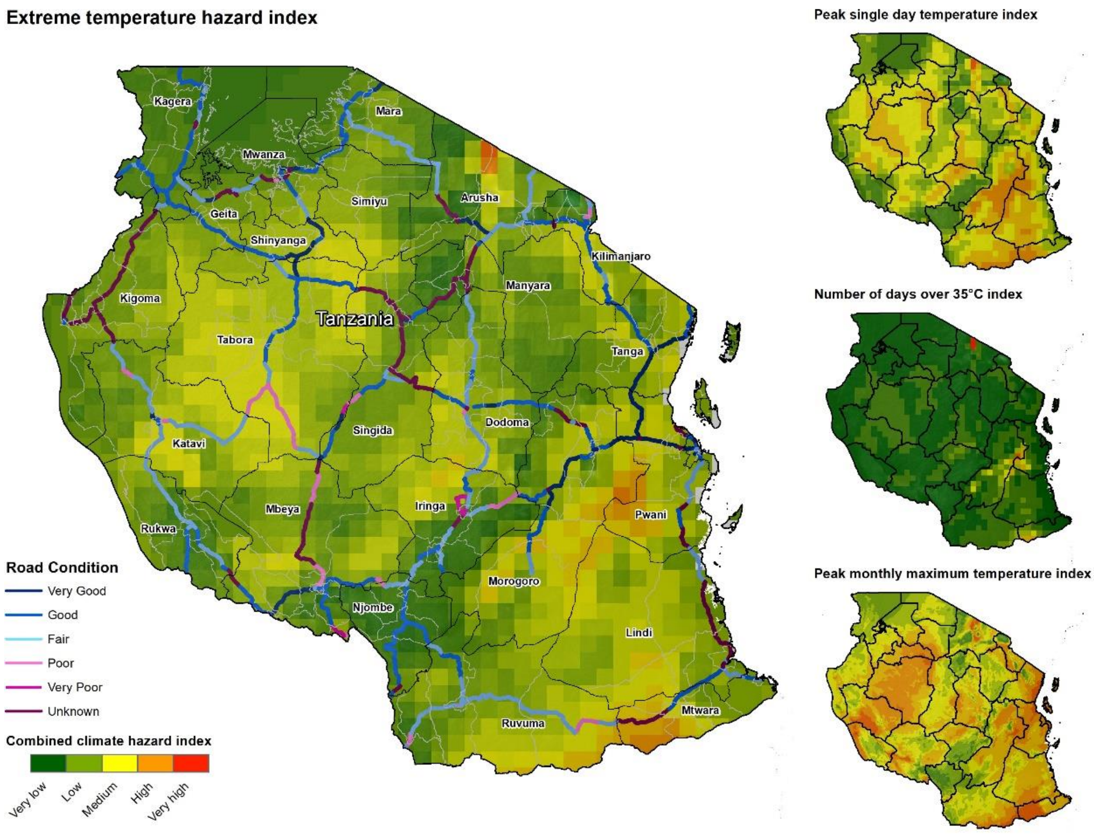

Figure 20. Current extreme temperature climate variables (right), combined extreme temperature hazard index and major road conditions (left)

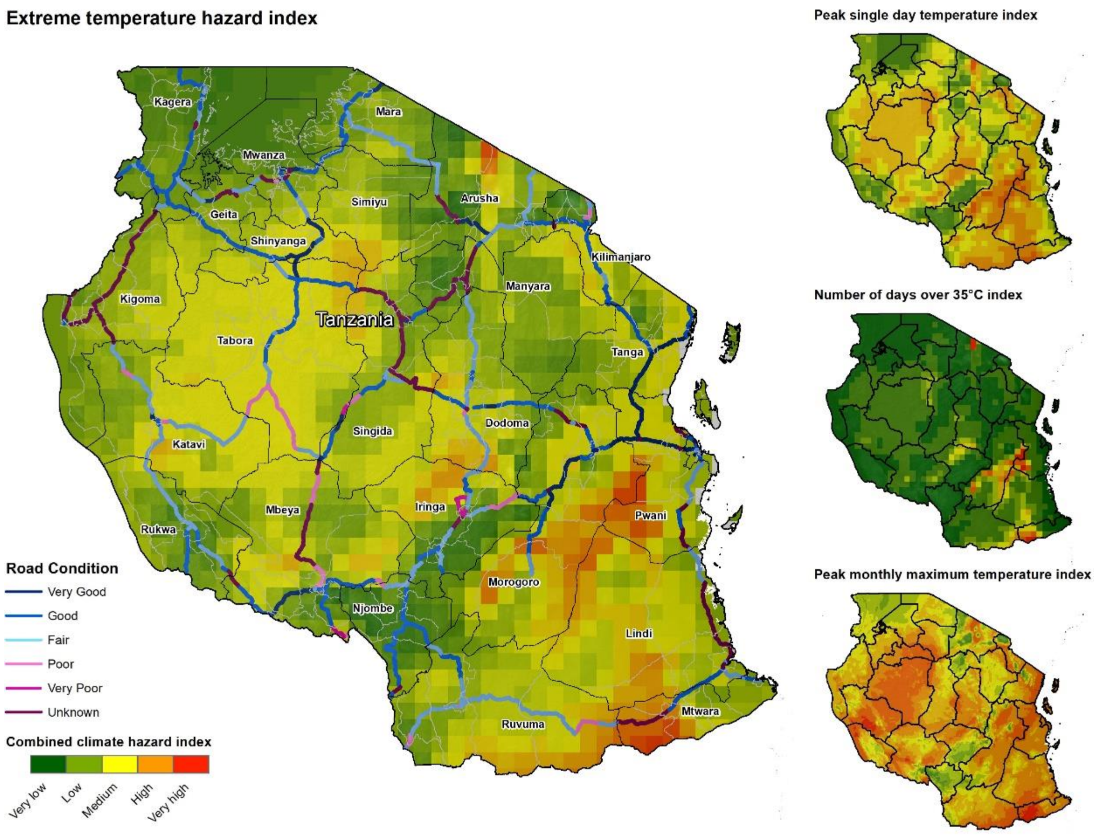

Figure 21. Projected 2020-2040 SSP2-4.5 extreme temperature climate variables (right), combined extreme temperature hazard index and major road conditions (left)

The overall climate related risk is calculated by multiplying the road condition index as a measure of vulnerability by the combined climate hazard index for the current climate and then by the future climate.

Shown below is the current and projected road risk highlighting the areas that have both poor road conditions and more severe extreme temperature hazards currently and in the future. These areas are shown in red. Areas in green include areas that have either very good road conditions and/or very low current and future climate hazard impacts. The difference between the current and future road risks is presented in the anomaly to the right below. This highlights areas where the largest change between current risk and future risk will be based on future climate changes and areas for prioritizing investments.

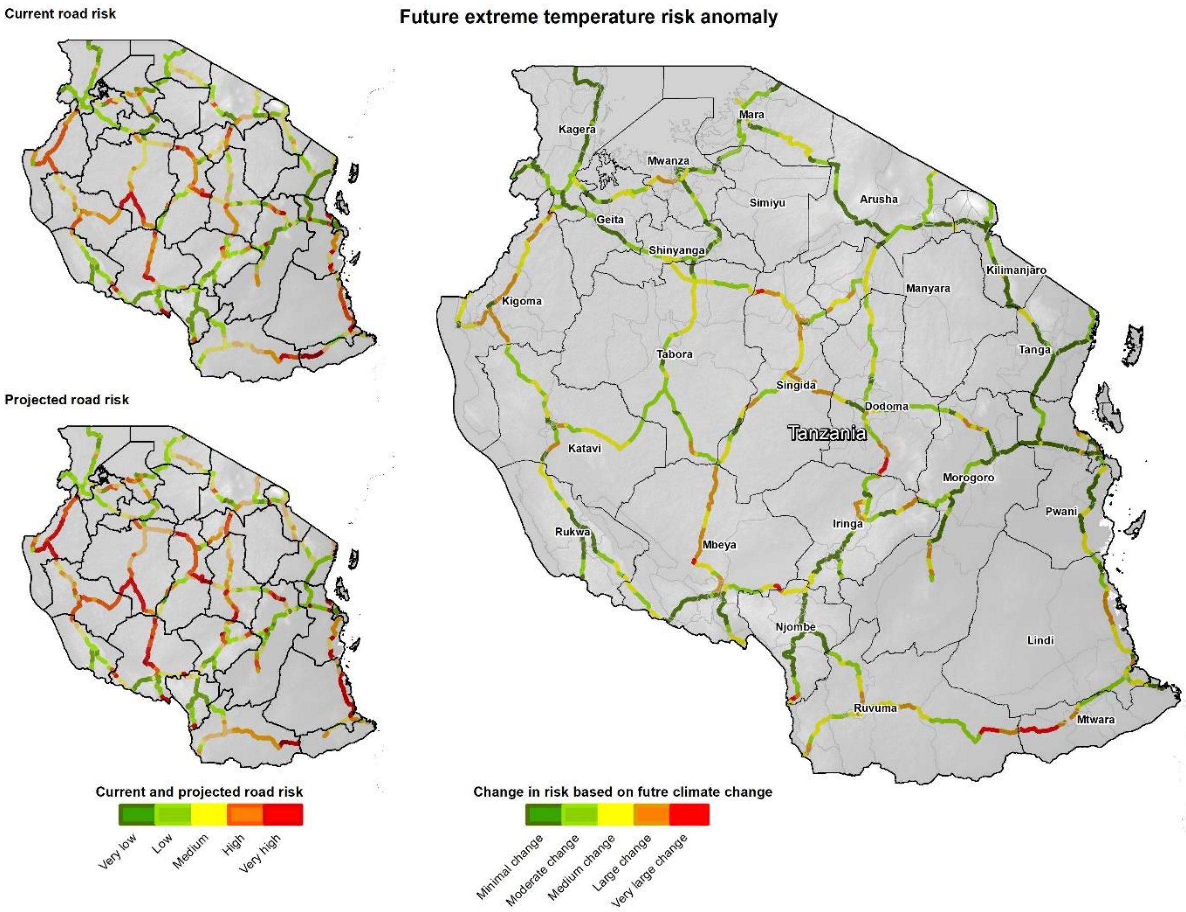

Figure 22. Current and projected 2020-2040 SSP2-4.5 extreme temperature road risks (left) and future extreme temperature risk anomaly (right)

Table 4-1. Current road distances in each condition, current and future risk category by area

