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Flood Disasters Risk Assessment and Climate Change Resilience in Niamey – Niger.

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By

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Dedication

*To Almighty God, for supporting, assisting, and filling me with His grace all my life. I dedicate this work to my lovely mothe***r Hadjia Haoua Amadou** *and late father* ***Alhaji Hassane Ounteini****, may his soul rest in peace. I also dedicate this work to my son Naguibou and my daughter Anifatou.*

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Abbreviations and Acronyms

ACMAD : African Centre of Meteorological Applications for Development

ANACOLD: Australian National Committee on Large Dams

AHP : Analytical Hierarchy Process

CCI : Climate Change Initiative

CCT : Centre de Cartographie et de Télédétection

ETCCDI : climate change detection and indices experts

DEM : Digital Elevation Model

DNPGCCA : National Framework for the Prevention and Management of Food Crises

DTM : Digital Terrain Model

DEM : Digital Elevation Model

GCM : Global Climate Model

GIS : Geographic Information System

HADCM3 : Hadley Centre Coupled Model, version 3

HMA : Hierarchical Multicriteria Analysis

IGNN : Institut Géographique National du Niger

INS : Institution National de la Statistique

IPCC : Intergovernmental Panel on Climate Change

ISCSU : International Council for Science Unions

LARS-WG : Long Ashton Research Station - Weather Generator

MCA : Multi-Criteria Analysis

MEDD : Ministère de l'Environnement et du Développement Durable

NBA/ABN : Niger Basin Authority

NGO : Non-Governmental Organization

OBIA : Oriented Based Image Analysis

OCHA : United Nation Office for the Coordination of Humanitarian Affaires

ORSTOM : Office de la Recherche Scientifque et Technique Outre-Mer "

RCSN : Red Cross Society of Niger

S O : Specific Objective

SRTM : Shuttle Radar Topography Mission

TM : Thematic Mapper

UST : Urban Structure Types

UNFCCC : United Nations Framework Convention on Climate Change

UNEP : United Nations Environment Programme

UNISDR : United Nations Office for Disaster Risk Reduction

UNSO : United Nations Sudano-Sahelian Office

USGS : United States Geological Survey

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

WCP : World Climate Program

WCRP : World Climate Research Program

WMO : World Meteorological Organization

Abstract

Climate change has become one of the most pressing environmental issues in recent decades, resulting in a significant increase in rainfall intensity and causing floods in various countries worldwide. Flooding is a natural calamity that, when combined with climate change, can cause severe damage in Niger. The capital city, Niamey, located in the western region of the country, is particularly vulnerable to flooding due to its susceptibility to rainfall, rapid population growth, and uncontrolled urbanization. In response to this problem, a study was conducted to identify, map, and simulate flood risk zones to enhance decision-making for better land use planning in the face of a changing climate. The study aimed to evaluate the degree of socio-economic and environmental threats related to flood disasters in the examined area. The data for the study were collected through a combination of field and archival research, including the use of a questionnaire. The data obtained were analyzed scientifically using frequency distribution tables, basic percentages, graphs, and charts. The study also analyzed the spatiotemporal land use/land cover change in relation to urbanization sprawl based on a series of Landsat images of 1981, 1991, 2001, 2011 and 2021. Additionally, satellite and GIS data were used, and statistical tools were applied to describe and identify the hydro-climatic causes of floods. The research found that flooding is the most common environmental disaster in the study area, occurring almost yearly and causing significant harm to socio-economic and environmental elements. Excessive rainfall, poor drainage infrastructure, and mismanagement of water reservoirs were identified as the primary causes of the flood disaster. The study also found that disaster management/response agencies are making efforts to respond to the flood threat in the area. However, statistics suggested that these interventions are insufficient in minimizing the hazards and threats of flood disasters in the examined area, with most efforts being aimed at relief and rehabilitative aid for the victims. Therefore, the study highlights the need for all stakeholders to accelerate efforts towards delivering a viable solution to the hazards and threats of flood disasters in the research area through preventive and mitigation measures.

Keywords: flood risks assessment, flood map, GIS, resilience, Niamey

Résumé

Le changement climatique est devenu l'un des principaux fléaux environnementaux les plus évidents au cours des dernières décennies. De même, l'intensité des précipitations a augmenté de manière drastique, générant des inondations dans plusieurs régions et pays au niveau international. Les inondations sont l'une des calamités naturelles qui se combinent avec le changement climatique pour produire des effets et infliger certains des dommages les plus graves au Niger. Niamey, la capitale du pays, est située dans la région ouest du pays qui est sensible aux précipitations. La croissance rapide de la population et l'urbanisation incontrôlée contribuent au problème du risque d'inondation. Cette étude a pour but d'identifier, de cartographier et de simuler les zones à risque d'inondation afin d'améliorer la prise de décision pour une meilleure planification de l'utilisation des terres dans le contexte de changement climatique. L'étude évalue le degré de menaces socio-économiques et environnementales liées aux inondations dans la zone. Une combinaison de données de terrain et d'archives a été utilisée, et une technique de recherche par sondage comprenant l'usage d'un questionnaire a été employée pour rassembler les informations importantes. Les données obtenues ont été présentées et analysées scientifiquement à l'aide de tableaux de distribution de fréquences, de pourcentages de base, de graphiques et de diagrammes. L'évolution spatio-temporelle de l'utilisation et de l'occupation des sols en relation avec l'urbanisation rapide a été analysée sur la base d'une série d'images Landsat de 1981, 1991, 2001, 2011 et 2021. Des données satellitaires et SIG ont également été utilisées. Des outils statistiques ont permis décrire et identifier les causes hydro-climatiques des inondations. Les résultats de la recherche suggèrent que les inondations sont la catastrophe environnementale la plus courante dans la zone d'étude, qu'elles sont souvent accompagnées de tragédies et qu'elles causent des dommages importants aux éléments socio-économiques et environnementaux. La fréquence des inondations dans les zones sinistrées est également assez régulière, se produisant presque tous les ans. Les résultats indiquent également que les précipitations excessives, les mauvaises infrastructures de drainage et la mauvaise gestion des réservoirs d'eau sont les principales raisons des inondations catastrophiques. Le phénomène des inondations a un impact considérable sur les pertes environnementales et socio-économiques. Les agences de gestion et de réponse aux catastrophes s'efforcent de répondre à la menace des inondations dans la zone examinée. Cependant, les statistiques suggèrent que ces interventions sont insuffisantes pour minimiser les risques et les menaces d'inondation dans la zone d'étude. Les activités sont principalement axées sur l'aide d'urgence et la réhabilitation des victimes. Il est absolument nécessaire que toutes les parties prenantes accélèrent leurs efforts pour trouver une solution viable aux risques et aux menaces d'inondation dans la zone étudiée grâce à des mesures de précaution/prévention et d'atténuation mises en évidence par l'étude.

Mots clés : évaluation des risques d'inondation, carte des inondations, SIG, résilience, Niamey

General Introduction

Research Problem

The scientific community considers "Climate Change" as one of the world's greatest human development challenges (Pörtner *et al.*, 2022). The world is facing an increasing number of weather extreme events, such as heat waves, cyclones, droughts, and floods (H. E. Brooks, 2013; IPCC, 2014). These phenomena affect negatively the environment and people's livelihood, particularly marginalized groups in the poorest regions, even though they are least responsible for these changes (Adawiyah and Abdullah, 2014). Natural disasters have caused severe damage to natural, modified, and human systems (UNISDR, 2009). These damages seem to increase with time due to both the higher intensity of the natural phenomena and the higher value of the elements at risk.

Furthermore, much of the increase in urban poverty takes place in locations highly vulnerable to natural disasters. These locations are expected to experience greater climate change impacts in years to come. Nearly 60 per cent of the cities with more than 300,000 inhabitants are at high risk of exposure to, at least one or more of, the following six natural disasters: cyclones, droughts, floods, earthquakes, landslides, and volcanic eruptions. It is worth pointing out that this number is on the rise (United Nations, 2018c). Seasonal, temporary, and permanent migration is already among the strategies that households utilize when faced with food and livelihood insecurity associated with climate variability. These climate-related migrations could become more prevalent in the future with an anticipated increase in the frequency and intensity of adverse climate events (UN, 2019) (World Urbanization Prospects, 2018 revision). Floods are one of the most destructive natural disasters affecting many countries, especially in the most flooded plain areas. Urban areas have been identified as breeding grounds for disaster, environmental, social, economic, and human risks and insecurities. For example, the 2011 World Urbanization Prospects highlighted that approximately 890 million people lived in areas of high exposure risk.

During the last two decades, the sub-Saharan region has experienced unusual floods that have significantly impacted the region. No official or exact figures are available on flood damages and their impacts on the population. In addition, the magnitude of these weather events is not easily estimated. Several studies have investigated this new threat using data derived from local media sources or world disaster databases. The Sahelian rural population is considered one of the most vulnerable on earth. This vulnerability is partly caused by the West African monsoon variability, the main water resource for agriculture. During the 70s and 80s, the Sahelian population experienced several droughts with severe consequences. Since the end of the 20th century, Sahelian countries have suffered from heavy rainfalls and devastating floods in many parts of the Niger basin. As a result, Niger continuously faces multiple emergencies. The floods are just adding to the crises already stretching the government and humanitarian agencies' capacity to respond. In Niger, floods are the most common disasters. Floods are overflows or irruptions of an enormous body of water over land not usually submerged. Flooding is the most common of all environmental hazards and regularly claims over 20,000 lives per year and adversely affects around 75 million people worldwide (Okpara *et al.*, 2013)

Nowadays, floods are frequently accompanied by the loss of lives, properties, and croplands. They affect people's livelihood, health, production, communication systems, and ecosystems. Further, floods have major impacts on human security. In 2018, the authorities, at the national level, said that floods have caused the death of 57 inhabitants and negatively impacted 132,528 other people. In late September 2019, 16,375 houses were destroyed and 211,000 people were affected, especially, in Zinder (80,534 people), Maradi (28,847 people), and Agadez (31,222 people), (OCHA 2019).

According to OCHA 2020, the flooding of the Niger River, at Niamey and vicinities, started on August 23, 2020, and resulted in the destruction of 868 homes. Additionally, a total of 2,283 homes (around 15,981 individuals) have been impacted. Many of these individuals have been relocated and have sought shelter with host families or local schools. There was one documented death.

Published information about this phenomenon in Niger is very scarce. To fill this gap, the present study entitled **“Flood Disaster Risk Assessment and Climate Change Resilience in Niamey-Niger”** attempts to understand how flood disasters act as threat multipliers to human security in Niamey and its vicinity. It further seeks to identify the causes of flood disasters in the area by applying Geographic Information Systems (GIS) and remote sensing techniques.

Research Questions

Main question

- How does flood disaster acts as threat multipliers to human security and affect the resilience capacity of the communities in Niamey?

Subsidiary questions

- ✓ What are the driven factors of floods disasters in climate change in Niamey and its vicinity?
- ✓ How to assess the level of flood disaster risk in Niamey?
- ✓ Are there any appropriate models for predicting flood disasters in Niamey and its vicinity?
- ✓ Which resilience measures have been taken by communities and the government to mitigate flood disasters?

Aim and objectives

This study aims to assess flood disaster risk and propose resilient methodologies for communities of Niamey and its vicinity.

The specific objectives of this research are:

- ✓ **(SO1) -** To identify the major factors contributing to flood disaster risk;
- ✓ (**SO2) -** To assess the flood disaster risks area along the River Niger in Niamey and its vicinity;
- ✓ **(SO3) -** To elaborate a model of flood forecasting mechanism to reduce the risks**;** and
- ✓ **(SO4) –** To promote climate resilience measures for reducing the adverse impacts of floods and its likelihood;

Hypothesis and Assumptions

- ✓ Climate change and the mode of land use in the floodplain are responsible for the increased flooding level in Niamey and its vicinity.
- ✓ In Niamey, floods threaten human security and land availability.
- ✓ The use of an appropriate model for flood forecasting can reduce flood-related risks in Niamey.
- ✓ Communities in Niamey build resilience capacity by effective adaptation and/or mitigation measures implemented by the government and local dwellers.

Significance of the study

The following points highlight the significance of the study:

- ✓ The study would give a detailed picture of the various processes involved in the flood tragedy. It would also show its effects on Niamey, Niger's capital, and flood dangers.
- ✓ It tries to pinpoint local flood disaster areas by using geographical information systems and remote sensing methods.

- ✓ The study's findings would give communities and economic players the information they need to decide how the flood disaster will affect their daily lives and the environment. Actors would be better prepared for this if they knew sustainable mitigation and adaptation techniques.
- ✓ Additionally, the study would add to our understanding of how to assess flood disaster risk in Niger and pave the way for further investigation.

Scope of the study

This thesis investigated the extent and impact of flooding on Niamey, the nation's capital. The study also revealed the effectiveness of the Analytic Hierarchical Approach (GIS) approach for multi-criteria analysis in flood assessment.

Expected results

This research project aims to contribute to the understanding of flood disaster causal factors and their implications for human security in Niger. Therefore, the expected results are:

- ✓ A better understanding of the role of combined meteorological factors (heavy rainfall), hydrogeological factors, topographical factors, and anthropogenic factors in floods in Niger;
- ✓ A better understanding of how flood disaster affects communities through a wide range of threats: buildings collapse, destruction of economic infrastructure and food items losses, health diseases, and contamination of ecological systems.
- ✓ A flood forecasting model is developed to reduce flood-related disaster risks in Niamey city.
- ✓ A few potential climate resilience measures to reduce flood impact and the likelihood of flood-related losses.

Theoretical Framework

Floods are influenced by several natural factors, such as climate, geographical location, geomorphology, soil types, and land cover. However, anthropogenic factors, such as population growth, intensive urbanization in flood-prone areas, land use and land cover changes, and inadequate development of flood control drainage may increase the potential impact of floods through increased runoff concentration, peak, and volume. Accordingly, floods occur due to natural and anthropogenic factors. In Figure 1, UNDRO (1980) conceptualizes disaster risk as a tributary to three elements: hazard, the element at risk, and vulnerability. Secondary data will be used for this research.

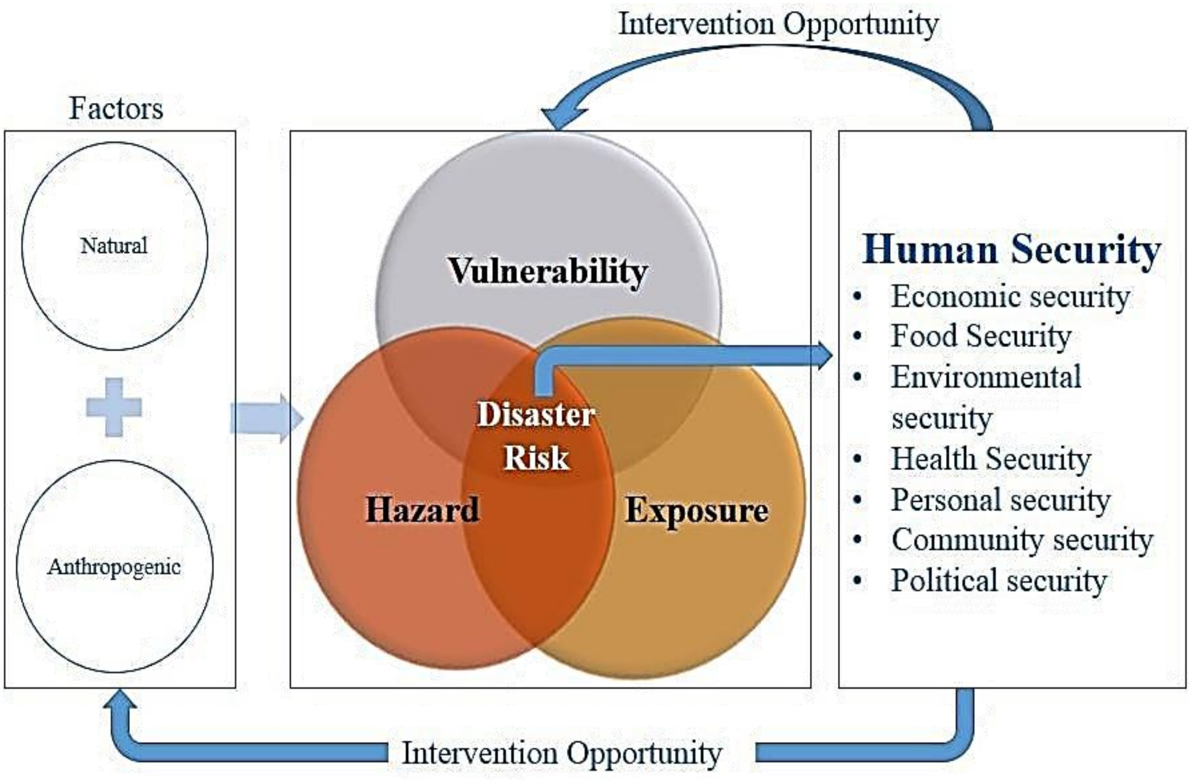

Figure 1: Framework for assessing disaster risk impact on human security **(**Source: Adapted from UNDRO (1980) representation of risk)

When a flood occurs and its impact is such that the local capacity to cope is exceeded, it then becomes a disaster. Furthermore, beyond direct physical destruction and disruption of socio-economic activities, floods affect in many ways all components of human security (Abubakar *et al.*, 2020). It impacts personal and community security by threatening livelihoods. Most often, the impact of the flood is followed by health problems (viz., mental health, malnutrition, malaria, …) and the outbreak of diseases, such as diarrhea and cholera. Therefore, flood affects health security. Moreover, by destroying agricultural crop fields and food production, it impacts local economies, food security, and environmental and ecosystem services. In other words, floods impact all aspects of human security. Thus, by reducing existing exposure, hazard or vulnerability, the risk may be reduced and human security may be improved. Alternatively, activities undertaken to reduce human insecurity can also reduce exposure and vulnerability. Similarly, improving human security and sustainable human development may reduce the anthropogenic causative factors of flood disasters. Based on the aforementioned considerations, this study conceptualizes the framework for assessing flood disaster risk on human security, as shown in Figure 1.

Limitations

This study has the following limitations:

Cost: Obtaining high-resolution satellite images is expensive, which forced the researcher to use publicly available archived satellite images provided by the United States Geological Services (USGS). Cost considerations also affected software, digital elevation data, and satellite imagery choices.

Satellite Data Availability and Quality: The majority of the satellite data for flood-prone dates had issues with significant cloud cover, making it challenging to evaluate them. As a result, the closest dates to the time of the flood's occurrence (with minimal cloud cover) were accepted and used in this study.

Lack of hydrological data for the Niger Basin: The lack of sufficient hydrological data for the Niger River Basin forced the employment of artificial means to produce the data needed for this study. Only a year's worth of stream discharge data was utilized to build a grading curve.

Structure of the Thesis

The structure of a thesis is a crucial aspect that provides a framework for organizing and presenting the research findings, analysis, and conclusions. While specific requirements may vary based on academic institutions and disciplines, this thesis is organized into six chapters and the structure includes the following components:

Chapter 1: Literature review

Chapter 2: Materials and Methods for the Research

Chapter 3: Flood types, Causes, and Effects in Niamey (OS1)

Chapter 4: Flood Risks Assessment in Niamey (SO2)

Chapter 5: Hydrography and Flood Modelling (SO3)

Chapter 6: Flood mitigation, resilience and adaptation measures (SO4)

1 Chapter 1: Literature Review

Background

Climate change is defined by the United Nations Framework Convention on Climate Change as "the change in climate that is attributed directly or indirectly to human activities that alter the composition of the Earth's atmosphere and that is in addition to the variability of natural climate observed over the comparable period" (UNFCCC, 2006). Climate change, the main environmental issue, is producing difficulties in the economy, public safety, food production, and food security.

The world is facing increasingly extreme weather events such as heat waves, cyclones, droughts, and floods due to climate change (H. E. Brooks, 2013). A recent IPCC Special Report (Pörtner *et al.*, 2022) shows that human activities have caused global warming of approximately 1.0 °C above the pre-industrial level. These phenomena negatively affect the environment and people's livelihood, particularly marginalised groups in the poorest regions, even though they are the least responsible for these changes (Adawiyah & Abdullah, 2014).

(Tarhule, 2005) first said that extreme flooding was becoming an essential issue for developing Sahelian countries. During the last 20 years, many authors (Tarchiani & Tiepolo, 2016; Tiepolo *et al.*, 2021; Tiepolo *et al.*, 2018) said there are increasing floods and flood-related impacts in West Africa. (Nka *et al.*, 2015) evaluated the flood trends with a regional perspective on 11 catchments and found a significant increase in flood magnitude and frequency in the Sahelian area. (Aich *et al.*, 2016) declared the positive trends of flood magnitude and their relationship with the number of people affected in the Sahelian part of the Niger River Basin. Fiorillo et al. (2018) showed a tremendous increase in flood events and related damages in Niger, particularly in the Tillaberi, Niamey, and Dosso regions (Massazza, Bacci, *et al.*, 2021).

(Fiorillo *et al.*, 2018; Tarchiani & Tiepolo, 2016), have analysed official data collected by the government on damages from 1998 to 2017 and demonstrated increased flooding nationwide in Niger. (Massazza, Bacci, *et al.*, 2021; Tang *et al.*, 2021; Tarchiani *et al.*, 2021; Tiepolo *et al.*, 2018, 2021) approved that, regarding the regional and sub-regional impacts of flood, the southwestern areas of Niger were found to be most exposed to flood risks. Over the past 20 years, the scientific literature has mainly focused on changes in the magnitude of floods in the Niger River, trying to understand both the ongoing changes in hydrological characteristics and the main factors triggering the increased flooding in the region. However, (Alou, 2018; Scheuer *et al.*, 2021; Tarchiani *et al*, 2014; Tiepolo & Braccio, 2016b) demonstrated that the Niger River is only one of the causes of flood risk in Niger and that most events are unrelated to river dynamics. (IPCC, 2014)

In late September 2019, 16,375 houses had been destroyed, and 211,000 people were involved, in particular in the three regions of Zinder (80,534 people affected), Maradi (28,847), and Niamey (31,222). (OCHA 2019). In 2020. According to estimates by the Ministry of Humanitarian Action and Disaster Management, as of 07th September 2020, 432,613 people (52,404 households) have been affected by these floods. The most affected regions are respectively Maradi (135,450 victims), Agadez (96,240 victims) and Niamey (48,507 victims). Sixty-five people have died in this lousy weather (OCHA, 2020). The balance sheet also reports 36,155 houses collapsed, thousands of hectares of crops buried, and heads of cattle destroyed. The damage recorded was notably heavier in the regions of Agadez and Niamey, which previously were not among the most affected areas. In Niamey, the capital, the raging waters invaded the neighbourhoods bordering the Niger River (Lamordé, Karadjé, Zarmagandey) as soon as the protective dike separated the river from these neighbourhoods gave way following the torrential rains of Saturday, 05th September 2020 (OCHA, 2020)

Mainly two types of flooding are distinguished: First, flash floods occur every rainy season in some neighbourhoods. Due to violent downpours, these floods often cause significant damage. The most exposed communities are those of Commune 5, particularly the informal sectors of Zarmagandey, Karadjé-Ganda and Nialga. Kirkissoye. In Niamey 4, the most affected localities are Saga. Gamkalley and Tondigamey.

Then slow floods are due to the river's overflow from its minor bed. This type of flooding often occurs during the dry season. This river flooding is linked to water coming from Guinea and Mali. It can also be devastating through its effects on houses, especially rice fields. This flood, unlike the previous one, concerns residents of the river and those located in its backwaters. These are mainly the Kombo and Saga neighbourhoods on the left bank and the informal sectors of Zarmagandey, Lamordé, Karadjé-Ganda, Nialga and informal Banga-Bana on the right bank. During January and February, there is an annual rise in water levels spread over several months and can generate violent floods (Tarchiani *et al*., 2020, 2021).

Located on the banks of the river Niger, Niamey is particularly prone to floods, which in its middle basin has two flood peaks: the red flood and the black flood. In 2020, the Niger River in Niamey reached its all-time highest levels following an abundant rainy season. On the other hand, the floods in Niamey have been widespread in the last decade, a symptom of a change in hydroclimatic behaviour already observed since the end of the significant droughts of the 1970s and 1980s, it is identified with the Sahelian Paradox (Massazza, Bacci, *et al.*, 2021).

The overflow of the Niger River affects Niamey, which is reaching increasingly high levels, causing recurrent flooding of built-up and cultivated areas, thus affecting thousands of people. But river floods are not the only hydrological risk in Niamey, as flash floods are also recurrent, mainly due to weak drainage systems and lack of maintenance.

To overcome the flood disaster, researchers and scientists attempted flood mapping (Bechler-Carmaux *et al*., 2000), opening the way with a flood vulnerability map that estimated the population and the major equipment exposed to flooding. At least three river flood event maps followed, which identified the flooded area (Tiepolo & Braccio, 2016a) (Psomiadis, 2016) and the flood depth (ABN/CRA 2007). (Tiepolo & Braccio, 2016b) used historical data and scenarios for flood risk preliminary mapping in Niamey and didn't consider the Digital Elevation model DEM at 30m.

1.1 Definition of Terms

Flood: a temporary covering by water of land normally not covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems

Flood risk: the combination of the probability of a flood event and the potential adverse consequences to human health, the environment and economic activity associated with a flood event.

Flood plain maps: indicate the geographical areas, which could be covered by a flood according to one or several probabilities: floods with a very low probability or extreme events scenarios; floods with a medium probability (likely return period >= 100y); floods with a high probability.

Flood hazard: Flood hazard maps are detailed flood plain maps complemented with type of flood, the flood extent; water depths or water level, flow velocity or the relevant water flow direction.

Flood risk: Flood risk maps indicate potential adverse consequences associated with floods under several probabilities, expressed in terms of the indicative number of inhabitants potentially affected; type of economic activity of the area potentially affected; installation which might cause accidental pollution in case of flooding; other information which the Member State considers useful.

Damage: the amount of destruction or damage, either in health, financial, environmental functional and/or other terms as a consequence of an occurred hazard.

1.2 Concept of Climate Change

Since numerous studies have extensively covered the threats posed by climate change to the survival of natural resources and human livelihood, particularly agriculture and food security at the macro and household levels (IPCC, 2014; Lee & Choi, 2018; Mamo *et al*., 2019; Pörtner *et al*., 2022), it is no longer news. Climate change, according to (Jeong *et al*., 2014), is one of the main factors contributing to flood catastrophes. The effects of climate change cause land degradation, which degrades soil quality and increases surface runoff, which diminishes water penetration rates (Dama *et al*., 2014). Precipitation prediction is more challenging than temperature forecast owing to the high degree of uncertainty. The degree of vulnerability in many cities throughout the globe, including Niger, is anticipated to rise as a result of severe hazard occurrences and the ongoing growth in exposures due to urbanisation (Bassirou *et al.*, 2022, 2023; Olagunju et al., 2021; Tarchiani *et al.*, 2021).

Due to interactions between climate change and non-climatic stressors that exacerbate the susceptibility of the area, notably its agricultural sector, West Africa is very sensitive to climate change and related natural disasters such as floods ‘In certain areas of West Africa, floods have become more frequent and severe during the last ten years (Alou, 2018; Roudier *et al.*, 2014)

According to (Tamagnone *et al*., 2019) some changes have already been seen in West Africa as a result of climate change, which is predicted to lead to increased fluctuations in rainfall patterns. Therefore, climate change is anticipated to gradually and considerably increase the danger of flooding over time. Low-lying coastal regions will be particularly in danger as sea levels rise and locations that are now not particularly prone to flooding will be at greater risk of flooding due to surface runoff and overloaded drainage systems.

1.3 Concept of Disasters

A disaster is a major disruption of a community or a society's ability to operate that causes widespread losses and effects in terms of people, things, money, or the environment. It also surpasses the capacity of the afflicted community or society to deal using its resources. Disaster effects may sometimes be quick and localised, but they are often extensive and may persist for a very long time. A community or society may not be able to deal with the consequences on their own and may need support from other sources. These outside sources may include those in adjacent countries or jurisdictions as well as those at the national or worldwide levels (UNISDR, 2009).

A disaster is defined as an emergency that results in a large change in conditions over a short period of time and is brought on by either natural disasters or human-induced acts (Mouhamed *et al.*, 2013). Disasters have one of the most catastrophic consequences on human and social life, agriculture, livelihoods, health, and economic development globally (Bigi *et al.*, 2018) Examples of typical effects include death, eviction, illness, loss of crops, harm to physical and service infrastructure, depletion of natural and social capitals, injuries to people, property damage, disruption of economic activity, loss of livelihood, ecological degradation, institutional deterioration, and a general disruption of economic and social activity. . Years of development progress may be undone in a single day by a calamity. Disasters may, however, also serve as a spark for change (Birkmann *et al.*, 2022).

The trend of disasters in Africa shows that the disaster started to increase from 1960 to 2020. As can be seen from Figure 2, three peaks were observed, respectively, in 2000 and 2006 and 2019. Meanwhile, there were two minor peaks in 1910 and 1940.

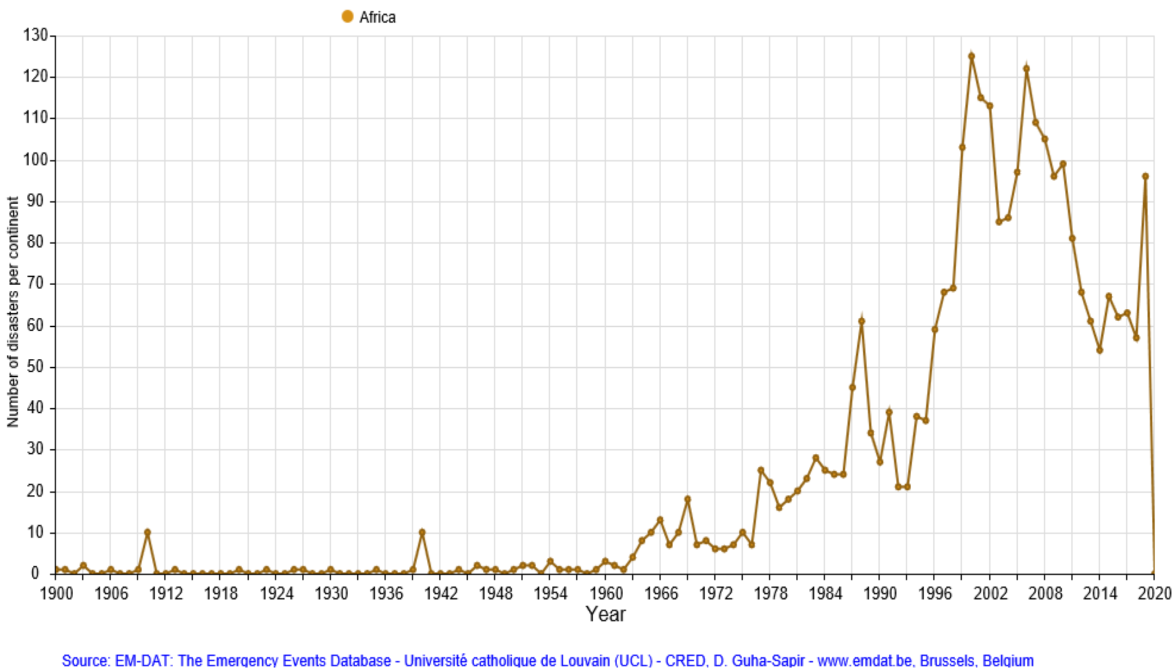

Figure 2: disaster trend from 1900-2020

Favreau *et al.* observed that, in semiarid regions, land cover changes may result in modifications to the water balance (Descroix *et al*., 2009). Higher runoff as a long-term consequence of land clearance and soil crusting was described at various scales in the Sahel, from small watersheds of a few tens of square kilometers to larger catchments of up to 21,000 km^2. As a result, Niger is affected by flood disaster.

1.4 Natural Disaster in Niger

Niger is a Sahelian country with an arid tropical climate. The annual rainfall (between 100 and 800 mm) is characterized by significant interannual and spatial differences. Niger has regularly faced extreme climatic variability: heavy rainfall in 2010, drought in 2011, and exceptional rainfall in 2012. In the context of Niger, climatic vagaries are amplified by aggravating factors, such as household poverty, inadequate building materials, construction of houses in flood-prone areas, weakness of protective structures (dikes), silting up of water points, inadequacy or absence of an urban development plan, weakness of information and alert mechanisms, and weakness of regional disaster management structures.

In Niger, the frequency of natural disasters, the number of people affected and economic losses have increased in recent years. The predominant phenomena are hydrometeorological hazards (drought, floods, strong winds), erosion in various forms and bushfires. It should be noted that, following the recent droughts, the government has mobilized to provide emergency aid to the affected populations. It was supported in these actions by its multilateral and bilateral development partners, as well as a large number of Non-Governmental Organizations (NGOs), both national and international.

Thus, the emergency situations caused by droughts and floods have considerably contributed to raising awareness of the need to invest in prevention against natural hazards. Despite this awareness, lessons learned and past experiences in managing climatic phenomena (which have caused significant loss of human life and equipment) have shown the country's weak capacity to cope with them. The conclusion of these reflections, therefore, remains that concerted and well-coordinated collective actions by all the actors are necessary. To do this to prevent and effectively manage disaster risks in the short, medium and long term.

Table 1: Summary of disaster types 1900-2020

Types of Disaster	**Events count**	**Total deaths**	**Total affected**	**Total damage ('000 US$)**
Animal accident	1	12	5	0
Drought	15	85000	27 374 486	0
Epidemic	44	110066	274205	0
Flood	29	556	2 399 665	272039
Insect infestation	6	0	0	0
Storm	1	4	1253	0
Total general	**96**	**195638**	**30049614**	**272 039**

Source: EM-DAT, 2020

Table 1 and Figure 3 presents the compilation of the main documented climate-related disaster and their human impacts (EM-DAT, 2020) in Niger from 1900 to 2020.

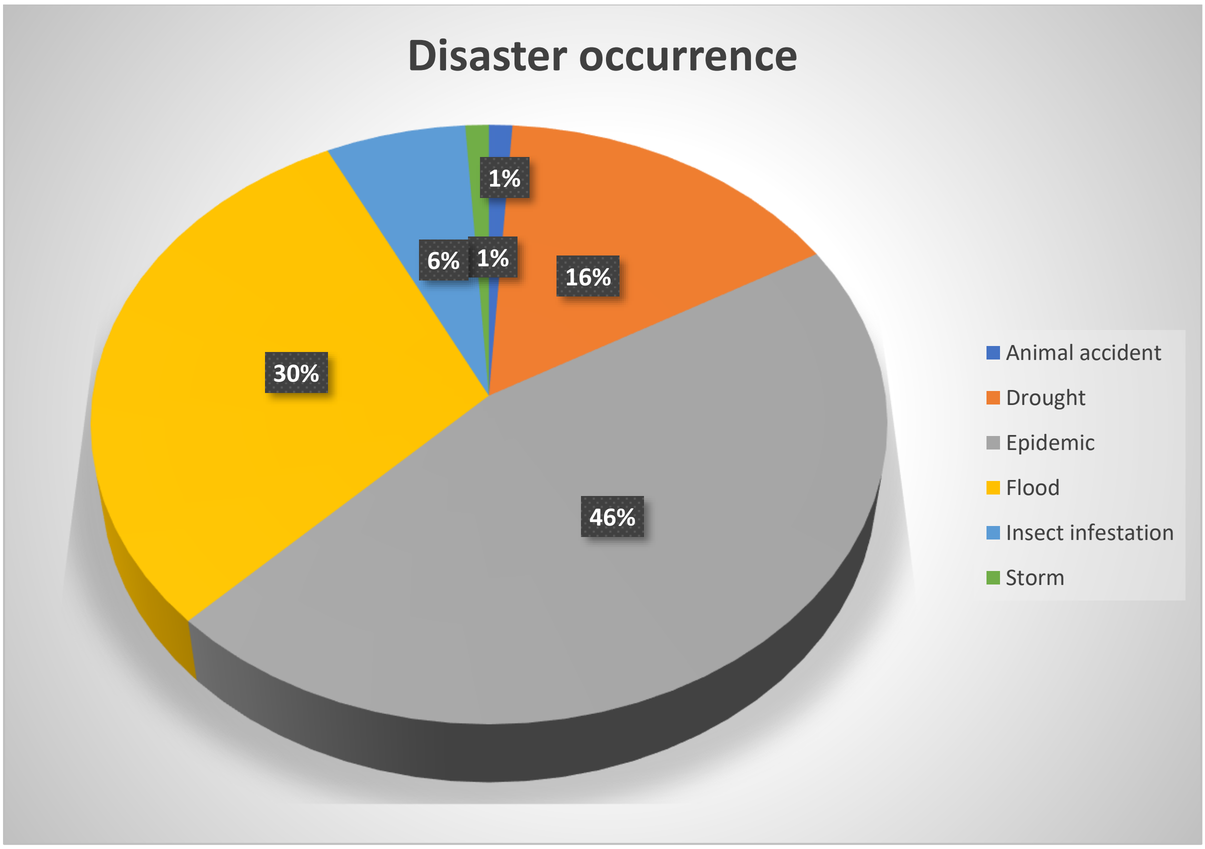

Figure 3: Disaster types occurrences

It has been recorded that between 1903 and 2011, droughts and floods had the greatest human impact (EM-DAT, 2020). Droughts are to blame for all climatic catastrophes that impact more than 1,000,000 people. The one in 2010 stands out especially because of the affected number of people nearly 7,900,000. Zinder and Maradi seemed to be the regions most impacted by these climate dangers, followed by Agadez. Take note that floods seem to occur more regularly in the Zinder and Maradi areas. The Sahelian and Sahelo-Saharan climate zones are shared by these two departments. However, the majority of their land is situated in the first, which is the region that receives the second-highest amount of precipitation (on average between 350 and 600 mm per year). Even while this information is intriguing and enables us to do a preliminary analysis, the truth remains that there is a dearth of information in Niger on economic harm that prevents us from fully appreciating the scope and significance of each of these incidents.

In Niger, the disasters to remember as causes of constant or periodic upheavals are:

- recurrent droughts;
- flooding / heavy rain;
- pests of crops (locusts, rodents, grain-eating birds, etc.);
- fires/bushfires, climate-sensitive diseases (measles, meningitis, cholera, etc.);
- animal epizootics (plague and peri-bovine pneumonia, avian flu, etc.);
- strong winds, sandstorms, and extreme temperatures.

However, we have to emphasize again that the two main climatic hazards that affect the country are droughts and floods (EM-DAT, 2009).

1.5 Concept of Flooding

Floods are natural occurrences where an area or land that is normally dry abruptly becomes submerged in water. In simple terms, a flood can be defined as an overflow of large quantities of water onto normally dry land. Flooding happens in many ways due to the overflow of streams, rivers, lakes or oceans or as a result of excessive rain. Whenever flooding takes place, there is the possibility of loss of life, hardship to people, and extensive property damage (Tazen *et al.*, 2019). This is because flooding can carry bridges, cars, houses, and even people. Flooding also destroys crops and can wipe away trees and other important structures on the land. Some floods occur abruptly and recede quickly whereas others take several days or even months to form and to recede because of variations in size, duration, and the area(s) affected (Fiorillo *et al.*, 2018; Shawul & Chakma, 2020).

Flood-prone areas and flooding hot spots are continuously being threatened by overbank flooding, especially during high flows (Oumarou Toure *et al.*, 2021). River bed and bank erosion also move hundreds of thousands of tons of sediments into the river channel and impede navigational activities during the dry season. These flood hot spot towns and villages suffer seriously from floods and may, over time, vanish from existence if protective measures are not taken up in the medium term. Floods are the most common natural disasters that affect societies globally (Dilley *et al.,* 2005). It is estimated that more than one-third of the world's land area is flood-prone affecting about 82% of the world's population(Dilley *et al*., 2005). Globally, about 196 million people in more than 90 countries are exposed to catastrophic flooding, and some 170,000 deaths or more were associated with flooding (Dilley *et al.*, 2005). These figures show that flooding is a major concern in many regions of the world. According to (Sa'adi *et al.*, 2019) floods are the most devastating natural disasters, claiming more lives and causing damage to properties than any other natural phenomena.

The intensification of flood risk is related to a combination of factors, such as recovering discharges which raise flood probability, rapid population growth rates and widespread poverty, which reduce coping capacity and resilience (D'haen *et al*., 2013; Fiorillo *et al*., 2018). Increasing river discharge is recognized as being due to two main drivers: climatic variations and land cover changes. Variability in climate, and especially in rainfall, plays a significant role in discharge variation.(Roudier *et al.*, 2014) , analyzed the impacts of climate change on runoff in West Africa and concluded that runoff changes are strictly linked to changes in rainfall. Recent scientific results suggest that the decades of abnormally dry conditions in the Sahel have been reversed by positive anomalies in rainfall. Moreover, researchers have reported a higher frequency of extreme events and a related higher proportion of the annual rainfall amount. (Aldhshan *et al.*, 2019; Mouhamed *et al*., 2013), stated that, during the 1960–2000 period, the cumulated rainfall of extremely wet days showed a positive trend in the West African Sahel and that extreme rain events had become more frequent during the last decade of the 20th century. Other studies reported an increase in both extreme rainfall events since the second half of the decade 2001–2010 and the proportion of annual heavy rainfall events. However, according to these authors, neither the number of events above certain thresholds nor the amount of rain falling during these events exceeded those observed during the 1950s and 1960s, before the drought period.

1.5.1 Types of Flood

Assessing flood risk requires a thorough understanding of the types of floods that might occur in a given location. There are several flood kinds, and each has its own characteristics in terms of dangers, occurrences, and repercussions (Eigege, 2014; Iliyasu, 2017). Several types of floods occur but based on the geomorphology of a location, the following are the frequent types of flooding identified according to:

- ✓ Pluvial (Surface) Flooding
- ✓ Riverine flooding
- ✓ Groundwater flooding (Ground failures)
- ✓ Coastal flooding

Surface water runoff commonly has an influence on pluvial, riverine floods, and ground collapse. When rain falls on the ground, the hydrological cycle which involves water entering the soil, evaporating, or flowing over the surface occurs concurrently (Harlan *et al*., 2019; Sophronides, 2016). The extent of each of these activities is greatly influenced by the ground cover, which may be made up of pavement (parking lots, roads), open space (grassland, agricultural fields, etc.), and built-up regions (residential areas, offices, and commercial places). Surface runoff occurs when the intensity of rainfall exceeds the soil's capacity for permeability and rate of evaporation, or when the ground cover is impermeable (WMO, 2013). The number of impervious surfaces rises while the amount of naturally occurring topography that can absorb rainfall declines as population density rises and more places get urbanised, which in turn causes an increase in floods associated with surface water runoff.

1.5.1.1 Pluvial (Surface) Flooding

The term "pluvial flooding" refers to flooding that does not include an overflowing body of water (Prinos, 2009). Urban drainage is the most prevalent kind of pluvial flooding.

Natural drainage systems exist in undeveloped areas, but as a region is developed, it becomes vital to discover methods to get rid of extra water that can't percolate into the earth because of impermeable surfaces (WMO, GWSP, 2015; Yadav & Sharma, 2023). Urban drainage is the concept of using a closed channel system to collect and get rid of extra surface runoff water after a rainstorm. According to this idea, the drainage system need to be able to contain and get rid of runoff regardless of how much rain falls or how long it lasts (Duong *et al.*, 2017).

1.5.1.2 Riverine Flooding

Riverine flooding occurs as a consequence of runoff water exceeding the capacity of channels, either natural or man-made, and overflowing into adjacent low-lying areas (Prinos, 2009). Riverine flooding dynamics vary with the terrain. Runoff in mountainous regions may occur minutes after heavy rainfall but in flat and low-lying areas, water may cover the land for days or weeks. There are two different types of riverine flooding and these are overbank flooding and flash flooding.

Overbank flooding: This occurs when the volume of water in a river or stream increases and exceeds its capacity and overflows onto adjacent floodplains due to surface water runoff after a heavy downpour, the spill of a dam, melting of snow or ice jams (Prinos *et al.*, 2008).

Flash flood: This is a fast and dangerous flow of high water into a usually dry area, or a swift rise in a stream or river above a predetermined flood level (Gruntfest & Handmer, 2001; Spitalar *et al.*, 2014). It is characterized by a high-velocity, intense gush of water that ensues in an existing river channel with little or no notice. Flash floods are more dangerous and destructive to life and property than overbank flooding because of the speed with which flooding occurs and the large amounts of debris carried with the flow (Gruntfest & Handmer, 2001).

1.5.1.3 Groundwater Flooding (Ground Failure)

The attack of certain floods comes from below ground. As the water table rises to the surface owing to extended periods of rainfall, it may wash away parts of the topsoil (Abdelkarim *et al*., 2019) This may create an array of ground failures which includes sinking soil (subsidence) and liquefaction; a process in which water-soaked silt loses stability and behaves like a liquid (Biswas & Bagade, 2022)Subsidence and liquefaction may lead to mud floods and mudflows. Mud flood suggests a flood in which the water delivers, roughly as much as fifty percent (50%) by volume, large masses of silt which may contain coarse debris (Burt *et. al*., 2002). Mudflow refers to a flood which is made up of mud and water: the make-up of the mud is a flowing mass of soft moist unconsolidated soil and fine-grained debris.

1.5.1.4 Coastal Flooding

Coastal flooding is caused by the combination of heavy storms or other extreme weather conditions together with high tides which causes sea levels to rise above normal and force seawater onto land (Jiménez *et al*., 2008). The causal agents for coastal flooding are storm surges and earthquakes. A storm surge is a rise in seawater above normal tide levels due mainly to low atmospheric pressure and wind action over a long expanse of open water. When there is a storm or hurricane, suction is created by the low pressure inside the eye of the storm and this creates a dome of water (Abdelkarim *et al.*, 2019). If the storm is near land, strong winds in the storm push the dome on to land as a surge. Underwater earthquakes, caused by the movement of tectonic plates, offset large extents of the ocean floor. The abrupt vertical shifts over such large extents displaces large amounts of water, generating long-range and destructive waves known as tsunamis (Biswas & Bagade, 2022).

1.5.2 Effects of flooding

Flooding affects every section of people, and systems in a city, some of them are summarised below:

1.5.2.1 Economic effects

- Damage to Public buildings, Public utility works, housing and household assets.
- Loss of earnings in industry and trade
- Loss of earnings to petty shopkeepers and workers
- Loss of employment to daily earners
- Loss of revenue due to Road, Railway Transportation Interruption
- High prices for essential commodities.

After flooding, the government has to put many resources for aid e.g., police force, fire control, aid workers and for restoration of flood-affected structures, persons, livestock etc. Flooding causes a great economic loss to the state, individual and the society

1.5.2.2 Environmental effects

Damage to surroundings, forests, ridges, wildlife, zoo, urban community trees, water bodies, shrubs, grass, fruits/vegetables in go downs etc results imbalance of the ecosystem of the city.

1.5.2.3 Effect on Traffic

Flooding results in the damage of roads, and the collapse of bridges causing traffic congestion which affect day-to-day life and other transportation system.

1.5.2.4 Effect on Human Beings

- **Human lives**: Every year floods in Niger cause lac people affected dead and become homeless.
- **Psychological impact**: People of all ages who are stranded in flooding suffer a great Psychological impact disturbing their whole lives and society as a whole.
- **Live Stock:** Livestock is the most affected living being due to urban floods. It is difficult to care for them particularly when human being itself is in trouble.
- **Disease**: Flooding usually brings infectious diseases, pneumonic plagues, dermatopathy, dysentery, common cold, Dengue, break bone fever, etc. Chances of

food poisoning also become more frequent when the electric supply is interrupted in food-storage areas due to flooding.

- **Public Inconveniences**: The flooding causes impairment of transport and communication systems due to which all people of all sections get stranded e.g. school children, college students, office goers, vegetable, milk vendors etc. The basic and essential commodities also do not reach the common person. This results in either starvation for poor persons or high prices to the common persons

1.5.3 Safety and Health Hazards

Floods pose a multitude of risks as they form, peak, and retreat. Throughout a flood, people are displaced at different points, the damage is done, and then the cleaning process may begin. The disruption of regular public services and the accumulation of debris and flood damage might endanger people's safety and health.

Health risks that floods bring with them and leave behind include animal carcasses, debris, and ponds that might operate as mosquito and bacterial breeding grounds. All flooded items that come into contact with people, including food, personal care products, medicines, stuffed animals, and baby toys, must be discarded. Dishes and clothes should be washed thoroughly.

Germs, mould, and mildew flourish in wet, humid areas. One health concern emerges when forced-air heating ducts are not properly cleaned after floods. When the furnace or air conditioner is turned on, the particles that are still in the ducts are circulated throughout the building and breathed by the occupants.

Floods, especially persistent flooding, are bad for people's mental health. Dealing with the loss of time, money, property, and sentimental goods like heirlooms causes stress. This is made worse by the weariness from the cleaning effort and the anxiety about financial loss, possible health risks, and the loss of priceless possessions. People of all ages may experience stress due to the disruption of their predictable routines, but youngsters and the elderly are disproportionately affected.

As they develop, crest, and recede, floods present several threats. People are displaced at various times throughout a flood, damage is done, and then the clean-up process may start. Normal public utilities being disrupted and the presence of flood damage and debris might pose a risk to people's safety and health.

Hazards occur when utilities are damaged. One cause of flood fatalities is electrocution, which occurs when a person drowns in an area that is carrying a live current that is produced when electrical components are short. Floods may also wreak havoc on stairways, floors and gas lines, leading to secondary concerns including gas leaks and unstable buildings. A boil order may be issued to safeguard humans and animals from tainted water if the water system loses pressure.

Additionally, Abubakar *et al*. (2020) cited Garg (2010), who noted that tangible losses caused by flooding are damages that can be measured in monetary terms. These losses include: loss of cattle and livestock, destruction of personal property, loss of earnings and services, loss of growing and pre-harvest crops in agricultural fields, decrease in property values, collapsing of bridges, buildings, roads, communication, infrastructures, destruction of schools, hospitals, loss incurable from loss of life, and loss incurable. (Dama *et al.*, 2014; Tiepolo *et al*., 2018) said that Floods have been identified to be caused by many factors including surcharges in water level due to natural or man-made construction on floodplains, sudden dam failure, inappropriate land use planning, mudflow, inadequate drainage capacity, ice jam, snowfall, and deforestation of catchment basins.

Globally, and in Niger in particular, widespread flooding progressively causes devastating ecological havoc by destroying lives, properties, agricultural lands and social infrastructures (Garba & Abdourahamane, 2023). Generally, the impacts of flooding are two types positive and negative effects. The negative impacts are categorized into two broad categories: these are the primary impacts and the secondary impacts and they are also known as tangible and intangible losses respectively (Hashizume, 2013).

1.5.4 Advantages of Flooding

Flooding has a variety of negative effects on habitation and economic activity. But flooding (especially the more frequent/smaller floods) can also provide many benefits. Benefits include replenishing groundwater, improving soil fertility, and supplying nutrients that the land lacks. Particularly in dry and semi-arid locations, where precipitation events can be highly unevenly distributed throughout the year, flood waters supply much-needed water resources. Freshwater floods in particular are crucial for maintaining biodiversity in floodplains as well as ecosystems in river corridors. Because of the substantial nutrient addition that flooding makes to lakes and rivers, fisheries are temporarily improved. This is also due to the floodplain's suitability as a spawning area (low predator activity and substantial nutrient addition).

Fish take advantage of floods to seek new habitats because they enjoy the weather. Birds benefit from the increase in productivity brought on by flooding in addition to fish. Ancient settlements along the Tigris-Euphrates Rivers, the Nile River, the Indus River, the Ganges, and the Yellow River, among others, depended on periodic flooding for their survival. In areas prone to flooding, hydrologically based renewable energy sources are more viable

1.5.5 Flood Mitigation

Given the devastating effects of floods on towns and individuals, including the loss of homes, farmlands, livestock, whole lifetimes of savings, and maybe even life, proper flood control is essential. A flood mitigation strategy must thus be created; a long-term solution to flooding is required since it would, in some ways, benefit the economy and the personal development of people.

In Niamey, people near River Niger Basin could implement the following mitigation measures proposed by (Abubakar *et al*., 2020) :

i) Drainage System: Drainages are important systems for preventing flooding in a community, especially in metropolitan areas. For water to flow freely during heavy rains, drainage systems need to be properly maintained and upgraded. It is advisable to expand smaller drainages to collect water so that they won't overflow after heavy rains. When debris and sediment have blocked a drainage system due to dumping, these wastes need to be removed and properly disposed of.

ii. River dredging: This method of preventing floods is very crucial. In order to keep the water coming from other streams, retain the water from heavy rains, and yet be prepared to take water from the unexpected, likely release of water from the dam. The most important method of preventing rivers from overflowing their banks is dredging.

Construction is another way to prevent the River from exceeding its banks, according to the option

iii. Construction: The river will still need to be widened to a standard width and dammed to a depth that will allow massive ships to float across the river. By doing this, the river will be able to accept water from tributaries, channel heavy rains, and receive water released from dams, among other things. In order to prevent further coastal erosion, river margins will be built. Additionally, it will boost a region's economy by luring large businesses and fostering commercialization, which creates jobs.

iv. Planned Settlement: Another method for preventing flooding in a neighbourhood is community planning. A water channel has some structures visible along it, indicating that either an artificial alternative was created or that the water created another course for itself, which might cause flooding. As a result, careful community planning is essential. In order to ensure that businesses and housing projects are seen by the desired pattern, ministries like the "Urban and Regional Planning Development Authorities" were established.

1.6 Flood Events in Niamey from 1998 to 2020

1.6.1 Flood 1998 2020

The Niamey region is severely impacted by the Niger River's overflow, which is rising to progressively high levels and flooding populated and agricultural regions regularly, displacing thousands of people. River floods are not the only hydrological concern in Niamey, however; flash floods also occur often, mostly because drainage systems are inadequate and are not maintained.

Table 2: Serious flood events in Niamey Region 1998-2020 **-**

Years	Type	People affected
1998	river	27,135
2010	river	17,624
2012	river	45,464
2013	river	65,037
2017	rained	49,294
2019	river	6,310
2020	river	119,809

Source (Tarchiani *et al*., 2021)

Due to their construction in flood-prone locations, some Niamey neighbourhoods are severely impacted. Although the right bank, which has been urbanised since the 1970s, is situated on alluvial deposits and consequently more susceptible, the left bank is often not prone to floods. On the right bank, Commune 5 was partially constructed amid the eddies of a river bed that regularly reactivates during floods.

Figure 4. CRA Agrhymet flooded in 2020 (Sources: Agrhymet, 2020)

Flood zones on the right bank affect the Zarmagandey-Karadjé-Saguia continuity, the Abdou Moumouni University, and the Lamordé neighbourhood. The areas of Goudel upstream and Saga downstream, which are situated on alluvial deposits, are especially vulnerable to floods on the left bank.

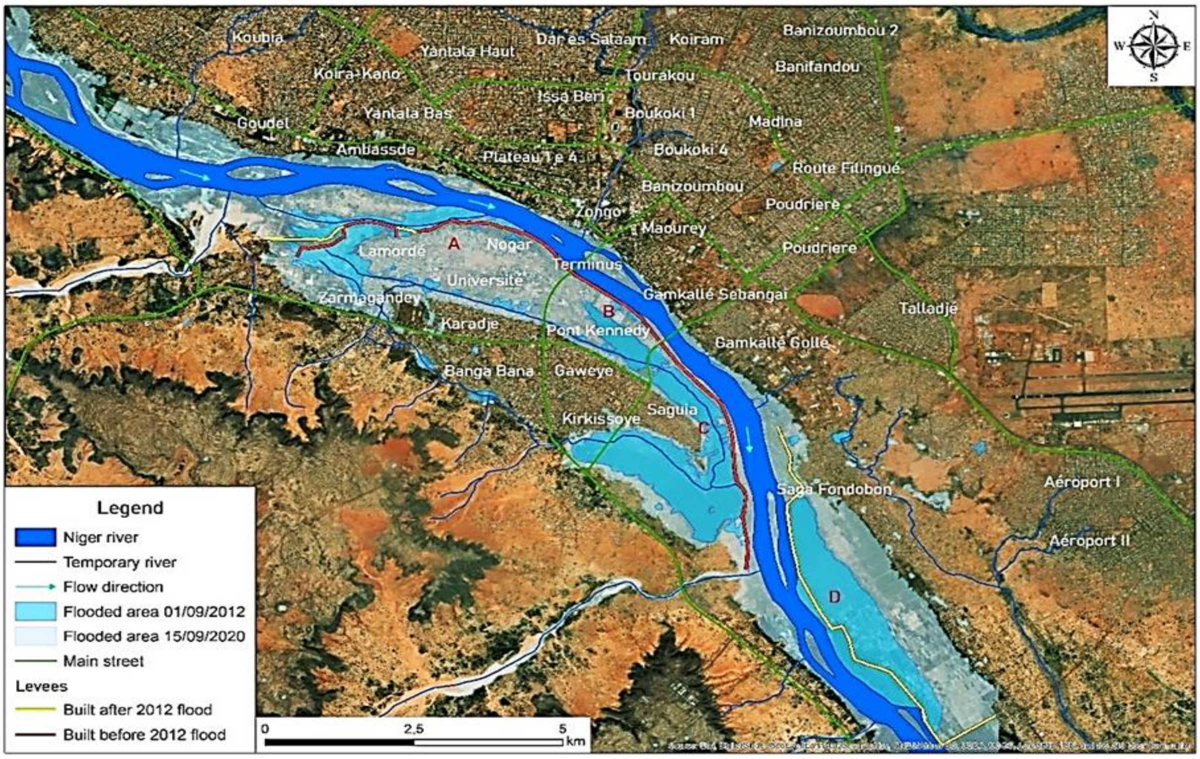

Figure 5: Comparison of Niamey flooded areas in 2012 and event 2020
Source (Massazza, Bacci, *et al.*, 2021)

Note: The red letters in Figure 4 identify the four levee sectors: (**A**) Lamordé, (**B**) bridges, (**C**) Kirkissoye-Saguia and (**D**) Saga

1.6.2 Flood of 2012 in Niamey

Several city citizens were impacted by the 2012 flood. The National System for the Prevention and Management of Disasters and Food Crises (DNPGCCA) reported that seven persons perished as a result of the floods in 2010. The DNPGCCA also reported that many more residents perished as a result of the floods in 2012. Compared to 14,908 in 2010 and 32,613 in 2013, over 45,500 persons were afflicted in 2012. Significant home damage was also caused by this catastrophe due to its size (see Figure 11). Compared to 839 homes destroyed in 2010 and 4196 homes destroyed in 2013, 8712 homes were destroyed in 2012. Thus, the populace was moved to evacuation centres or relatives' homes in various areas of the city as a result of this occurrence that caused the collapse of numerous homes in the inundated districts.

The Niger River's many dispersed tributaries throughout its basins and slopes were first damaged by floods. The 2012 flood was brought on by an abrupt downpour of very high intensity – in August, Niamey had a daily maximum of 119 mm, which was followed by a top of 78 mm upstream from Tillabéri. Still upstream, 200 mm of rain occurred on the Sirba and Gorouol basin slopes (Sighomnou *et al*., 2013). In contrast to prior years, the increase in water levels has also been unusually quick, as we went from an instantaneous flow of 1000 to 2492 m^3/s^{-1} in a week. If the water flow in Niamey's Niger River was 2120 m^3/s in September 2010 (corresponding to a height of 566 cm), it was 2492 m^3/s in August 2012 and 2472 m^3/s in August 2013 (corresponding to a height of 616 cm). The plain areas were fully flooded by this storm, with some locations receiving more than one metre of water (see Figure 10). The return duration of this rare occurrence is projected to be 125 years based on a statistical study of the chronicle of maximum flows from the Niamey station (Sighomnou *et al.*, 2013).

The 2012 flood affected Niamey and other parts of the Republic of Niger. Heavy rains and the overflow of the Niger River and its tributaries caused major flooding in the city. This Flood cause the flooding of 400 hectares, according to the government, including 40 hectares in the capital Niamey. “We will be inundated” as of December 5, Niamey governor Aichatou Kane Boulama told a press briefing Figure 6.

Figure 6 Irrigated Agricultural land and Garden flooded, 2012 sources https://www.caritas.org/2012/12/niger-on-high-alert-from-floods/

. The floods displaced thousands of people and destroyed homes and infrastructure. Agricultural land was also submerged, leading to crop losses and food security problems. The government, in collaboration with national and international partners, has put in place emergency response measures to assist affected communities, including shelter, food and health care (figure 7).

Figure 7; Homes collapse after 2020 Flood in Saga, ***Floods in Niger, July 2021. Photo: UNOCHA Niger*** **Niameyhttps://floodlist.com/africa/niger-flash-floods-niamey**

The torrent rapidly surpassed the level of the 2012 floods, which had led to the fortification of the compound and a new berm constructed around the school (figure 8)

Figure 8 a school flooded in 2012 Source (https://www.bbc.com/news/world-africa-41081108)

1.6.3 Flood of 2020 in Niamey

Following a plentiful rainy season in 2020, the Niger River in Niamey reached its all-time greatest levels. On the other hand, Niamey has seen an increase in floods during the last ten years, which is a sign of a shift in hydroclimatic behavior that has been noticed since the end of the severe droughts of the 1970s and 1980s and is known as the Sahelian Paradox.

The Niger River has surpassed the red alert threshold on August 12, 2020. The authorities attempted to strengthen and elevate the protective dikes in response to the warnings issued by the Department of Hydrology in July and well earlier about the seasonal predictions, which had often held for many days. Due to the significant rainfall that occurred in the upstream sub-basins during the preceding several days, a fresh increase in water levels was seen starting on Saturday, August 22. The Niger River flood pressure caused the dikes to start giving way and collapsing in a few locations on August 23, 2020, at a height of 659 cm. The lower-lying right-bank neighborhoods were the first to experience flooding. Water from Harobanda (right bank) poured onto the tarmac and moved towards the Total station, passing the entirely submerged AGRHYMET Regional Center. In order to control the water, an earthen dike was quickly built at the edge of the parking lot in front of Abdou Moumouni University. In Niger, the rice fields below the Kennedy Rice Bridge were entirely submerged. Numerous roadways close to the river have been shut off. Following the rains that fell in Niamey and in the sub-basins upstream, the Niger River hit a new height at 7 a.m. on September 6 at 680 cm, which had never been attained before. The elevated Lamordé dike ultimately gave way, fully flooding the districts of Lamordé, Zamargandey, Karadjé, and the low spots along the right bank of the river, in addition to Gamkalley and Saga on the left side. The inhabitants of the flooded areas fled. The Lamordé Hospital (CHU) and the EMIG (School of Mines, Industries and Geology) were also submerged (Moumouni, 2020).

Figure 9 : Flooded Road near Agrhymet 24 August 2020

According to (Moumouni, 2020), the Red Flood of 2020 registered the highest water level ever reached at 701 cm (8 September at 7 a.m.) since the installation of the Niamey gauging station in 1929. The flood of paddy fields and suburban neighborhoods had begun three weeks before, but it was only on September 6th that largely built areas in Municipality 5 of Niamey, as well as the districts of Gamkalley and Saga on the left bank, were flooded due to the breach in the Lamordé levee (Figure 10). At that point, the flood wave reached a plateau and a slow decline began (Figure 10). Diachronic NDFI mapping of flooded areas shows that several tens of hectares of built neighborhoods remained flooded for almost one month even after the river level had declined below the red alert threshold (620 cm), because levees, obstacles and low areas prevented water from returning to the river bed(Moumouni, 2020).

Figure 10 : Niamey's Niger River on September 7, 2020 the right bank's Lamordé area and levee as seen from an overhead perspective looking downstream.

(Source : Direction Générale de la Protection Civile du Niger,2020).

The City's 21.78 km flood prevention system has four sectors:
A. Lamordé (6.87 km): right bank upstream of the Kennedy bridge for the protection of residential areas (Lamordé, Nogar, Zarmagondé, Karadjé, and Université districts);
B. Bridges (1.96 km): right bank between the Kennedy and Chinese bridges for the protection of residential areas (AGRHYMET area);
C. Kirkissoye-Saguia (4.72 km): right bank downstream of the Chinese bridge for the protection of residential areas.

The flood of 2020 was another major event in Niamey. It was triggered by heavy rains that caused rivers to burst their banks, resulting in major floods in the city. Many neighborhoods were submerged, displacing thousands of residents. Numerous infrastructures, including roads, schools, and health facilities were severely damaged. The floods also disrupted the transportation system and access to basic services. According to (CARE, 2020) NIAMEY, 14 September 2020, severe floods caused by torrential rain in Niger have caused death and destruction of properties across the country, affecting 432,613 people and leaving them in need of shelter, water, food, and essential items.

1.7 Review of Related Literature

(Bello and Ogedegbe, 2015), uses a time series of (2002, 2003 and 2004 and 2010) satellite images to evaluate the water coverage, level and dynamics around their study area, Geospatial Analysis of Flood Problems in Jimeta Riverine Community of Adamawa State, Nigeria Innocent. The water level was determined by differentiating the high (deep) areas from the low (shallow or silted) areas and the 3D terrain visualization of vulnerable areas was carried out using ArcScene. The study confirms that the major cause of the flood in Jimeta is not just rainfall but dam failure and silted waterways and that the water spatial coverage and extent have been on the decrease since 2002 resulting in the siltation of parts of the river. Using GIS analysis, the multiple buffering proximity analysis carried out shows that based on 0-50m buffer; fewer people were more vulnerable than when a buffer of 50-100m was applied. This study also shows that most part of the river has been silted (sand-filled: shallow) thus responsible for the inward flow of water that ultimately flooded the neighbourhood.

(Isma & Saanyol, 2013) in their study Application of Remote Sensing (RS) and Geographic Information Systems (GIS) in flood vulnerability mapping: Case study of River Kaduna This work creates a flood map of the Middle Course of the River Kaduna using remote sensing and GIS methods. To pinpoint flood-prone locations along the river's Middle Course, a Digital Elevation Model was created using high-resolution images and ArcGIS. Using a flow accumulation model and an equal interval of separation depending on elevation, the DEM was classed into high-risk, moderate-risk, and low-risk zones. A vulnerability map of the region was created by overlaying this on the local map. In order to identify places at danger of flooding, the research also interviewed a sample of local inhabitants in several of these locations. We found that a flood map may be utilised efficiently for flood risk management, disaster response planning, and public education.

(Haq *et al.,* 2012), used MODIS images and a standard supervised maximum likelihood classification "for flood monitoring and damage assessment A case study of Sindh province, Pakistan". The topographic maps of the area were intersected with accumulated inundated area in order to extract different types of information layers for damage assessment. In this regard, cumulative and temporal flood extent maps were prepared. It was found that severe flood occurred in Badin and inundated it by 3820.39km^2, Mirpurkhas by 1836.26km^2, Jacobabad by 1352.32km^2, Shahdadkot by 1597.50km^2, Dadu by 1887.57km^2 and Sanghar by 2494.18 km^2, in cumulative. Furthermore, the above-mentioned districts contributed 61% of the total inundated area among 23 districts in Sindh. The study identified that the flood was mostly because of rainfall and observed the highest ever recorded monsoon rain in Sindh starting from Aug 11, 2011 to Sept 14, 2011.

(Udo. *et al*., 2015) in their study, the spatial locations of some flooded communities were also acquired with the use of Garmin 72 GPS, an administrative map from where political boundaries and roads were digitized, and population data from the Nigerian Population Commission was gathered. This study considered DEM (Digital Elevation Model), flow accumulation, slope map, population density, land use and proximity to the river as the parameters used to generate a flood risk map of the study area because the study employs the use Analytical Hierarchical Process (AHP) method. Population vulnerability analysis was also conducted. The results show that flow direction and negative slope direction are towards the River Niger and Anambra River Basins thereby exposing these areas vulnerable to higher risk of flood. They further concluded, that flood risk mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily read, rapidly accessible charts and maps that can facilitate administrators and planners to identify areas at risk and prioritize their mitigation and response efforts.

1.8 Factors of risk

In disasters, there are three broad areas of risk: the hazard that can cause damage, exposure to the hazard and the vulnerability of the exposed population (figure 11)

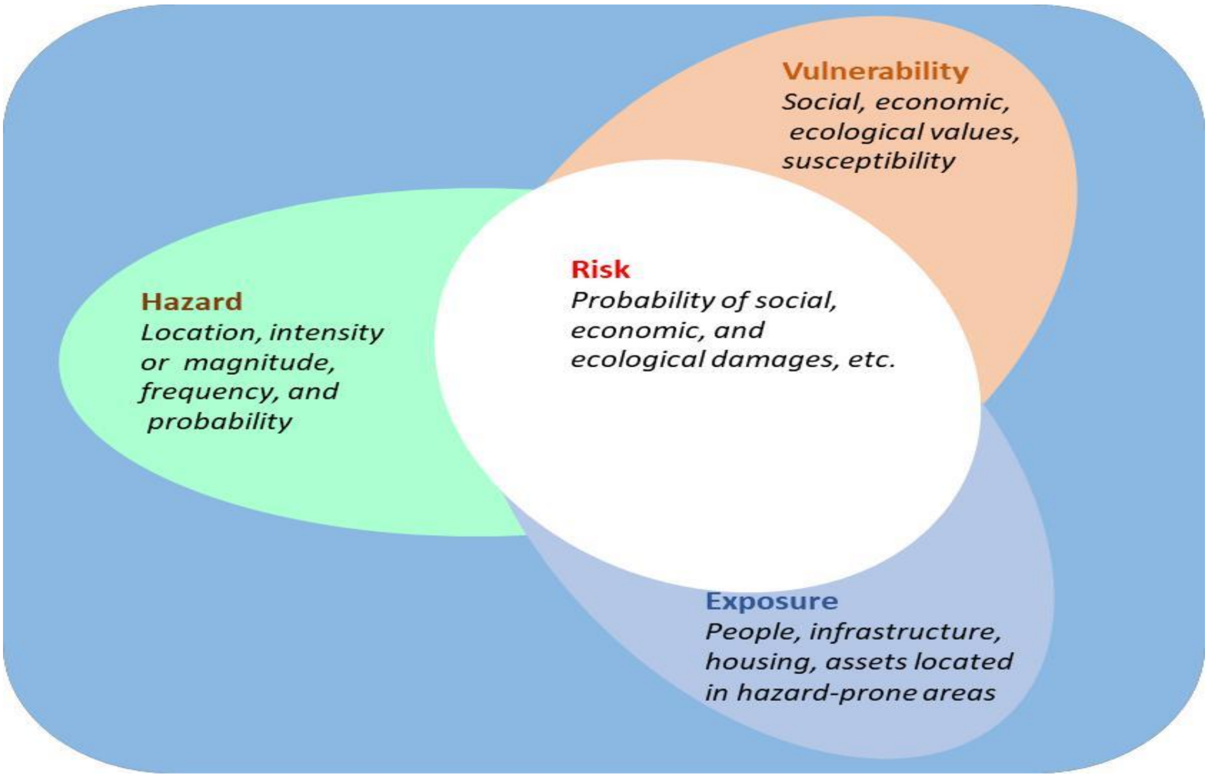

Figure 11 Conceptual framework of risks and the linkage between hazard, exposure and vulnerability (Source: UNISDR, 2009).

1.8.1 Hazard

A hazard stands for a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (UNISDR, 2009). It can occur with different probabilities and magnitudes. For example, an infrastructure located in a floodplain may be damaged by a 10-year flood and 0.5 m water level as well as by a 50-year flood and 1.5 m water level. At some times, hazard was ascribed the same meaning as risk, but it is now widely accepted that it is a component of risk and not risk itself (Cardona *et al*., 2012b; Echendu, 2020). Floods, earthquakes, and volcanic eruptions are some examples of natural hazards.

1.8.2 Vulnerability

In relation to hazard, vulnerability is broadly defined as the “potential for loss”(Pe’er & Safriel, 2016) or the “capacity to suffer harm and react adversely” (Kates, 1985). Depending on the research application, the term vulnerability has many definitions. For example, (Tomety, 2017) defined vulnerability as the likelihood that an individual or group will be exposed to and adversely affected by a hazard, whereas Alexander (1993) defined vulnerability as a function of the costs and benefits of inhabiting areas at risk from natural disasters. In some cases, vulnerability is defined as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of natural hazards (Pörtner *et al.*, 2022), and in others in terms of exposure, capacity and potentiality (Lee & Choi, 2018). According to the latter definition, measures to reduce vulnerability should reduce exposure, enhance coping capacity and minimize damaging consequences (Pörtner *et al.*, 2022).

Also, vulnerability is defined as the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. Vulnerability to flood is considered as a combination of different types of vulnerabilities such as social, physical, economic and environmental (Vojtek & Vojteková, 2016). Social vulnerability focuses on the population, particularly the reaction, response and resistance of people to a flood event. Among the various characteristics which impact social vulnerability to environmental hazards, there are age, gender, education as well as densities, whether the population is rural or urban; livelihoods, family structure, access to medical services, access to information, institutional capacity, etc. (Cutter *et al*., 2003). Physical vulnerability refers mainly to the type of house unit and the density of the population. People who are living in flood-prone areas with unplanned and weak houses are considered at higher flood risk than those who are living in formal settlements. In addition, when people are concentrated in a limited area, a flood hazard will have a greater impact than if people are dispersed (Bollin & et al., 2015; Wanninayake *et al.*, 2023). Economic vulnerability stands for the susceptibility of an economic system, including public and private sectors, to potential disaster damage and loss(Pe'er & Safriel, 2016) and refers to the inability of affected individuals, communities, businesses, and governments to absorb the damage. Besides, (Cardona *et al*., 2012a) note that economic vulnerability to natural hazards has been inexactly defined in the literature and conceptualizations often have overlapped with risk, resilience or exposure. Environmental vulnerability includes environmental conditions and environmental degradation. For instance, the presence of forests increases the infiltration rate of the soil and reduces the overland flow which contributes to a reduced flood. Environmental degradation increases the intensity of natural hazards and is often the factor that transforms the hazard into a disaster (Birkmann *et al.*, 2022).