		Road condition (km)						Current risk based on climate and road condition					Projected risk based on climate and road condition				
Area	Road (km)	Very Good	Good	Fair	Poor	Very Poor	Unknown	Very low	Low	Medium	High	Very high	Very low	Low	Medium	High	Very high
Arusha	**448.1**	69.5	51.2	260.1	-	-	67.3	38.3	82.4	256.6	70.8	-	13.0	95.7	227.9	111.5	-
Dar es Salaam	**55.7**	28.1	22.9	0.7	1.5	-	2.5	-	28.1	23.7	1.5	2.5	-	28.1	22.9	2.3	2.5
Dodoma	**523.4**	17.6	181.7	312.4	9.3	-	2.3	-	33.2	312.4	172.8	5.0	-	23.2	259.8	204.7	35.7
Geita	**247.9**	18.6	117.2	61.8	-	-	50.3	-	18.6	179.0	50.3	-	-	18.6	179.0	1.0	49.3
Iringa	**488.6**	-	94.1	225.6	62.6	70.7	35.5	-	152.8	192.5	117.0	26.2	-	133.1	200.1	92.7	62.7
Kagera	**564.2**	-	423.5	127.9	-	-	12.7	-	449.8	105.6	8.8	-	-	266.4	281.5	13.4	2.8
Katavi	**449.0**	23.5	8.2	372.9	42.8	-	1.5	-	23.5	160.2	244.8	20.6	-	23.5	90.5	286.1	48.9
Kigoma	**395.9**	-	7.6	-	-	-	388.4	-	7.6	-	307.1	81.3	-	1.7	5.9	96.1	292.3
Kilimanjaro	**303.2**	-	226.0	54.5	17.0	-	5.6	-	68.4	199.8	29.8	5.1	-	50.8	217.4	29.8	5.1
Lindi	**302.2**	-	52.1	97.8	-	-	152.3	-	-	115.5	76.3	110.5	-	-	57.9	92.1	152.3
Manyara	**210.6**	-	14.7	5.4	-	-	190.6	-	4.5	103.3	80.1	22.7	-	-	55.5	98.6	56.5
Mara	**402.3**	21.0	160.3	221.0	-	-	-	-	169.7	232.6	-	-	-	21.9	259.8	120.6	-
Mbeya	**729.7**	107.4	280.5	2.2	140.1	26.4	173.0	-	228.3	214.9	154.7	131.8	-	194.0	198.9	136.9	200.0
Morogoro	**549.4**	149.8	297.6	39.6	1.1	-	61.3	-	228.0	219.5	56.8	45.2	-	210.8	207.7	85.7	45.2
Mtwara	**212.8**	-	94.7	17.0	-	-	101.1	-	-	111.7	-	101.1	-	-	78.3	33.5	101.1
Mwanza	**262.1**	33.7	99.4	79.7	2.0	-	47.3	7.0	74.5	98.6	82.1	-	-	78.3	87.1	58.0	38.7
Njombe	**387.4**	-	306.5	51.0	11.0	-	18.9	-	280.0	78.3	29.0	-	-	261.2	75.1	29.8	21.3
Pwani	**432.1**	202.1	28.1	101.6	-	-	100.3	-	202.1	55.1	74.6	100.3	-	202.1	28.1	101.6	100.3
Rukwa	**355.3**	-	124.8	221.5	-	-	9.0	-	192.4	127.5	35.4	-	-	112.9	173.7	59.8	9.0
Ruvuma	**638.6**	-	78.1	469.9	90.2	-	0.3	-	36.5	416.7	120.3	65.1	-	0.3	213.3	336.8	88.1
Shinyanga	**218.8**	124.3	82.0	12.6	-	-	-	-	124.3	82.0	12.6	-	-	124.3	82.0	12.6	-
Simiyu	**56.1**	-	56.1	-	-	-	-	-	41.0	15.0	-	-	-	18.9	37.2	-	-
Singida	**600.1**	34.9	157.9	58.2	21.0	-	328.1	-	88.4	180.1	234.4	97.2	-	34.9	164.9	162.0	238.3
Tabora	**669.1**	40.2	296.0	116.4	191.7	24.8	-	-	40.2	298.3	141.2	189.3	-	40.2	249.2	165.6	214.1
Tanga	**322.9**	146.9	174.6	1.4	-	-	-	-	156.7	164.8	1.4	-	-	156.7	164.8	1.4	-
Total	**9 826**	**1 018**	**3 436**	**2 911**	**590**	**122**	**1 748**	**45**	**2 731**	**3 944**	**2 102**	**1 004**	**13**	**2 098**	**3 618**	**2 332**	**1 764**

A map showing the sections of the road network that are considered to be currently exposed to a high (<1:25-year RI), medium (<1:100-year RI), low (<1:1000-year RI) and very low (>1:1000-year RI) level of risk for potential fluvial (i.e. river) flooding are shown in Figure 23. This confirms that only a relatively small portion of the overall road network (5%) is in the high risk category for river flooding, that there are sections where quite significant portions of the current road network are highly exposed to the potential for river flooding and that these areas are the most vulnerable if there is an increase in either the potential magnitude or the frequency of future flooding events in Tanzania. These sections of the road network should be considered as priority sections for climate change adaptation particularly if they are also considered to be of critical importance either for local communities or for the national economy. The potential that these sections of the road network could also be impacted by potential catchment degradation that contributes to increased erosion and sedimentation, should also be considered when prioritizing efforts to invest in improved catchment management and Nature-based Solutions (NbS).

The total length of road in each province that is in each of the hazard classes for river flooding and landslide risk is given in

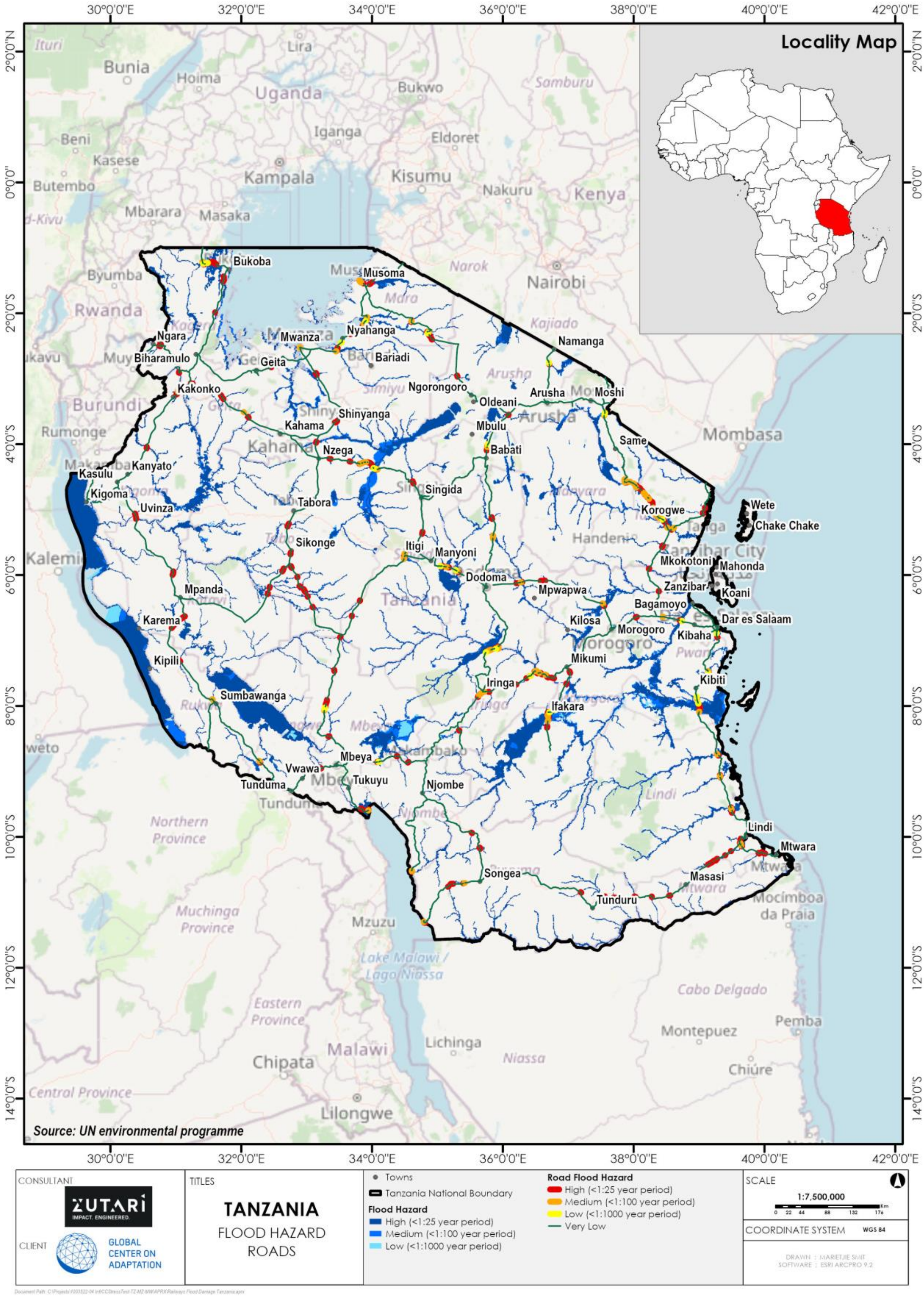

Figure 23: Sections of the existing road network currently exposed to river flooding in Tanzania.

Table 4-2. These results show that in total only 5% of the national roads are in the high-risk category for exposure to river flooding, i.e. within the 1: 25-year flood line and around 4% are in the high category for exposure to landslide risk. In terms of individual provinces, the province with the highest level of exposure to river flooding is Tanga with 22% of the roads in the high exposure category for river flooding (i.e. within the 1:25 year flood area), while the provinces with the highest exposure to landslide risks are Ruvuma and Morogoro both with 10% of their roads in the high exposure category for landslides risk due to the nature of the topography and soils.

Figure 23: Sections of the existing road network currently exposed to river flooding in Tanzania.

Table 4-2: Length of roads (in kms) exposed to river flooding and landslides in each province in Tanzania

Provinces	Exposure to River Flooding				Exposure to Landslides			TOTAL
	High (<1:25)	Medium (<1:100)	Low (<1:1000)	Very Low (>1:1000)	High	Medium	Low	
Arusha	4.94	0.00	1.04	439.32	15.28	12.63	417.44	445.30
Dar-Es-Salaam	0.77	0.00	1.01	100.77	0.00	0.00	102.55	102.55
Dodoma	26.53	5.09	0.19	488.40	2.18	13.16	504.91	520.21
Iringa	41.67	13.33	3.40	888.16	67.39	33.32	845.79	946.56
Kagera	38.07	1.92	1.79	572.73	0.15	0.00	614.39	614.51
Kigoma	14.15	0.18	0.00	384.84	30.61	0.00	368.54	399.17
Kilimanjaro	7.44	5.65	1.05	294.98	5.48	17.23	286.43	309.12
Lindi	29.80	4.97	0.00	318.24	0.00	0.00	352.99	353.01
Manyara	11.00	1.17	0.94	196.28	0.00	4.86	204.54	209.39
Mara	26.51	14.67	0.48	372.06	2.09	0.00	411.68	413.72
Mbeya	24.21	2.37	1.98	688.34	62.15	0.00	654.74	716.90
Morogoro	33.98	5.38	1.49	426.60	48.86	33.44	385.06	467.45
Mtwara	12.45	0.00	0.00	188.41	0.00	0.00	200.84	200.86
Mwanza	12.81	1.59	2.01	387.49	0.00	0.00	403.90	403.90
Pwani	28.24	3.29	3.38	392.97	0.00	0.00	427.88	427.88
Rukwa	29.46	1.41	0.00	765.98	42.35	6.46	748.06	796.85
Ruvuma	20.54	0.98	0.00	608.23	63.79	0.00	565.98	629.75
Shinyanga	9.51	0.41	0.00	318.35	0.00	0.00	328.28	328.27
Singida	28.96	3.94	1.02	560.01	0.00	0.93	592.98	593.93
Tabora	51.16	6.16	2.18	609.81	0.00	0.00	669.32	669.31
Tanga	71.32	12.90	0.20	233.04	5.67	0.34	311.45	317.46
Total	**523.52**	**85.41**	**22.16**	**9235.01**	**346.00**	**122.37**	**9397.75**	**9866.10**
Total (%)	**5%**	**1%**	**0%**	**94%**	**4%**	**1%**	**95%**	**100%**

The overall climate related risks for the six identified climate hazards are shown in Figure 30.. These results show an increase in the length of road in the high and very high-risk category for extreme temperatures, more than doubling in the near future and three times as many in the far future. The results show a relatively large proportion of roads in the high to very high category for flooding risk, but there does not seem to be a significant change as a result of the climate change scenario and there is also a relatively small percentage of roads exposure to increases in sea level rise and storm surges as proportion of the national road assets. There are several roads in a high to very high category for landslide risk and there does seem to be an increase in the high-risk category for landslides due to climate change impacts.