1.8.3 Exposure and coping capacity

Exposure describes the people, the value of infrastructures and economic activities that will experience a natural hazard and may be adversely impacted by it (Bollin *et al*., 2015). Broadly, exposure refers to an inventory of elements in an area where a hazard event may occur (Wu et al., 2020). It is worth noting that the literature mistakenly combines exposure and vulnerability but they are distinct because it is possible to be exposed to a hazard but not vulnerable (Cardona *et al.*, 2012b). For instance, one can live in a floodplain and has sufficient means to modify building structure and behavior to reduce potential damages.

Coping capacity is defined as the "ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies, or disasters" (UNISDR, 2009). The strengthening of coping capacities usually builds resilience (the capacity of exposed systems or communities to adapt by resisting) to withstand the effects of natural and human-induced hazards (Wanninayake *et al*., 2023). It is worth mentioning that the relationship between coping capacity and vulnerability is described in the literature by two schools of thought (T. Brooks, 2013; Lee & Choi, 2018; Olayinka-Dosunmu *et al*., 2022; Pörtner *et al.,* 2022): the first considers vulnerability as the lack of coping capacity while the second considers vulnerability and coping capacity as opposite so that increasing coping capacity leads to a reduced vulnerability and high vulnerability means low capacity.

1.9 Concept of resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. (Rohland & García-Acosta, 2020).The concept of resilience Depending on the degree of risk exposure, many adaptation strategies are proposed by researchers. (Thomas-maret *et al.*, 2012) in research within the scope of the Hyogo framework for action (2005-2015) whose fundamental goal is to know the vulnerability and to establish the resilience of communities in the face of disasters by a considerable reduction of losses due to disasters by 2015, insist on the need to adopt more particularly a "prevention, adaptation, resilience building" type approach, as opposed to an "emergency management and reaction" type approach . According to (Beucher, 2008) the attacks of July 7, 2005, and the floods of 2007 in London contributed to increasing reflection on the improvement of crisis management plans. Hence, resilience mechanisms are needed for all types of crises. Many researchers(Alou, 2018; Bechler-Carmaux *et al.*, 2000; Garba & Abdourahamane, 2023; Issaka, 2010; Issaka & Badariotti, 2013) were interested in the situation that Niamey have been facing for several years on the risk of flooding. Most of these researchers insisted on the delimitation of risk areas and risk vulnerability factors but did not emphasize the resilience of populations to this phenomenon.

The Sendai Framework for Disaster Risk Reduction (2015-2030) building the Resilience of Nations and Communities to Disasters, also outlines the need for better comprehension of disaster risk in all of its manifestations of exposure, vulnerability, and hazard characteristics; the need to strengthen disaster risk governance, including national platforms; accountability for disaster risk management; the need to "Build Back Better"; recognition of stakeholders and their roles; and the need to mobilize risk-sensitive investment to prevent new risks.

1.10 Some Flood Risk Assessment Techniques

(Ologunorisa, 2004) undertook an assessment of flood risk in the Niger Delta region in Nigeria using hydrological parameters and some measurable physical characteristics of floods including depths, duration, perceived frequency of occurrence, relief/elevation, proximity to water bodies and perceived extent of flood damage. Three flood risk zones resulted from his analysis: Severe flood risk zone, moderate flood risk zone and low flood risk zone.

From the examined methodologies, it is evident that flood risk assessment entails the use of hydro-metrological and geological characteristics to establish the circumstances that contribute to flood occurrences and also identify the hazards connected with the recurring event.
This research also employs hydro-metrological factors like rainfall data, water level and discharge data in the evaluation of the causes, nature and dangers associated with flood catastrophes in the studied region.

1.10.1 ANCOLD Flood Risk Assessment Model

For the purpose of identifying and estimating flood hazards, the Australian National Committee on Large Dams (ANCOLD, 2003) provides a methodological framework. This model's estimate of flood risk is based on the following criteria (figure 12):

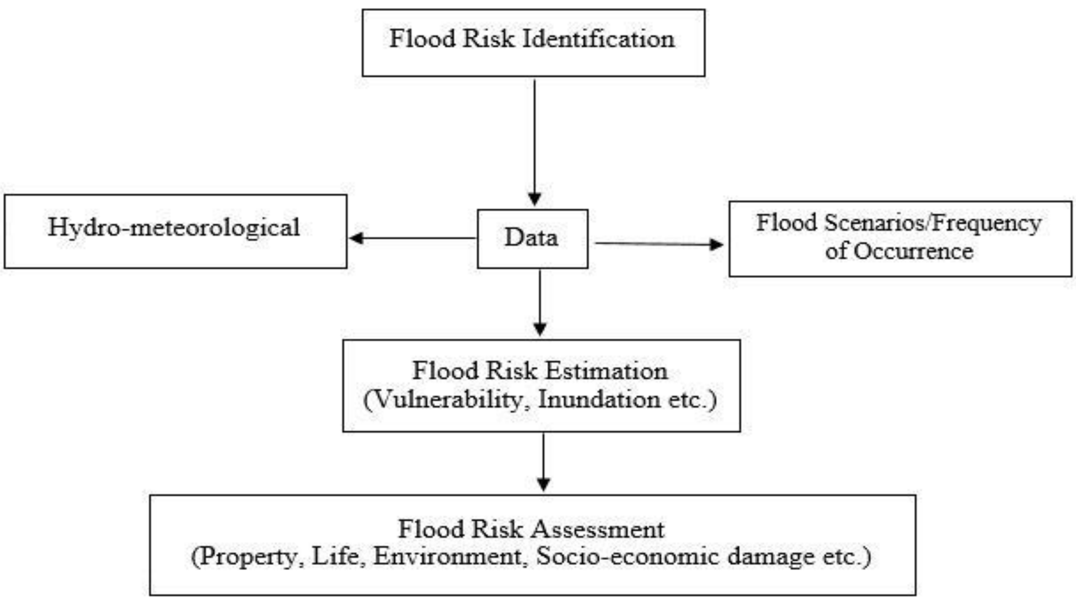

Figure 12: Flood Risk Assessment Model (ANCOLD, 2003)

Model Specification

a. **Flood Risk Identification:** This involve the identification of hazard source considering hydrological and meteorological data, flood scenarios, frequency of occurrence, damage assessment of the inundated areas etc. to determine whether there may be any flooding event and its anticipated consequences.

b. **Flood Risk Estimation:** This involves the probabilistic quantification/qualification of annualized flood risk. It involves the estimation of the flood risk occurrence, actual consequences and vulnerability estimation based on the probability theory.

c. **Flood Risk Assessment:** Flood risk assessment is the process by which hydrologists estimate the likelihood that flood will inundate an area so as to provide a guide on low and high-risk areas based on the level of tolerance. The flood risk assessment helps to identify what risk can be tolerated and what risk reduction measures will be applied.

1.10.2 Digital Elevation Model (DEM)

Geographic Information Systems (GIS)-obtained remote sensing data is fast gaining popularity and finding extensive use in the study of geography, cartography, hydrology, climatology, geology, etc. Digital elevation models (DEMs) may be produced using photogrammetry, remote sensing data, or topographic maps (Balasubramanian, 2017; Shingare & Kale, 2013).

Geographical raster representations of terrain elevations arranged in a sequence of south-north profile coordinates are known as digital elevation models (DEMs). The manipulations and terrain analysis of a region often make use of the terrain elevations, which are sampled at regularly spaced horizontal intervals. A vital tool for analyzing many disciplines, including geology, hydrology, geography, climatology, meteorology, etc., is the digital elevation model (DEM)(Emmanuel & Eyoh, 2017). The Digital Elevation Model (DEM), a crucial GIS tool, offers the chance to simulate, evaluate, examine, digitise, show, and illustrate physical phenomena including topography, relief, vegetation, drainage, and hydrology, among others (Suma, 2014).

Three different structures may be used to store and retrieve Digital Elevation Model (DEM) data for processing and analysis. These structures are:

a. Grid Based Network (GBN)

b. Triangular Irregular Network (TIN)

c. Contour Based Network (CBN)

The kind of structure chosen mostly relies on the data's accessibility, the surface's characteristics, size, and data resolution, as well as the method to be used for data processing and analysis.

However, the most widely used digital elevation model (DEM) data in flood disaster studies structure is the grid-based network (GBN) due to its availability, flexibility and computational efficiency. (Shingare & Kale, 2013).

1.11 Institutional Arrangements for Disaster Management in Niger

The responsibility for Natural Disaster Risk Reduction has been assigned to the Prime Minister's Office, ensuring that this issue remains a top priority for the government. Various structures directly affiliated with the Prime Minister's Office have been established to contribute to risk reduction, disaster preparedness, and management.

Given the concerning frequency of droughts in Niger since the 1980s, consultation structures and frameworks have been established to address various food crisis situations. The initiative to create an Early Warning System (EWS) in Niger was first introduced in 1988 during a national round table on rural development. The System for the Prevention and Management of Food Crises (SAP) was officially established within the Prime Minister's Office on August 23, 1989, through Decree No. 89/003/PM. This decree was subsequently amended on May 31, 1995 (Decree No. 95/081/PM) to include a component focused on disaster management.

In response to the increasingly recurrent crises, the Nigerien government, with the support of its primary development partners, established the National Device for the Prevention and Management of Food Crises (DNPGCCA) in 1998 (figure 13). A Statement of Conclusions, initially signed in 1998 and later amended in 1999, served as the framework for the operation of this new system. It aimed to foster coordination and collaborative management of intervention mechanisms between Niger and its partner organizations.

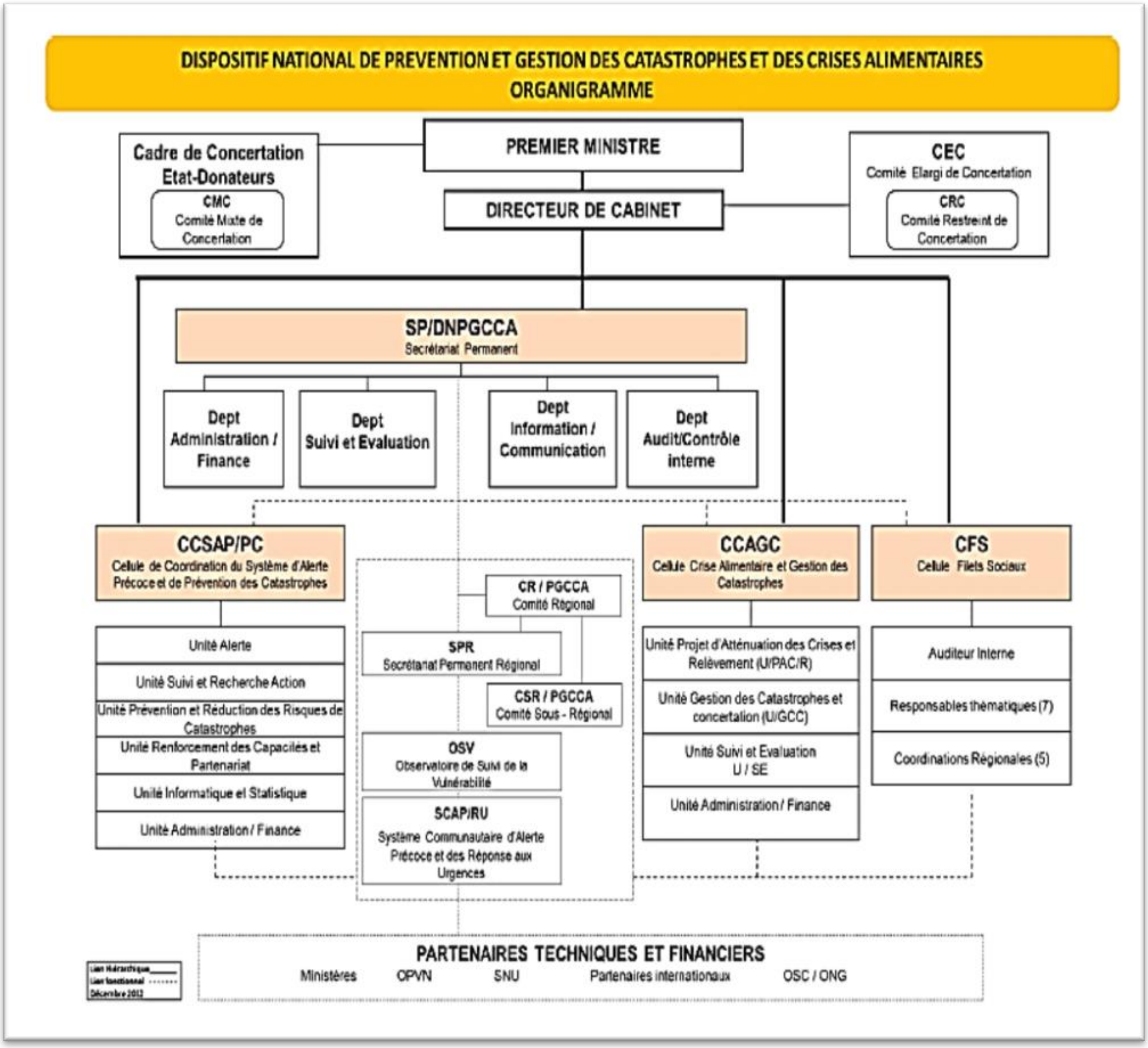

Figure 13: Framework chart of the disaster Management organ of Niger

In 2005, the System was fortified with the signing of the Framework Agreement, which superseded the Statement of Conclusions. This expansion also welcomed new partner organizations, increasing the total to 12 by September 2007. These partners collaborated closely with the government to address prevention and management of food crises.

More recently, in 2015, the system underwent further transformations, broadening its mandate to encompass disaster prevention and management. This led to its present-day structure. The primary mission of this Mechanism is to contribute to the reduction of vulnerability among Niger's population by enhancing coordination and management of actions carried out by various stakeholders. This involves implementing strategies for preventing food crises, empowering communities to protect themselves from crises, establishing measures to respond to disaster crises, and enhancing the coherence and efficiency of the public response to food crises.

1.11.1 The structure for decision-making, coordination and supervision

The Government/Donor Partnership Framework, known as the Mixed Consultative Commission (CMC), plays a pivotal role in aligning efforts between the Nigerien State and the primary signatories of the Framework Agreement, along with other donor organizations. This collaborative framework aims to ensure coherence across various levels of intervention.

The CMC convenes semi-annually and comprises a technical entity, the Restricted Consultation Committee (CRC), and the Expanded Consultative Committee (CEC), which convene bi-monthly. These two committees work collaboratively to evaluate intervention strategies, ensure consistency, and assess financial requirements. Additionally, they monitor the progress of field operations and are responsible for approving and validating operational budgets for the utilization of shared funds. They also evaluate the financial performance of ongoing operations.

1.11.2 Operational Technical Structures

1.11.2.1 The Permanent Secretariat of the DNPGCCA (SP / DNPGCCA)

To enhance the efficiency of the DNPGCCA, the permanent secretariat of the DNPGCCA has been reactivated with a specific mandate. This reactivation aims to streamline the coordination of the system and promote improvements through its four (4) departments:

i) Administrative and Financial Management,

ii) Internal Control to ensure adherence to established procedures, both by the State and donors, and to identify potential risk factors,

iii) Monitoring and Evaluation System, responsible for assessing the effects and impacts of actions and compiling comprehensive reports on the system's interventions,

iv) Information, Communication, and Advocacy.

The overarching objective is to fortify the existing mechanisms, enabling the DNPGCCA to operate with greater efficiency while adhering to the directives set forth by the CMC. Furthermore, there is an aspiration to expand its mandate to encompass the risks associated with increasingly frequent disasters. This expansion seeks to establish synergy with technical ministries along the emergency-development continuum and explore avenues for integrating ad hoc committees (INS, 2016).

1.11.2.2 Ministry of Humanitarian Action and Disaster Management

The Ministry of Humanitarian Action and Disaster Management in Niger holds the responsibility of formulating, executing, and upholding the state's policies pertaining to humanitarian aid and the management of natural disasters. Its primary aim is to enhance the resilience of the population in the face of food shortages and natural calamities.

In alignment with the government's directives, the Ministry of Humanitarian Action and Disaster Management continually updates the DPPD (Disaster Prevention and Preparedness Plan) for the 2023–2025 period. Additionally, to ensure the effective execution of this DPPD, the current Project Annual Performance (PAP) for the year 2023 has been established. This PAP serves as the cornerstone for crafting the state's annual budget for 2023 and the LOLF 2023, thereby consolidating the execution of the government's budget program. The overarching objective of PAP 2023 is to bolster resource mobilization for the successful implementation of the Ministry's planned activities.

1.11.2.3 The Coordination Unit of the Early Warning and Disaster Prevention System (CC / SAP / PC)

The CC / SAP / PC (Coordination and Communication Support for the Food Crises Prevention and Management Mechanism) serves as the information hub of the system. It consists of six (6) operational units, each with specific responsibilities. These units are tasked with generating, gathering, processing, analyzing, and disseminating information related to food security and disaster risk. They also play a crucial role in identifying areas at risk and proposing measures for the prevention or mitigation of food and nutrition crises. Additionally, the CC / SAP / PC is responsible for evaluating the outcomes of initiatives conducted by the Food Crises Unit.

To carry out its functions effectively, the CC / SAP / PC collaborates with regional and sub-regional committees dedicated to food crisis prevention and management. Furthermore, it operates in coordination with an interdisciplinary working group (GTI / SAP / PC), which comprises senior officials from relevant ministries and technical services involved in information provision. This collaborative effort encompasses various information systems, including the Regional Center Agrhymet, Fews-Net, SIM cattle, SIM agricultural, SNIS, and more.

1.11.2.4 Humanitarian Coordination Unit.

The humanitarian coordination cell, established in August 2012 within the Office of the Prime Minister and subsequently integrated into the DNPGCCA in 2013, plays a vital role in coordinating and monitoring prevention, rescue, and assistance efforts for various categories of people affected by disasters and crises. These include victims of floods, fires, armed conflicts, inter-community violence, industrial disasters, as well as displaced persons, returnees, and refugees.

Specifically, the humanitarian coordination cell is responsible for the following:

- Collecting comprehensive information related to floods, fires, the consequences of armed conflicts and inter-community violence, industrial disasters, and the situations of displaced persons, returnees, and refugees.
- Ensuring a cross-cutting approach to humanitarian interventions to promote harmonious and effective crisis response. This involves identifying gaps in intervention during crisis management.
- Proposing coordinated responses and action plans to address the needs of individuals affected by floods, fires, armed conflicts, inter-community violence, industrial disasters, as well as displaced persons, returnees, and refugees.
- Monitoring the activities conducted by humanitarian organizations and actors in support of victims of floods, fires, armed conflicts, inter-community violence, industrial disasters, and displaced persons.
- Participating in the development of contingency plans and integrated action plans.
- Contributing to the formulation of the national humanitarian policy and its associated action plan.
- Engaging in active advocacy efforts with bilateral and multilateral actors to encourage the incorporation or strengthening of humanitarian considerations in their policies and actions.
- Preparing programmatic and budgetary frameworks to support prevention and assistance initiatives for individuals affected by floods, fires, and other crises.

In summary, the humanitarian coordination cell serves as a crucial component in coordinating and facilitating humanitarian responses to various emergencies and disasters, aiming to alleviate the suffering of affected populations and improve overall disaster management in the country.

1.11.2.5 Regional and Sub-Regional Committees for The Prevention And Management Of Disasters And Food Crises

The Crisis Management Committees are presided over by the Assistant General Secretaries (SGA) of the Governorates and the Prefects. Their primary responsibility is to oversee both the strategic and operational aspects of crisis prevention and management within their respective regions. The specific composition and functioning procedures of these committees are established through decrees issued by the Governors and the Prefects.

These committees serve as a forum for bringing together all relevant stakeholders, including technical services, non-governmental organizations (NGOs), and civil society representatives. Their key functions include:

a) Gathering, verifying, and analyzing information about the prevailing situation within their administrative jurisdictions.

b) Validating the collected data to ensure its accuracy and reliability.

c) Coordinating and harmonizing crisis prevention and management efforts undertaken by various actors within their regions.

1.11.2.6 The Directorate General of Civil Protection (DGPC)

The DGPC (Directorate General of Civil Protection) operates as a specialized entity within the Ministry of Internal Affairs. Its establishment and functions are outlined in decree n ° 086 / MI / SP / D / AR, issued on February 14, 2012. This decree defines the organizational structure of the central administration of the MISPD / AR (Ministry of Interior, Public Security, Decentralization, and Religious Affairs) and outlines the responsibilities of its leaders.

The primary mandate of the DGPC encompasses the following areas:

a) Formulating and implementing Civil Defence measures.

b) Developing policies for the protection of the population.

c) Undertaking proactive measures for the prevention of various civil risks.

d) Planning and executing measures related to Defence and Security.

Following its establishment, the DGPC proceeded to establish decentralized branches, namely the Regional and Departmental Directorates of Civil Protection. This expansion was formalized through decrees n ° 0165 / MI / SD / AR / DGPC and n ° 0166 / MI / SD / AR / DGPC, both dated March 8, 2011. These decrees delineated the roles and responsibilities of Departmental Directors and Regional Directors of Civil Protection.

Through these decrees, the DGPC extended its presence by setting up eight (8) regional directorates and over 30 departmental directorates across the country. This decentralized structure ensures that Civil Protection efforts are effectively coordinated and implemented at both regional and departmental levels.

Partial Conclusion

In summary, this chapter made it feasible to describe the conceptual area in which this study lies. A conceptual framework based on the defining of the issue of flooding and resilience, the explanation of ideas and the evaluation of the literature. Indeed, the study of this literature review clearly reveals that flood disaster risk assessment is a sensitive problem to which many writers have not stayed indifferent. Through their study, numerous writers have clearly illustrated the varied character of rain both in location and in time. This spatiotemporal variability of rainfall has consequences on the communities.

In order to prevent any misunderstanding in the general and comprehensive explanation of this technique, it is necessary to provide the methodologies employed for this study.

2 Chapter 2: Materials and Methods of Research

2.1 Study Area

2.1.1 Presentation of Niger

Niger is a landlocked Sahelian country located in the heart of West Africa, covering an area of 1267 million km2 between 11 65 0 and 23 550 N and 0 200 E and 16 00 0 E. The country can be divided into three zones: (i) the northern zone, which covers more than half of the country and is mostly in the Sahara; (ii) central Niger, which is semi-arid and part of the Sahel, defined by annual rainfall between 250 and 600 mm, and is essentially pastoral land; (iii) the southern part of the country, which is where rainfed agriculture is practiced with a mean annual rainfall that rarely exceeds 800 mm. The growing season in the central and southern zones lasts about 3 to 5 months, after which there is a long dry season of 7 to 9 months. Rained agriculture is the major farming practice, and the main cereal crop is millet, followed by sorghum. The principal river, the Niger, flows across the southwestern region and its seasonal flood contributes to recessional and irrigated farming along its banks. The economy of Niger is dominated by subsistence rain-fed agriculture and animal husbandry. The capital city is Niamey, located in the southwest corner

With 4,200 km, the river Niger is Africa's third-longest river (figure 14). Nine states, including Niger, share its vast basin, which spans an estimated 1.2 million km2. The Niger Basin Authority (ABN), with its headquarters located in Niamey, is in charge of overseeing its water resources. The river is crucial to many commercial and agricultural endeavors, as well as to the generation of hydroelectric power and the supply of potable water. As such, it is extensively studied and under constant observation. Within the discipline of hydrology, these investigations concentrated on assessing water resources as well as possible projects for hydroelectric and hydro-agricultural development, as well as the spread of floods.

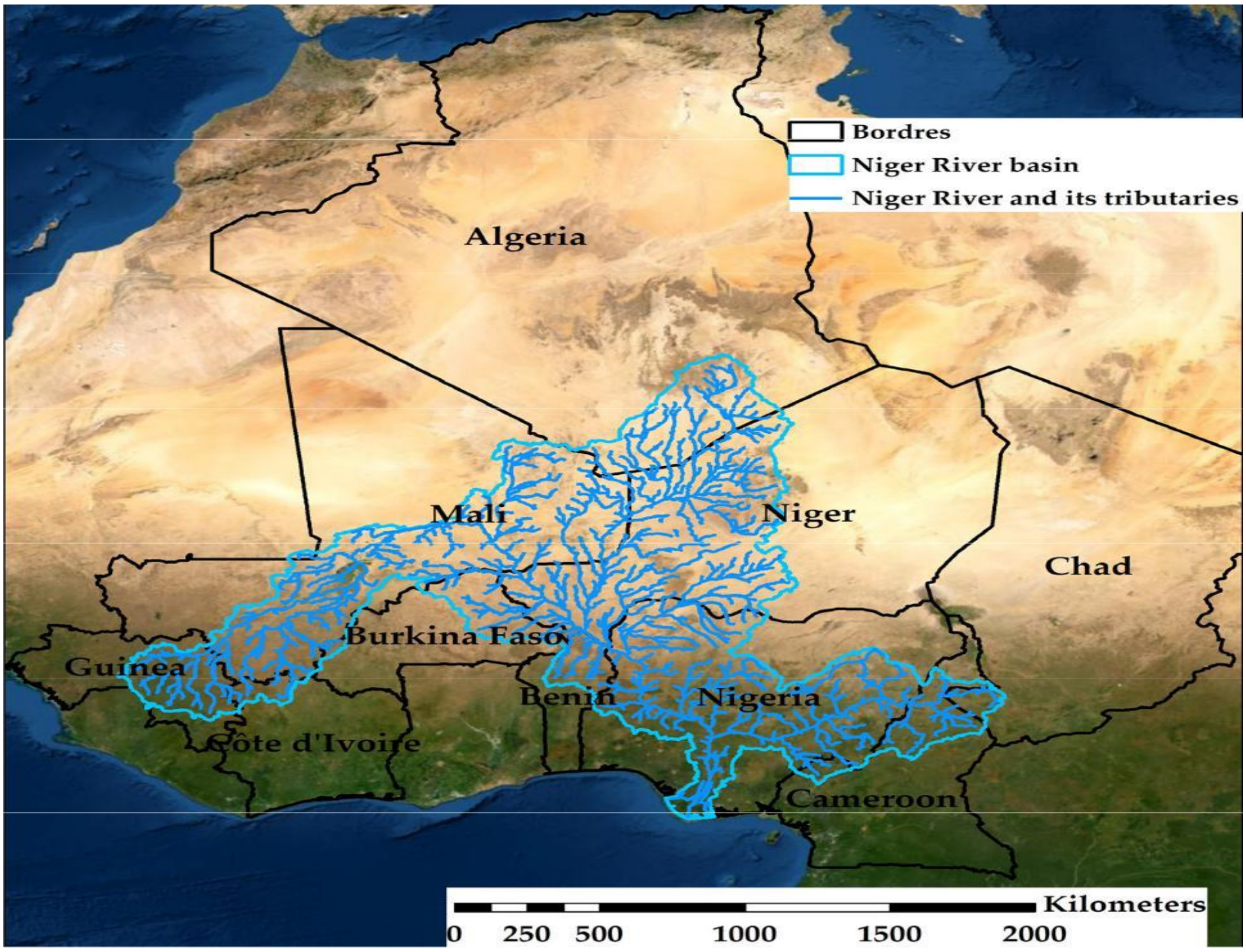

Figure 14: Map of Niger River Basin source (Abdoulaye *et al*., 2021)

Map of the Niger River basin. The map shows the ten countries in the basin and the river's tributaries. The map was constructed on a satellite image from the ESRI (Environmental Systems Research Institute) base map.

- **Precipitation**

The precipitation recorded on the territory of Niger is characterized by spatio-temporal irregularities with rainfall varying from 0 to 800 mm/year for a rainy season which lasts 3 to 4 months (from June to September). The ratio between annual precipitation in the wet ten-year year and the dry ten-year year reaches 2.5 towards the 500 mm/year isohyet (Niamey, Zinder) and more than 3 towards the 200 mm/year isohyet (Agadez, Nguigmi,). Figure 15 shows the agroclimatic zones of Niger.

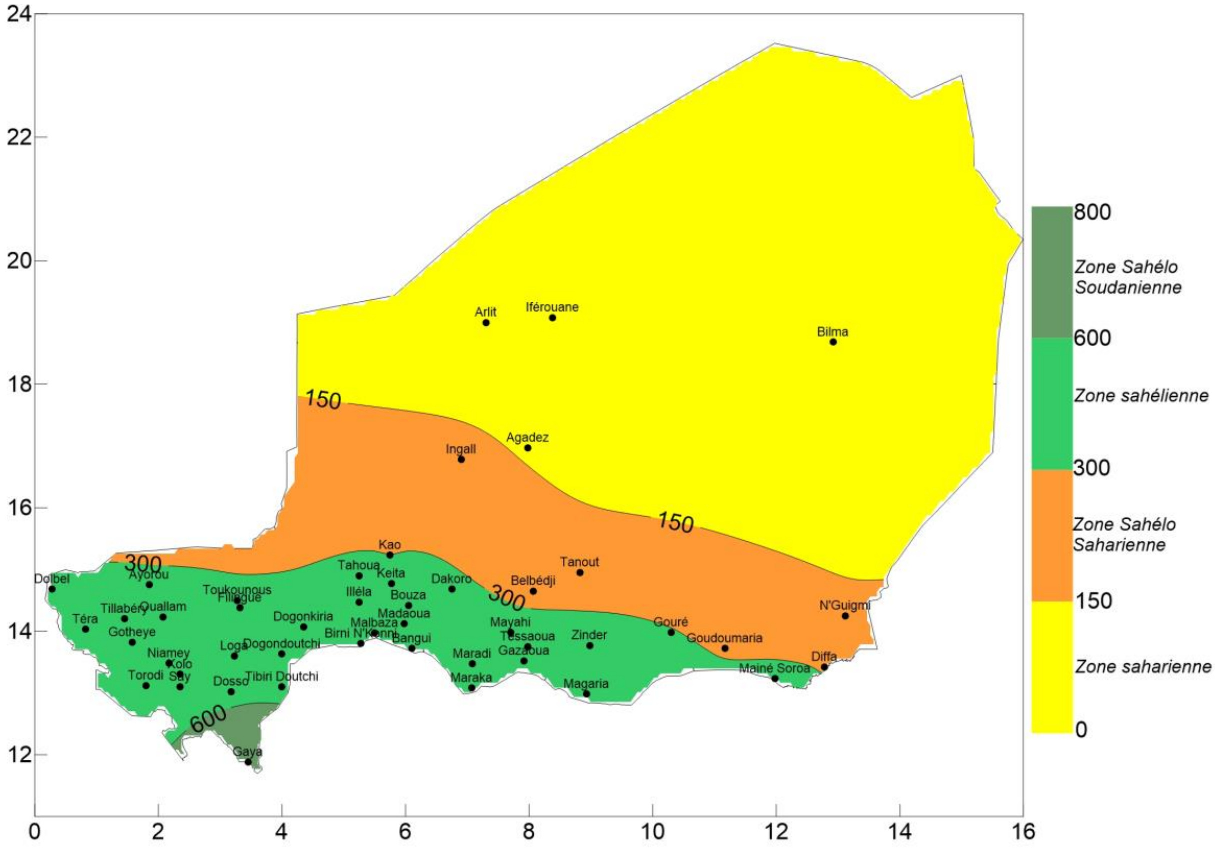

Figure 15: Map of Niger with Climatic zones (Source DMN, 2020)

❖ **Geomorphology and geology**

The geological structure of Niger is rather straightforward, it contains two big groups: • The Phanerozoic sedimentary basins, the most significant of which are those of Illumenden in the West and those of Lake Chad in the East. The Precambrian base formations that flowed into the Liptako, the Aïr, the Ténéré, the Damagaram Mounio, and the south Maradi are among the continental complexes and marine-influenced deposits that characterise the stratigraphic series of these basins, whose ages range from the Cambrian to the Pleistocene. Fundamentally, they are composed of granitoids, gabbros, dolerites, basalts, andesites, rhyolites, basic to intermediate tuffs, etc. There is a lot of different and substantial mining possibilities in these rocks.

❖ **Hydrology**

The Niger River has two annual peaks in its middle basin (figure 16): The Sahelian flood, known as red flood, occurs during the rainy season, between August and September, and is caused primarily by inflows from the right bank tributaries upstream of Niamey (Gorouol, Dargol, and Sirba); • The Guinean flood, known as black flood, occurs later in the season, between November and February, and is caused by rains occurring in the upper basin watersheds located The time lag is caused by the propagation delay along the river channel as well as the NID's reservoir effect.

Historically, the black flood had a bigger size than the red flood, but since 1984, the red peak has begun to surpass the black one (Figure 16), and an inversion of magnitude has been recorded in the past decade, with the levels of the red peak consistently exceeding those of the black one. The mean annual hydrographs of Niamey vividly depict the humid reference era until the 1960s, the dry period in the 1970s and 1980s, and the recent three decades, which show an early start and a rise in red peak.

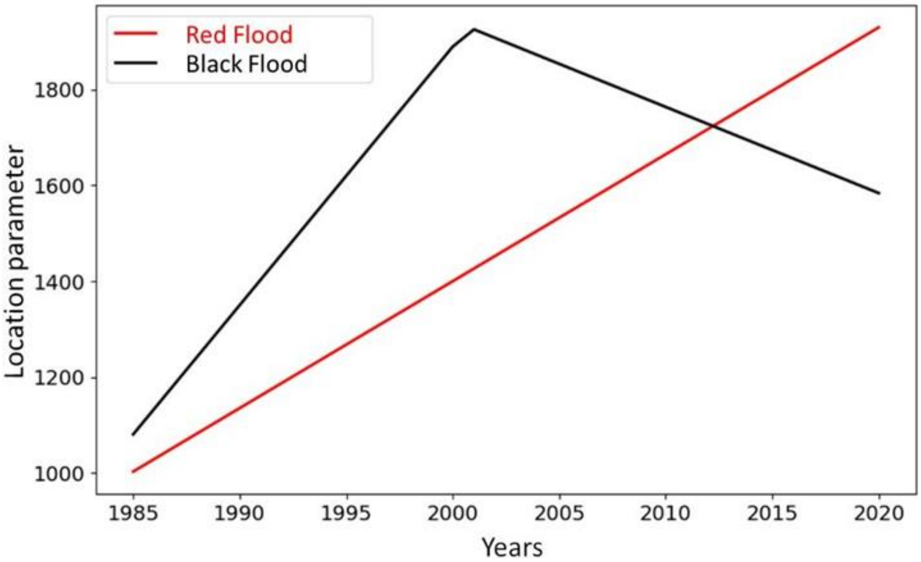

Figure 16: Evolution over time of the GEV location parameter giving the best fitting results to the AMAX series of the red and black floods.

2.1.2 Localisation of Niamey

Niamey, the capital city of Niger, is 555 square kilometers in size. It is situated between the latitudes 13°28' and 13°35' North and 2°03' and 2°10' East (Figure 17). The city is situated on an alluvial plain on the right bank of the Niger River and on a plateau overlooking the river's left bank. Niamey is one of Niger's eight administrative regions, with a population of 1,203,766 inhabitants (INS, 2018). The latter population is composed of 598,488 males and 605,278 women. The city's annual growth rate is 4.5%. This demographic flow creates a high human concentration that has negative effects on the social and environmental spheres. These include issues with waste management, housing, potable water availability throughout the city, and health.

To address the obvious effects of increased urbanization, it will be necessary, among other factors, to improve the living conditions of the residents.

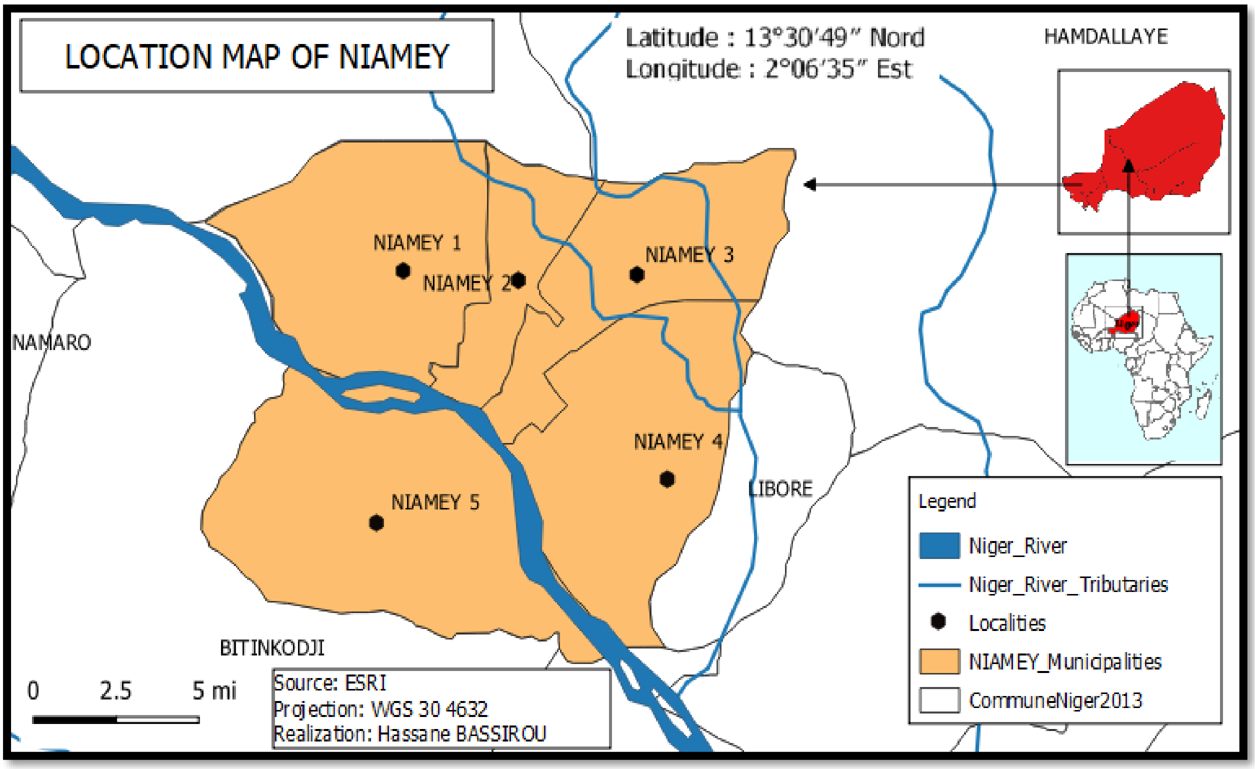

Figure 17: Location map of the study area (Source: Bassirou, 2022)

Three main vegetation types, including fallow savanna, crop fields on sandy soils, and tiger bush on lateritic plateaus, make up the extremely fragmented vegetation cover. Pearl millet grown in rainy conditions dominates the agricultural production system. Because it relies on rainfall for both agriculture and livestock, the region is particularly susceptible to climate change (D'Herbès and Valentin 1997).

2.1.3 Biophysical environment

2.1.3.1 Relief

The plateau of the left bank and the plain of the right bank constitute the two (2) fundamental elements of the relief of the region of Niamey. The average altitude of the plateau on the left bank is around 250 m. Overlooking a drop of 20 to 25 m, this plateau occupies the largest urbanized space (INS, 2016). The plain on the right bank is the zone par excellence for urban and peri-urban market gardening.

With an average altitude of 125 m, this plain extends over several kilometers. Also, it should be noted the presence of fossil dunes from the arid periods of the Quaternary. These dunes were formed at the level of the plateau's sandy covers or longitudinal dune cords in an East-West direction.

2.1.3.2 Climate

Niamey and its vicinity have a Sahelo-Sudanian climate characterized by a short rainy season (June to September) and a long dry season (October to May).

There are also two (2) types of winds:

- The harmattan, a hot and dry wind, which blows from North-East to South-West from September to May;
- The monsoon is a cool and humid wind that blows from West to East during the months of June to October.

The analysis of the region's rainfall data (Figure 18) shows an irregularity in the evolution of the annual accumulations recorded from 2010 to 2019 with, however, a slight stability between 2013 and 2016. During this decade, the year 2017 was the rainiest with an annual total of 833.2 mm. It experienced a vertiginous drop in 2018 with 442.4 mm and a slight increase in 2019. Overall, 2011 was the least wet year with an annual total of 359.8 mm.

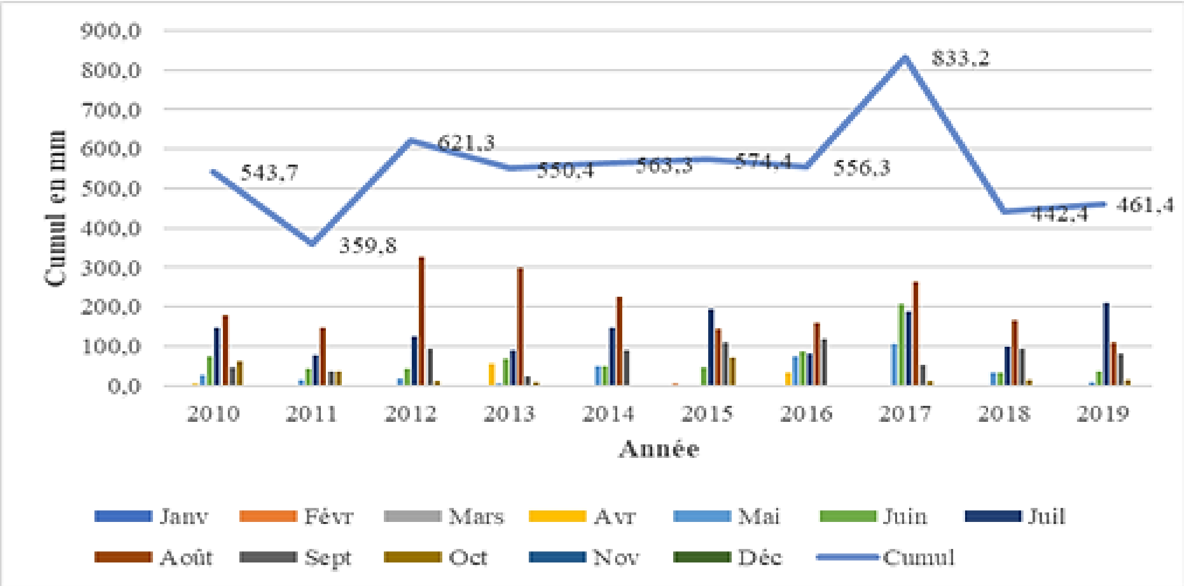

Figure 18 : Analysis of rainfall data

The average monthly maximum temperature during the period 2010-2019 in the region varies between 30.2°C observed in December 2015 and 42.6°C observed during the months of March 2013 and May 2015 (see Figure 19).

As for the average monthly minimum temperature, it varies between 16.2°C observed in January 2015 and 30.1°C observed in May of the same year (see Figure 20).

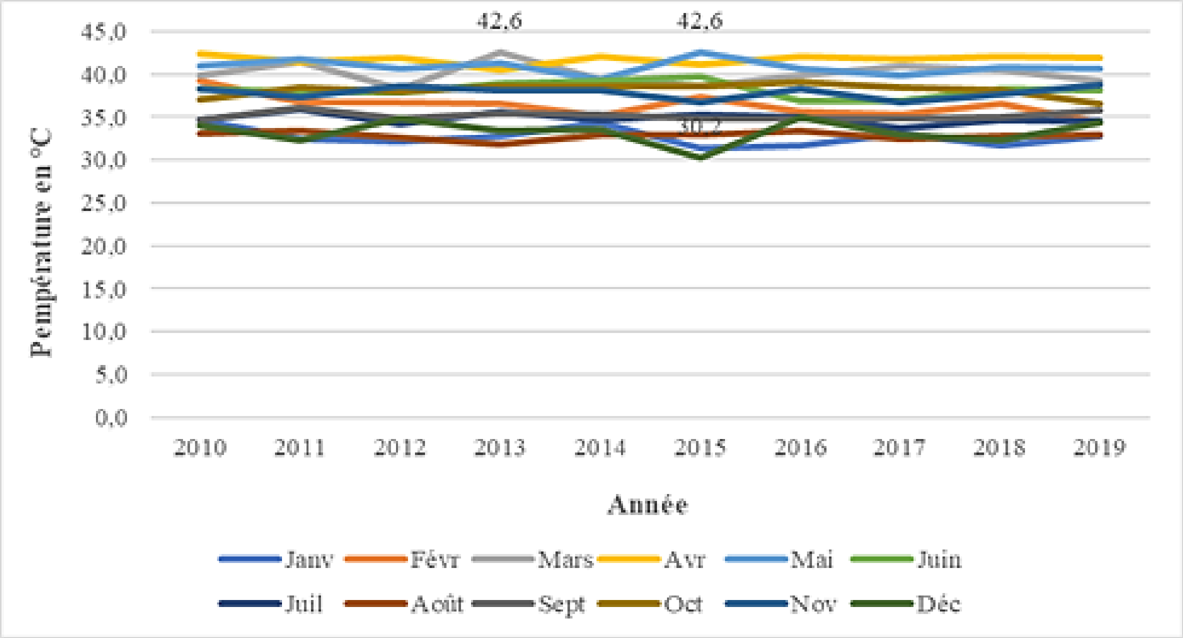

Figure 19: Evolution of maximum temperatures

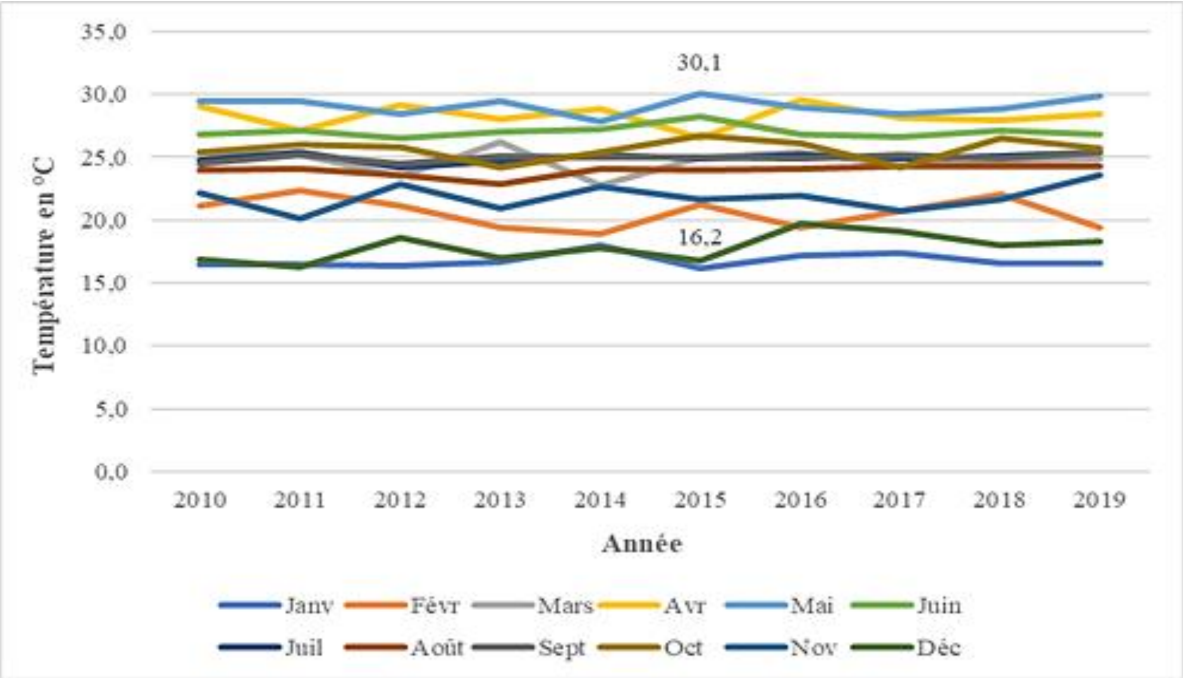

Figure 20: Evolution of minimum temperatures

Concerning the wind, Figure 15 below shows that its average monthly speed varies between 0.2 m/s observed in October 2010 and 4.5 m/s observed in December 2015.

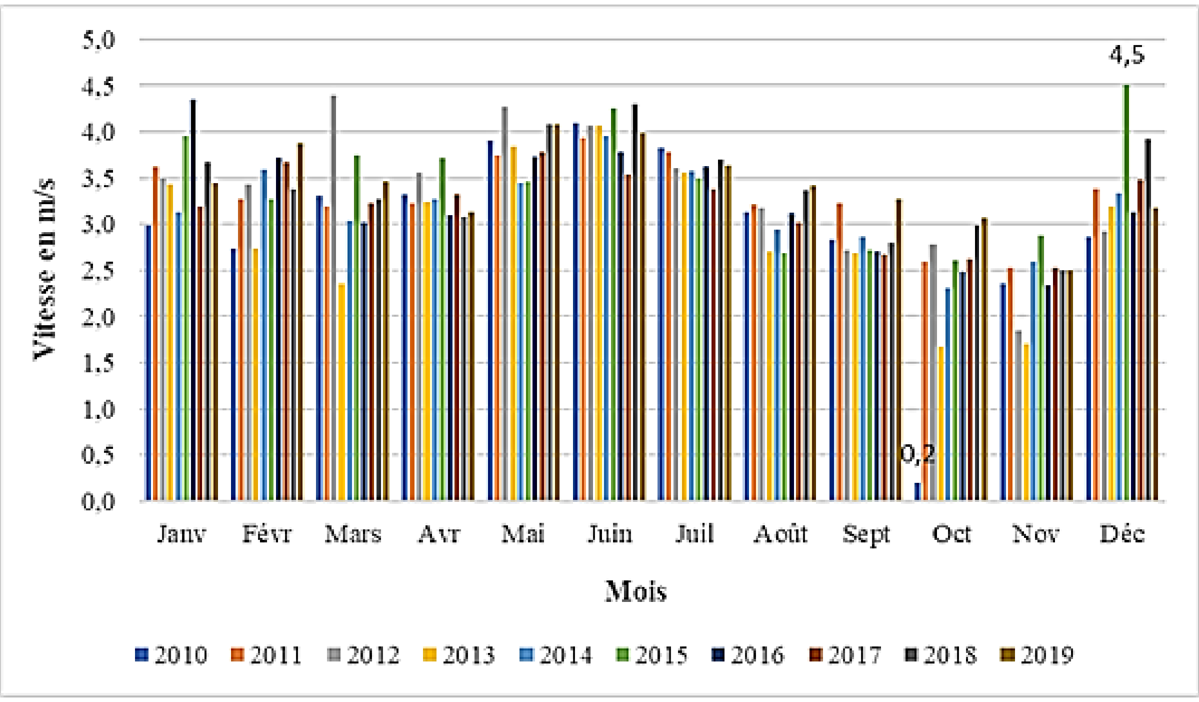

Figure 21: Wind speed

Insolation is very strong in the region, particularly in April and May. This is mainly due to the nature of the climate marked by high temperatures. This insolation drops with the onset of the rainy season.

2.1.3.3 Soils

There are three (3) types of soil in the project area (INS, 2016) These include in particular:

- Soils of the ironclad plateaus, which are very degraded and offer no agricultural possibilities due to their depth and their permeability and especially their extreme aridity;
- Sandy-textured soils including tropical ferruginous soils of sandy valleys;
- Hydromorphic soils are located in the Niger River valley. They are reserved for off-season crops and are home to most of the capital's orchards because of their fertility and the irrigation possibilities offered by the river.

2.1.3.4 Water resources

Water resources consist of groundwater and surface water. Thus, groundwater is confined in the worn or fissured strata of the Precambrian basement. There are three (3) aquifers associated to continental terminal sandstone and alluvial deposits.

For the aquifers situated in the basement regions, the average flow rate of the boreholes ranged from 2.3 to 4.1 m^3/h in the granitoid formations and from 3.7 to 7.6 m^3/s in the volcano-sedimentary formations (INS, 2016).

The transmissivities of the aquifers range between 3.10-5 and 10-2 m^3/s depending on the lithology, the fracturing and the severity of the alteration.

The alluvial deposits made up of gravel, sand and clay are predominantly found on the quaternary terraces classified T4 and T3. Their thickness ranges from 4 to 20 meters and provides them a more or less considerable aquifer potential depending on the location. These aquifers are largely utilised for the watering of gardens.

Concerning surface water, the network of the Niamey area consists of a single watercourse, the Niger River with a maximum flow of 2340 m^3/s passing this administrative unit for a length of more than 15 km (INS, 2016). However, the river is undergoing a disturbance of its regime and a decline in its flow owing to the phenomena of silting and sedimentation due to erosion. To this, we must mention the presence of several permanent and semi-permanent ponds.

The sole artificial reservoir is the Goudel sill, created to contain a capacity of 3,000,000 m^3 to sustain the water supply of the city of Niamey. However, during the development of the drinking water supply master plan for the city of Niamey (2017), a bathymetric study carried out at the level of the Goudel water reservoir showed that the current capacity is 800 000 m^3 (representing 7 days of production), which indicates significant silting up of the dam. This is what caused SPEN to continue in an artisanal fashion to raise the Goudel dike by adding sandbags over almost 75 cm, thereby increasing the capacity of the reservoir to reach 1,400,000 m3. i.e. an autonomy of 15 days of pumping in the case of a complete cessation of the flow of the river (SPEN, 2021).

The hydrological regime of the Niger river at Niamey is characterised on the one hand by flows from the upper Niger basin, whose peak arrives at Niamey during the dry season during the period December - January, and on the other hand, by the inflow from the tributaries of the right bank during the rainy season. Thus, two strong flood peaks describe Niamey's hydrograph (figure 16). The flood associated with the inflows of the tributaries of Burkina is called the local flood (or black flood) because of its localised character in time and space, in contrast to the second flood called the Malian flood, which is generated by distant inflows from the upper Niger basin: Guinea, Ivory Coast, and Mali.

The examination of mean hydrographs in Niamey: 1) supports the new hydrological behaviour previously stated by numerous authors since the beginning of the century and 2) underlines the extraordinary behaviour recorded from 1964 to 2020 (Figure 22). These two flood episodes, although if identical in peak size, are considerably different regarding flood duration and persistence in the red alert (Q > 2045 m^3/s), triggering levee failures in the city.

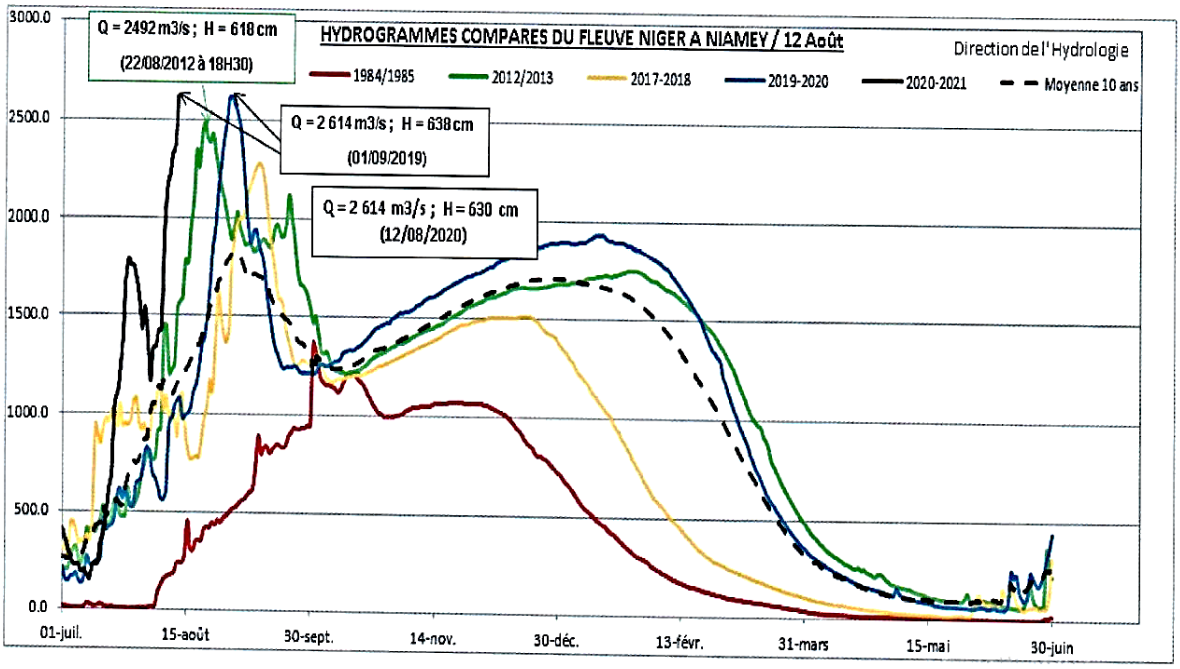

Figure 22: hydrograph comparison of river Niger at Niamey

According to the mean intra-annual hydrographs, the Niger River in Niamey's hydrological year runs from July 1 to June 31 and includes the four hydrological periods (1984–1985, 2012–2013, 2019–2020, and 2020–2021), as well as the cataclysmic years 2012 and 2020.

Table 3 lists the warning levels for the city of Niamey with the corresponding flows. It was feasible to determine the levels and flows that the city's protective dykes can hold using the new calibration scale and the consequences of flooding seen in the 2020 flood.

Table 3: Hydraulic hazard scenarios for the city of Niamey.

Script	Magnitude	Height [cm]	Flow [m3/s]
Grey	Low water alert	0 - 140	0 – 25
green	Normal condition	140 – 530	25 – 1443
yellow	Frequent flooding	530 – 580	1443 -1766
orange	Severe flooding	580 – 620	1766 -20 45
red	Catastrophic flooding	620 = 750	2045 - 3084
Top dikes	Large flood in the city	660	2 344

Source : (Massazza, Tarchiani, et al., 2021)

2.1.3.5 Vegetation

The vegetation is an essential element of soil stabilization. It is the result and a witness indicator of the evolution of the other components of the physical environment and natural resources, in particular the climate, water resources, and soil. In the study area, the vegetation consists mainly of:

- a natural flora along the river, the Koris and on the plateaus composed respectively of *Hyphaene thebaïca*, *Borassus aethiopum*, *Faidherbia albida*, *Balanites aegyptiaca, Combretum (glutinosum, Combretum micranthum, Combretum nigricans, Combretum aculeatum), Prosopis africana, Eucalyptus camaldulensis, Terminalia mentali, Azadirachta indica, etc.*,
- a herbaceous cover is dominated by *Sida cordifolia* in practically all areas and by the species *Cenchrus biflorus* on the plains, and
- Multi-even-aged artificial plantations (green belt and green spaces) with an area of more than 2000 hectares composed mainly of *Azadirachta indica* and Eucalyptus spp (INS, 2021).

2.1.3.6 Wildlife

The Niamey region is home to small game (squirrels, birds, guinea fowl, and fish), a few reptiles, caimans, hippopotamuses and wild animals in captivity at the Boubou Hama National Museum and in private homes. As for the big game, it has practically disappeared due to the degradation of its habitat.

Furthermore, the presence of the river and ponds makes the Niamey region one of the richest areas in fishery resources. Indeed, according to the National Institute of Statistics (INS, 2021) and (Wang et al., 2018), the Niger River is full of aquatic species: hippos, crocodiles, wild ducks, fish, etc.

2.1.4 Human environment

2.1.4.1 Population

The population of Niamey and its vicinity is estimated in 2021 at 1,365,927 inhabitants – 678,572 men and 687,355 women. The characteristic of this population is its extreme youth.

Indeed, 50% of the population are people aged 15 to 49, while people over 65 represent only 2.3% (INS, 2021)

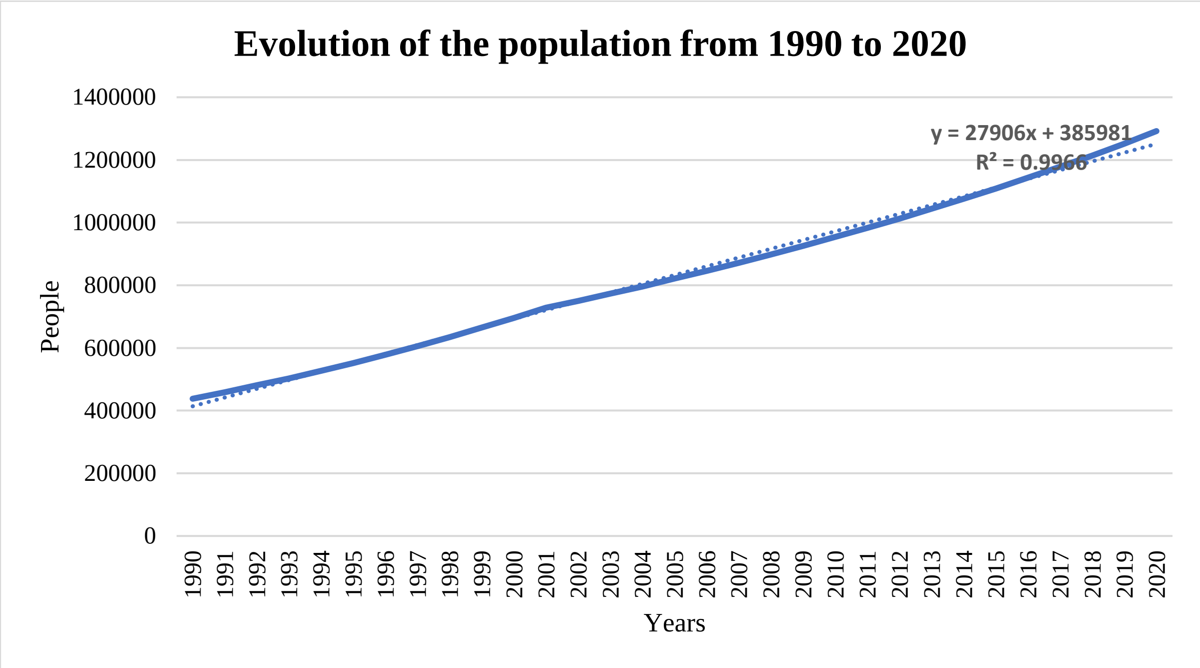

Figure 23: Evolution of the population of Niamey from 1990 to 2020

The population trend of Niamey, the Niger's capital, is shown in this figure 23 from 1990 to 2020. It demonstrates how Niamey's population has grown over time. The population was predicted to be 438,000 in 1990; by 2020, it was estimated to be 1,292,000. This demonstrates a three-decade era of noticeable population growth in the city. We can see the population changes each year by looking at the data for each year. In the beginning, population growth was fairly slow, increasing by 20,000 to 30,000 people annually in the early 1990s. The rate of population increases started to quicken during the middle of the 1990s. The population of the city increased more quickly each year, by 50,000 to 70,000 people on average. The 2000s and the 2010s saw a continuation of this rapid expansion. Population growth has changed while examining particular years. For instance, the population increased by 28,000 in 1997 and by 31,000 in 2000.

This shows that the growth rate can vary from one year to the next. It appears that throughout time, the annual growth rate has gradually risen. The growth rate was initially quite low (1990), but between 2000 and 2010, it significantly increased. From 1990 to 2020, Niamey's population is projected to grow steadily. Natural increase (births exceeding deaths) and rural migration are two variables that have contributed to the city's steady demographic rise. This statistic emphasises the significance of tackling issues like the provision of suitable housing, healthcare, education, and employment opportunities, and the management and reduction of disaster risks such as floods that are related to a rapidly rising urban population.

2.1.5 Socio-Economic Activities

2.1.5.1 Agriculture

In the Niamey region, agricultural activity is practiced in rice fields or gardens along the river or the Gountou Yéna valley and on dune land. Cultivated speculations are essentially food crops, millet, sorghum, etc (table 4). Along the banks of the river, rice cultivation and market gardening are practiced. According to the final results of the 2020 agricultural campaign, the yields, areas as well as the productions of the different speculations are given in Table 6 below.

Table 4: Yields, areas and productions by speculation

SPECULATION	VARIABLES		
	AREA	**YIELD**	**PRODUCTION**
Mil	3,680	428	1,575
Sorghum	660	439	290
cowpea	2,914	364	1,061
Peanut	27	612	17
Voandzou	14	529	7
sorrel	29	511	15

Source: MA, 2021

2.1.5.2 Breeding

The Niamey region is not a pastoral zone. Nevertheless, there are a few practitioners, especially in commune V. Thus, despite the lack of grazing areas, the Niamey region is full of large livestock whose situation from 2015 to 2017 expressed in the number of heads is illustrated in Figure 24.

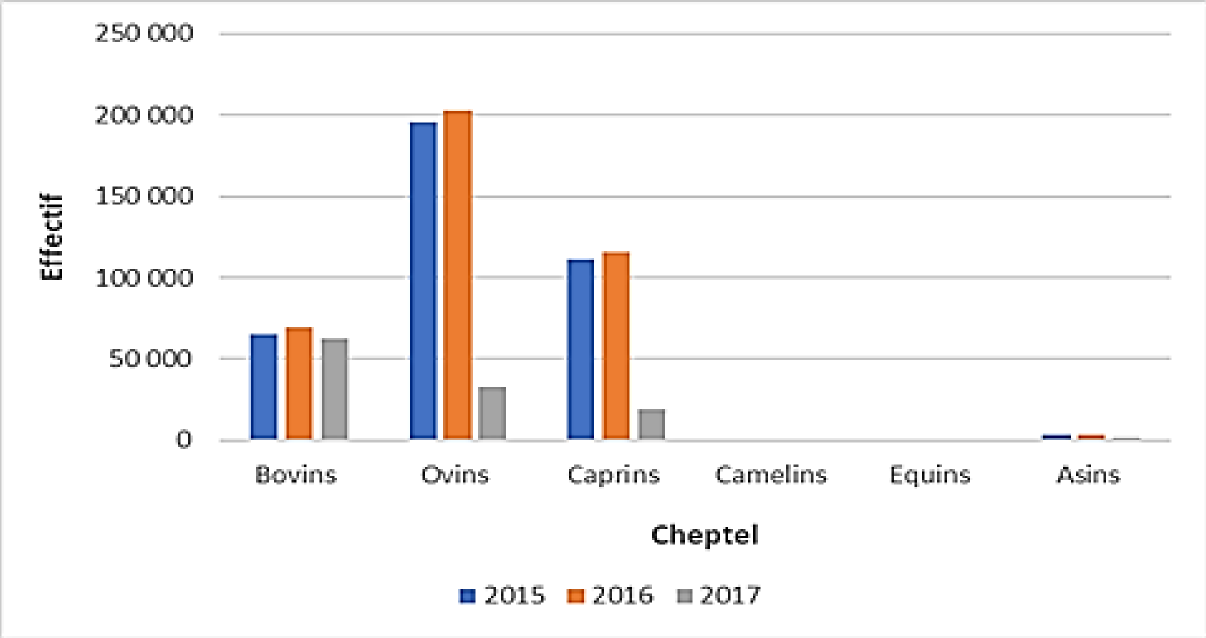

Figure 24: Situation of livestock in the city of Niamey

2.1.5.3 Fishing

Despite the tremendous hydraulic potential, fish output in Niamey is poor, far from fulfilling the ever-increasing demand. Fishing is performed largely on the river and in the permanent ponds of Kongou Gorou and Tondibia Gorou.

The principal fish species caught include Lates, Synodontis, Clarias, Labeo, Tilapia aulunglanus, etc. But it should be mentioned that it is impossible to measure the fish productivity of the area given the preponderance of informal fishing. However, the status of fish production from 2017 to 2020, stated in kg is depicted in Figure 25 below.

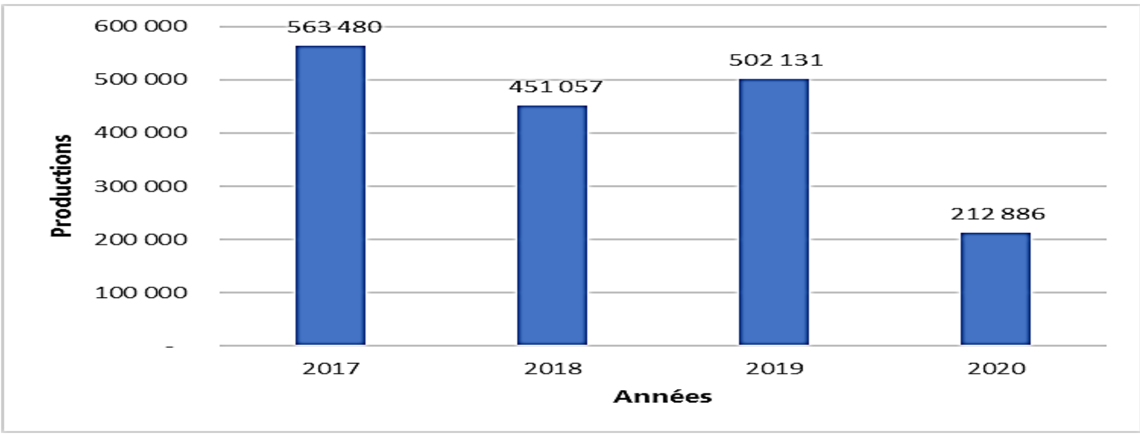

Figure 25: Fish production from 2017 to 2020 (Source**:** DRE/LCD NY report, 2021)

2.1.5.4 Arts and crafts

Handicrafts in the Niamey area include largely leather items, jewellery, ceramics, embroidery, stitching, pot making, etc. There are four (4) important craft hubs in Niamey: the Ibrahim Moussa craft hamlet of Wadata, the Center des Métiers et d'Art du Niger, the Boubou Hama National Museum and the Gamkallé tannery. Handicraft goods are offered on local marketplaces and beyond the nation.

2.1.5.5 Trade

Trade consists of two (2) parts: internal trade and foreign trade, both of which are dominated by the region's informal sector, which accounts for more than 70% of total economic activity. Because there is little data, it is difficult to regulate internal commerce.

Most of the nation's exports come from the Niamey area. Equipment, food, and textiles make up the majority of imported items. Exports from the area, however, are quite meagre. The majority of export goods go from different areas to other countries in transit. Uranium, tiger nuts, cotton, onions, groundnuts, etc. are examples of this.

2.1.6 Basic infrastructures

2.1.6.1 Education

The area of Niamey stays and is the locomotive of the other regions in terms of rates of coverage and access to education. Indeed, 79.7% of enterprises are situated in metropolitan areas, which suggests simple accessibility. Niamey practically provides equality between girls and boys with well-established private education (one kid on four, is private). The regional education system adheres to the national system defined by a pyramidal structure encompassing three (3) levels of education: elementary, secondary and higher.

Concerning school infrastructure, at the level of first-degree education (primary), the Niamey area had 5,573 classrooms at the start of the 2016-2017 school year for a staff of 248,129 pupils, i.e. a ratio of 45 students per class. The Gross Enrolment Rate (TBS) of 148.3% and the Net Enrolment Rate (NER) of 93% for the same time (INS, 2018).

At the level of the CEG, the number of classrooms at the start of the 2016-2017 school year was 539 for a workforce of 27,947 pupils, i.e. a ratio of 52 students per class. The TBS was 105.3% and the NER was 74.4%. In addition, Niamey concentrates the main higher education establishments of the country including the Abdou Moumouni University, the School of Mines, Industry and Geology (EMIG), the African School of Meteorology and Civil Aviation (EAMAC), the National School of Administration and Magistracy (ENAM), the Regional Agro-Hydrometric Center (AGRHYMET), the African Center of Meteorological Application for Development (ACMAD), the International Crops Research Institute for Semi-Arid Protics (ICRISAT).

2.1.6.2 Health

With a health coverage rate of 98% in 2016 and 98.8% in 2017, the Niamey area is the best covered in terms of health infrastructure. Indeed, at the level of this area, the state of the aforementioned infrastructures from 2013 to 2017 is presented in Table 5 below.

Table 5: infrastructures situation from 2013 to 2017

TYPES OF INFRASTRUCTURE	YEARS				
	2013	**2014**	**2015**	**2016**	**2017**
National hospital	2	2	2	2	2
Regional Hospital Center	1	1	1	1	1
District Hospital	1	1	1	1	1
Maternity referrals	1	1	1	1	1
Integrated Health Center I	24	29	26	25	26
Integrated Health Center II	26	21	24	35	35
Health Box	9	9	8	6	5
CAB MED/Clinical	51	60	69	85	57
Treatment room	66	65	63	36	109

In more of all these infrastructures, are added specialized institutions among which we can mention:

- Niger Society of Pharmaceutical Industries (SONIPHAR);
- National Public Health and Expertise Laboratory (LANSPEX);
- Medical and Health Research Center (CERMES);
- National Blood Transfusion Center (CNTS);
- National Reference Center for Obstetric Fistula (CNRFO);
- National Reference Center for Sickle Cell Disease (CNRD);
- National Center for Reproductive Health (CNSR);
- National Anti-Tuberculosis Center (CNAT);
- Ambulatory Treatment Center (CTA);

- Emergency Medical Aid Service (SAMU);
- National Center for the Fight against Cancer (CNLC);
- Etc.

The population-to-health-staff ratio remained below the WHO standard. Thus, in 2018, the region's doctor/inhabitant ratio was 1/18,559 (the WHO standard is 1/10,000). In the same year, the proportion of nurses per population is 1/2751 although the WHO standard is 1/5000 (INS, 2019).

Finally, ailments the more prevalent in the Niamey region, especially during floods, include malaria, digestive infections, diarrhea and dysentery.

However, malaria remained the most dominant with 286,743 and 240,156 cases documented respectively in 2016 and 2017 (INS, 2018).

2.1.6.3 Hydraulics and Sanitation

Like other places in the nation, drinking water distribution in the metropolitan core of Niamey is supplied by the Société des Eaux du Niger (SEEN) which signed a lease deal with the Société du Patrimoine des Eaux du Niger (SPEN). According to the National Institute of Statistical (INS, 2018), in 2017, the Niamey area has 17 storage reservoirs with a total capacity of 28,900 m3. Drinking water coverage is given, in addition to the SEEN supply network, by water points modern, well cemented, boreholes fitted with human-powered pumps and autonomous water stations.

The indicators of access to water at the level of the region are shown in the following table 6 in comparison with the indicators at the national level.

Table 6: Water access indicators

INDICATORS	**NIGER**	**NIAMEY**
Drinking water supply rate	95.22	83.80
Theoretical hit rate	46.31	35.31
Geographic coverage rate	71.14	71.72
Failure rate	8.37	6.83
New equipment	8,309	45

Source: MHA, 2019

In terms of sanitation, the household access rate to the various services in 2018 compared to the national average is illustrated by figure 26 which follows.