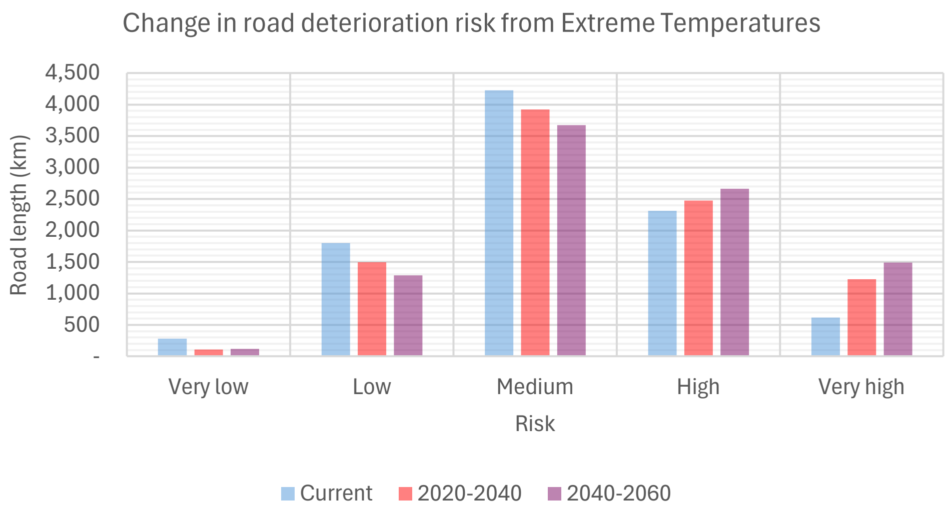

Figure 24: Current and future climate change road deterioration risk for Extreme Temperatures

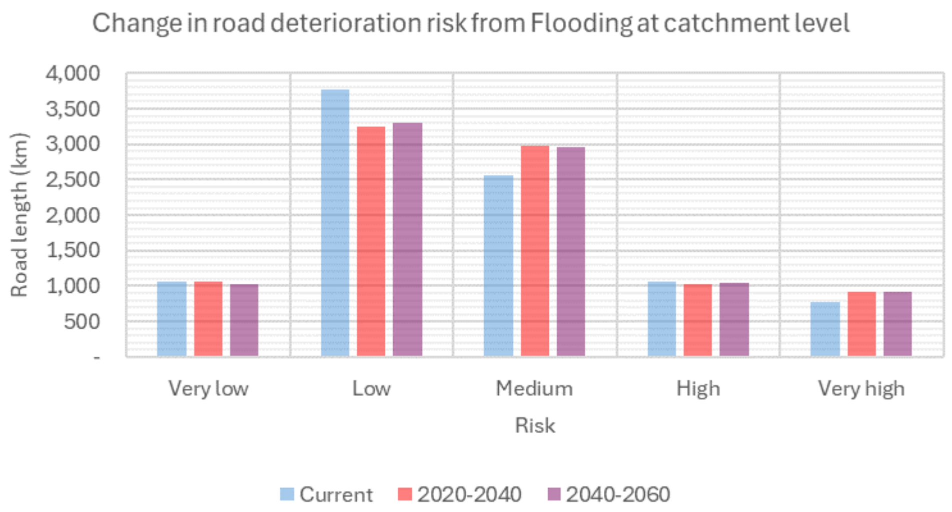

Figure 25: Current and future climate change road deterioration risk for Flooding

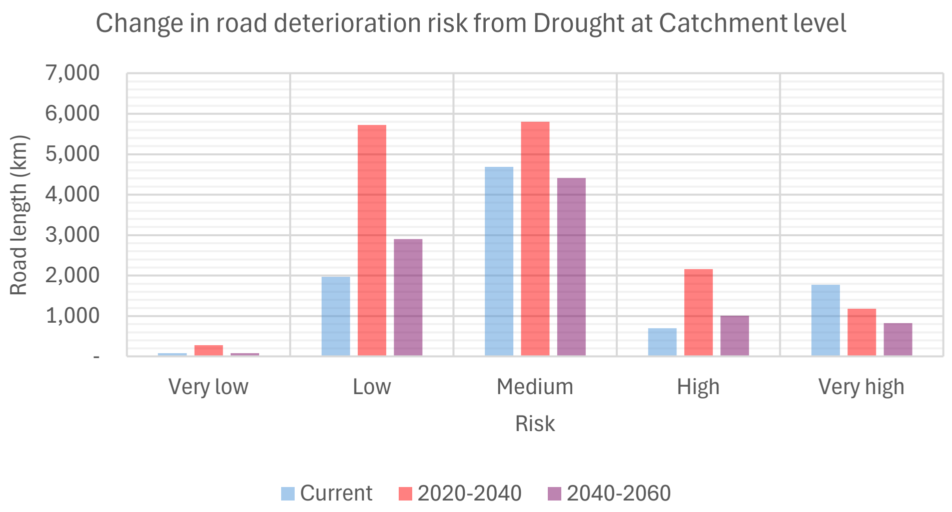

Figure 26: Current and future climate change road deterioration risk for Drought

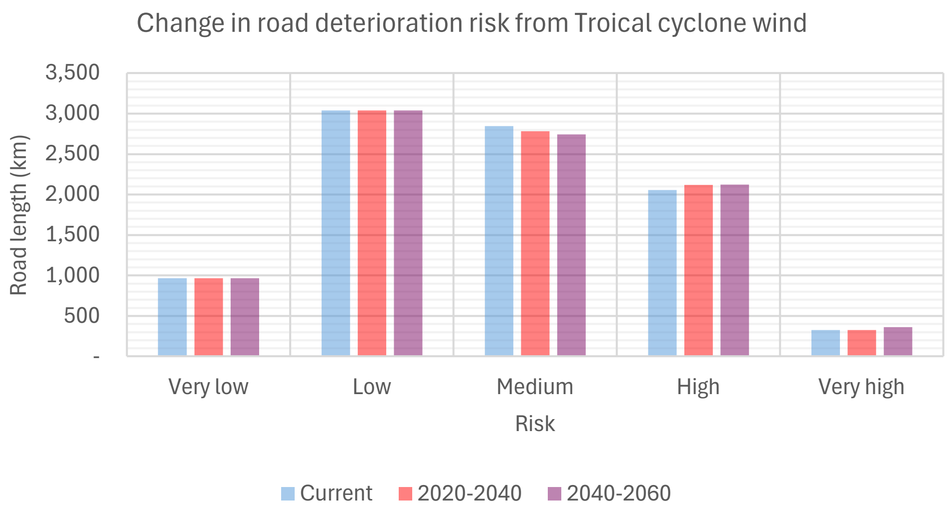

Figure 27: Current and future climate change road deterioration risk for Tropical Cyclones and Windt

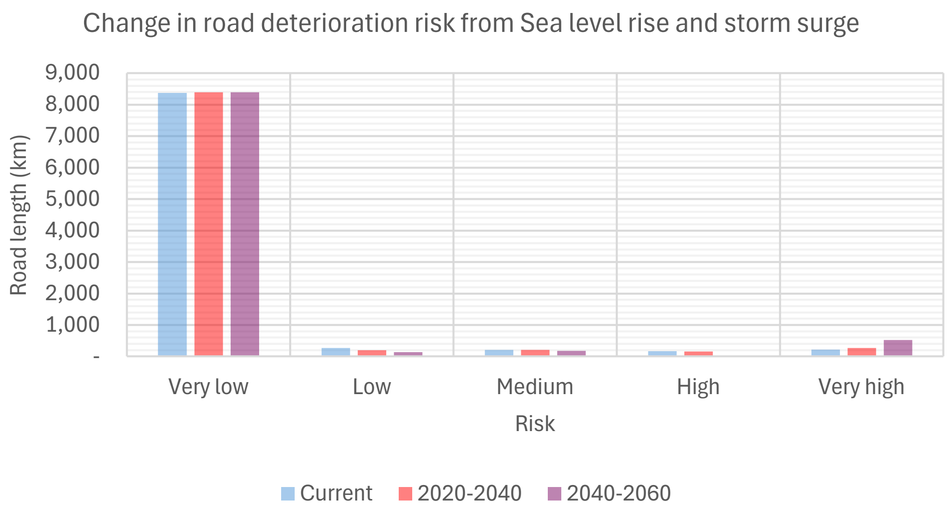

Figure 28: Current and future climate change road deterioration risk for Sea Level Rise and Storm surge

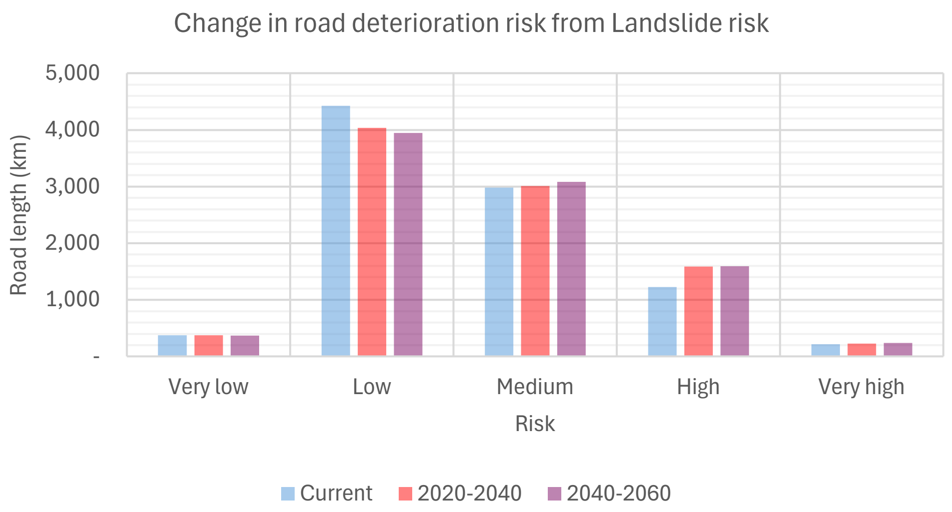

Figure 29: Current and future climate change road deterioration risk for Landslide Risk