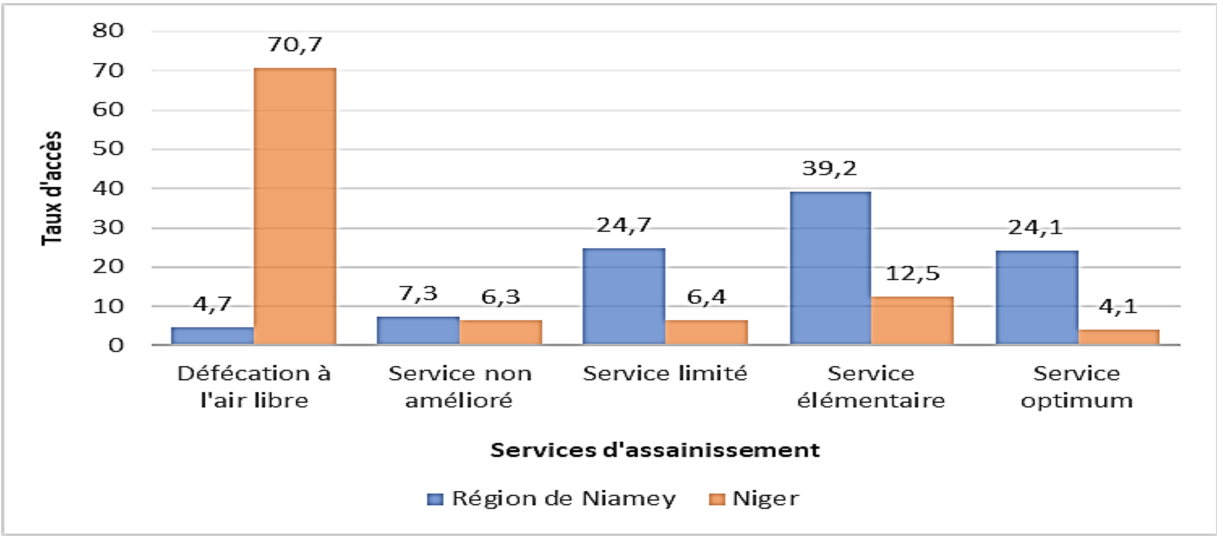

Figure 26: Situation of access to sanitation services (Source: INS, 2019)

The analysis of Figure 20 above shows that, at the scale of the Niamey region, the household access rate to the optimum sanitation service in 2018 is 24.1% was well above the national average, which was 4.1% only. The elementary service (39.2%) is also above the national average, which was 12.5%. The rate of defecation in the open air was 4.7%, thus very largely below the national average, which was 70.7% in 2018. Finally, the access rate to unimproved service was 7.3%, exceeding the national average of 6.3% (MH/A, 2019).

2.2 Method

This chapter discusses the various methods and techniques used to collect, process, and interpret flood risk assessment data in the study area. The methodology employs both quantitative and qualitative approaches. The three steps of the study's execution were documented research, primary and secondary data-gathering methods, and data processing.

2.2.1 Type of Data Required

The research employed a mix of field and archive data. The field data were acquired utilising a survey research method comprising the use of questionnaire/interview technique in acquiring information on the type, frequent causes, and effects of flood risk disasters in the study area. The questionnaire is made up of carefully crafted questions depending on the research issue.

Archival data including rainfall data, discharge data and records of flood damage in the affected areas (within the temporal scope of the study: 1990-2020) were also collected from reports made available by hydro-meteorological agencies like:

- ✓ Niger Basin Authority,

- ✓ Regional Center AGRRYMET CCR AOS,
- ✓ Dispositif National de Prévention et de Gestion des catastrophes et Crises Alimentaires (DNPGCCA),
- ✓ National Disaster and Food Crisis Prevention and Management Framework,
- ✓ Ministry of Environment and Sustainable Development,
- ✓ Ministry of Water Resources,
- ✓ Ministry of Disaster Risks Management,
- ✓ Sustainable Development and Environment Council (CNEDD),
- ✓ General Direction of Civil Protection, and
- ✓ Nation Meteorological Agency.

Other data sources used for the purpose of the study include Satellite data on land use and land cover patterns, Drainage systems, Digital Elevation Model (USGS DEM), Maps, Newspapers, Magazines, and Journals.

2.2.2 Source of Data

The study was based on two sources: Primary and Secondary sources of data (Table 7).

Table 7: Data sources

GIS dataset	Sources
Map of Niger at 1km Resolution	Institut Géographique National du Niger (IGNN)
Landcover, road network,	Niger Basin Authority, AGRHYMET
Administrative boundaries	Ministry of Plan
Geomorphology, hydrography.	National Institute of Geography
Hydrological data	Direction Générale de l'Eau (DG-Eau Niger)
Climate data (for 3 decades)	Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar (ASECNA, Niger) Direction National de la Météorologie
Population data	Institut National de la Statistique (INS)
Statistical agricultural data	Ministry of Agriculture
Statistical Health data	Ministry of Heath
GPS DATA	Field

Table 8: Geospatial Data

LIST OF DATA		
MAIN TYPE	**DATA LAYER**	**Source**
Flood inventory	Flood type, frequency, duration, magnitude, flood map.	Archive studies; ground-based networks; visual image interpretation
Environmental data (permanent factors)	**Relief:** DEM (altitude difference, slope steepness, slope direction); **Hydrology:** DEM (flow direction, channel network, drainage map, watershed map, flood extend map), ground water table, soil moisture, run off; **Geomorphology**: landforms; Soil type; **Land use:** land use map, land cover map (vegetation characteristic, natural resources, vegetation changes, land use changes, infrastructure, building, road), satellite images.	STRM; Earth explorer, etc. Open street map; Satellite images from Sentinel;
Triggering data	• Rainfall Extend of the flow area, and temperature. Wind speed and direction • Overflow of River Niger	Meteorological stations/NBA/AGRHYMET

2.2.3 Sampling Techniques and Sample Size

A purposive sampling method was employed to select the respondents. Field surveys, questionnaires, and interviews were employed to achieve the objectives of this research. According to (Oyatayo et al., 2016; Yamane, 1967) the minimum sample size of a population of more than 100,000 persons is 400 using Equation (1) at a +/-5% level of precision; Thus Niamey with a population of 1,203,766 inhabitants (INS, 2018) , 192 976 household.

Formula 1

$$n= \frac{N}{1 + N(e^2)} \qquad (1)$$

where n is the sample size; N is the population, i.e., census population figure, and e is the level of precision/sampling error.

Out of the 123 locations in the five districts of Niamey, 27 were randomly chosen. The questionnaires were given to the five designated regions by 507 respondents in total (figure 27) . In order to gather data on the research goals and demand in the study area, the questionnaires include both open-ended and closed-ended questions. The researcher or the field assistant mostly conducted face-to-face interactions or interviews to collect the data. The questions were distributed using the Kobo toolbox.

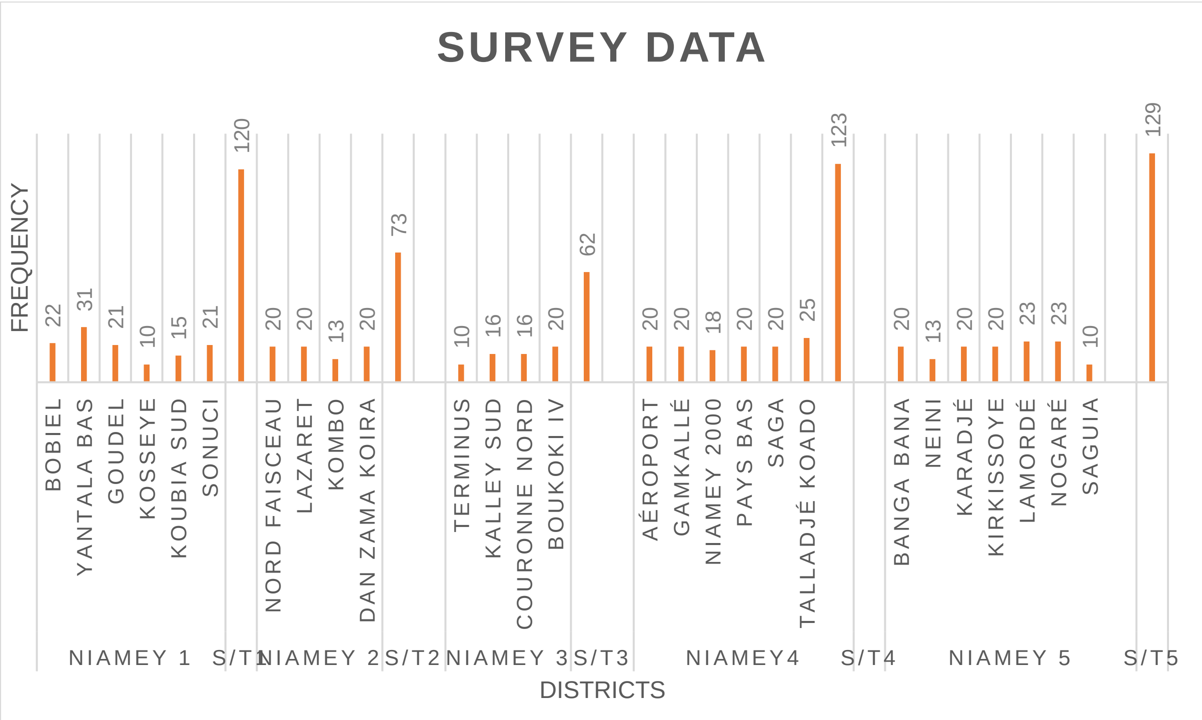

Figure 27: Survey data 2022

Figure 28 map displays the locations where the respondents' questionnaires were distributed. The available people, time, and logistical assistance, together with the disaster's geographic distribution and the population's heterogeneity or homogeneity, all had a role in determining the sample size. The "Key informants" criteria are used in the interview selection process. The key informants were persons who had previous information or expertise about the flood risk in Niamey, Niger River Valley. They were selected in light of their roles as community leaders responsible for managing floods, their professional occupations, personal experiences, and/or other factors. The sample technique employed takes into consideration the principle of representativeness of the sampling base which resides in the prudent choice of places, respondents and their distribution in the geographical space of the research region. Thus, the sample procedures were based on the present administrative division made up of 5 districts.

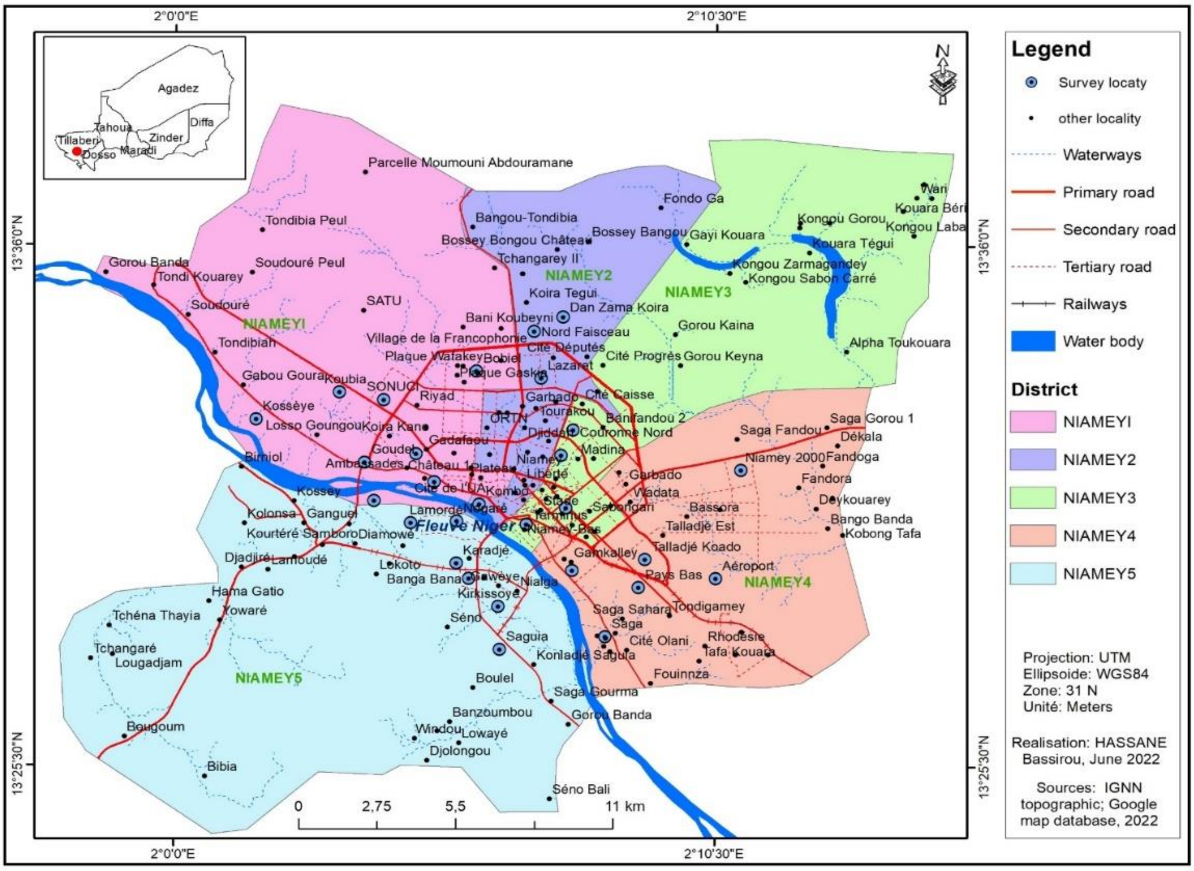

Figure 28: Localities where the survey was conducted

2.2.4 Methodological Framework

A set of guidelines, techniques, and instruments known as a methodological framework serve to organise and shape the research process. It offers a framework for carrying out research, gathering and analysing data, and coming to conclusions. The framework defines the procedures that must be followed when conducting a research project, including the formulation of the research question and hypothesis, as well as the methods for gathering and analysing the necessary data.

To address research topics from many perspectives, this framework blends quantitative and qualitative research approaches. It entails gathering both numerical and non-numerical data and analysing the data using both statistical analysis and interpretive techniques.

In order to discover and solve practical issues in real-world situations, this framework incorporates cooperation between researchers and participants. To enhance a certain circumstance or practice entails a cyclical process of planning, acting, reflecting, and evaluating in the context of flood disaster risk assessment in Niamey, The methodological framework of the study is illustrated in Figure 29 below

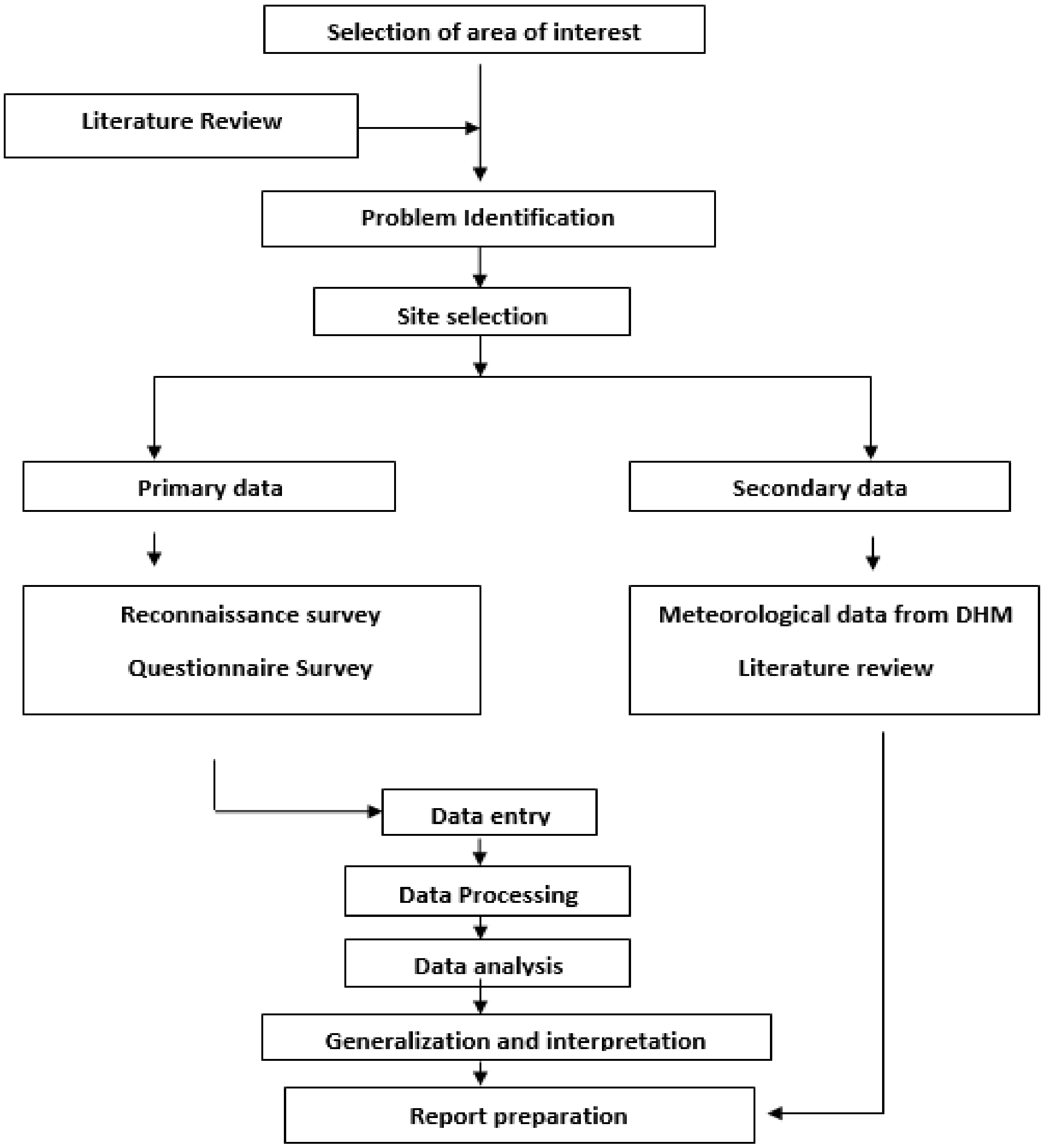

Figure 29: Methodological Flow chart of the study

2.2.5 Data collection

2.2.5.1 Primary data collection

The primary data were collected through: 1) Reconnaissance survey, 2) Questionnaire survey, and 3) Focus group discussions.

2.2.5.1.1 Reconnaissance survey

For the purpose of building a report, general field observations were conducted in order to familiarize the study area with the communities. The researcher visited respondents' homes and communities during the research period. The respondents' residences and neighbourhoods were inspected during a walking stroll through the survey area. Additionally, informal interviews and discussions were conducted along the river ‘s edges. The researcher found this technique helpful for triangulating information and collecting information in-depth. Field observations are often conducted. During the field trip, we made observations regarding the disasters and risks associated with them. Some relevant facts were recorded. The region was captured on camera for later illustration.

2.2.5.1.2 Fieldworks

During the fieldwork, participatory methods and technologies were used to collect the main data needed for the study. Some of the tools employed include focus groups, field workshops, field observations, transect walks, one-to-one in-depth interviews, and GIS-assisted household surveys. The goal of both the FGDs and the field workshops was to acquire comprehensive data to understand and learn from the viewpoints of local communities. To identify public buildings that could be used as safe shelters in case of severe floods, measurements of the floodwater level will be taken to supplement the data gathered during a transect walk and field observations of the nature of buildings and housing conditions (location of houses, level of plinth, house type). A bias-free representative sample accurately reflects the population's traits. It is essential to create a sampling method that keeps error at a manageable and desirable level. In this investigation, every step including the sampling technique was strictly followed.

2.2.5.1.3 Questionnaire Survey

This study has used a social science methodology. To gather first-hand information and other people's internal experiences of prior events, a questionnaire survey was undertaken with the Kobo toolbox. A questionnaire survey was carried out by distributing a set of specially created questions to each household (Annex I). The study employed a non-probability sampling technique to determine the sample for the study. Specifically, a sample of 507 households was selected for the questionnaire survey. The goal of the household survey was to learn more about local perceptions of the effects of climate change (CC) on water supplies and risks. The survey also sought to reveal to impacts of CC on livelihoods, like crop production, livestock raising, and coping/adaptive mechanisms used by the community. The statistical method of determining sample size was used to determine the number of HHs to be interviewed.

Throughout the research period, the researcher paid visits to the respondents' homes and neighborhoods. The latter dwellings were carefully screened. At the farmhouse, a number of unofficial interviews and talks were also held. This method was beneficial to the researcher for both in-depth data collection and triangulating information. Field observations were often made. On the field excursion, observations were made regarding the disasters and susceptibility. Notable details were noted and recorded. The area was photographed for future reference.

2.2.5.1.4 Focus Group Discussions

The FGD was included as a part of the study to have a holistic perspective of the residents of the study area on various matters related to climate changes, floods, climate change-induced floods, flood resilience, vulnerability, local livelihood related to flood disaster, current coping and adaptive strategies adopted by communities to improve livelihood. The detailed information and list of participants in the FGD are given in appendix 2.

In order to gain a comprehensive understanding of the residents of the study area on a variety of topics related to flood, climate change, water resources, resilience, local livelihood related to water resources, current coping and adaptive strategies adopted by communities to improve livelihood, the FGD was included as part of the study. The FGD participant list and detailed information are provided in appendix 2.

2.2.6 Secondary Data Collection

Reviewing the literature published in journals, essays, theses, magazines, websites, and other formats allowed for the collection of secondary data. Secondary data are information that has previously been obtained for another study or piece of research. Because description and analysis form the basis of this study, secondary data are crucial. A comprehensive evaluation of pertinent books, journals, articles, research papers, and reports was done to collect the secondary data. Also, part of the secondary data utilized in this study came from Regional Center AGRHYMET, Niger Basin Authority ABN, and other organizations, as well as libraries and websites of relevant research institutions. The required information was given by governmental and non-profit organizations, including the National Institute of Statistics (INS).

In order to understand the historical weather patterns and examine trends and fluctuations in temperature, rainfall, and severe occurrences, climate data from 1990 to 2020 were collected. The primary source of data utilized to evaluate the pattern of climatic changes were the temperature and rainfall reports of Niamey, the capital city of Niger. These reports were produced by the National Directions of Meteorology, water resources, and other relevant entities. The meteorological information needed for the investigation was gathered via the Climate Data Portal.

2.2.7 Reliability

The findings of the survey were deemed accurate for the study's intents and objectives since there was no bias present and participants' observations were used to complete the questionnaire, while they were out on the field. For the researcher to get accurate and objective replies, comparable questions were asked to the same family members. Follow-up questions were posed to senior citizens on the field to verify the data gathered during interviews. These techniques, together with targeted group discussions and key informant interviews, assisted in gathering information on the ground and verifying the data. Observation was also helpful in determining the correctness of the information acquired in the field in order to corroborate the accuracy of the data obtained.

2.2.8 Method of Data Processing, Analyzing, and Interpretation

The supervisor reviewed the first-hand information for the data analysis after the fieldwork was completed, and the results of the interview on the households' (HH) questionnaires were then recorded. Quantitative data were entered into a computer using a spreadsheet. The findings were then tabulated accordingly.

Qualitative data were, if feasible, first coded and then converted into quantitative type before analysis. Data quantification was also done while the questionnaire was being prepared, where it was practical to do so. For the ensuing computations, a variety of statistical tools—in particular, SPSS, Kobo Toolbox, and Excel were used in accordance with the objectives of the study. The material in this research was based on a descriptive analysis backed by the household-based replies that had been tabulated and quantified for an easy-to-read presentation in tables, charts, and graphs. Discussions were based on document analysis and cross-verification of the variables from each of the frequencies. The data collected was analyzed using both descriptive and inferential statistical methods. The 2010 version of Microsoft Office Excel was used to total and statistically analyze the data. Descriptive statistics were used to characterize the socioeconomic characteristics of the respondents, including their sex, age, ethnicity, employment, level of education, and knowledge. The annual temperature and precipitation trends were investigated using a DHM report that was published. To supplement and contribute to the quantitative information acquired from home interviews and the weather stations, manual analysis and interpretation of key informant interviews and group discussions were conducted. The DHM data was processed, examined, and analyzed using the appropriate statistical tools, tables, graphs, charts, and graphical representations. All of the statistical information was recorded and analyzed using spreadsheets. The maps were produced using GIS and other relevant computer programs. However, manipulating a large range of geographical and time series data is required for the understanding of hydrological phenomena. The digital elevation model (DEM), a semi-distributed, physical-based hydro-topographic modelling system, GIS and remote sensing methods were employed to simulate flood catastrophes. At the AGRHYMET-CCR AOS GIS Lab, the modelling was finished using ArcGIS version 10.5 and the Digital Earth Africa sandbox platform.

2.2.9 Ethics of Research/Considerations of Ethics

Dowling (2009) defines research ethics as a researcher's conduct, duties, and commitments to all parties engaged in the study. This includes the study's subject but also sponsors and the wider public. Dowling (2009) further defines "research ethics" as how researchers conduct themselves, respect study participants, and ethically engage with them when it comes to problems like permission, privacy, secrecy, and power. Privacy, confidentiality, and respondent anonymity are the main concerns I need to confirm as part of my study ethics. The respondents' responses were kept private and secret. The local leaders of the study region were briefed on the study's details. The respondents, particularly women who had already verbally consented to the interview, were asked for their informed consent. I have to explicitly explain my current role as a researcher and constantly "put my research hat on" since I interview stakeholders with whom I have had prior professional connections.

Partial Conclusion

This Chapter offers a comprehensive viewpoint by considering geographical, human, socio economic and methodological aspects. The geographical analysis emphasises the differences in both natural and human factors, emphasising how various variables influence economic activity and the distribution of settlements. The susceptibility of ecosystems to human-induced pressure and flood catastrophes, exacerbated by multiple human pressures and unpredictable precipitation patterns. Niamey is consistently exposed to the threat of flooding, which is further exacerbated by sudden and intense flash floods.

The research employs a rigorous methodology, including both quantitative and qualitative data collected from surveys and agencies. The study is guided by three essential components: documentary investigation, data collecting, and analysis. The approach used in the field research aims to acquire meteorological data, comprehend public views of rainfall variability, and investigate adaptive methods.

Ultimately, the study not only reveals the complexities of geographical and human factors, but also utilises a rigorous technique to investigate climate patterns. An analysis of physical, human, and climatic aspects allows the research to provide useful insights into the difficulties posed by environmental dynamics, so contributing to a nuanced comprehension and viable solutions for sustainable development.

3 Chapter 3: Flood types, Causes, and Effects in Niamey

Introduction

Three major categories of floods caused by rain have been recognised in Niger: 1) pluvial floods, which happen when torrential rain falls on a location for a very brief period of time; 2) floods caused by the overflow of watercourses (rivers, Kori, Maggia, valleys); and, 3) floods caused by a rise in the water table, particularly by a resurgence of water of a shallow aquifer following in significant underground flows. For instance, in Niger, floods during the rainy seasons of 2010 and 2012 caused huge problems that impacted more than 500,000 people.

The understanding of Niamey's susceptibility to floods and the potential reduction of the latter depend heavily on efficient flood risk assessment strategies. Niamey, which is situated on the banks of the Niger River prone to severe rains, has already been the victim of disastrous floods that caused fatalities, damage to infrastructure, and financial difficulties. Therefore, understanding flood risk is crucial for efficient catastrophe response planning, as well as for increasing population resilience. The methodical review of several elements, such as hydrological conditions, rainfall patterns, terrain, land use, and infrastructure vulnerability, is part of the process of assessing flood risk. Stakeholders may identify high-risk regions, evaluate possible effects, and create specialized plans to lower flood risks by looking at these factors. In order to achieve a comprehensive understanding of flood risk and facilitate an informed decision-making process for sustainable development and disaster risk reduction, this session provides an overview of flood types, causes, and effects in Niamey. It does so by emphasizing on land use land cover dynamic, and stakeholder involvement.

3.1 Socio-Economic Characteristics of Respondents

The questionnaires contain respondents' socio-demographic data. The data were analysed using frequency distribution, percentages, and descriptive statistics through SPSS Version 20 (table 9).

Table 9: Socio-economics Characteristics of respondents

Variables	Districts Areas (Total)	Niamey 1	Niamey 2	Niamey 3	Niamey 4	Niamey 5
Number of respondents *n (%)*	507 (100%)	120 (23.7%)	73 (14.4%)	62(12.2%)	123(20.3%)	129(25.4%)
Gender *n (%)*						
Male	279 (55%)	62 (85%)	45 (61.6%)	32 (53.3%)	25 (62.5%)	47 (78.3%)
Female	228 (45%)	58 (15%)	28 (38.4%)	28 (46.7%)	15 (37.5%)	13 (21.7%)
Age (years) *n (%)*						
Below 20	24 (7.7%)	1 (0.83%)	9 (13.33%)	1 (1.62%)	2 (1.63%)	11 (8.53%)
20-39	186 (36.7%)	37 (30.83%)	28(38.36%)	22 (35.48%)	41(33.33%)	58 (44.96%)
40-59	218 (43.0%)	67 (55.83%)	26 (35.62%)	35 (56.45%)	46(37.40%)	44 (34.11%)
Above 60	79 (15.6%)	15 (12.51%)	10(13.70%)	4 (6.45%)	34 (27.64%)	16(12.40%)
Educational Level *n (%)*						
No Formal Education	241 (47.53%)	45(37.50%)	40(55.56%)	24(38.71%)	71(57.72%)	61(47.29%)
Apprenticeship/Vocational	8(1.56%)	2(1.67%)	2(2.78%)	0	3(2.44%)	1(0.78%)
Primary Education	135 (26.63%)	40(33.33%)	15(20.83%)	24(38.71%)	25(20.33%)	31(24.03%)
Secondary Education	85 (16.76%)	26 21.67%)	10(13.89%)	10(16.13%)	19(15.45%)	20(15.50%)
Tertiary/High Education	37(7.30%)	7 (5.83%)	5(6.94%)	4(6.45%)	5 (4.07%)	16(12.40%)
Occupation *n (%)*						
Farmer	72 (14.2%)	8(6.67%)	11(17.07%)	5(8.06%)	18(16.63%)	30(23.26%)
Breeder	5(1%)	3 (2.50%)	2 (2.74%)	0	0	0
Fisher	15(3%)	2 (1.67%)	5 (6.65%)	4 (6.45%)	3(2.44%)	1(0.78%)
Trader	168 (33.1%)	43(35.83%)	28 (38.36%)	23(37.10%)	44(35.77%)	30(23.26%)
Salary Worker	88 (17.4%)	20(16.67%)	6 (8.22%)	11(17.74%)	24(19.51%)	27(20.93%)
Unemployed	83 (16.4%)	16 (13.33%)	13 (17.81%)	11(17.74%)	14(11.38%)	29(22.48%)
Art and craft	39(7.7%)	17(14.17%)	2(2.14%)	6(9.68%)	10(8.13%)	4(3.10%)
Others	37(7.3%)	11(9.16%)	6(08.22%)	2(3.23%)	10(8.13%)	08(6.02%)
Monthly income (FCFA) *n (%)*						
Less than 30,000	284(56.02%)	67(55.83%)	43(58.90%)	33(53.23%)	61(49.59%)	80(62.02%)
30,000-50,000	181 (35.70%)	43(35.83%)	23(31.51%)	28(45.16%)	47(38.21%)	40(31.01%)
50,000-100,000	33 (06.51%)	8(6.67%)	6 (8.22%)	1(1.61%)	9(7.32%)	9(6.98%)
More than 100,000	9(1.77%)	2(1.67.0%)	1(1.37%)	0 (0.0%)	6(4.88%)	0 (0.0%)
Length of stay in current residence (years) *n (%)*						
Less than 20	14 (3.5%)	4 (10.0%)	0 (0.0%)	2 (3.4%)	2 (5.0%)	1 (1.7%)
20-29	54 (13.5%)	5 (12.5%)	11 (18.3%)	12 (20.3%)	6 (15.0%)	1 (1.7%)
21-30	109 (27.3%)	12 (30.0%)	10 (16.7%)	11 (16.9%)	4 (10.0%)	10 (16.7%)
Over 30	223 (55.7%)	19 (47.5%)	39 (65.0%)	35 (59.3%)	28 (70.0%)	48 (80.0%)

3.1.1 Results

The collected data provided valuable insight into the diverse demographic and socio-economic profiles of the various respondents from different parts of Niamey. The results were presented as a combination of percentages and raw figures, covering a range of variables, such as gender, age, education, occupation, income, and leasing information.

The gender breakdown of respondents revealed a clear majority of men (55%), with the remaining 45% being women. This distribution was consistent across all the district areas for example, in Niamey 1, men represented 85% of respondents.

Age demographics vary between Districts. For example, in Niamey 1, approximately 30.83% of respondents were in the 20-39 age bracket, indicating a distinct age distribution.

Level of education was classified into several categories, including no formal education, apprenticeship/vocational training, primary education, secondary education, and tertiary/higher education. These education categories were distributed differently across the Districts. In Niamey 2, for example, 55.56% of respondents had no formal education.

Occupational categories cover a wide spectrum, encompassing professions, such as farmers, herders, fishermen, shopkeepers, salaried workers, unemployed, artisans, and others. The distribution of occupations varied from one District to another. In Niamey 4, shopkeepers were the largest group with 37.10%, followed by salaried workers with 17.74%.

The monthly income was divided into distinct brackets: less than FCFA 30,000, FCFA 30,000-50,000, FCFA 50,000-100,000, and more than FCFA 100,000. The majority of respondents fell into the bracket below 30,000 FCFA, although the distribution of income varies from one District to another.

Respondents' leasing period was segmented into categories, such as under 20 years, 20-29 years, 21-30 years, and over 30 years. Length of stay varies between Districts. Remarkably, in Niamey 5, a significant proportion (80%) of respondents have been living in their current locality for more than 30 years.

In summary, the results provided a comprehensive description of the demographic and socio-economic characteristics of respondents across the various Districts of Niamey. The data highlighted the diversity of the population in terms of gender, age, level of education, occupation, income, and length of residence (lease period). This information was of considerable value for informed decision-making and the formulation of targeted policies that responded to the specific needs of distinct segments of the population.

3.1.2 Discussion

The results pointed to a multifaceted picture of the socio-economic landscape in Niamey's various local authorities. The distribution of respondents across the different local governments reveals varying ratios of men to women in the different regions of Niamey. It is interesting to note that some regions, such as Niamey 1 and 5, have a significantly higher percentage of male respondents, while Niamey 2 and 3 have a higher proportion of female respondents. The gender distribution across the different local governments highlights distinct gender disparities that appear to be linked to specific geographical regions. The variation in gender proportions suggests the presence of localized gender dynamics that may be influenced by the unique cultural and societal norms prevalent in each region. These disparities in gender representation could reflect differences in economic roles, access to education, and cultural norms between different localities. This geographical disparity between the sexes could reflect a complex interplay between cultural norms, economic opportunities, and historical context. An intriguing correlation between age, education, and occupation emerges. Respondents in higher age categories tend to have higher levels of education, indicating a potential link between age and education. Older respondents, particularly in the 40-59 and over-60 age groups, appear to have pursued further education, suggesting a potential generational tendency to value education more over time. This trend can be attributed to changing societal perspectives and increased accessibility to education. In addition, the distribution of educational attainment across occupations highlights the influence of educational attainment on occupational choices. As the level of education increases, respondents are more likely to enter occupations that require a higher skill set. In addition, the distribution of education levels across different occupations highlights the role of education in career orientation. People in skilled occupations often have higher levels of formal education, while jobs that require less formal education tend to be concentrated in younger age groups. The intersection between monthly income and occupation reveals some intriguing patterns. Respondents in higher-skilled occupations, such as salaried workers and shopkeepers, experience a wider range of incomes, including higher brackets. This correlation underlines the importance of skills-based occupations in increasing potential earnings. Conversely, jobs such as agriculture and livestock farming, which generally require fewer formal skills, often generate lower incomes. This relationship underlines the importance of skills acquisition for socio-economic progress. Unsurprisingly, the data shows that income is closely linked to both occupation and education. The link between occupation and income is clear, as respondents in occupations requiring higher skills (such as employees and shopkeepers) have a wider range of incomes, including those in the higher brackets. This reaffirms the idea that skill-intensive jobs often offer better income opportunities. Furthermore, the correlation between higher levels of education and higher income brackets highlights the important role that education plays in socioeconomic advancement and the potential for upward mobility. Examination of the length of stay in the current residence provides an insight into the stability and integration of different local communities. Niamey 4 and 5 have a significantly higher percentage of respondents who have lived in their current residence for more than 30 years. This suggests that these areas have a more established population, which could indicate long-standing community ties and infrastructure development. Shorter lengths of stay in Niamey 1 and 2 could indicate factors such as urbanization, migration patterns, and housing availability. Analysis of the length of stay in the current residence in the different local administrative areas provides valuable insights into residential stability. In particular, Niamey 4 and 5 have a higher proportion of respondents who have lived in their current residence for more than 30 years. This suggests a more entrenched community presence in these areas, probably influenced by factors such as social networks, infrastructure development, and cultural ties. In contrast, the shorter stays in Niamey 1 and 2 may reflect the influx of migrants or rapid urbanization.