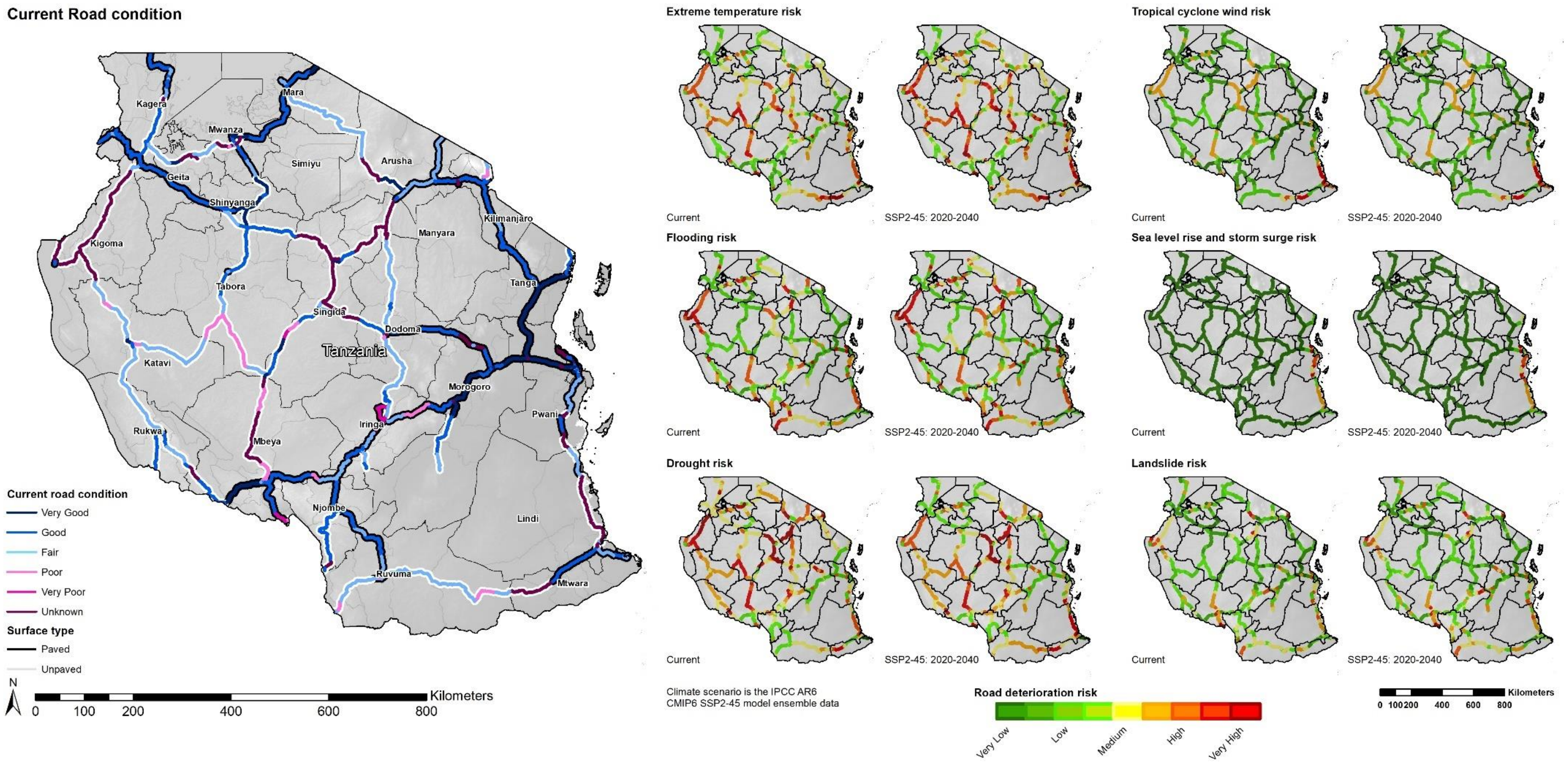

Figure 30: Climate change risk assessment results for roads for all climate hazards including road condition (Current and Future Risk for SSP2.45: 2020-2040)

4.2 Railways

The length of railways currently exposed to river flooding and landslides is given in Table 4-3. These results indicated that a significant proportion of the railways (9%) are located in high-risk areas for river flooding (i.e. likely to be impacted by flooding with a recurrence interval of 1 in 25 years or annual exceedance probability of 4%) and around 2% of railways are located in high hazard areas for potential landslides.

Table 4-3: Length of railways currently exposed for river flooding and potential landslide risk

	Exposure to River Flooding				Exposure to Landslides			
Provinces	**High (<1:25)**	**Medium (<1:100)**	**Low (<1:1000)**	**Very Low (>1:1000)**	**High**	**Medium**	**Low**	**TOTAL**
Arusha	0	0	0	50	0	0	50	50
Dar-Es-Salaam	0	0	0	167	0	0	167	167
Dodoma	55	6	1	157	2	7	210	218
Iringa	20	0	1	117	1	2	136	138
Kigoma	13	9	2	200	5	0	220	224
Kilimanjaro	10	7	0	204	1	0	220	222
Manyara	1	0	0	1	0	0	1	1
Mbeya	13	1	0	301	17	0	297	314
Morogoro	89	18	3	696	33	63	710	807
Mwanza	0	0	0	116	0	0	116	116
Pwani	37	5	8	394	0	0	444	444
Rukwa	25	2	0	82	0	0	108	108
Shinyanga	5	1	1	164	0	0	171	171
Singida	24	0	2	249	0	0	276	276
Tabora	30	7	2	593	0	0	631	631
Tanga	73	12	4	201	10	1	278	289
Grand Total	**395**	**68**	**24**	**3691**	**69**	**73**	**4035**	**4177**
	9%	**2%**	**1%**	**88%**	**2%**	**2%**	**97%**	**100%**

A map showing the sections of the railway network that are considered to be currently exposed to a high (<1:25-year RI), medium (<1:100-year RI), low (<1:1000-year RI) and very low (>1:1000-year RI) level of risk for potential fluvial (i.e. river) flooding are shown in Figure 23. This confirms that only a relatively small portion of the overall railway network (9%) is in the high risk category for river flooding, that there are sections where quite significant portions of the railway network are highly exposed to the potential for river flooding and that these areas are the most vulnerable if there is an increase in either the potential magnitude or the frequency of future flooding events in Tanzania. These sections of the road network should be considered as priority sections for climate change adaptation particularly if they are also considered to be of critical importance either for local communities or for the national economy. The potential that these sections of the road network could also be impacted by potential catchment degradation that contributes to increased erosion and sedimentation,n should also be considered when prioritizing efforts to invest in improved catchment management and Nature-based Solutions (NbS). The section indicated by the box includes a section of the railway network currently being study by GCA as part of an asset level climate risk and vulnerability assessment where it has been confirmed that this section of the railway network is highly exposed to river flooding under both current and future climate scenarios and that the risk is increased as a result of very high levels of sedimentation particularly in recent years.

The current and future climate risks for railways for each of the six climate hazards is given in Figure 32.

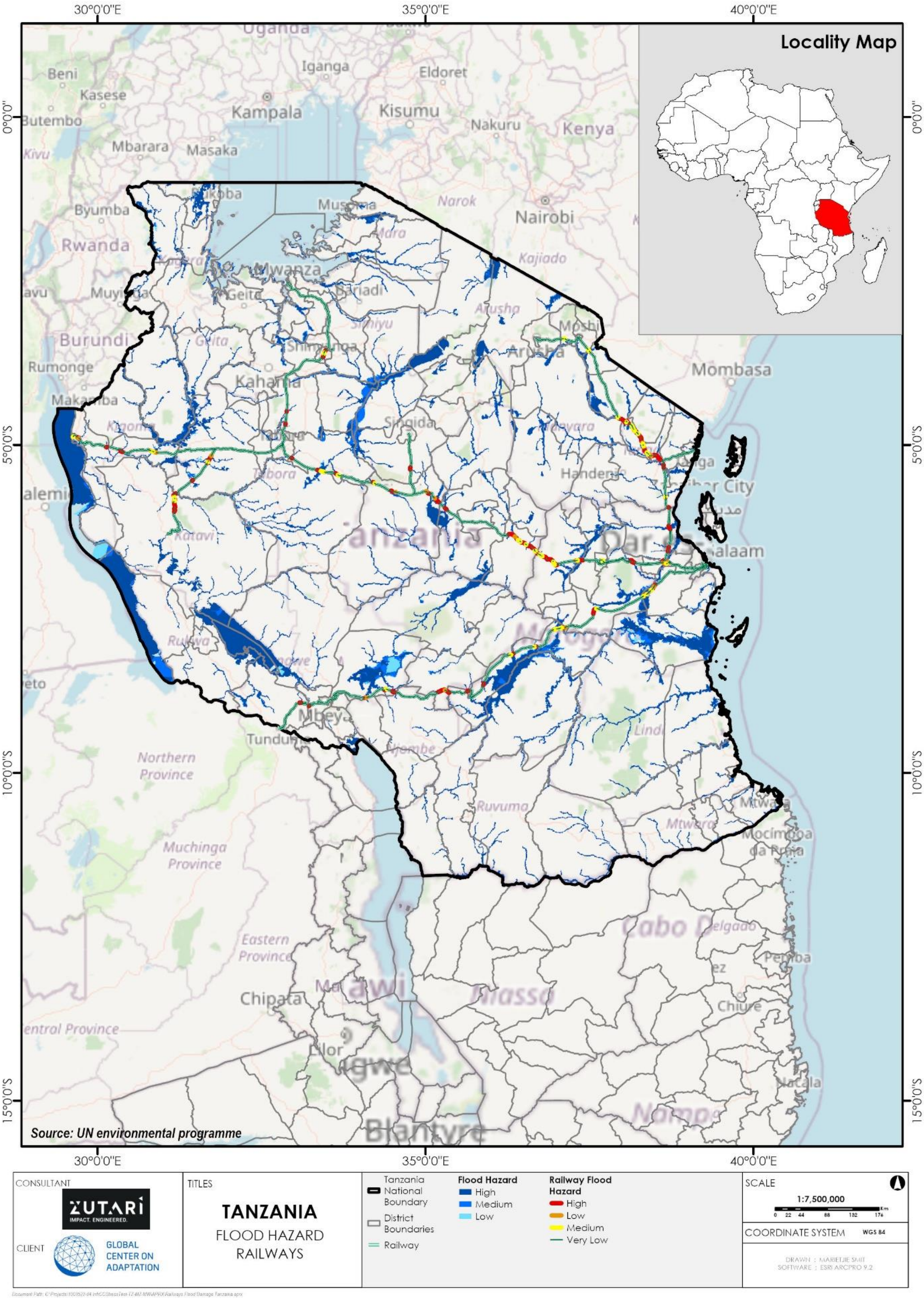

Figure 31: Sections of the existing road network currently exposed to river flooding in Tanzania.