The intriguing link between gender, age, and occupation highlights how the interaction of socio-demographic factors shapes occupational choices. Notably, certain occupations display a gender bias, with men dominating roles, such as agriculture, commerce, and wage labor, while women are more present in animal husbandry, fishing, and arts and crafts. This suggests the intersection of factors such as gender norms, age-related expectations, and societal perceptions that influence occupational preferences. The interweaving of gender, age, and occupation introduces an intriguing narrative. The predominance of men in certain professions such as agriculture and commerce, suggests the presence of traditional gender roles, where men are more involved in primary economic activities. On the other hand, occupations such as animal husbandry and fishing appear to have a higher representation of women. In addition, age-related nuances reveal generational changes in occupational preferences. This complex relationship highlights the impact of age, gender, and social norms on occupational choices. The link between the level of education and monthly income highlights an essential relationship. Respondents with higher levels of education tend to have higher incomes, reflecting the income-education gradient. This correlation between education and income reaffirms the role of education as a catalyst for economic empowerment, potentially enabling individuals to access better employment opportunities and higher earning potential. Looking at education levels in different occupations reveals an interesting picture. Occupations that require specialist skills, such as salaried workers and tradespeople, tend to attract people with higher levels of education. Conversely, occupations such as agriculture and commerce have a higher proportion of respondents with no formal education at all. This corresponds to the concept of skill-based occupational stratification, where certain jobs require specific levels of education and expertise.

The results combine the variables of gender, age, education, occupation, income, and length of stay in a complex web of relationships. The models that emerge highlight the considerable implications of these factors for individuals' lives, career paths, and socio-economic status. Recognition of these complex links is crucial for policymakers and stakeholders to tailor interventions that respond to the unique challenges and opportunities faced by different segments of the population, ultimately working towards a fairer and more inclusive society. In the complex tapestry of socio-economic dynamics, the variables of gender, age, education, occupation, income, and length of stay weave a compelling narrative. These interrelations offer a nuanced understanding of how individuals' lives are shaped by their demographic characteristics and societal context. This multi-faceted perspective is invaluable in developing targeted policies and interventions that address the unique needs and challenges faced by different segments of the population, thereby promoting a more inclusive and equitable society.

3.2 Climate Hazards in The Localities

Figure 30 provides a comprehensive overview of how communities in Niamey, Niger, perceive and prioritize different climate-related risks. These perceptions are essential as they guide local preparedness, adaptation, and resilience strategies, shaping the response to potential environmental challenges. At the forefront of these perceptions is 'flooding (from rain and rivers)', cited by an overwhelming 78% of the communities surveyed. This statistic underlines the significant impact of heavy rainfall and flooding rivers on communities. This high percentage suggests that flooding is a recurring and serious concern with the potential to damage infrastructure, displacement, and disruption to daily life. The need for effective flood management and early warning systems becomes clear to address this major concern.

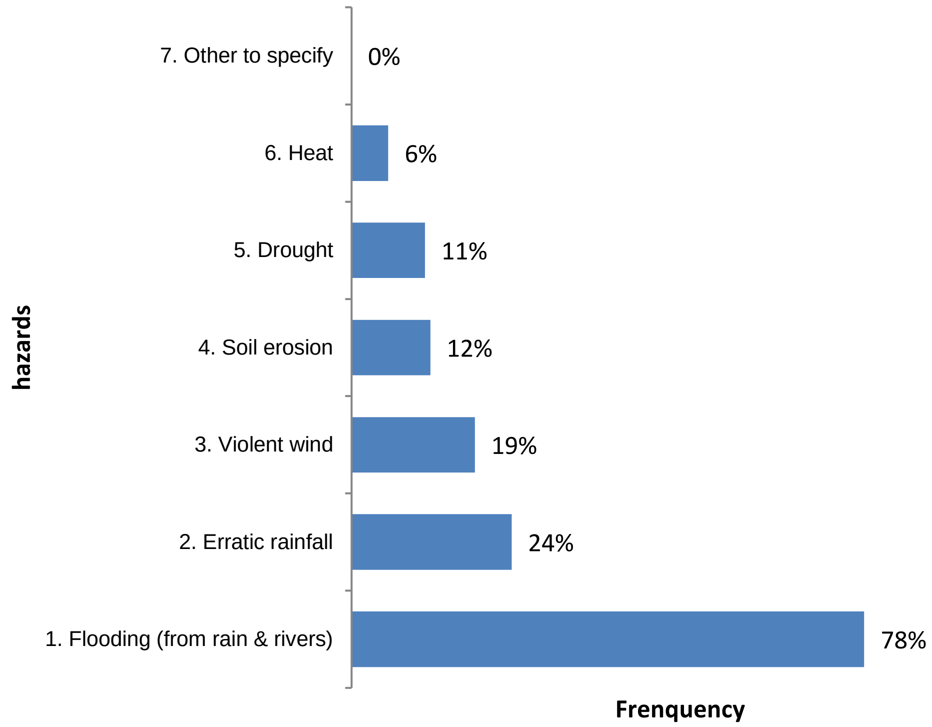

Figure 30: Climate-related hazards in Niamey (Source: Field survey,2022)

Irregular rainfall, mentioned by 24% of communities, highlights the unpredictability of rainfall patterns. The relatively low percentage compared to flooding may indicate that, although erratic rainfall is a problem, it may not be as immediate and widespread as flooding. Nevertheless, erratic rainfall can hurt agricultural activities and water availability, hence the need for sustainable water management and drought-resistant crops. The fact that 19% of communities recognize 'strong winds' as a hazard means that they are aware of the destructive power of strong winds, such as cyclones or hurricanes. This perception reflects the risk of damage to infrastructure, disruption of electricity supplies, and damage to human settlements. Building wind-resistant infrastructure and promoting community preparedness can minimize the impact of these events.

Soil erosion is a concern for 12% of communities. This indicates that communities recognize soil degradation caused by factors, such as poor land management and intense rainfall. This percentage suggests that while soil erosion is a concern, it may not be as immediate a threat as other hazards. Sustainable land use practices and erosion control measures could solve this problem. The perception of 'drought' as a hazard by 11% of communities shows that they understand the adverse effects of a prolonged water shortage. This percentage reflects the importance of water availability in a region where resources may already be limited. Drought-resistant agriculture, water conservation practices, and community water storage systems could be key strategies for mitigating the impacts of drought.

Heat, mentioned as a concern by 6% of communities, highlights their awareness of extreme temperatures and heat waves. Although this percentage is relatively low, it suggests recognition of the health and environmental risks associated with heat stress. Implementing heat action plans, improving urban planning for heat resilience, and raising awareness of heat-related health risks are key to addressing this concern. Surprisingly, none of the respondents provided additional categories under the heading "Others to be specified". This could mean that the hazards listed comprehensively reflect the main concerns of the communities surveyed, indicating that the pre-determined categories correspond well with community perceptions.

In conclusion, the table highlights that flooding is the main climate hazard perceived by communities in Niamey, followed by erratic rainfall and high winds. These perceptions guide the prioritization of strategies aimed at disaster preparedness, adaptation, and resilience. Approaches tailored to each hazard, community involvement and the integration of traditional knowledge with modern techniques can enable these communities to effectively combat climate hazards' challenges.

3.3 Level of Negative Impact on Household

Figure 31 provides a compelling snapshot of how communities in Niamey, Niger, assess and categorize the extent of negative impacts on their households resulting from various hazards. This assessment is crucial as it enables the development of policies, interventions, and support systems tailored to the specific vulnerabilities of each level of impact. The most striking observation is that the majority of communities, 59%, rated the negative impact on their households as "high." This large percentage reflects a significant proportion of households experiencing severe direct consequences from the hazards. This indicates that a large proportion of the communities surveyed have been severely affected by events such as flooding, erratic rainfall, heavy winds, and other hazards. These households may have experienced significant material damage, loss of livelihood, and disruption to their daily lives. As a result of the high rating, targeted interventions are urgently needed to provide immediate assistance, support recovery, and strengthen the resilience of the most vulnerable.

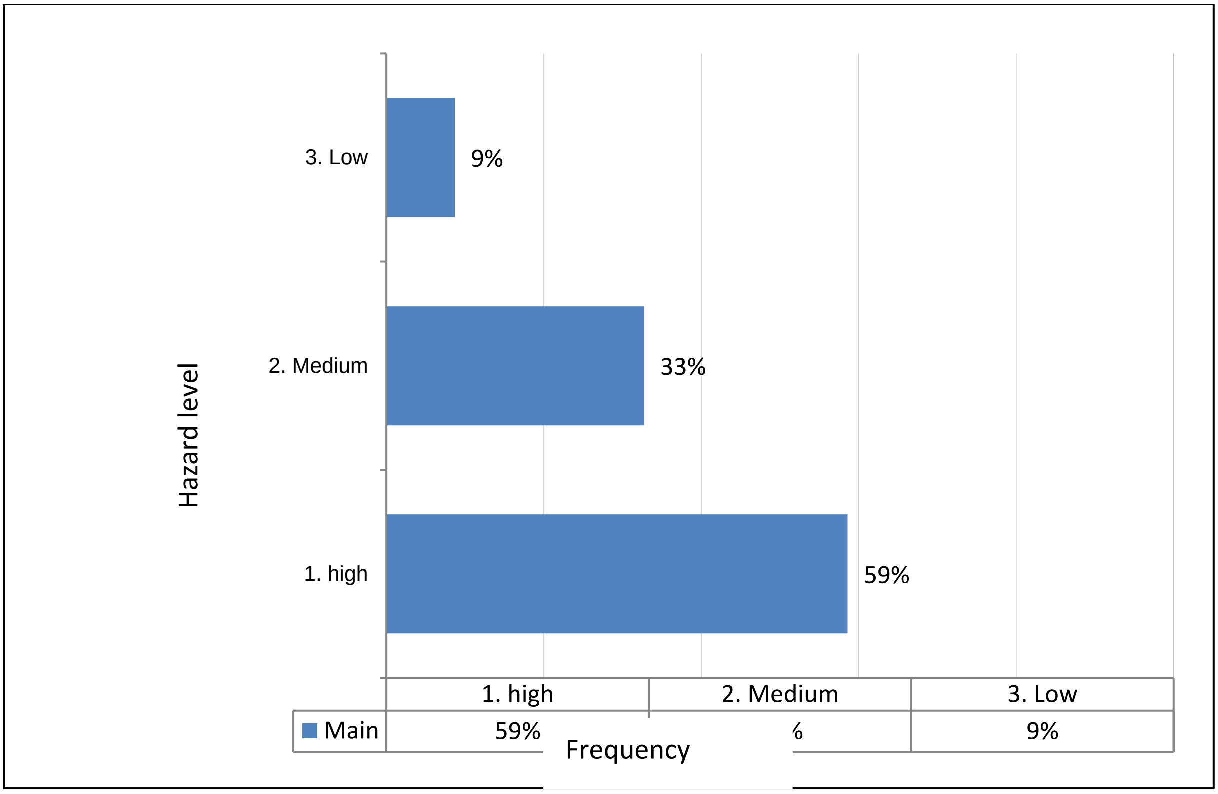

Figure 31: Level of negative impacts on household **(**Source: Field survey,2022**)**

33% of communities classified the impact as 'medium'. This percentage highlights a large group of households that have been adversely affected by the hazards, but not to the same extent as those in the 'high' category. This may indicate that, although the impact was not as severe, these households still experienced disruption and losses that warrant attention. A 'medium' rating indicates that action is needed to reduce vulnerabilities and improve preparedness to mitigate risks due to hazards. Interestingly, only 9% of communities perceive the negative impact as 'low'. This group presumably represents households that were fortunate enough to experience only minimal effects from the hazards. Although the percentage is relatively small, these households are not immune to future hazards, and their views could provide insights into effective practices that have contributed to their resilience. Their experience could be used to develop strategies that other households could adopt to minimize negative impacts.

Overall, the table shows a distribution of impact levels that highlights the different degrees to which households have been affected by hazards. The significant presence of the 'high' impact category is a call to action, highlighting the need for immediate support and interventions in the most vulnerable communities. The 'medium' and 'low' impact categories represent a range of challenges and experiences that can inspire comprehensive community resilience strategies.

Authorities and organizations can improve their response effectiveness to climate hazards by adapting their responses based on these different levels of impact. The lessons learned from these assessments can inform long-term initiatives aimed not only at mitigating negative impacts but also at building the capacity of communities to cope with future challenges.

3.4 The social groups vulnerable to flooding in Niamey

Figure 32 provides a significant insight into how communities in Niamey, Niger, perceive the vulnerability of different social groups to flooding. This understanding is crucial to developing targeted interventions, policies, and support systems that respond to the unique needs and challenges faced by each group. Top of the list of vulnerable groups is 'children', with 84% of respondents recognizing that they are highly vulnerable to flooding. This statistic shows that communities are aware of the high risk that children face in the event of flooding. Children are particularly vulnerable because of their limited mobility, their dependence on careers, and their increased vulnerability to health risks in unsanitary and disrupted environments. This high percentage underlines the need for child-focused disaster preparedness plans, safe evacuation routes, and access to essential services during and after floods.

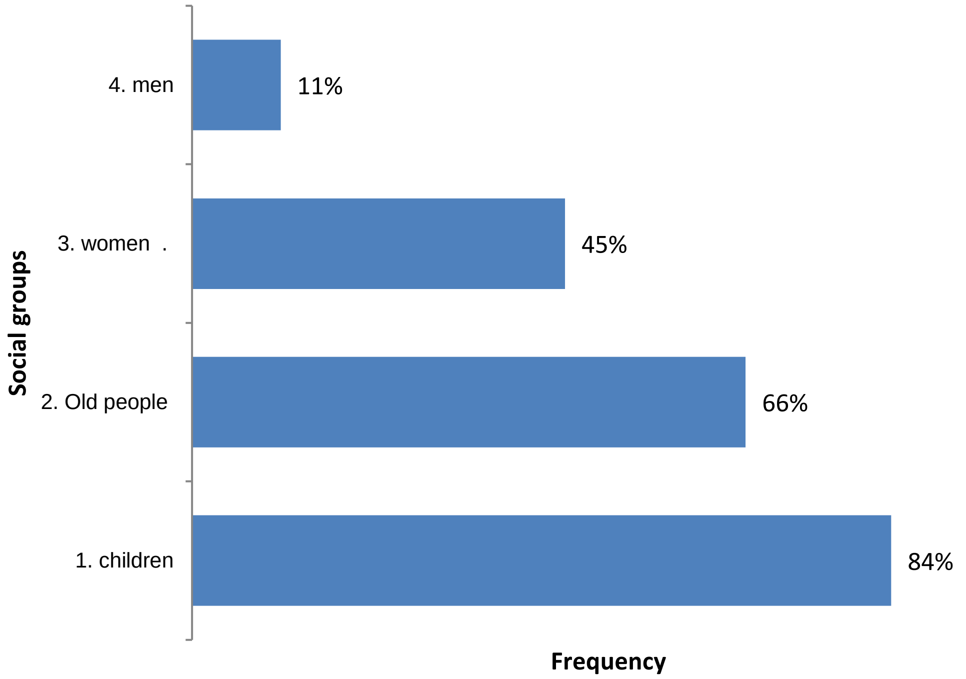

Figure 32: Social groups vulnerable to flood (Source: Field survey, 2022)

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The perceived vulnerability of 'older people' (66%) shows that older people face significant challenges in the event of flooding. Their reduced mobility, health problems, and potential isolation put them at greater risk in emergencies. The relatively lower percentage than for children may suggest a slight reduction in the level of perceived vulnerability, but it is still a significant proportion. Strategies tailored to older people, including accessible shelter, medical support, and community awareness, are essential to ensuring their safety and well-being.

Women are considered vulnerable to flooding in 45% of communities. This percentage shows that women may face particular difficulties during and after floods because of their roles and responsibilities in society. Ensuring access to hygiene and sanitation facilities, addressing the specific needs of men and women, and providing support for the care of dependents are essential aspects of addressing women's vulnerability. It is interesting to note that 'men' are only perceived as vulnerable to flooding by 11% of communities. This low percentage suggests that communities generally consider men to be less vulnerable than other groups. This perception may stem from traditional gender roles and norms, which often attribute roles to men who are perceived to be less vulnerable in the event of a disaster. However, it is important to note that vulnerability is not solely determined by gender and can vary according to other factors such as age, health, and socio-economic status.

In summary, the table highlights the diversity of perceptions of vulnerability to flooding among different social groups. Children and the elderly are particularly seen as highly vulnerable, while women are also recognized as facing unique challenges. The lower perception of vulnerability among men may be influenced by traditional gender norms. Recognizing and acting on these perceptions is essential to creating inclusive disaster management strategies. These strategies must consider the specific needs of each group, ensure equitable access to resources, and prioritize the safety and well-being of all members of the community, regardless of age or gender.

3.5 The drivers of the vulnerability to flooding

Table 10 provides a significant insight into how communities in Niamey, Niger, perceive the underlying causes of their vulnerability to flooding. Understanding these factors is essential to developing effective strategies and policies that address the root causes and mitigate the impacts of flooding. Poverty is widely perceived as a major factor in vulnerability, as 60% of those surveyed acknowledged. This perception highlights the interaction between economic disparities and vulnerability. Poverty limits access to resources and options for preparedness and resilience. It suggests that marginalized communities may not be able to afford safe housing, invest in flood-resistant infrastructure, or access timely information in the event of a disaster. Tackling poverty through inclusive development initiatives and targeted support systems is essential to breaking the cycle of vulnerability.

Table 10: causes of vulnerability to flood in the communities

What is responsible for your vulnerability to flooding?	
Responsible of vulnerability	**Frequency**
Poverty	60%
Environmental degradation	52%
Climate change	36%
Inadequate support	35%
Cultural attachment	29%
Other, please specify	1%

Source: Field survey,2022

"Environmental degradation is considered an important factor by 52% of communities. This suggests that communities recognize the link between environmental factors and their vulnerability. Degradation of natural resources such as wetlands, deforestation, and inappropriate land use can exacerbate flooding. This perception underlines the importance of sustainable land management, reforestation, and ecosystem restoration as measures to reduce vulnerability. Around 36% of respondents attributed vulnerability to 'climate change'. This perception reflects an understanding that climate change is contributing to an increase in the frequency and intensity of floods. It underlines the need for adaptation strategies that take account of long-term climate trends and incorporate climate-resilient infrastructure and practices. "Inadequate support" is cited as a factor by 35% of communities, underlining the perception that insufficient assistance during and after floods contributes to vulnerability. This includes aspects such as emergency response, access to information, and post-disaster recovery efforts. Strengthening disaster management systems, improving early warning systems, and increasing the effectiveness of relief efforts are key to addressing this concern.

"Cultural attachment is considered a vulnerability factor by 29% of communities. This suggests that cultural norms and practices can influence decisions about where to settle and how to respond to alerts. Understanding and respecting cultural values while promoting safety and resilience can contribute to effective community engagement and preparedness. A minority of

1% identified "Other, please specify" factors. Although not detailed in the table, this response could potentially represent a range of localized factors that contribute to vulnerability, highlighting the diverse and context-specific nature of this question.

In conclusion, the table highlights the multifaceted perceptions of flood vulnerability among communities in Niamey, Niger. The recognition of poverty, environmental degradation, climate change, inadequate support, and cultural attachment as contributing factors highlights the complex interplay of socio-economic, environmental, and cultural dynamics. Developing global solutions requires collaborative efforts between government agencies, NGOs, community leaders, and international organizations to address these underlying causes. By combining short-term relief efforts with long-term development strategies, communities can build resilience and improve their ability to withstand and recover from the impacts of flooding.

3.6 Flood experience and other impact factors

According to Table 11, respondents in different Districts Areas in Niamey share their perceptions and experiences. By dissecting the data, we can discern valuable information that highlights the complex relationship between flood experience and critical impact factors. This analysis highlights the importance of tailored policies and strategies for flood management and education that address the diverse concerns and perspectives of different communities. The first segment of the table shows the frequency of flooding experiences reported by respondents. The data indicates a notable shift towards more frequent flooding, with a striking 68.44% of respondents stating that they experience flooding on an annual basis. While responses are consistent in the "Every year" category across all Districts, discrepancies appear in the lower frequency categories. This indicates the need for increased preparedness and mitigation strategies as flooding incidents become more frequent, particularly in areas such as Niamey 5, where the largest number of respondents reside.

Table 11: The distribution of respondents regarding Flood experience and other important impact factors

Variables	Districts Areas (Total)	Niamey 1	Niamey 2	Niamey 3	Niamey 4	Niamey 5
Number of respondents *n (%)*	507 (100%)	120 (23.7%)	73 (14.4%)	62(12.2%)	123(20.3%)	129(25.4%)
Flood experience						
Every five years	3(0.59%)	0 (0.00%)	1(1.37%)	1 (1.61%)	1 (0.81%)	0 (0%)
Every four years	34(06.71%)	6 (5.00%)	10(13.70%)	5(8.06%)	3(2.44%)	10 (7.74%)
Every two years	123(24.26%)	39(32.50%)	14 (19.18%)	14 (22.58%)	31(25.20%)	25 (19.38%)
Every year	347(68.44%)	75 (62.50%)	48(65.75%)	42(67.74%)	88 (71.54%)	94(72.87%)
Flood education K *n (%)*						
Agree	126(24.85%)	19(15.83%)	18(24.66%)	14(22.58%)	34(27.64%)	41(31.78%)
Disagree	101(19.92%)	31(25.83%)	26(35.62%)	13(20.97%)	13(10.57%)	18(13.95%)
Neither agree nor disagree	156(30.77%)	29(24.17%)	14(19.18%)	19(30.65%)	49(39.84%)	45(34.88%)
Strongly agree	57(11.24%)	18(15%)	5(6.85%)	4(6.45%)	12(9.76%)	18(13.95%)
Strongly disagree	67(13.22%)	23(19.17)	10(13.70%)	12(19.35%)	15(12.20%)	7(5.43%)
Don t know						
Flood management *n (%)*						
Bad	133(26.23%)	42(35%)	27(36.99%)	17(12.38%)	16(13.01%)	31(24.03%)
fair	173(34.12%)	40(33.33%)	23(31.51%)	18(29.03%)	56(45.53%)	36(27.91%)
Good	134(26.43%)	24(20%	13(17.80%)	15(24.19%)	36(29.27%)	46(35.66%)
None	33(6.51%)	4(3.34%)	10(13.70%)	5(8.06%)	4(3.25%)	10(7.75%)
Very well	34(6.71%)	10(8.33%)	0	7(11.29%)	11(8.94%)	6(4.65%)
Flood vulnerability *n (%)*						
Neutral	17(3.35%)	4(3.33%)	3(4.11%)	1(1.61%)	8(6.50%)	1(0.78%)
Highly vulnerable	105(20.71%)	15(12.50%)	21(28.77%)	9(14.52%)	25(20.33%)	35(27.13%)
less vulnerable	57(11.24%)	8(6.67%)	11(15.07%)	11(17.74%)	15(12.20)	12(9.30%)
Not highly vulnerable	157(30.97%)	43(35.83%)	24(32.88%)	20(32.26%)	35(28.45%)	35(27.13%)
vulnerable	171(33.73%)	50(41.67%)	14(19.18%)	21(33.87%)	40(32.52)	46(35.66%)
Trust in Government action n *(%)*						
indifferent	49(9.67%)	10(8.33%)	19(26.03%)	4(6.45%)	4(3.25%)	12(9.30%)
less Satisfactory	158(31.16%)	39(32.50%)	11(15.07%)	15(24.19%)	47(38.22%)	46(35.66%)
No satisfactory	117(23.08)	40(33.33%)	18(24.66%)	21(33.87%)	14(11.38%)	24(18.60%)
Satisfactory	154(30.37%)	23(19.17%)	22(30.14%)	16(25.81%)	51(41.46%)	42(32.56%)
Very satisfactory	29(5.72%)	8(6.67%)	3(4.10%)	6(9.68%)	7(5.69%)	5(3.88%)

Looking at the responses regarding flood education, a remarkable 24.85% of respondents indicated that they agreed that they had received flood education. However, the disparities between LGAs in terms of agreement raise questions about educational initiatives' availability and effectiveness. While Niamey 5 shows a high level of agreement, other Districts show mixed opinions, suggesting a potential need for targeted education campaigns in certain areas to bridge the knowledge gap. The next section looks at respondents' perspectives on the quality of flood management. The diversity of opinions is evident as respondents range from "poor" management (26.23%) to "very good" (6.71%). These responses reflect the multi-dimensional nature of flood management, which can involve complex elements of infrastructure, policy, and community engagement. The divergence between Districts highlights the need to tailor flood management strategies to the specific needs of each area. The data on perceptions of vulnerability to flooding reflect respondents' self-assessment of their vulnerability to flooding. The "Very vulnerable" category stands out, with 20.71% of respondents identifying themselves as such. In particular, Niamey 2 and Niamey 5 reported relatively higher rates of vulnerability. This trend highlights the need to assess risks and take adaptation measures in areas where vulnerability is perceived to be high.

Lastly, public sentiment can be gauged by confidence in government action on flooding. Responses varied considerably from one District to another, illustrating different levels of satisfaction. The "Less satisfactory" category attracted the attention of 31.16% of the respondents, particularly in Niamey 4. These results underline the importance of transparent and effective communication in fostering community confidence and engagement in flood management initiatives.

The data in this table present a comprehensive narrative that highlights the complexities of the flood experience and impact factors. Variations in responses between Districts indicate that a one-size-fits-all approach to flood management, education, and policy may not be effective. Instead, a localized, community-focused strategy that considers the unique characteristics and concerns of each area is essential. By drawing on this information, decision-makers and stakeholders can develop targeted and informed interventions that promote effective flood management, education, and community resilience.

There is significant variation in the frequency of flooding reported in different district areas. Areas such as Niamey 2 and Niamey 3 report higher frequencies of flooding every four years, which may suggest that certain geographical or environmental factors influence these patterns. It would be useful to study whether factors such as proximity to rivers, altitude, or urban planning contribute to these differences. There appears to be a link between flood education and perceptions of flood management. In Niamey 5, where agreement on flood education is highest, the percentage of respondents rating flood management as "Fair" is also high. This could indicate that more educated respondents are more critical of assessing management practices. It may be interesting to investigate whether better education leads to higher expectations of flood management efforts. The data suggest a potential link between perceptions of vulnerability and confidence in government action. Areas with higher levels of vulnerability, such as Niamey 2 and Niamey 5, also tend to have lower levels of confidence in government action. This could mean that residents who feel more vulnerable are less likely to have confidence in the government's ability to deal effectively with flood-related issues. Further qualitative research could help uncover the underlying reasons for this relationship.

There may be an interesting correlation between the frequency of flooding and confidence in government action. Respondents in Niamey 1, which reports the highest frequency of annual flooding, also have relatively lower confidence in government action (23.08% rate it as 'unsatisfactory'). This might suggest that recurrent flooding could lead to increased skepticism about the government's response efforts. The distribution of flood management ratings across categories of vulnerability is worth investigating. Notably, areas reporting higher rates of vulnerability, such as Niamey 1 and Niamey 5, also have relatively higher proportions of respondents rating management as "Poor" or "None". This may suggest that perceived vulnerability influences perceptions of the effectiveness of management efforts. There may be a link between confidence in government action and the perceived quality of flood management. In Niamey 4, which has the highest rate of "Least Satisfactory" in confidence ratings, there is a higher proportion of respondents who rate management as "Poor". This indicates that dissatisfaction with government action may translate into skepticism about the quality of flood management. There may be a relationship between flood education and perceived vulnerability. Areas where more respondents agree with statements about flood education (e.g. Niamey 5), tend to have lower proportions of respondents categorizing themselves as 'Very Vulnerable'. This could suggest that education could contribute to a better understanding of flood risk and how to mitigate vulnerability.

To draw more definitive conclusions and establish statistically significant correlations, further quantitative analysis, such as correlation coefficients and regression analysis, would be required. In addition, qualitative research to gather more in-depth information from respondents could uncover the underlying factors that contribute to the observed relationships.

These findings may then inform policies and interventions to tackle flooding and its effects in these district areas.

3.7 Drivers of Flooding in Niamey

3.7.1 Heavy Rainfall

Heavy rainfall in Niamey can cause significant flooding due to its intensity and duration. During the rainy season, which usually lasts from June to September, the city experiences heavy downpours, often for short periods. This intense rainfall exceeds the capacity of the soil to absorb water, resulting in rapid runoff. The excess water accumulates on the surface, overwhelming drainage systems and causing flooding. Niamey's topography, with its relatively flat terrain and limited natural drainage, further exacerbates the impacts of heavy rainfall by preventing the efficient flow of water away from urban areas. Heavy rainfall is the primary cause of flooding identified all over the globe (WHO, 2018). When heavy rain occurs both floodplains and rivers can overflow. In fact, it can be said that 55% of flooding is attributed to heavy rainfall (Rhoda et. al., 2017) because when there is a poor drainage plan in a community rain tends to accumulate and overflow the drainage systems or when people constantly keep dumping refuse along a water way it also causes flooding. The commonest known flooding of heavy rain is 'river overbank flooding'. Overbank flooding occurs when downstream rivers receive more rain from their tributaries than normal, for this reason, excess water overloads the rivers and flows out onto the floodplain. Based on this research this is the case of the River Niger Basin.

3.7.2 Hydrological Factors

Niamey's vulnerability to flooding is influenced by hydrological factors, including riverbed movement, sediment deposition and bank erosion. Over time, the River Niger and its tributaries can undergo natural changes to their riverbeds, altering the path of the water. These changes can redirect water towards populated areas, increasing the risk of flooding. In addition, the deposition of sediment in rivers reduces their transport capacity, leading to higher water levels during floods. Bank erosion weakens the stability of the banks, making them more susceptible to collapse and further contributing to the risk of flooding in Niamey.

3.7.3 Urbanisation and Land Use Changes

Rapid urbanisation and inadequate land-use planning have intensified flood risks in Niamey. The expansion of urban areas has resulted in the conversion of natural land cover, such as vegetation and permeable soils, into impermeable surfaces such as roads, buildings and pavements. These surfaces prevent rainwater from infiltrating the soil, leading to increased surface runoff. As a result, during heavy rainfall, water runs off in excess onto these impervious surfaces, overwhelming limited drainage infrastructure and exacerbating flooding in low-lying areas. Unregulated construction in flood-prone areas further exacerbates the problem, as these areas lack adequate protection and drainage infrastructure.

3.7.4 Deforestation and Soil Erosion

Deforestation and soil erosion in the upstream areas of the Niger River Basin have consequences for flooding in Niamey. The removal of trees and vegetation reduces the natural protective cover, making the soil more susceptible to erosion. This results in increased sedimentation in the rivers, reducing their flow capacity and increasing the risk of overflow during periods of heavy rainfall. The influx of sediment from upstream areas also contributes to the silting of river beds, reducing their capacity to carry water efficiently and exacerbating the risk of flooding downstream in Niamey.

3.7.5 Inadequate Drainage Infrastructure

The inadequacy of drainage infrastructure significantly contributes to flood risk in Niamey. The existing drainage systems often lack the capacity to handle the volume of rainfall during heavy storms. Outdated and undersized drainage networks struggle to cope with the rapid runoff, leading to water accumulation in low-lying areas. Insufficient maintenance exacerbates the problem, as blocked or poorly maintained drains impede the proper flow of water. Additionally, improper waste disposal practices, such as the dumping of solid waste in drains and water channels, further obstruct the drainage system, compounding the flood risk.

3.7.6 Damming

Damming is another major cause of flooding, especially along the study area (Tadahiko, 2006). This is mainly as a result of poor management or an unaware breakage in the dam. The Niger Dam has been posing a serious threat to communities leaving downstream River Niger causing rivers to flow over their bank unto floodplain surfaces (Toro, 1997). This is because sometimes they can occur with little or no warning on clear days when people are not expecting, much less a flood.

3.7.7 Sedimentation

Silting is a factor that, in the present, poses a threat to the river's inhabitants. Due to the fact that sand takes up the majority of the river bed, this aspect makes floods more severe and extends them significantly in space. The koris that flow into the Niger River contribute to its silting process by transporting a significant amount of sand throughout the winter and depositing it on the riverbed. During times of low water, this behaviour can be seen. Because of how crucial transportation is, koris have places where sand is spreading (figure 13). The river is now in danger because of this process. In recent years, sand formations have been seen in locations where they were previously unheard of (picture 6). The likelihood of another flooding similar to the 2012 disaster is, in fact, still concerning. navigation and recreation.

3.7.8 Climate Change

Although the direct relationship between climate change and flooding in Niamey may be complex to establish, there are potential impacts of climate change that contribute to flood risk. Alteration of precipitation patterns may lead to more intense rainfall events in a shorter time frame. This increase in rainfall intensity and concentration can overwhelm the city's drainage systems and cause flooding. In addition, although Niamey is not directly affected by sea level rise due to its inland location, it may still experience indirect impacts. Sea level rise can influence river and tidal levels, affecting the flow and drainage of rivers in the River Niger basin. These influences, combined with heavy rainfall, can exacerbate the risk of flooding in Niamey. In addition, climate change may influence other factors such as temperature and humidity, which may contribute to changes in the hydrological cycle and precipitation patterns, further influencing flood dynamics in the region. Understanding and addressing these climate change-related factors is crucial for effective flood risk management and adaptation strategies in Niamey.

3.8 Analyses of The Causes of Flood in Niamey

Niamey is a city whose citizens battle with the frequent issue of floods. The voices of these local communities resonate across the data, revealing insights into their perspectives about the underlying issues that contribute to the flooding of their areas. At the core of these perspectives is the awareness of the great power carried by nature. In table 12, 67% of respondents mention significant precipitation happening over a short timeframe as a main trigger for floods. These deluges, typified by a rapid spike in rain, have the potential to swiftly exceed the city's ability to handle extra water. Paving the way for worries regarding the city's resilience, 41% of the community blames floods to a lack of effective drainage infrastructure and the absence of dams. This perspective underlines the crucial role of urban design, underlining the necessity for comprehensive water management techniques to divert and control the flow of water during severe downpours. In a city where the rhythm of life harmonizes with the changing seasons, 40% of respondents stress the effect of long-duration rainfalls. Their observations show the relationship between constant rainfall and the saturation of the earth, resulting in an ecosystem that cannot absorb any more moisture a situation that results in extensive floods.

Table 12: Causes of flooding in Niamey

What do you think are the causes of flooding in your locality? Mention all that apply	
Causes of flood	**Frequency (%)**
Extreme precipitation in a short time	67%
Lack of drainage infrastructure and dams	41%
Long period of rain	40%
Climate Change	34%
Saturated or wet soil	30%
Poor management of the dam	27%
River overflow	25%
Construction of houses near the river	24%
God’s Will	23%
Lack of waste management	21%
Siltation of the river and tributaries	16%
Deforestation	9%
Rising groundwater level	8%
Don’t Know	1%
Other (Specify)	0%

Source: Field survey,2022

Within the perspectives in Table 12, a realization of global developments arises. A noteworthy 34% of respondents relate floods to the wider problem of climate change. This insight points to a greater grasp of the interdependence of local weather patterns and global environmental processes. Beneath the surface lurks a small but significant component: the state of the earth itself. About 30% of the population considers saturated or damp soil as a driving element behind floods. Their views underline that the land's ability to absorb water plays a vital role in deciding the result of severe rainfall. In this tale of water's ebb and flow, the management of dams emerges as a topic of concern. Around 27% of respondents see inadequate dam management as contributing to floods. This acknowledgement highlights the necessity for proper water reservoir management to control downstream water levels and decrease the danger of floods. As the lifeblood of the city threads its way, the river's function becomes a focal point. A quarter of respondents, 25%, acknowledge river overflow as a cause of floods. The river, once a source of nourishment, may suddenly convert into a harbinger of flooding when its banks are broken.

As the city expands and changes, so too does the interplay between man and the environment. Approximately 24% of the population links floods to the development of dwellings along the river. Their discoveries shed light on the effects of urban growth trespassing on flood-prone regions. Amidst the physical considerations lurks an intangible acceptance and acknowledgement of forces beyond human control. A sincere 23% ascribe floods to "God's Will," suggesting a spiritual worldview that defines natural phenomena within the framework of a higher power. Within the mosaic of causes, a key problem arises: waste management. For 21% of respondents, the relationship between insufficient garbage disposal and floods is evident. This illustrates the complicated interaction between human activities and their influence on urban drainage systems. In the city's hydrological narrative, the river's history intertwines with sedimentation. Around 16% of responders perceive the siltation of the river and its tributaries as an influencing factor. Their observations underline the effects of silt buildings on limiting water-carrying capacity. As the urban environment changes, the function of nature arises. Approximately 9% of the population considers deforestation as a contribution to floods. Their conclusions reflect an awareness of the biological function that trees play in reducing runoff and controlling water absorption. Beneath the surface, hidden forces are at play. For 8% of respondents, the increasing groundwater level is a factor they consider contributing to floods. Their ideas underline the interdependence of underlying hydrology and the apparent impacts of floods.