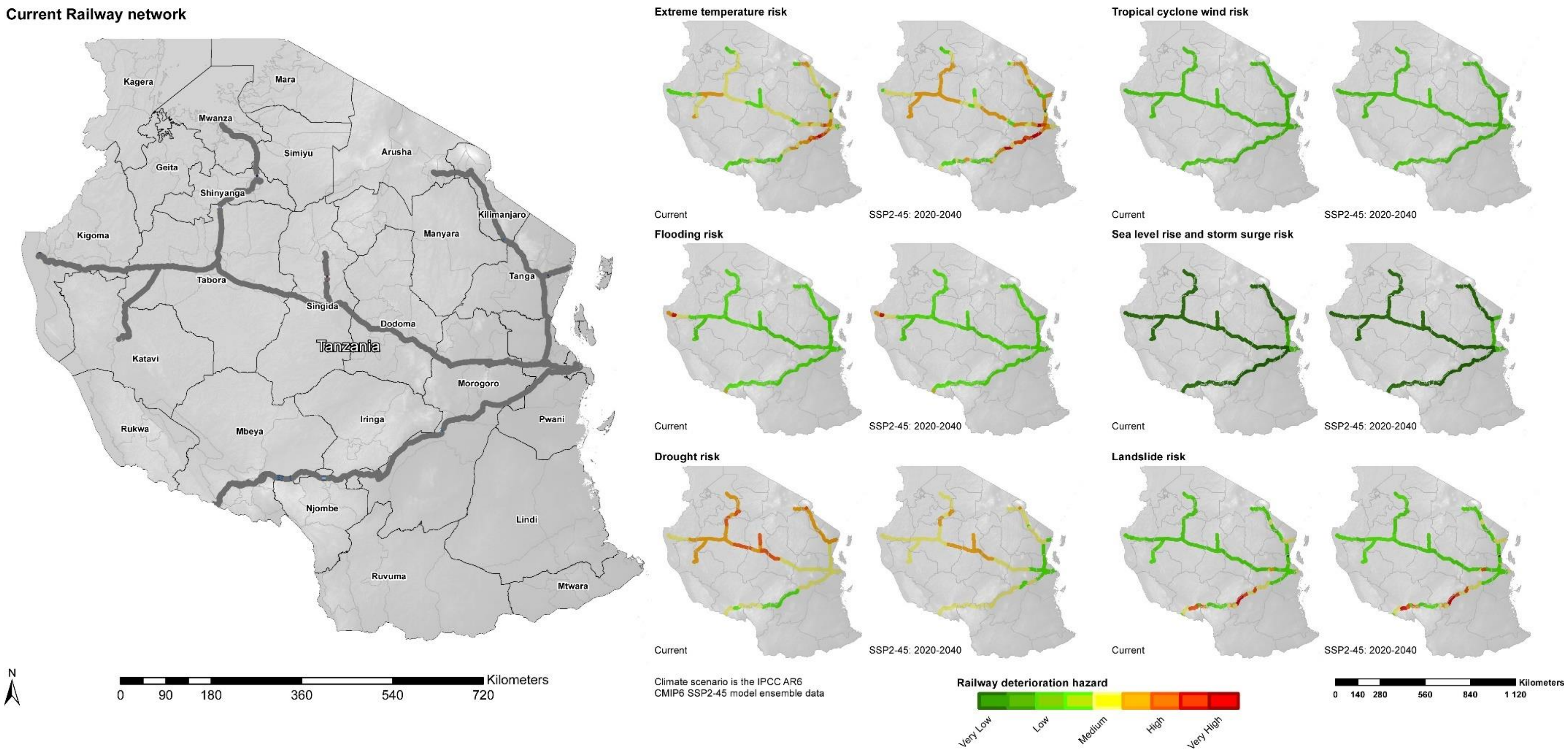

Figure 32: Climate change risk assessment results for railways in Tanzania (SSP2-45, 2020-2040)

4.3 Power Stations

The number of power plants identified by type in Tanzania are given in Table 4-4 with the total number of power plants exposure to river flooding and landslide risk are shown in Table 4-5. It is not surprising that Tanga province has the highest number of power plants in the highest category for exposure to flooding as these are all hydro-power plants, while Morogoro has both of the power plants in that province located in areas of high risk for landslides. This includes one hydropower plant and one biomass power plant.

Table 4-4: Number of power plants identified by type in each province in Tanzania

Province	Biomass	Hydro	Thermal	Total
Dar-Es-Salaam	0	0	6	6
Iringa	1	3	1	5
Kagera	0	1	1	2
Mara	0	0	1	1
Mbeya	0	0	1	1
Morogoro	1	1	0	2
Mtwara	0	0	2	2
Mwanza	0	0	1	1
Shinyanga	0	0	1	1
Tabora	0	0	1	1
Tanga	0	3	0	3
Grand Total	2	8	15	25

Table 4-5: Number of power plants exposed to river flooding and landslide risk in Tanzania

Province	Exposure to River Flooding Risk				Exposure to Landslide Risk			Total
	High (1:25)	Medium (1:100)	Low (1:1000)	Very Low (<1:1000)	High	Medium	Low	
Dar-Es-Salaam	0	2	0	4	0	0	6	6
Iringa	2	0	0	3	1	1	3	5
Kagera	1	0	0	1	0	0	2	2
Mara	0	0	0	1	0	0	1	1
Mbeya	0	0	0	1	0	0	1	1
Morogoro	1	0	0	1	2	0	0	2
Mtwara	0	0	0	2	0	0	2	2
Mwanza	0	0	0	1	0	0	1	1
Shinyanga	0	0	0	1	0	0	1	1
Tabora	0	0	0	1	0	0	1	1
Tanga	3	0	0	0	0	0	3	3
Total	**7**	**2**	**0**	**16**	**3**	**1**	**21**	**25**

The results of the climate change risk assessment for the different types of power stations identified in Tanzania under the current, intermediate and future climate scenarios are given in Table 4-6.

Table 4-6: Climate change risk assesment results for powerstations in Tanzania

CLIMATE : DROUGHT															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Biomass Power Plant															
Hydropower Plant		1	4	3			1	3	4				5	3	
Thermal Power Plant		2	11	2				3	12				5	10	
Other				2				2					2		

CLIMATE : FLOOD															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Biomass Power Plant															
Hydropower Plant				3	5				3	5				3	5
Thermal Power Plant				2	13				2	13				3	12
Other				1	1				1	1				1	1

CLIMATE : TROPICAL CYCLONE & WIND															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Biomass Power Plant															
Hydropower Plant					8					8					8
Thermal Power Plant				2	13				2	13				2	13
Other					2					2					2

CLIMATE : EXTREME TEMPERATURE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Biomass Power Plant															
Hydropower Plant				6	2			3	3	2			4	4	
Thermal Power Plant			1	11	3			2	12	1			2	12	1
Other				1	1				1	1				1	1

CLIMATE : LANDSLIDE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Biomass Power Plant															
Hydropower Plant		1	2	3	2		2	1	3	2		2	1	3	2
Thermal Power Plant			1	10	4		1		11	3		1		11	3
Other				2					2					2	

4.4 Transmission Lines

The results of the climate change risk and vulnerability assessment for transmission lines is shown in Figure 34. The results suggest an increase in the extreme temperature risk in the Morogoro province as well as the Mtwara district and a significant current and future landslide risk in the Iringa Province.

The location of transmission lines currently exposed to river flooding in Tanzania are shown in Figure 33.

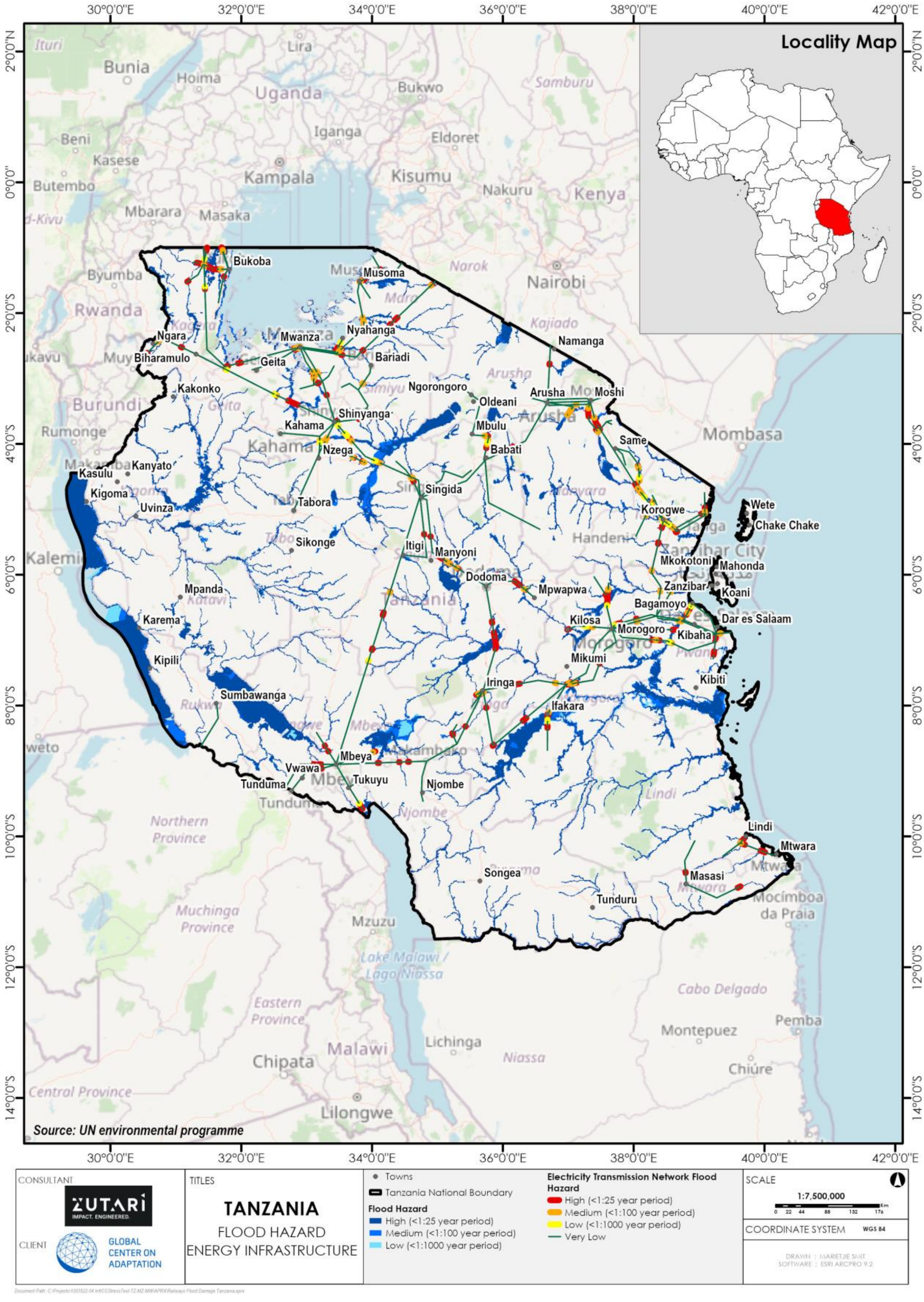

Figure 33: Sections of the existing energy transmission lines currently exposed to river flooding in Tanzania.

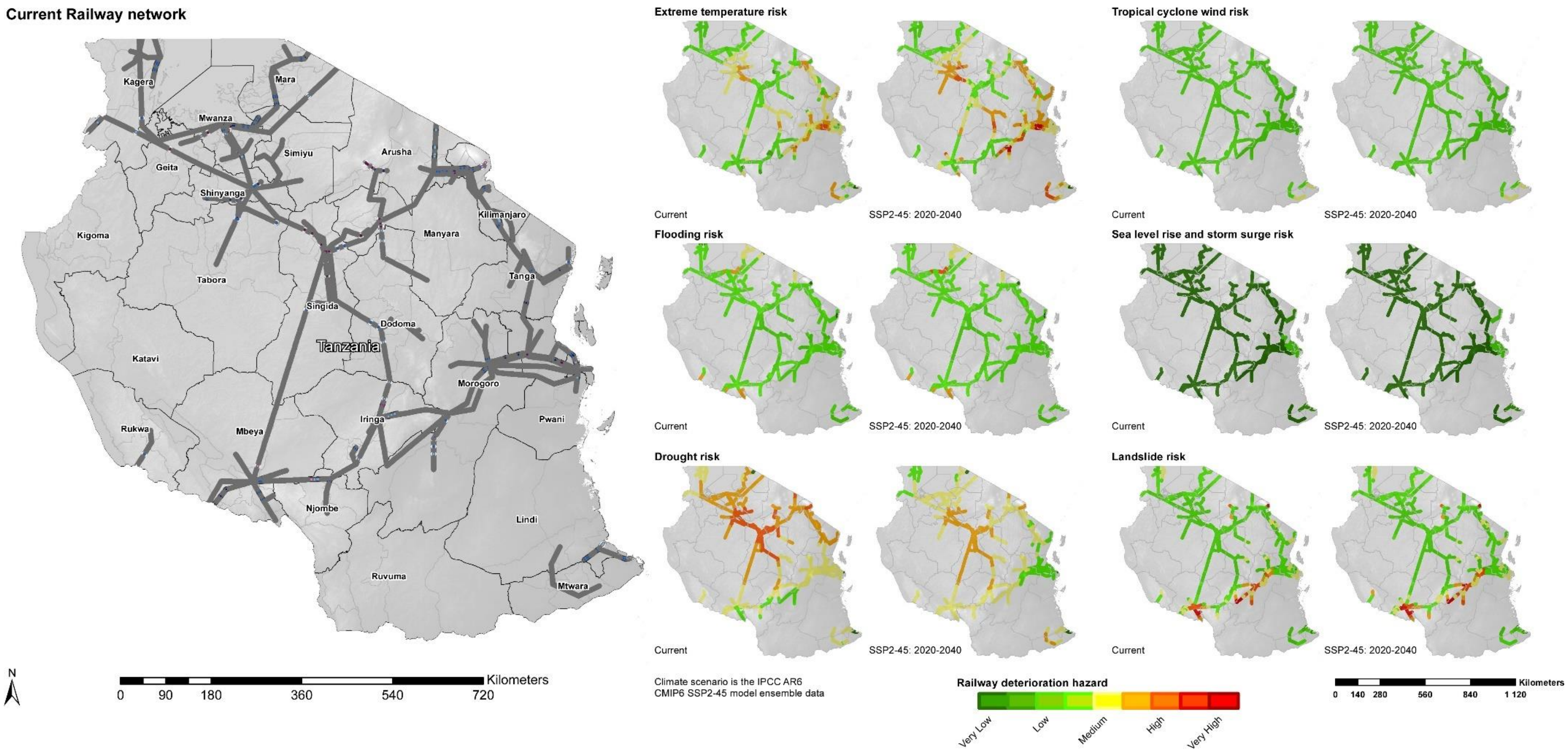

Figure 34: Climate change risk assessment results for electricity transmission lines in Tanzania (SSP2-45, 2020-2040)

4.5 Healthcare Facilities

The location and type of health care facilities identified in Tanzania are shown in Figure 35.

The number of healthcare facilities exposed to river flooding and landslide risk are given in Table 4-7. The healthcare facilities include hospitals (432), clinics (1228), dentists (44), doctors (89), FixMe (1), Main Laboratories (1), laboratories (1), pharmacies (2193) and traditional (1) with the total numbers given in brackets. The results show a total of 102 (3%) of healthcare facilities in the high flood hazard zone. A total of 20 healthcare facilities are located in high-risk areas for landslide susceptibility. Other critical risks for healthcare facilities include increasing extreme temperatures and drought in terms of water security.

A summary of the climate risk assessment results for healthcare facilities are shown in Table 4-8.

Table 4-7: Number of healthcare facilities exposed to river flooding and landslide risk in Tanzania

Province	Exposure to River Flooding Risk				Exposure to Landslide Risk			Total
	High (1:25)	Medium (1:100)	Low (1:1000)	Very Low (<1:1000)	High	Medium	Low	
Arusha				93	1		92	93
Dar-Es-Salaam		1	3	1316			1320	1320
Dodoma	12	3	3	312	1	7	322	330
Iringa	6	1		83	1	5	84	90
Kagera	8	3		182			193	193
Kaskazini-Unguja				29			29	29
Kigoma	4	5		74			83	83
Kilimanjaro	1			56	2	8	47	57
Kusini-Pemba				16			16	16
Lindi			1	11			12	12
Manyara		1		23	1		23	24
Mara	1	6		270	1		276	277
Mbeya	44	1		207	12		240	252
Morogoro	5			155	1	1	158	160
Mtwara	1			10			11	11
Mwanza		15	1	413			429	429
Pwani				8			8	8
Rukwa	1			40			41	41
Ruvuma				6			6	6
Shinyanga	5			149			154	154
Singida	5	1		46			52	52
Tabora	1			60			61	61
Tanga	8		1	191		3	197	200
Zanzibar South and Central				22			22	22
Zanzibar West				131			131	131
Total	**102**	**37**	**9**	**3903**	**20**	**24**	**4007**	**4051**
	3%	1%	0%	96%	1%	1%	98%	

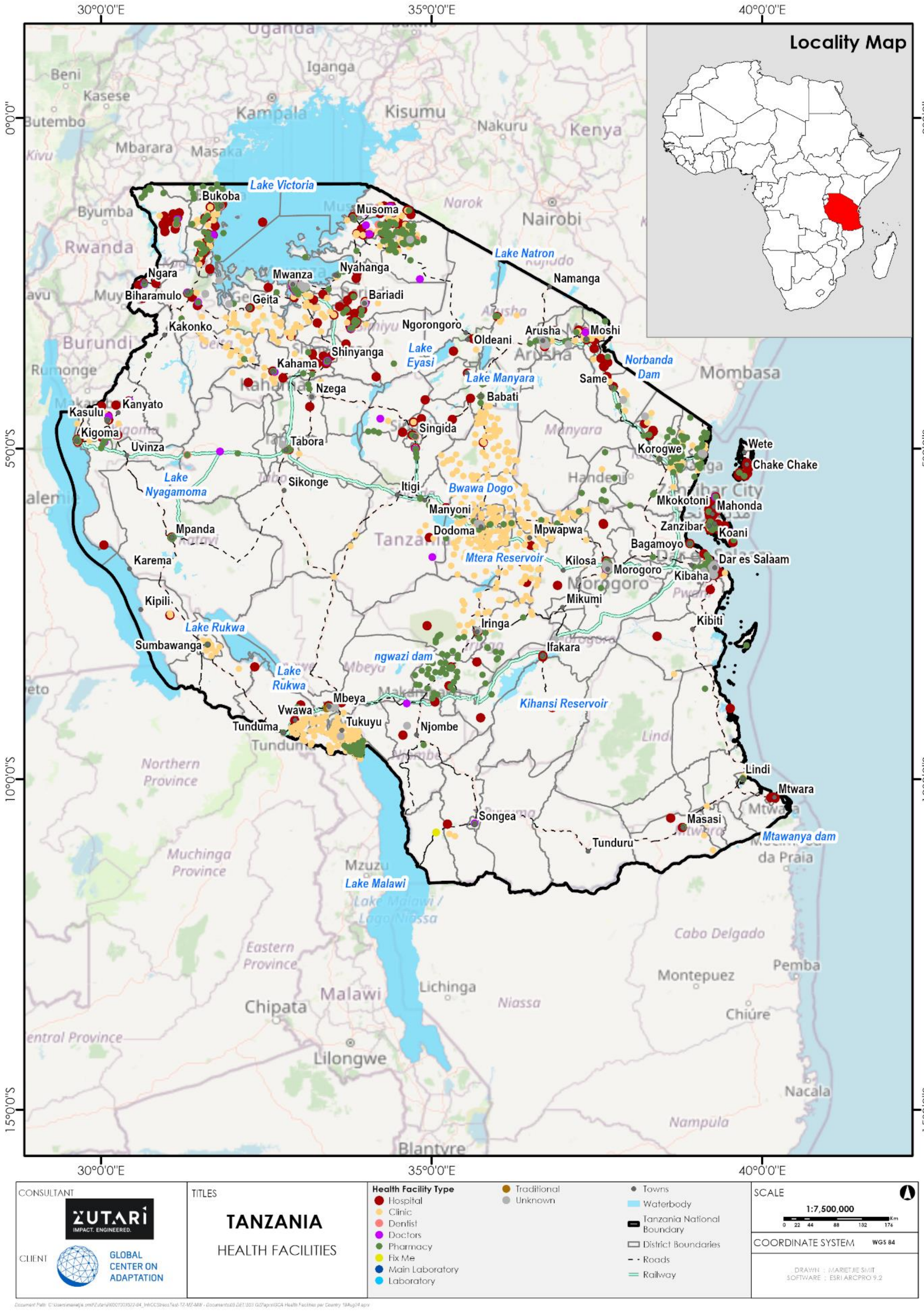

Figure 35: Location and type of healthcare facilities identified in Tanzania

Table 4-8: Climate risk assessment results for healthcare facilities in Tanzania

CLIMATE : DROUGHT															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown		15	39	7			3	22	36			44	7	10	
Hospital		109	288	35			24	138	270			257	17	148	10
Clinic		436	565	194	33		220	443	565			940	23	248	17
Dentist		17	26	1			1	22	21			24	3	16	1
Doctors		16	72	1			3	21	65			35	2	44	8
Health Post															
Fixme				1				1				1			
Main Laboratory			1						1			1			
Laboratory			1					1				1			
Pharmacy	1	334	1,640	199	19		62	483	1,648			1,637	59	492	5
Traditional				1					1			1			

CLIMATE : FLOOD															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown				13	48			1	15	45			1	15	45
Hospital			8	62	362			8	69	355			8	75	349
Clinic			29	173	1,023			53	199	976			53	207	968
Dentist				5	39				6	38				7	37
Doctors			1	17	71			1	28	60			1	29	59
Health Post															
Fixme				1					1					1	
Main Laboratory					1					1					1
Laboratory				1					1					1	
Pharmacy			33	226	1,934			34	295	1,864			34	300	1859
Traditional				1					1					1	

CLIMATE : TROPICAL CYCLONE & WIND															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown					61					61					61
Hospital				6	426				6	426				7	425
Clinic				7	1,221				7	1,221				7	1221
Dentist					44					44					44
Doctors					89					89					89
Health Post															
Fixme					1					1					1
Main Laboratory					1					1					1
Laboratory					1					1					1
Pharmacy				7	2,186				7	2,186				7	2186
Traditional					1					1					1

CLIMATE : EXTREME TEMPERATURE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown			6	42	13			11	39	11			11	44	6
Hospital			33	231	168		5	71	219	137		7	95	239	91
Clinic			74	836	318			278	709	241		6	336	698	188
Dentist				27	17			2	27	15			3	29	12
Doctors			1	54	34			4	60	25			10	72	7
Health Post															
Fixme					1				1					1	
Main Laboratory				1					1					1	
Laboratory				1					1					1	
Pharmacy			131	1,514	548		1	292	1,454	446		2	314	1604	273
Traditional					1				1					1	

CLIMATE : LANDSLIDE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown			5	44	12			5	44	12			5	44	12
Hospital		1	48	242	141		1	48	242	141		1	48	242	141
Clinic		35	117	651	425		35	117	651	425		35	117	651	425
Dentist			1	28	15			1	28	15			1	28	15
Doctors			1	68	20			1	68	20			1	68	20
Health Post															
Fixme			1					1					1		
Main Laboratory				1					1					1	
Laboratory				1					1					1	
Pharmacy		21	122	1,686	364		21	122	1,686	364		21	122	1686	364
Traditional		1					1					1			

4.6 Education Facilities

The location and type of health care facilities identified in Tanzania are shown in Figure 36.