In the cacophony of viewpoints, a tiny proportion, 1%, confesses to not understanding the specific causes of floods. Their honesty underlines the intricacy of these events and the many opinions that coexist within the society. Strikingly, no respondents identify other reasons, demonstrating that the offered alternatives collectively cover their knowledge of the elements that lead to floods.

In summary, the mosaic of viewpoints provides a multidimensional understanding of the reasons behind Niamey's floods, one that incorporates scientific discoveries, urban planning concerns, cultural beliefs, and a recognition of both human and natural factors. This collective expertise has the potential to lead comprehensive initiatives aimed at minimizing the effects of floods and developing community resilience.

3.9 Consequences of Flood

The geomorphological and geological characteristics of the Niger River Basin and the intense meandering river pattern lead to flash flood phenomena in the broader area. The flood control drainage infrastructure is inadequate and certainly needs further improvements. In addition, the fact that main anthropogenic activities (agriculture and industry), extensive roads and constructions, critical facilities, and the more significant part of the city population lies in the area lead to the actuality that the flood disaster risk of the area is extremely high.

Several districts of Niamey are significantly affected because they are built in flood-prone areas. While the left bank is not generally prone to flooding, the right bank, which has been urbanised since the 1970s, is located on alluvial deposits and is therefore more vulnerable. Commune 5, on the right bank, was partly built in the eddies of a river bed, which is periodically reactivated after floods. Flood zones on the right bank concern the Lamordé district, Abdou Moumouni University, and the Zarmagandey-Karadjé-Saguia continuum On the left bank, the upstream district of Goudel and the downstream zone of Saga, located on alluvial deposits, are also particularly exposed to flooding.

Some authors attribute to Niger river bed silting the basic cause of Niamey's increased flooding frequency(Alou, 2018; Alou *et al.*, 2019; Massazza, Bacci, *et al.*, 2021). Nevertheless, independently of the discharge, the Niger River is reaching increasingly higher levels, causing recurrent floods of built and crop areas and affecting thousands of people (Figure 7). Riverine floods are not the only hydrological hazard in Niamey because flash floods are also recurrent, mainly due to poor drainage systems and lack of maintenance. The strong current and projected demographic growth in Niger and the urbanisation process of Niamey neighborhoods are likely to increase the exposure to floods, both for formal and informal settlements in flood-prone areas (Alou, 2018). These areas are particularly vulnerable because of the high poverty levels, aggravating flood risk, and associated adverse impacts. The urbanisation of the rural population following the droughts of the 1970s and 1980s generated enormous housing difficulties, and public authorities gave newcomers the freedom to settle even in flood-risk zones (Alou, 2018; Alou *et al.*, 2019; Issaka & Badariotti, 2013; Massazza, Bacci, *et al.*, 2021), unaware of the risk or forced to accept it.

According to (Bassirou *et al*., 2023)The overlapping of the recorded inundated area on the classified land cover map demonstrates that the flood affected approximately 149.541 Km^2, Built-up area highly prone to flooding: 18.325 km^2, Cropland area highly prone to flooding: 26.252 km^2, Built-up area medium prone to flooding: 79.318 km^2, Cropland area medium prone to flooding: 13.26 km^2.

While Built-up area unaffected to flooding: 8.724 km^2 and Cropland area unaffected to flooding: 3.662 km^2.

3.9.1 Effect of Flood on Household in Niamey

Figure 33 provides a crucial overview of the multifaceted impacts of flooding on the lives of communities in Niamey, Niger. Understanding these effects is essential to designing effective strategies and interventions that respond to the various challenges posed by flooding. The most widespread impact is that of a "flooded house", with 63% of respondents mentioning this effect. This highlights the immediate and direct consequences of flooding, where homes are inundated with rising water. A flooded house can lead to displacement, loss of shelter, and potential health risks due to unsanitary conditions. The high percentage suggests that a significant proportion of the communities surveyed experience this highly disruptive effect during flooding.

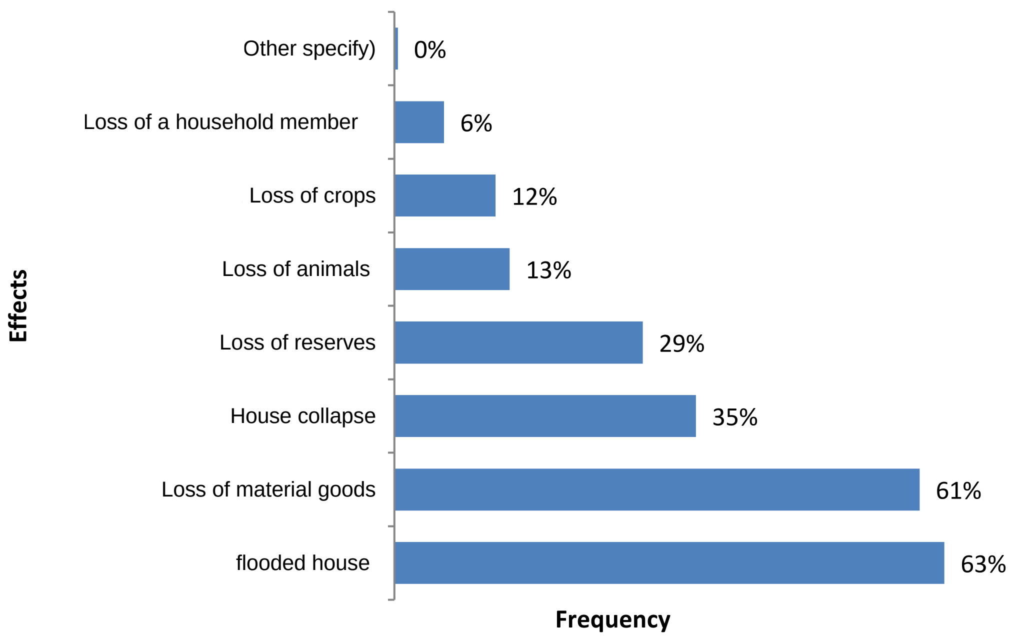

Figure 33: Effects of flood on households (Source: Field survey,2022)

Loss of various goods was cited by 61% of residents. This impact includes the destruction or damage of personal belongings, household items, and property by floodwaters. These losses can have emotional and economic consequences for affected families, potentially affecting their quality of life and well-being. The similar percentage of flooded homes highlights the widespread nature of property losses during floods. House collapse is identified as having an impact on 35% of communities. This suggests that a significant proportion of households face structural damage, which can lead to the complete or partial collapse of homes. This impact is of particular concern, as it not only disrupts daily life but also puts lives at risk. Strengthening building codes, promoting resilient building practices, and providing access to safe housing are essential to mitigating this effect. Around 29% of respondents said that "loss of reserves" had an impact. This could be food, water, or other essential supplies. The loss of supplies highlights the immediate challenge of maintaining access to basic necessities during flooding. This impact underlines the importance of disaster preparedness, including putting supplies and contingency plans in place.

The "loss of animals" effect was mentioned by 13% of communities. This effect highlights the economic and livelihood losses suffered by communities that depend on livestock and animals for their subsistence and income. Loss of livestock can impact food security, livelihoods, and community resilience. Crop loss is reported as an impact by 12% of communities. This impact highlights the vulnerability of farming activities to flooding, which can lead to reduced food production and income for farming households. Effective water management, flood-resistant crops, and agricultural diversification are crucial strategies for addressing this impact. Loss of a household member was identified by 06% of communities. This devastating impact highlights the loss of human life due to flooding. Although the percentage is relatively low, it highlights the tragic consequences that flooding can have on families and communities. Interestingly, the category "Other (specify)" has a frequency of 0%, indicating that the impact categories proposed comprehensively reflect the perceived effects of flooding by the communities surveyed.

In conclusion, the table highlights the complex and multifaceted impacts of flooding on communities in Niamey, Niger. The range of effects, from flooded houses to loss of life, illustrates the diversity of the numerous challenges due to floods. Developing effective disaster management strategies requires a holistic approach that addresses immediate needs, promotes infrastructure resilience, ensures food security, and supports the emotional well-being of affected communities.

3.9.2 Negative Effects of Flood in The District of Niamey Due to Flooding

Table 13 provides an overview of how communities in Niamey, Niger, perceive the diverse and often devastating impacts of flooding on their districts. These effects provide a better understanding of the challenges faced by communities and are essential for developing targeted strategies to mitigate and remedy the consequences of flooding. "Damaged or flooded house is the most frequently mentioned effect, with 56% of respondents. This highlights the immediate and personal consequences of flooding when homes are damaged or flooded, leading to displacement, loss of shelter and potential health risks. This high percentage suggests that a significant proportion of communities experience this effect during flooding.

Table 13: Effect of flood in the district of Niamey

What negative effects does your district experience due to flooding?	
Effects of flood	**Frequency**
Residence house damaged/flooded	56%
Property damage	54%
Damaged/loss of goods and merchandise	45%
Damaged roads, bridges electricity	45%
Damage to public infrastructures (Market, school, health centre)	43%
Environmental pollution	20%
Difficult trips	18%
Lack of food	16%
Disruption of education/Schools have been closed	14%
Loss of income	13%
Loss of important plants/trees/ecosystems	13%
Social life has been disrupted	12%
Polluted of drinking water/drinking water scarcity	11%
Flood related illnesses	10%
Deaths	07%
Injuries	04%
Other (Please specify)	0%

Source: Field survey,2022

Property damage was cited by 54% of communities, highlighting the wider impact on property beyond just homes. This can include damage to businesses, infrastructure, and personal property. The effect highlights the economic cost that flooding can have on individuals and the community as a whole. Damage to/loss of goods and property was mentioned by 45% of respondents. This effect highlights the impact on economic activities and livelihoods, as goods and merchandise can be damaged or lost during flooding. The interruption of trade can have far-reaching effects on the economic stability of the community. Similarly, 45% of communities reported that roads, bridges, and electricity had been damaged. The deterioration of critical infrastructure can isolate communities, hinder access to services, and disrupt essential public services. This highlights the interconnectedness of the different sectors affected by flooding.

Some 43% of respondents reported "damage to public infrastructure (market, school, health center)". This highlights the vulnerability of community services and resources, which can be severely affected by flooding. Damage to public infrastructure can hamper recovery and exacerbate the difficulties faced by communities. Environmental pollution" was mentioned by 20% of communities, indicating an awareness of the negative impact of flooding on the environment. Pollution can come from a variety of sources, including waste and sewage carried by floodwaters. This effect highlights the importance of good waste management and disaster planning in mitigating environmental damage. Difficult travel", mentioned by 18% of respondents, reflects the impact on mobility and transport. Flooded roads and disrupted transport networks can hamper access to essential services and resources, exacerbating the difficulties faced by communities.

Around 16% of the residents mention the 'lack of food' as an effect, highlighting the food insecurity resulting from flooded agricultural fields and disrupted supply chains. This effect highlights the immediate need for food aid during and after the floods. "Disruption to education/closure of schools" was reported by 14% of communities. This outcome highlights the interruption of education due to flooding in schools, leading to delays in student learning and development.

Perceived "loss of income" was reported by 13% of communities. This highlights the economic impact of flooding, where the disruption of economic activities can lead to a reduction in household and individual incomes. 13% of communities mention the loss of important plants/trees/ecosystems and disruption to social life. These effects reflect the wider implications of flooding on the environment and community cohesion. "Polluted drinking water/scarcity of drinking water" and "flood-related illness" are reported by 11% and 10% of communities respectively. These effects highlight the health risks posed by contaminated water sources and the potential for epidemics following flooding.

Interestingly, the effects of 'death' and 'injury' are mentioned by 07% and 04% of communities respectively. Although these percentages are relatively low, they highlight the tragic human toll of flooding and the importance of effective disaster response and preparedness. Finally, the absence of responses under the heading 'Other (please specify)' suggests that the impact categories provided comprehensively reflect the perceived negative impacts of flooding on the communities surveyed.

3.10 Classification of Land Use Land Cover Changes in the Municipality of Niamey from 1981 to 2021

3.10.1 Background

The causes of land use land cover change are attributed to deforestation, rangeland modifications, agricultural intensification and urbanization. High rates of deforestation within a country are most commonly linked to population growth and poverty, shifting cultivation in large tracts of forests (Mather & Needle, 2000).

In Africa, particularly in the Sahel region, it is often described as the hotspot of global environmental change. This is due to demographic change, intensive human activities and recurrent severe droughts in the 1970s and 1980s. These environmental disturbances have turned into land degradation and have threatened vegetation growth and food security on this continent (Asenso Barnieh et al., 2020). Leroux *et al.* (2017) also attribute these changes to human activities. In addition, D'haen et *al.* (2013) argue that in the Sahel particularly in Niger, the cause of the land changes is the expansion of agriculture and the dynamics and sustainability of the human-environmental systems depend heavily on land management. Niger has one of the fastest rates of population increase in West Africa, with an annual growth rate of 4.0 per cent. The most notable change in Niger's landscapes has been the expansion of agriculture, which is being driven by the country's rapid population increase and rising food consumption. Consequently, land use and land cover change over time (USGS, 2023). The study seeks to investigate the dynamics of land use and land cover between 1981 and 2021. Eight land cover units were considered: Shallow, Irrigated agriculture, Settlements, water body, Sahelian short grass savanna, steppe, rocky land, agricultural land.

3.10.2 Materials And Methods

3.10.2.1 Data Source

To determine the Land use land cover changes, primary (Landsat images) and secondary data (Regional and communal division boundary of Niger) are used (table 14). For primary data, the Landsat TM, ETM+, and OL_TIRS multi-resolution satellite data for five distinct Landsat images of the years 1981, 1991, 2001, 2011, and 2021 are the primary data used in this study. These images are used in order to determine the land cover units. The satellite, sensor, path, row, number of bands and date of capture are used to determine these images. These Landsat images were downloaded from the USGS (United States Geological Survey http://earthexplorer.usgs.gov/) of the City of Niamey.

Regarding the secondary data (the regional and communal division boundary of Niger) from the National Geographic Institute of Niger (IGNN) are used for mapping land use land cover changes in the study area. These Landsat images date from the October period and come from different sensors:

Table 14: Landsat images' information (1981, 1991, 2001, 2011, and 2021) of Niamey municipality

Primary data					
Satellite	**Sensor**	**Path/Row**	**Band number**	**Resolution**	**Acquisition date**
Landsat 5	TM	189/49	7	30m	1981
Landsat 5	TM	189/49	7	30m	1991
Landsat 7	ETM+	189/49	8	30m	2001
Landsat 7	ETM+	189/49	8	30m	2011
Landsat 8	OLI_TIRS	187/48	11	30m	2021
Secondary data					
Data	**Format**			**Scale**	**Source**
Regional and communal division boundary of Niger	Shapefile			1/ 110,000	IGNN

Source: (http://earthexplorer.usgs.gov/) / IGNN

3.10.2.2 Methodology

In this study, Geographic Information System is used to determine the land use land cover change from 1981 to 2021. Data processing and analysis was employed through the software ENVI 4.5 and Arc GIS 10.4.1. The following flowchart, presented in figure 33, summarizes the workflow that was used in this study.

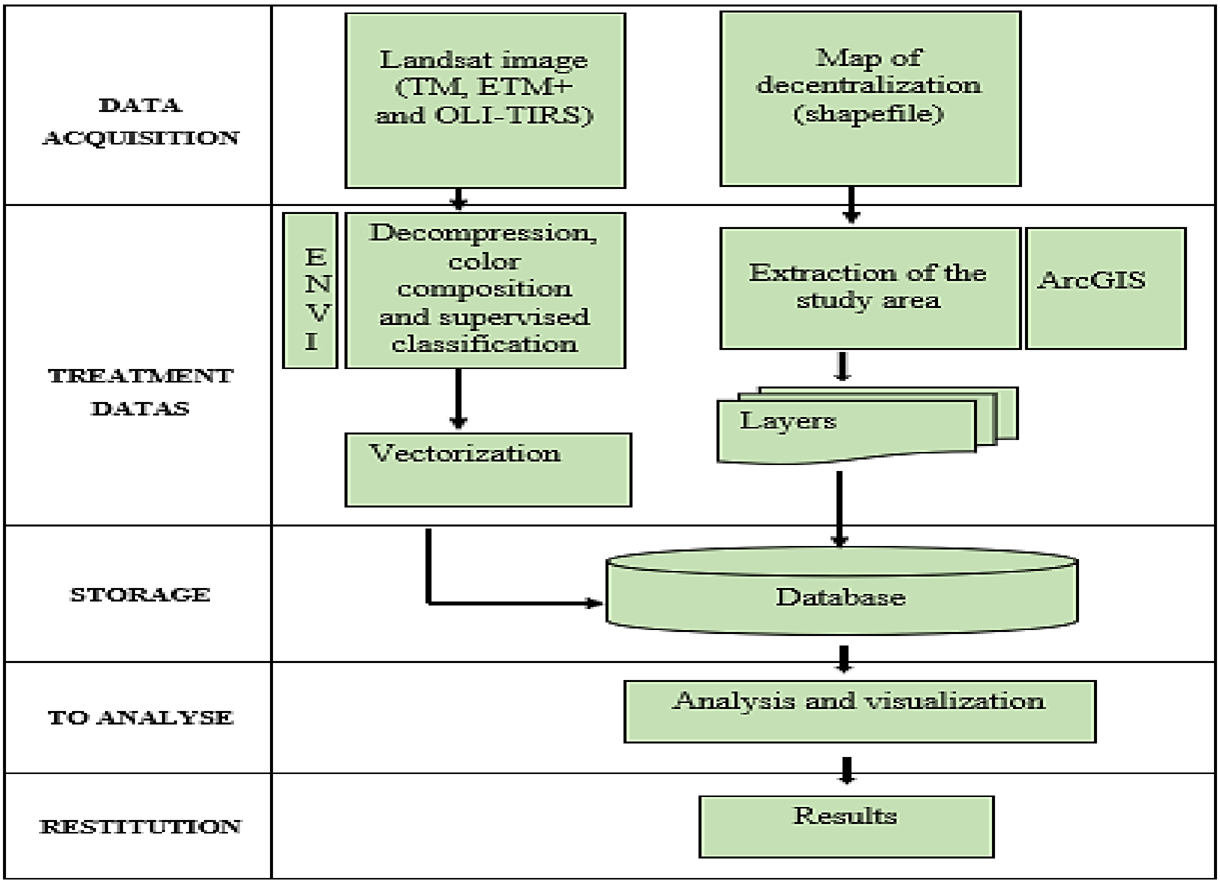

Figure 34: Flow chart showing the methodology adopted in this study (Source: Bassirou,2022)

3.10.2.3 Image processing

Since the satellite images acquired were already geo-referenced and geocoded, they were processed directly. In the ENVI software, this processing was carried out according to the following steps.

3.10.2.3.1 Band composites and the study area delimitation

This grouping is carried out by the “Layer stacking” operation. It is essential because it makes it possible to group the bands (which are most often individual at acquisition) in order to better carry out the manipulations to come. After the grouping, the study area was extracted using the 'Spatial Subset' tool from the 'Basic tools' menu of the 'Resize data' submenu of the ENVI software.

3.10.2.3.2 Contrast enhancement, band composites, and Visual Interpretation

The visual quality of the images used was improved by contrast enhancement using the 'linear' method. This enhancement allows a clear thematic identification. The analysis of the spectral signatures of the different land cover entities is very important for the choice of the TM, ETM+ and OLI channels of the Landsat scenes and the visual interpretation of the images.

About the color composite, the combination of three (03) spectral bands of the image was done. It is a color display of the scene for the identification of the different land use units. Color composition techniques consist of displaying each spectral band in one of the display planes making up the color screen. The display planes are the three primary colors: red, green, and blue listed in composition order. The following composite bands are used:

- Composition 4-3-2 was used for the TM and ETM+ images;
- Composition 7-4-3 was used for the OLI-TIRS image.

Regarding visual interpretation, it is a process of extracting useful information by inspection, identification and recognition of objects present on satellite images by simple observation. This technique requires a good knowledge of the zone of interest, which supposes the perfect recognition of the object so that the latter will be assigned an identity on the image. The keys to interpretation are the shape, size, texture, shade, pattern, and location have made it possible to identify the following land occupation units: Shallow, Irrigated agriculture, Settlements, Water body, Sahelian short grass savanna, Steppe, Rocky land, and Agricultural land.

3.10.2.3.3 Supervised classification

This is the image segmentation stage, i.e., the automatic grouping of pixels by the theme of interest through the definition of training sites and the use of a grouping.

This method was based on a classification system consisting of the definition of all the classes before carrying out the classification. The classification took place in ENVI 4.5 in four essential phases, which are:

- The definition of the legend of the ROI (Region Of Interest): to do this, a combination was made with the composition in false color;
- The description of the different classes;
- The choice of training plots (or regions) to be assigned to each ROI;
- The choice of the classification algorithm: the classifier which gave the best results is that of the maximum likelihood for the scenes of 1981, 1991, 2001, 2011 and 2021.

3.10.2.3.4 Validation

The classification is validated by the confusion matrix which is a statistical tool for detecting confusion between classes based on a ground truth. It can be characterized either from field readings or by using the test areas entered (hence the importance of the quality of these test areas if this matrix is to make sense). Ideally, the definition of the areas which will be used for the validation of a supervised classification must be done randomly so as not to truncate the validation. The comparison between the classified or "predicted" land cover and the photo-interpreted land cover is made by constructing and discussing a confusion matrix (or contingency table).

The confusion matrix is characterized by a classification quality indicator: the kappa. The kappa index expresses the proportional reduction of the error obtained by a classification, compared to the error obtained by a completely random classification.

It is expressed from the matrix of confusion.

3.10.2.3.5 Post classification

This is the stage of refining and smoothing the classification before transforming raster classes into polygons. Without further clarification, the Sieve (elimination of isolated pixels) and Clump (homogenization of classes) tools of ENVI will be used, which will allow us to obtain a fairly smooth and low-noise image.

3.10.2.3.6 Vectorization

Vectorization is the transition from a raster image (where the information is contained in pixels) to vector data (the information is contained in point, line, and polygon-type entities). As part of this project, the classified images were vectorized in the ENVI 4.5 environment using the 'Classification to Vector' tool. They were then exported in ArcGIS Shapefile (.shp) format to facilitate proper manipulation and presentation of the information. In the ArcGIS environment, the vector file was dissolved by theme (Dissolve) and cut according to the boundaries of Municipality of Niamey.

3.10.3 Results

Table 15 resumed the different land cover units' changes for the years 1981, 1991, 2001 2011 and 2021. The land cover data provides a comprehensive snapshot of the changing landscape over four decades, offering valuable insights into flood risk assessment. The notable trends include the expansion of settlements and agricultural land, alongside changes in natural landscapes such as Sahelian short grass savanna and steppe.

Table 15: Land use land cover in Niamey municipality from 1981 to 2021

Area (Km^2)										
Land cover units	**1981**	**%**	**1991**	**%**	**2001**	**%**	**2011**	**%**	**2021**	**%**
Shallow	21.53	3.83	21.56	3.84	21.57	3.84	21.78	3.88	21.82	3.89
Irrigated agriculture	12.55	2.23	14.86	2.64	15.25	2.71	15.25	2.71	15.25	2.72
Settlements	68.88	12.28	75.92	13.53	96.80	17.26	149.03	26.57	207.17	36.94
Waterbody	21.60	3.85	21.72	3.87	22.03	3.92	20.00	3.56	20.45	3.64
Sahelian short grass savanna	160.57	28.63	146.23	26.07	137.25	24.47	29.83	5.32	2.24	0.39
Steppe	80.61	14.37	73.16	13.04	55.35	9.86	45.81	8.16	45.93	8.19
Rocky land	42.43	7.56	42.43	7.56	42.43	7.56	42.43	7.56	42.43	7.56
Agricultural land	152.58	27.2	164.87	29.4	170.08	30.33	236.63	42.19	205.46	36.64
Total	560.76	100	560.76	100	560.76	100	560.76	100	560.76	100

Table 16 is about the changes detection of the different land cover units changes from 1981 to 2021. The data reveals a complex interplay between land cover changes and flood risk in Niamey. Urban expansion, agricultural intensification, and alterations in natural landscapes contribute to changes in flood vulnerability by modifying surface characteristics, hydrological processes, and ecosystem services.

Table 16: Detecting changes in land use units at ten-year intervals from 1981 to 2021

Land cover units	**Net Loss / Gain (Km^2)**				**Average changes**
	1981-1991	**1991-2001**	**2001-2011**	**2011-2021**	
Shallow	0.03	0.01	0.20	0.0	0.07
Irrigated agriculture	2.31	0.39	0.00	0.0	0.68
Settlements	7.04	20.87	52.24	58.1	34.57
Waterbody	0.12	0.31	-2.04	0.5	-0.29
Sahelian short grass savanna	-14.34	-8.98	-107.42	-27.6	-39.58
Steppe	-7.45	-17.82	-9.54	0.1	-8.67
Rocky land	0.00	0.00	0.00	0.0	0.00
Agricultural land	12.29	5.21	66.55	-31.2	13.22

These results show that the average changes of shallow, irrigated agriculture settlements and agricultural land along the period 1981-2021 are estimated at 0.07 km^2, 0.68 km^2, 34.57 and 13.22 km^2, respectively. Whereas, the water body, Sahelian short grass savanna and steppe record negative, rates with -0.29 km^2, -39.58 km^2 and -8.67 m^2 respectively.

3.10.3.1 Land cover units in 1981

Human settlements represented the largest land use category in 1981; they took up around 68.9 million square meters or 12.3% of the total area. This shows that Niamey was a heavily urbanized area, with both residential and commercial structures occupying a sizeable amount of land. Regarding agricultural land, it should be mentioned that agricultural operations occupy more than 152.6 million square meters, or almost 27.2% of the total area. 15.2 million square meters are used for irrigation in agriculture. This suggests that agriculture, both irrigated and rain-fed agriculture, is a significant land use in Niamey. It should be noted that the Sahelian short-grass savannah and steppe make up a sizeable amount of the overall area, with the Sahelian short-grass savannah accounting for around 28.6% of the total area and the steppe for about 14.4% (figure 35).

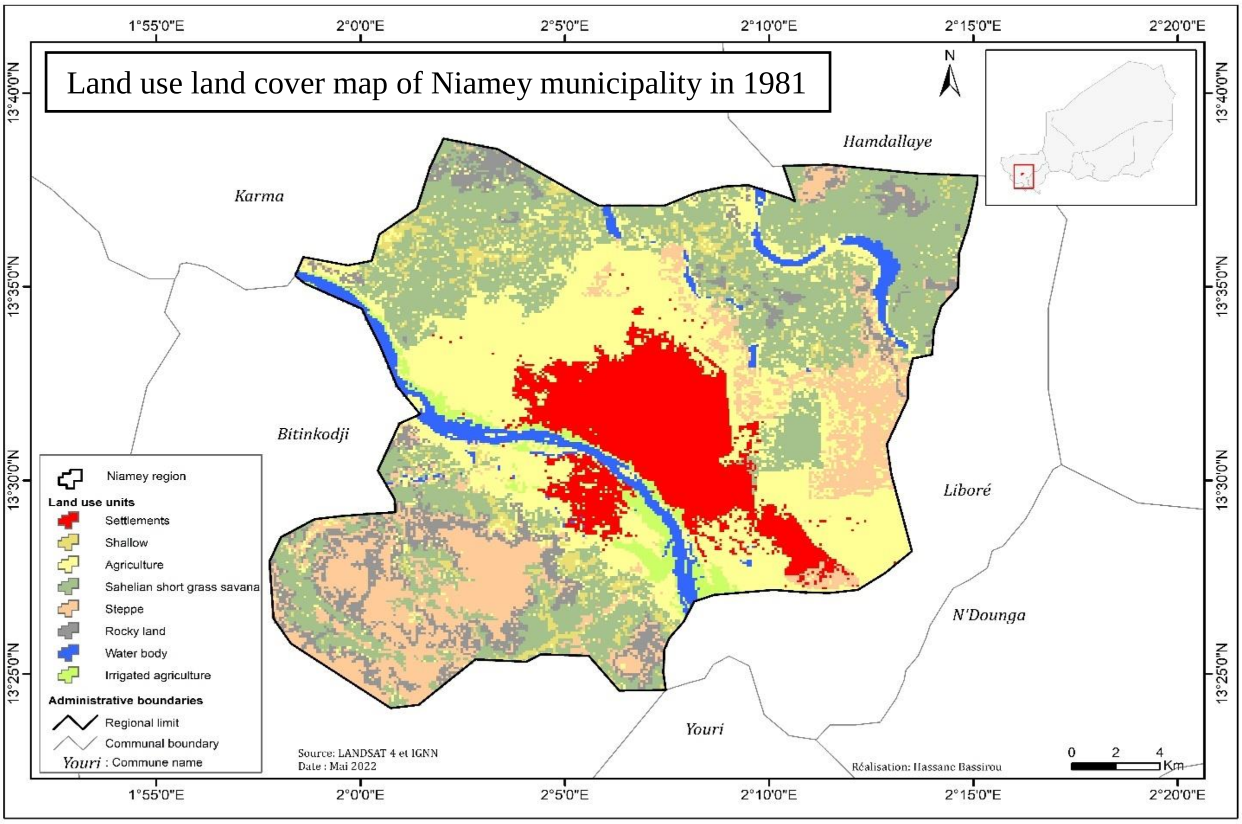

Figure 35: Land use land cover changes in Niamey, 1981

These types of land uses are common in the Sahel region, distinguished by a dry environment and little vegetation. The fact that the water bodies category represents around 3.8% of the total area suggests that Niamey has abundant water resources (River Niger). 7.6% of the total area was made up of rocky ground, indicating that some portions of Niamey are not suitable for building or agriculture due to their rocky character. The land use pattern generally indicates that Niamey was largely urbanized in 1981, with a sizeable amount of areas devoted to housing and agriculture. Significant savannah and Sahelian short grass steppe areas, as well as rocky terrain and water bodies, may also be seen in Niamey.

3.10.3.2 Land cover units, 1991

In 1991, the largest land use category was human settlements, accounting for about 75.9 million square metres, or 13.5% of the total area. This demonstrates how densely populated Niamey was, with both residential and commercial constructions taking up a large portion of the land. It should be noted that agricultural enterprises use more than 164.9 million square meters of land, or over 29.4% of the total area, for their operations. Agriculture uses irrigation on 14.8 million square metres as can be seen in Figure. 36.

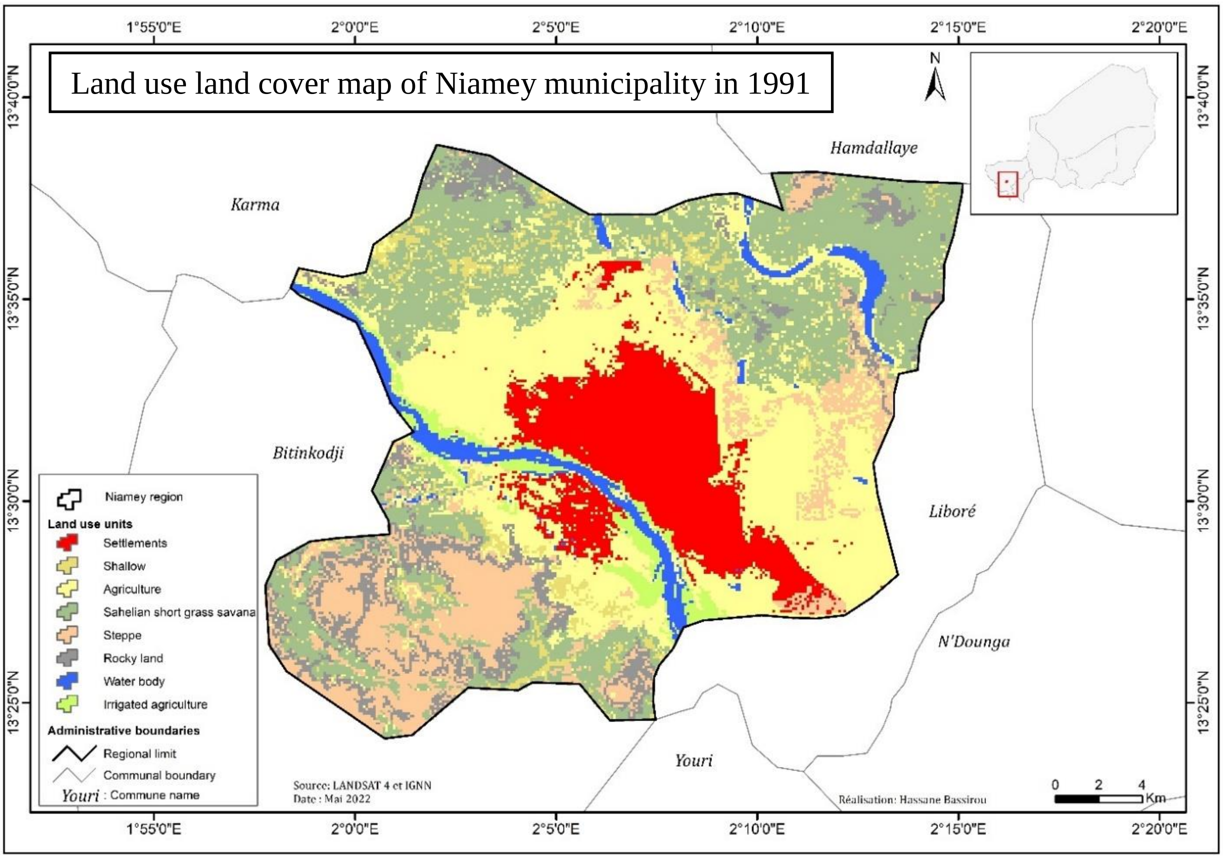

Figure 36: Land use land cover changes in Niamey, 1991

This shows that Niamey has a substantial amount of irrigated and rain-fed farmland. It should be noted that the Sahelian short-grass savannah and steppe make up a sizable portion of the total area, with the steppe accounting for around 13.1% and the Sahelian short-grass savannah for approximately 26.1%. Certain types of land uses are typical of the Sahel region with its dry climate and sparse vegetation. Niamey has a lot of water resources, including the River Niger, evidenced by the fact that the water bodies category accounts for about 3.9% of the total area. Rocks make up 7.6% of the total area, showing that some areas of Niamey are not suitable for construction or agriculture due to their rocky nature. According to the overall land use pattern, Niamey was primarily urbanized in 1991, with a sizeable portion of the region set aside for housing and agriculture. Niamey also has sizable savannah and Sahelian short grass steppe areas, as well as rocky terrain and water bodies.

3.10.3.3 Land cover units, 2001

Human settlements made up the largest land use category in 2001, making up around 96.8 million square meters, or 17.3% of the total area illustrated in figure 29.

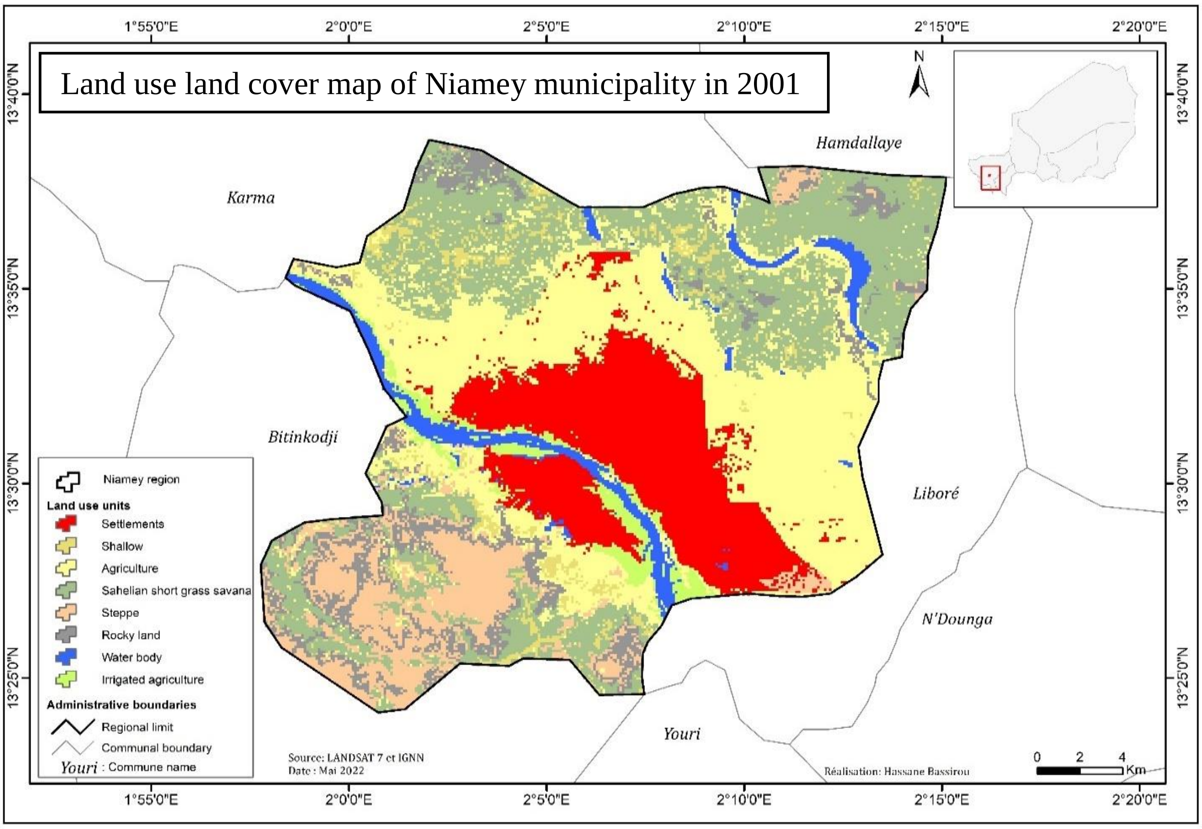

Figure 37: Land use land cover changes in Niamey, 2001

This illustrates how crowded Niamey was, with both domestic and commercial structures occupying a big landscape. It should be noted that both the steppe and the Sahelian short grass savannah occupied a sizeable amount of the total area, with the steppe making up roughly 9.9% and the Sahelian short grass savannah about 24.5%. Some types of land use are characteristic of the Sahel region, which is characterized by a dry environment and scant vegetation. 7.6% of the total area was made up of rocks, demonstrating that some regions of Niamey are not suited to cultivation or development due to their rocky nature. The fact that the water bodies category makes up around 3.9% of the total area indicates that Niamey has a lot of water resources, especially the River Niger. It should be emphasized that more than 170.1 million square meters, or more than 30.3% of the total area, are used by agricultural firms for their operations. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. Niamey was predominantly urbanized in 2001, with a sizeable amount of the area designated for housing and agriculture, according to the general land use pattern. Along with vast regions of savannah and Sahelian short-grass steppe, Niamey also includes rocky terrain and bodies of water.