At total of 21,375 education facilities are identified in Tanzania including colleges (293), kindergartens (601), schools (20,419), universities (34) and unknown (28). Of these 978 (5%) are located in areas of high hazard for river flooding (<1:25 year RI) and 325 (2%) are in high hazard areas for landslide susceptibility.

A summary of the climate risk assessment results for healthcare facilities are shown in Table 4-10

Table 4-9: Number of education facilities exposed to river flooding and landslide risk in Tanzania

Province	Exposure to River Flooding Risk				Exposure to Landslide Risk			Total
	High (1:25)	Medium (1:100)	Low (1:1000)	Very Low (<1:1000)	High	Medium	Low	
Arusha	6	1		647	2	19	633	654
Dar-Es-Salaam	2	7	3	1577			1589	1589
Dodoma	49	8	2	817	1	28	847	876
Iringa	28	10		1017	45	46	964	1055
Kagera	91	13	1	1237			1342	1342
Kaskazini-Pemba				83			83	83
Kaskazini-Unguja				92			92	92
Kigoma	54	13	4	690	20		741	761
Kilimanjaro	31	12	1	937	13	98	870	981
Kusini-Pemba				80			80	80
Lindi	34	1	2	533			570	570
Malawi	1						1	1
Manyara	28	8	1	636	1	13	659	673
Mara	31	40	10	916	1		996	997
Mbeya	127	17	3	1170	94		1223	1317
Morogoro	122	26	8	973	32	111	986	1129
Mtwara	22	1		720			743	743
Mwanza	52	14	5	1509			1580	1580
Pwani	57	11	5	570			643	643
Rukwa	39	3	1	614	18	1	638	657
Ruvuma	11	1	1	780	42		751	793
Shinyanga	52	13	5	1450			1520	1520
Singida	42	5	3	694			744	744
Tabora	26	4	3	898			931	931
Tanga	73	8	2	1102	56	38	1091	1185
Zanzibar South and Central				119			119	119
Zanzibar West				257			257	257
TOTAL	**978**	**216**	**60**	**20118**	**325**	**354**	**20693**	**21375**
	5%	1%	0%	94%	2%	2%	97%	100%

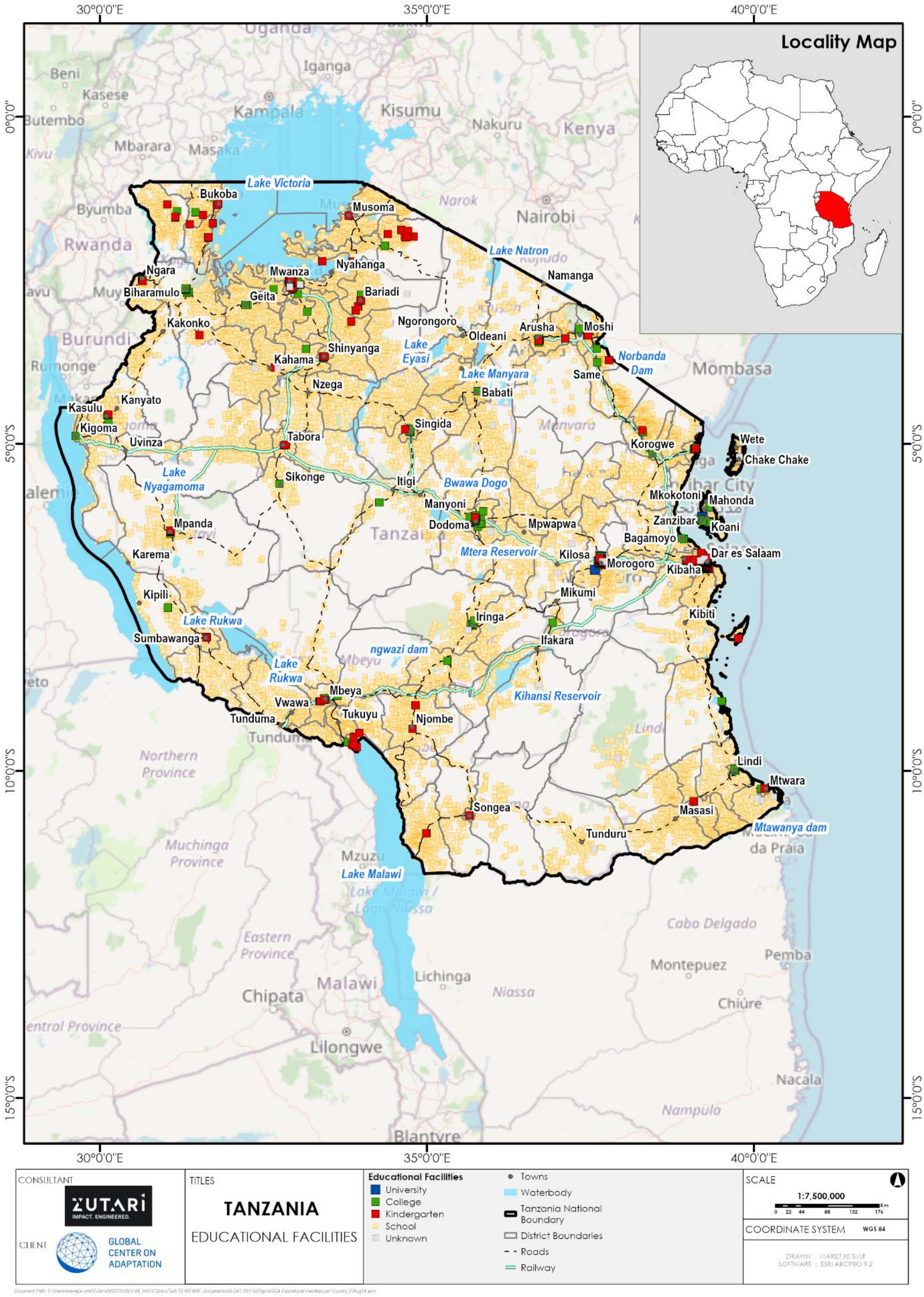

Figure 36: Location and type of education facilities identified in Tanzania

Table 4-10: Climate change risk assessment result for education facilities in Tanzania

CLIMATE : DROUGHT															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown		6	17	5			4	15	9			1	11	14	2
College		71	194	28			26	81	186				87	202	4
Kindergarten		29	557	11	4		3	103	495				31	570	
School	57	6,150	10,584	3,393	235		1,767	10,218	8,434			571	9,393	9,911	544
University		3	30	1			3	15	16				3	31	

CLIMATE : FLOOD															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown				5	23				7	21				9	19
College			3	46	244			3	56	234			3	56	234
Kindergarten			1	69	531			1	72	528			1	72	528
School		62	603	3,184	16,560		58	760	3,594	16,007		58	724	4,014	15,623
University				19	15				18	16				18	16

CLIMATE : TROPICAL CYCLONE & WIND															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown				4	24				4	24			1	3	24
College				4	289				4	289				5	288
Kindergarten				3	598				3	598				3	598
School				1,274	19,145				1,292	19,127			30	1,286	19,103
University					34					34					34

CLIMATE : EXTREME TEMPERATURE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown			4	19	5			9	15	4			7	18	3
College		1	32	186	74		3	79	173	38		7	87	166	33
Kindergarten			57	340	204		4	147	320	130		8	154	329	110
School		30	1,984	12,436	5,969		252	4,728	11,359	4,080		522	5,446	11,332	3,119
University			2	19	13			4	19	11			5	19	10

CLIMATE : LANDSLIDE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Unknown			3	18	7			3	18	7			3	18	7
College		6	28	164	95		6	28	164	95		6	28	164	95
Kindergarten		3	24	413	161		3	24	413	161		3	24	413	161
School		502	2,021	11,933	5,963		502	2,021	11,933	5,963		502	2,021	11,933	5,963
University			2	28	4			2	28	4			2	28	4

4.7 Airports, Bridges, and Dams

In addition to the critical infrastructure sectors presented above (i.e. for roads, railways, power stations, transmission lines, health care facilities and education facilities), the location of airports, bridges and dams were also identified and compared with the current and future climate hazards to evaluate the current and future climate related risks for these infrastructure types. The results presented her are very much a first order risk assessment as there are many factors affecting the current and future climate change related risks for airports, bridges and dams that would require a more detailed asset level climate risk and vulnerability assessment to be undertaken, particularly for high risk assets.

The locations of bridges were determined based on identifying where a road or railway crossed a river, canal or drainage line. It was assumed that a bridge (or culvert) of some type would be needed at these locations, but specific details of what type of bridge or culvert were not considered. In addition, the local hydraulic conditions are not taken into consideration which is a significant factor in determining the risk.

The location for road and railway bridges are shown in Figure 32 while the results of the climate change risk assessment for airports, bridges and dams are shown in Table 4-11, Table 4-12 and Table 4-13 respectively.

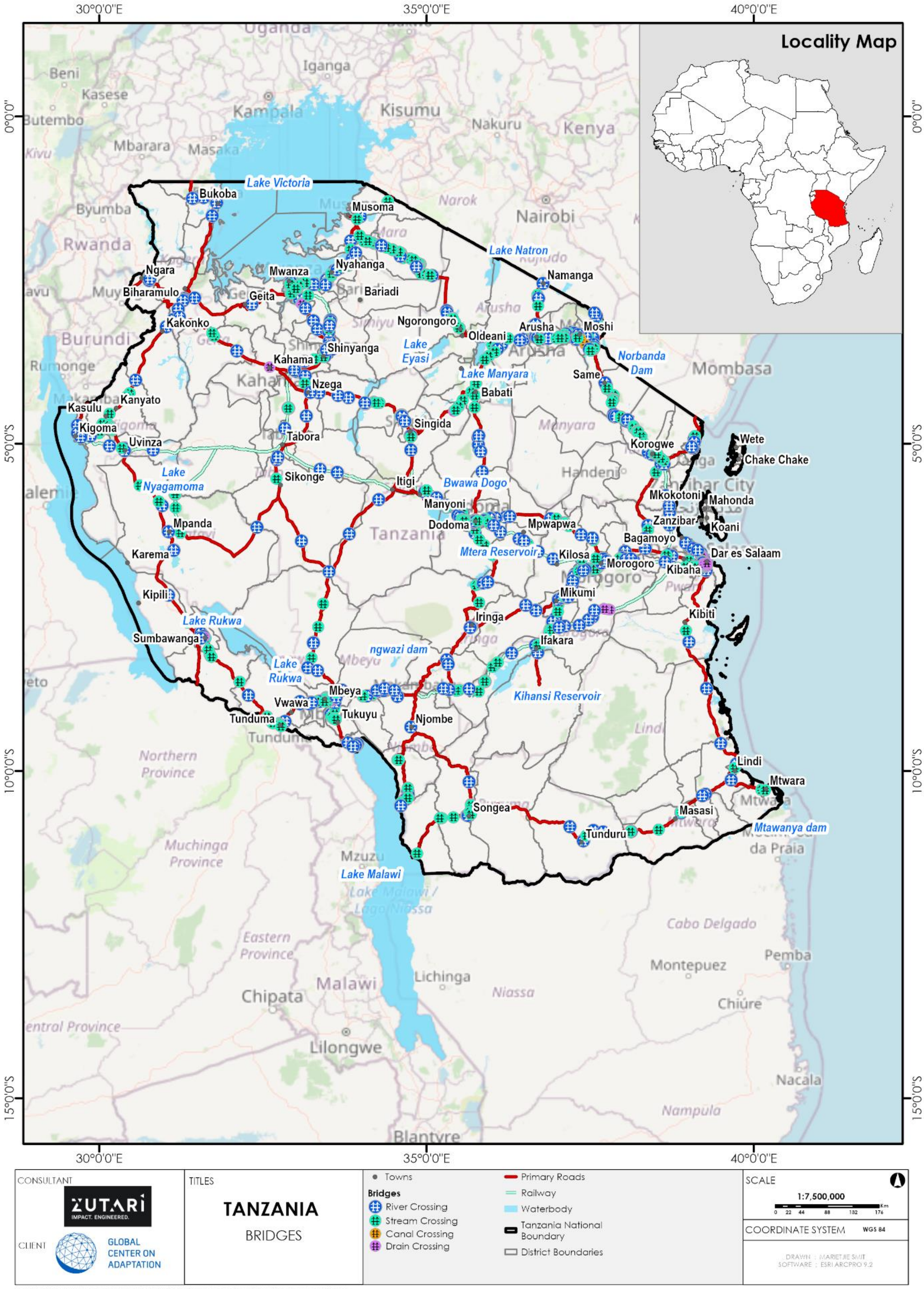

Figure 32: Location of road and railway bridges identified in Tanzania

Table 4-11: Climate change risk assessment results for airports in Tanzania

CLIMATE : DROUGHT															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Large airport			2						2					2	
Medium airport		4	4	2			2	4	4			1	4	5	
Small airport		66	91	34	3		30	123	41			11	111	68	4

CLIMATE : FLOOD															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Large airport					2					2					2
Medium airport				3	7				4	6				4	6
Small airport			7	21	166			7	24	163			7	28	159

CLIMATE : TROPICAL CYCLONE & WIND															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Large airport					2					2					2
Medium airport				1	9				1	9				1	9
Small airport				8	186				9	185				10	184

CLIMATE : EXTREME TEMPERATURE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Large airport				2					2					2	
Medium airport			2	5	3			3	5	2			3	7	
Small airport		1	32	115	46		10	64	87	33		19	65	81	29

CLIMATE : LANDSLIDE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Large airport			1	1				1	1				1	1	
Medium airport		1		6	3		1		6	3		1		6	3
Small airport		2	8	109	75		2	13	106	73		2	15	102	75

Table 4-12: Climate change risk assessment results for bridges in Tanzania

CLIMATE : DROUGHT															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Railway		81	161	37			35	111	133				137	133	9
Road		218	361	121	4		81	290	333			10	320	331	43

CLIMATE : FLOOD															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Railway		3		33	243		3		40	236		3		40	236
Road		3	13	100	588		3	15	118	568		3	14	140	547

CLIMATE : TROPICAL CYCLONE & WIND															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Railway					279					279					279
Road				21	683				21	683				21	683

CLIMATE : EXTREME TEMPERATURE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Railway			33	213	33		5	102	162	10		13	109	155	2
Road			69	468	167		6	153	413	132		9	169	413	113

CLIMATE : LANDSLIDE															
Type	HISTORY					INTERMEDIATE					FUTURE				
	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
Railway		5	26	131	117		10	21	136	112		10	21	142	106
Road		7	38	227	432		15	44	246	399		15	43	260	386

Table 4-13: Climate change risk assessment results for dams in Tanzania.

CLIMATE : DROUGHT														
HISTORY					INTERMEDIATE					FUTURE				
VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
	9	5	5	4		4	9	10				14	9	

CLIMATE : FLOOD														
HISTORY					INTERMEDIATE					FUTURE				
VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
			6	17				6	17				6	17

CLIMATE : TROPICAL CYCLONE & WIND														
HISTORY					INTERMEDIATE					FUTURE				
VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
				23					23					23

CLIMATE : EXTREME TEMPERATURE														
HISTORY					INTERMEDIATE					FUTURE				
VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
		3	15	5			9	13	1		1	9	13	

CLIMATE : LANDSLIDE														
HISTORY					INTERMEDIATE					FUTURE				
VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL
	3	3	10	7		3	3	10	7		3	3	10	7

5 CONCLUSION AND RECOMMENDATIONS

The climate change risk assessment for the critical infrastructures systems (I.e. combining the hazard, exposure and where possible vulnerability) will then be summarized at both a national and a sub-national level. This additional information will be used to further inform the analysis using the Green Economy Model (GEM) as well as the individual policy briefs and recommendations developed for each country.

5.1 Inputs to the Green Economy Model (GEV) and economic risk assessment

The climate change risk and vulnerability assessment to be undertaken using the Green Economy Model (GEM) in Component 2 of this study is done at a national level. The relevant results from this report that are included in the GEM are the number and length of different asset classes exposure to the various climate related hazards. This includes for example the percentage of the road network exposure to river flooding and landslide risk as well as the number of power stations, healthcare and education facilities.

The analysis carried out with the GEM considers the "High" and "Medium" categories for a realistic representation of adaptation ambition and costs. This is also justified by the fact that the "Medium" category of risk is defined as the assets subject to a 1:100-year RI design flood estimate which is used in most country as an engineering design standard for infrastructure. These results are shown in Table 5-1.

The buildings value is the average of the hazard classification results for health and education facilities.

Table 5-1: Assets at risk considered in the Green Economy Model (GEM)

Assets at Risk		
Asset	**Unit**	**Tanzania**
Roads (km)	%	8.0%
Buildings (Buildings)	%	11.0%
Power Generation Capacity (MW)	%	52%
Transmission Lines (km)	%	16%

5.2 Identifying Hotspots for Climate Change Adaptation

The priority hotspots for climate change adaptation can be identified in terms of the overall climate change related risk which combines hazard, exposure and vulnerability. The priority areas should be identified either in terms of the current hot spots for individual risk, or on the future hazard assessment. The priority areas could also be based on the change in the level of the overall hazard or risk (i.e. anomaly) which would indicate hotpots where climate-related changes are most significant. In terms of priority hotspots for climate change adaptation, the most significant increasing hazard is extreme temperature therefore the areas of highest increase in extreme temperature variables should be prioritized. In terms of river flooding, the priority hotspots could be on critical infrastructure assets located in the high hazard category for river flooding (i.e. located within the 1 in 25-year flood impacted areas) and then these can be further prioritized based on areas of greatest increase in extreme rainfall. In this regard it would be important to consider additional risk amplifiers such as areas of high deforestation rates and catchment degradation.

5.3 Improved road conditions for added resilience

A critical factor contributing to the increasing risk of damage to critical infrastructure due to climate change is the poor condition of many infrastructure assets. Improving the condition of these assets will assist in making them more resilient to the potential impacts of climate change and hence reduce potential social and economic impacts, as well as overall maintenance costs. Unfortunately, information on the conditions of critical infrastructure assets is limited both at a national and regional level. Some information on current road condition is available from global datasets such as the World Bank dataset used in this study, and this showed that a large proportion of roads are in a poor to very poor condition. Importantly, many more roads are in an unknown condition. The roads in poor condition when combined with exposure to key hazards such as flooding and extreme temperature increase the overall risk of further deterioration and potential damage to the road. This result highlights the importance of investing in improving the condition of existing critical infrastructure assets to become more climate resilience. In some countries there is more detailed data available on the condition of critical infrastructure including for example through a Road Asset Management System (RAMS) which can be used to fine tune the approach of identifying critical assets that require maintenance. Similar data on the condition of other critical infrastructure such as railways, harbors, education and health facilities as well as dams, water and wastewater treatment infrastructure should also be captured at national level in order to prioritize investments to improve operational efficiency and reduce climate related risks.

5.4 Recommendations for updating design standards

Two of the most critical climate related design considerations for critical infrastructure are maximum temperatures and extreme rainfall. In design, historical values of these key climate variable are often used. In terms of recommendations for updating design standards, the review of key climate variables such as maximum daily rainfall or average daily maximum temperature can be used to give an indication of how historical design parameters may need to be adjusted to account for the impacts of climate change (Figure 37). In this regard it is worth considering the more distant future to account for the expected long-term lifespan of infrastructure, but consideration should also be given to testing the sensitivity of design to changes in these extreme variable as it may be more cost effective to adopt a risk-based approach to managing the impact of extreme events, rather than maximizing the design capacity.

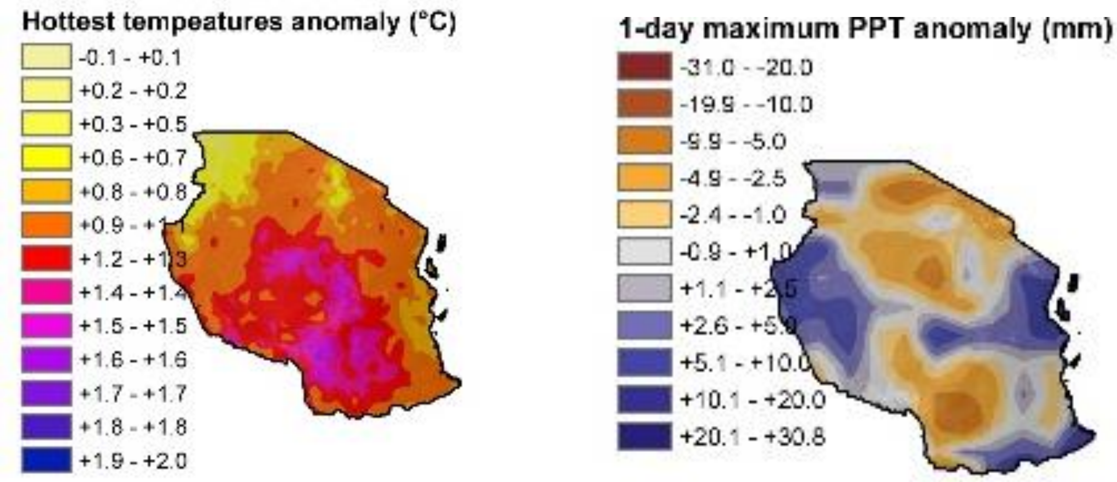

Figure 37: Hottest temperature (left) and maximum 1 day rainfall anomaly (right) due to climate change (SSP2-45 2020-2040) that could be used to adjust existing design standards for critical infrastructure in Tanzania.

5.5 The importance of investing in catchment management and natural systems

Key climate related hazards for critical infrastructure such as river flooding and landslide risk are increased as a result of poor catchment management and the degradation of natural systems. These not only increase the magnitude of the flood following an extreme rainfall event, but also increase the rate of erosion and sedimentation which contributes additional risk to the downstream infrastructure. The degradation of wetlands, coastal dunes and mangroves also increases the risk of flooding, sea level rise and storm surges. Adding a layer showing areas of current land degradation and prioritizing the protection of existing natural systems such as forests, wetlands and riparian banks can also help in identifying critical areas for investing in climate change adaptation and reducing the risk to infrastructure.

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