3.10.3.4 Land cover units, 2011

It should be emphasized in 2011 that agriculture accounted for the most significant land use category, with businesses using more than 236.6 million square meters of land, or more than 42.2% of the total area, for their activities figure 38. On 15.3 million square meters, irrigation was used in agriculture. This fact demonstrates a sizeable area for irrigated and rain-fed farmland in Niamey. Approximately 149 million square meters, or 26.6% of the total area, fall under the category of settlement. This illustrates how crowded Niamey was, with both domestic and commercial structures occupying a large amount of the landscape. It is important to note that the steppe and Sahelian short grass savannah make up a significant amount of the total area, with the steppe accounting for approximately 8.2% and the Sahelian short grass savannah for around 5.3%. Some types of land use are part of the characteristics of the Sahel region, which is characterized by a dry environment and scant vegetation.

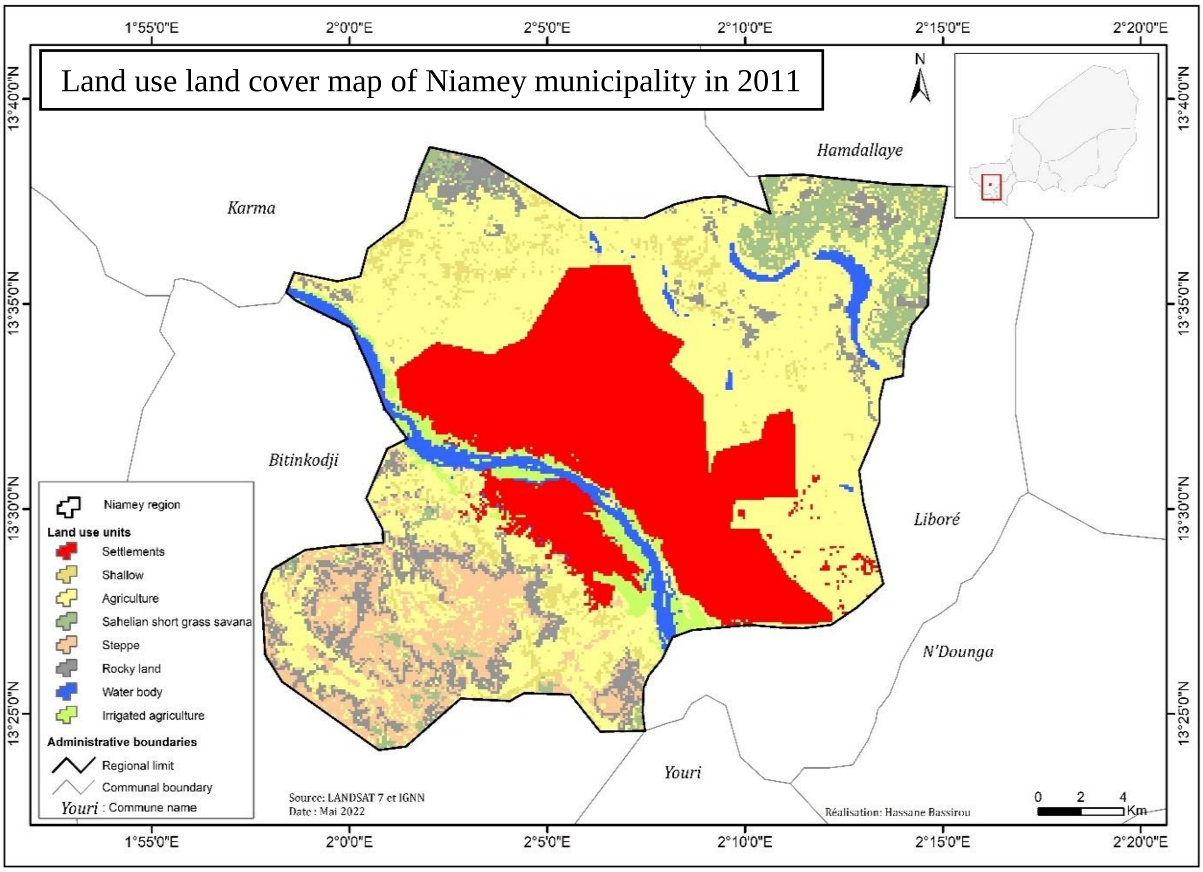

Figure 38: Land use land cover changes in Niamey, 2011

The fact that the water bodies category represents around 3.6% of the total area indicates that Niamey has plenty of water resources, especially the River Niger. There is likely shallow groundwater in some regions of Niamey since shallow areas total 3.9% of the gross area. 7.6% of the total area was predominantly rock. This demonstrates that some regions of Niamey are not suited to cultivation or development due to their rocky character. In 2011, Niamey was distinguished by a predominance of agricultural land, with a sizeable share of the territory set aside for agriculture, according to the general land use pattern.

3.10.3.5 Land cover units, 2021

In 2021, human settlements accounted for almost 207 million square meters or 37% of the total land area. This demonstrates how densely populated the city of Niamey was, with both residential and commercial constructions taking up a large portion of the land. It should be noted that agricultural enterprises use more than 205.5 million square meters of land, or over 37% of the total area, for their operations figure 39. Agriculture uses irrigation on 15.3 million square meters.

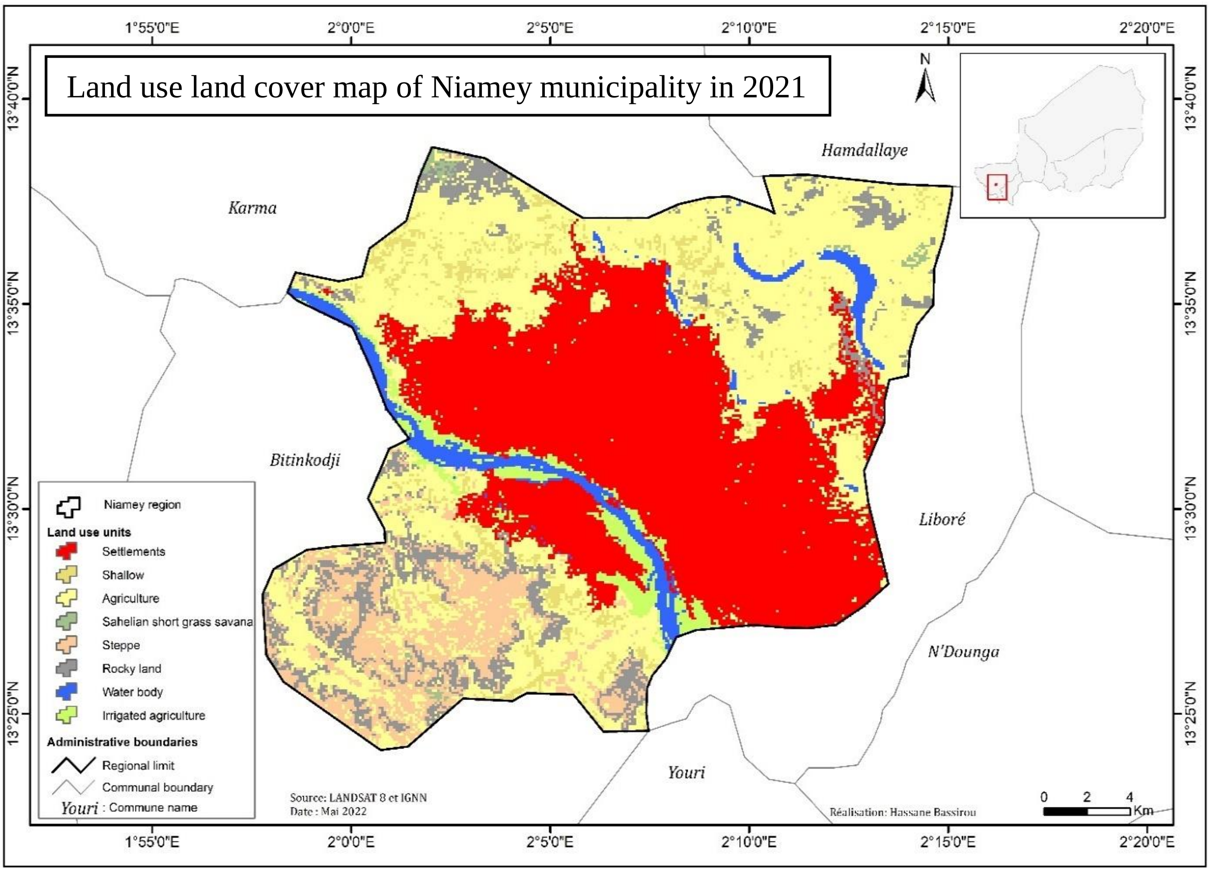

Figure 39: Land use land cover changes in Niamey, 2021

This shows that Niamey has substantial irrigated and rain-fed farmlands. It should be noted that the Sahelian short grass savannah and steppe make up a considerable portion of the total land, with the steppe accounting for around 8.2% and 0.4%, respectively. In the Sahel region, defined by a dry climate and sparse vegetation, certain types of land use are typical. Niamey likely has a lot of water resources (River Niger), as the water bodies category accounts for about 3.6% of the total area. Shallow groundwater is likely present in some regions of the study area given that shallow areas form about 3.8% of the overall area. Rocks make up 7.6% of the total area, showing that some areas of Niamey are not suitable for construction or agriculture due to their rocky nature. Overall, the findings point to a predominance of urban areas and agricultural land in the research region. The aforementioned region exhibited a lesser amount of steppe, rocky terrain, water bodies, shallow areas, and Sahelian short grass savanna in 2021.

3.10.3.6 **Discussion**

The land cover units were classified into eight units: Cultivation area, Steppe, Sahelian savannah, Rocky terrain, Body of water, Dwellings, Shallows, and Irrigated crops. These units are characterized by changes over the period 1981–2021 and are characterized by positive and negative changes. In terms of settlements, the changes in areas occupied by habitations made up the largest land use category in 1981, taking up around 68.9 million square meters, or 12.3% of the total area. This shows that Niamey was a heavily urbanized area, with both residential and commercial structures occupying a sizeable amount of land. In 1991, settlements, which accounted for about 75.9 million square meters, or 13.5% of the total area showed an increase. In 2001, human settlements made up the largest land use category, making up around 96.8 million square meters, or 17.3% of the total area. In 2021, approximately 149 million square meters, or 26.6% of the total area, fell under the category of settlement. The greatest land use type was human settlements, which accounted for almost 207 million square meters, or 37% of the total area. This demonstrates how densely populated Niamey was, with both residential and commercial constructions taking up a large portion of the land.

Regarding agricultural land changes during the period 1981-2021, an increase in land used for agricultural activities is noted. In Niamey, in 1981, it should be mentioned that agricultural operations occupied more than 152.6 million square meters or almost 27.2% of the total area. 15.2 million square meters are used for irrigation in agriculture. This suggests that agriculture, both irrigated and rain-fed agriculture, is a significant land use in Niamey. In 1991, the areas occupied by agricultural activities used more than 164.9 million square meters of land, or over 29.4% of the total area, for their operations. While irrigated agriculture shows a decrease estimated at 14.8 million square meters. In 2001, it was noted that more than 170.1 million square meters, or more than 30.3% of the total area, were used by agricultural firms for their operations. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. In 2011, agriculture accounted for the largest land use category, with businesses using more than 236.6 million square meters of land, or more than 42.2% of the total area, for their activities. On 15.3 million square meters, irrigation is used in agriculture. This demonstrates that there is a sizable area of irrigated and rain-fed farmland in Niamey. In 2021, Niamey was distinguished by a predominance of agricultural land, with a sizeable share of the territory being set aside for agriculture, according to the general land use pattern. It should be noted that agricultural enterprises use more than 205.5 million square meters of land, or over 37% of the total area, for their operations. Agriculture uses irrigation on 15.3 million square meters. This shows that Niamey has a substantial amount of irrigated and rain-fed farmland. From 1981 to 2021, the portion of land occupied by agriculture showed an increasing trend. This situation can be explained by ongoing population growth due to well-being and prosperity. Hence, these factors led to an intensive use of the land around the capital city to be employed for agricultural purposes. For clarity, the land cover units' changes from 1981 to 2021 of the city of Niamey and vicinity are presented in figure 40 .

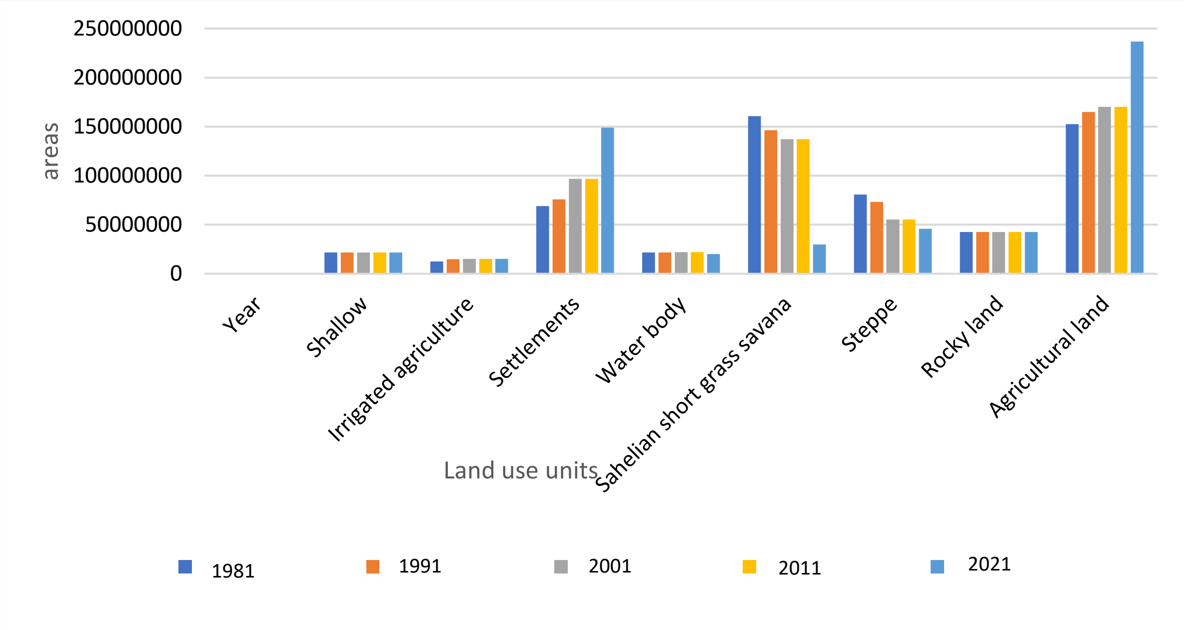

Figure 40: Land cover units' changes, 1981 to 2021, Niamey (Source: Bassirou,2022)

Land use has cumulatively transformed land cover on a global scale. The consequences have been significant not only for land cover, particularly vegetation cover but also for climate, atmospheric composition, biodiversity, soil conditions and water and sediment flows. These types of impacts are generated both by modification involving changes in vegetation cover and conversion of vegetation cover to another, e.g. from forest to grassland by clearing for grazing (B.L. Turner, Meyer, and Skole 1994).

However, in a study (Leroux et al., 2017), it is widely acknowledged that rainfall affects vegetation differences in the Sahel. According to several studies (Boschetti et al. 2013, Fensholt et al. 2013, Helldén and Tottrup 2008, Herrmann, Anyamba, and Tucker 2005, Hoscilo et al. 2015, Huber, Fensholt, and Rasmussen 2011, Rasmussen et al. 2014), local NDVI trends might not be fully explained by local causal factors like changes in land use. The shift in vegetation can be explained by a variety of non-anthropogenic factors, such as the intra-annual distribution of rainfall events, humidity, or temperature, according to Rishmawi and Prince (2016). Therefore, distinguishing between changes in biomass caused by the climate and changes caused by other variables, both anthropogenic and natural, is crucial for describing the primary forces behind vegetation dynamics (Knauer *et al.* 2014, Mbow *et al.* 2015 in Leroux *et al.* 2017). In addition, Mather and Needle (2000) argued that population growth and poverty are the two factors most frequently associated with high rates of deforestation within a nation, with shifting cultivation occupying large areas of forest. However, Allen and Barnes (1985) stated that it would be a mistake to say that poverty and population growth are the reasons for deforestation (Lambin *et al.*, 2001).

In Niamey, it is noted that the Sahelian short grass savannah and steppe represent a significant share of the total area, with the Sahelian short grass savannah representing about 28.6% of the total area and the steppe about 14.4% in 1981. In 1991, it should be noted that the Sahelian short grass savannah and the steppe represented a significant share of the total area, with the steppe representing about 13.1% and the Sahelian short grass savannah about 26.1%. In the Sahel region, which is characterized by a dry climate and sparse vegetation, certain land use types are typical. In 2001, the steppe accounted for about 9.9%, and the Sahelian short grass savannah for about 24.5%. In 2011, the steppe accounted for about 8.2% and the short grass Sahelian savannah about 5.3%. In 2021, the Sahelian short-grass savannah and steppe represented a considerable share of the total land area, with the steppe accounting for about 8.2% and 0.4%, respectively. Certain land use types are characteristics of the Sahel region, which is characterized by a dry environment and scarce vegetation. It is important to note that the steppe and the Sahelian short-grass savannah represented a significant share of the total area during the period 1981-2021. However, it is important to note that a decreasing trend for the Sahelian short grass savannah and steppe is observed during the period 1981-2021 (Figure 41). This can be explained by the fact that during this period human activities through urbanization and agricultural activities showed an increasing trend in Niamey.

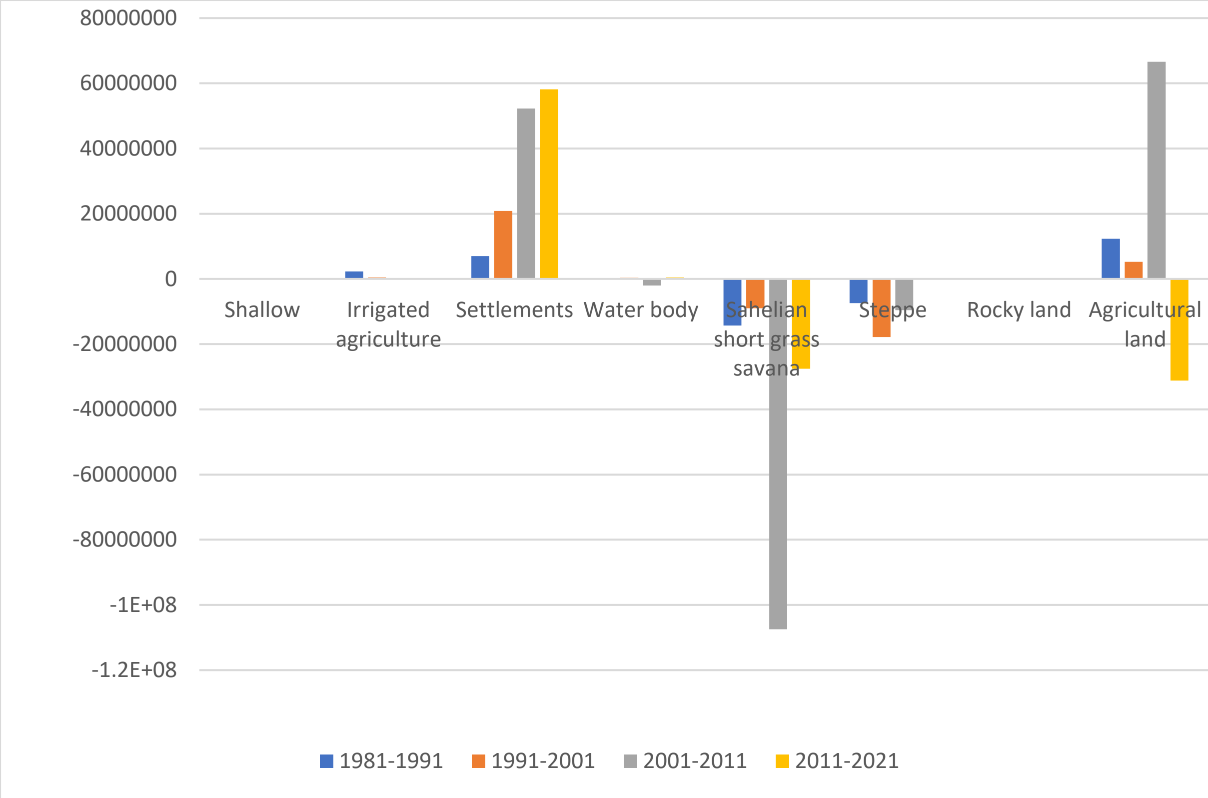

Figure 41: Detecting changes in land use units at ten-year intervals from 1981 to 2021
Source: Bassirou.2022

According to the general land-use plan (figure 33), Niamey was largely urbanised in 2011 and 2021, with a significant share of areas devoted to housing and agriculture. Large areas of savannah and Sahelian short grass steppe, as well as rocky terrain and water bodies, can also be observed in Niamey. Overall, the results indicate a predominance of urban areas and agricultural land in the research region, with lesser amounts of the steppe, rocky terrain, water bodies, shallow areas and Sahelian short grass savannah in 2021. Niamey has many water resources, including the River Niger, as evidenced by the fact that the water body category represents about 3.9% of the total area. Shallow groundwater is present in some areas of Niamey as the shallow areas that do not exceed 3.9% of the total area and 7.6% of the total area were rocky soils, indicating that some parts of Niamey are not suitable for construction or agriculture due to their rocky nature during the period 1981-2021.

3.10.4 Land use land cover and Flooding in Niamey

Based on the data presented, we may draw the following basic conclusions about the link between land use/land cover and floods in Niamey:

This form of land use, which represents bodies of water, might be very important in floods. Flooding during periods of high rainfall or river overflow may be exacerbated by the existence of bodies of water such as lakes, rivers, or reservoirs. Increased impervious surfaces, such roads and buildings, are often linked to urban areas (agglomeration), which may result in more runoff during rains. Localised flooding may be caused by urban areas with inadequate drainage infrastructure. Flooding in agricultural regions may be caused by poor drainage systems or poor water management, even if irrigated agriculture can be beneficial for food production. The existence of urban areas (Agglomeration) and water bodies indicates a possible risk of floods. Whether they are rained farms or irrigated farms, agricultural lands may flood, particularly after heavy rainstorms. The dynamics of floods may be influenced by rocky surfaces and riparian formations.

In order to effectively address the multifaceted problem of urbanisation and floods in Niamey, government agencies, communities, and other stakeholders must work together. Reducing the danger of flooding in urban areas requires the implementation of sustainable urban development strategies that give priority to community well-being, environmental protection, and resilience.

3.10.5 Summary

In summary, the changes in land use in Niamey during the period 1981-2021 are mainly attributable, not only to human causes through habitation and agricultural activities but also to environmental factors with variations in meteorological indices such as rainfall and temperature. These two primary facts (settlements and agricultural activities) are driven by the availability of water sources and the suitability of soils for agricultural operations. The data reveal that land use is the principal driver of land cover changes in Niamey that may accelerate flooding. It was reported that, between 1981 and 2021, the average changes in shallow areas, irrigated agricultural areas, and agricultural land were expected to be 71479, 675554.5, 34572542, and 132208440 m^2, respectively. This shows that human activities associated with urbanization and agriculture are the principal causes of land cover changes. The Sahelian short grass savannah, the steppe, and the waterhole, on the other hand, all display negative rates of -287416, -39583425, and -8669576 m^2, respectively. Overuse of land by people has an impact on vegetation and water supplies. The consequences of climate change, such as desertification and drought, intensify this situation.

Partial conclusion

In summation, the mosaic of perspectives reveals a multifaceted view of the causes behind Niamey's floods, one that combines scientific insights, urban planning considerations, cultural beliefs, and a recognition of both human and natural forces. A focus has been made on land use land cover dynamic. The changes in land use in Niamey during the period 1981-2021 are mainly attributable, not only to human causes through habitation and agricultural activities but also to environmental factors with variations in meteorological indices such as rainfall and temperature. This collective wisdom has the potential to guide comprehensive strategies aimed at mitigating the impact of flooding and fostering community resilience. In conclusion, It has been provided a comprehensive picture of the myriad of challenges that flooding poses to communities in Niamey, Niger. The range of effects, from physical damage to infrastructure to health risks and economic setbacks, underlines the urgent need for holistic disaster management strategies. Addressing these consequences requires collaboration between government agencies, NGOs, community leaders and international organisations to provide rapid assistance, support recovery and build community resilience to the multifaceted challenges posed by flooding. Thus, it is important to carry out flood risk assessment

4 Chapter 4: Flood Risk Assessment in Niamey

Introduction

GIS and Remote Sensing techniques were utilized to assess flood risks in Niamey and the vicinity. Extreme precipitation, high river flow, and the compounding effects of different flood causes are some of the most common and destructive natural disasters. In order to streamline, automate, and map geographically accurate flood inundation extents, this study offers a novel multi-source remote sensing and GIS approach that makes use of both multi-spectral optical imagery and the weather- and illumination-independent properties of synthetic aperture radar (SAR) data. This procedure makes use of Google Earth Engine's (GEE) near real-time and cloud computing capabilities to speed up data collection and enable extensive flood monitoring.

4.1 Methodology

4.1.1 Data used

Two types of data were acquired during this research. These were satellite images and cartographic data.

4.1.1.1 Satellite images used

These are:

- the Sentinel 2 satellite image of 2022 in Geo-Tiff format. This image was downloaded from the United States Geological Survey (USGS) website for land cover and land use mapping;
- the 2015 SRTM satellite image in Tiff format, obtained from the same United States Geological Survey (USGS) website, for the digital terrain model, slope maps, drainage density and stream influence zone.

4.1.1.2 Map data used

These are:

- the reconnaissance soil map of the Republic of Niger: Niamey at 1:500 000.
- The administrative data in vector format (shapefile) covering the Region of Niamey was acquired from the IGNN and the Google Maps database.

The Hierarchical Multicriteria Analysis (HMA) method created by (Saaty, 1980)was used to identify the areas at risk of flooding in the Municipality of Niamey. This method considers a weighting table that allows the allocation of weights to the different criteria according to their importance.

4.2 Standardization of criteria

Before drawing up the criteria maps, it is important to reclassify the different criteria, considering the scale chosen, which allows them to be quantified according to their capacities. In spatial analysis, two normalisation procedures are most often used for multi-criteria evaluation. The first is binary normalisation, which produces a map characterised by the binary values 0 and 1. The second is based on continuous reclassification (Jiang and Eastman, 2006), which normalises the continuous factors by a range of common numerical values before mapping the criteria themselves. This method was applied to the remaining factors.

4.3 Soil suitability criteria

Soil suitability is an important factor in the hydrology of a catchment, as it directly controls or regulates, through the infiltration process, the component of the hydrological cycle responsible for groundwater recharge. The more impermeable a rock is, the more it tends to favour runoff, in contrast to a permeable rock (ASCONIT Consultants et al., 2007).

The soil types were obtained after georeferencing, digitisation, rasterization and reclassification of the 1:500,000 soil recognition map of the Republic of Niger: Niamey sheet. According to the water retention capacity of the soil types, the criteria presented in table 17 were retained.

Table 17: Normalisation of soil layers

Criteria	**Null**	**Low**				**High**
	0	**1**	**2**	**5**	**7**	**9**
Soil layers		Poorly developed tropical ferruginous soils with modal input on stratified heterogeneous colluvium	Leached tropical iron soils with concretions on a mixture of aeolian sands and products from clayey sandstones	Poorly leached and poorly differentiated tropical iron soils on sandy formations	Crude mineral eroded soils on iron conglomerate	Hydromorphic mineral soils

Source: ORSTOM, 1967

4.3.1.1 Criterion of the slope of the land

Slopes are very important indicators for the determination of flood-prone areas. They translate the different undulations of the terrain into percentages and give a better indication of the runoff speed. Indeed, water tends to run off on sloping ground. This flow is more important if the slope is steep and negligible if it is weak or even null.

The slopes were generated automatically in ArcGIS with the Slope tool. The SRTM image was used as input data. These slopes were standardised according to the slope value (table 18).

Table 18: Standardisation of slopes

Critères	**Null**	**Low**			**High**	
	0	**1**	**2**	**5**	**7**	**9**
Slope (%)		>20	10-20	5-10	2,5-5	0-2,5

Source: SRTM, 2015

4.3.1.2 Drainage density criterion

Drainage density is one of the morphometric indicators for analysing a river system. In fact, this density allows us to categorise the aptitude of a drain to let the retained gravity flow more or less easily and quickly in a natural way. Thus, the Dd is captured with the assistance of Formula 2.,

Formula 2

$$Dd = \frac{\sum Li}{A} \tag{2}$$

Where, **Dd** is the drainage density (km/km^2), **A** represents the area of the municipality, and **Li** stands for the length of the watercourse in km.

The latter was obtained automatically from the hydrographic network of the basin using ArcGIS software. Thus, the denser a network is in a basin, the higher the concentration of runoff is likely to be at the outlet (ASCONIT Consultants *et al.*, 2007). The existing thresholds are not standardised. They vary from one study to another, each time adapted to the specific climatic and geological conditions of the study area (Sreedhar *et al.*, 2009) (Table 19).

Table 19: Drainage density standardisation

Criteria	Null	Low			High
	0	1	2	5	7	9
Drainage density (km/km^2)		> 0,05	0,05-0,15	0,15-0,30	0,30-0,40	0,40-0,90

Source: SRTM 2015

4.3.1.3 River influence zone criterion

The river network has been used to delineate flood propagation areas. The zone of influence of the main rivers is therefore mapped (Sharon and Burnett, 2003). The criterion of the area of influence of the rivers is classified in the range of constraints. On this basis, this factor was normalised to a binary value. Areas within the major riverbed are coded with a value of 1 and those outside the major riverbed are coded with a value of 0 (table 20).

Table 20: Standardisation of the area of influence of rivers

Criteria	Null	Low				High
	0	1	2	5	7	9
Watercourse influence zone	**Not available**	**Available**	**Available**	**Available**	**Available**	**Available**

Source: SRTM, 2015

4.3.2 Weighting of criteria

The method is based on the comparison of the different characteristics, two by two, from the construction of a square matrix (Ramos *et al.*, 2014) (table 21).

Table 21: Comparison matrix and calculation of their eigenvector

Criteria	C_1	C_2	C_3	….	C_n	W_i
C_1	$1/\sum C1$	$W21/\sum C2$	$W31/\sum C3$	….	$Wn1/\sum Cn$	$\sum C1/n$
C_2	$W12/\sum C1$	$1/\sum C2$	$W32/\sum C3$	….	$Wn2/\sum Cn$	$\sum C2/n$
C_3	$W13/\sum C1$	$W23/\sum C2$	$1/\sum C3$	….	$wn3/\sum Cn$	$\sum C3/n$
….	….	….	….	….	….	….
C_n	$W1n/\sum C1$	$W2n/\sum C2$	$W3n/\sum C3$	….	$1/\sum Cn$	$\sum Cn/n$
	$\sum C1$	$\sum C2$	$\sum C3$	….	$\sum Cn$	

Source: Ramos *et al. 2014*

Wij represents the quantitative judgment of the feature pair Ci, Cj, and is defined by the following rules:

If $wij = \alpha$, then $wji = 1/\alpha$, $\alpha \neq 0$

If we consider Ci to be of relatively equal importance to Cj, then $wij = 1$, $wji = 1$ and $wii = 1$ for all i.

The eigenvector of the matrix can be found by the following formula:

Formula 3

$$wi = \left(\Pi_{j-1}^{n} wij\right)^{1/n} \quad \textbf{(3)}$$

The relative importance of one characteristic compared to another is assessed using an appropriate scale. (Saaty, 2008) suggests using the scale presented in table 22.

Table 22: Scale proposed by Saaty (2008)

Comparison of one criterion with another	Intensity of importance
Same importance as	1
Moderately more important than	3
Significantly more important than	5
Very strongly more important than	7
Extremely more important than	9
Moderately less important than	1/3
Significantly less important than	1/5
Very significantly less important than	1/7
Extremely less important than	1/9

Source**:** Saaty, 2008

Once the comparison matrix is completed, the eigenvalue of each feature and the corresponding eigenvector are calculated. The eigenvector indicates the priority order or hierarchy of the features considered. This result is important for the probability assessment, as it will be used to indicate the relative importance of each operating criterion. The eigenvalue is the measure by which the consistency or quality of the resulting solution can be assessed, which is another advantage of this method.

To test the consistency of the response, which indicates whether the data are logically related, Saaty (2008) proposes the following procedure:

Value calculated on the basis of the Saaty index

Formula 4:

$$\lambda \max = \sum\left(\sum ci.wi\right) \qquad \textbf{(4)}$$

Value calculated on the basis Coherence Index (CI):

Formula 5:

$$IC = \frac{\lambda \max - n}{n - 1} \qquad \textbf{(5)}$$

Value calculated on the basis the consistency ratio (CR):

Formula 6:

$$RC = \frac{IC}{IA} \qquad \textbf{(6)}$$

C = column, n the number of factors and λ max, a value calculated on the basis of the Saaty matrix and CI the consistency index.

If RC> 10%, there is no consistency in the pairwise comparison of criteria. The matrix should be re-evaluated.

IA is a random index defined according to the number of criteria. Table 23 shows the random indices as a function of the number of criteria.

Table 23: AI values as a function of the order of the matrix

n	1	2	3	4	5	6	7	8	9	10	11
IA	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51

Source: Saaty, 1980

4.3.3 Aggregation of criteria

Once the partial units were established and weighted, they were aggregated by weighted linear combination using the following formula in ArcGIS.

Formula 7:

$$\sum_i wixi \times \prod_j cj \qquad \textbf{(7)}$$

Where **x** is the factor, **w** is the weight and **c** is the constraint.

This formula is made possible in GIS by map algebra, which is a general method of cartographic modelling. The various elementary cartographic operations are represented in a mathematical structure where the variables are planes of information and the operators are those of spatial analysis and modelling. These operators, when applied to the different input information planes, generate new information planes. The Map Algebra extension of the spatial analysis module of ArcGIS software was used to perform this operation.

4.3.4 Flood hazard mapping

The hazard is composed of the natural elements of the environment which, when combined, can contribute to the danger. Several methods are used to determine the flood hazard. Given the existing data, the hierarchical multi-criteria method was used to determine the flood hazard in the Municipality of Niamey. It was obtained by weighting and aggregating in a raster GIS four layers, namely: soil types, land slope, drainage density and watercourse influence zone.

4.3.5 Mapping of areas at risk of flooding

It represents the elements of the land use that are exposed to flooding. It is the result of the superposition of two raster maps: the hazard map and the land use map. The land use map was obtained by digital processing of the Sentinel 2 satellite image of 2022.

4.3.6 Flood vulnerability mapping

Vulnerability is the totality of the damage that people can suffer both in terms of their physical integrity and their property. Vulnerability is not the same everywhere and increases with the installation of new populations in the flood plains. It was carried out using data from field surveys, SRTM satellite images and data from the Climatic Information and Forecasting

Development Project (PDIPC). The thresholds (low, moderate and high) were generated automatically in ArcGIS.

4.3.7 Mapping of flood risk areas

Flood risk is the product of two components: flood hazard and flood vulnerability.

Formula 8:

$$\textbf{Risk} = \textbf{hazard} \times \textbf{vulnerability} \quad (8)$$

Flood risk has been determined by overlaying the flood vulnerability map with the flood hazard map, which is the trigger for flooding. The hazard here is flooding. A risk exists when elements of land use are susceptible to damage. The degree of damage suffered reflects the degree of vulnerability. The risk is a combination of the hazard and the elements exposed to vulnerability. Figure 35 shows the step-in flood risk mapping.

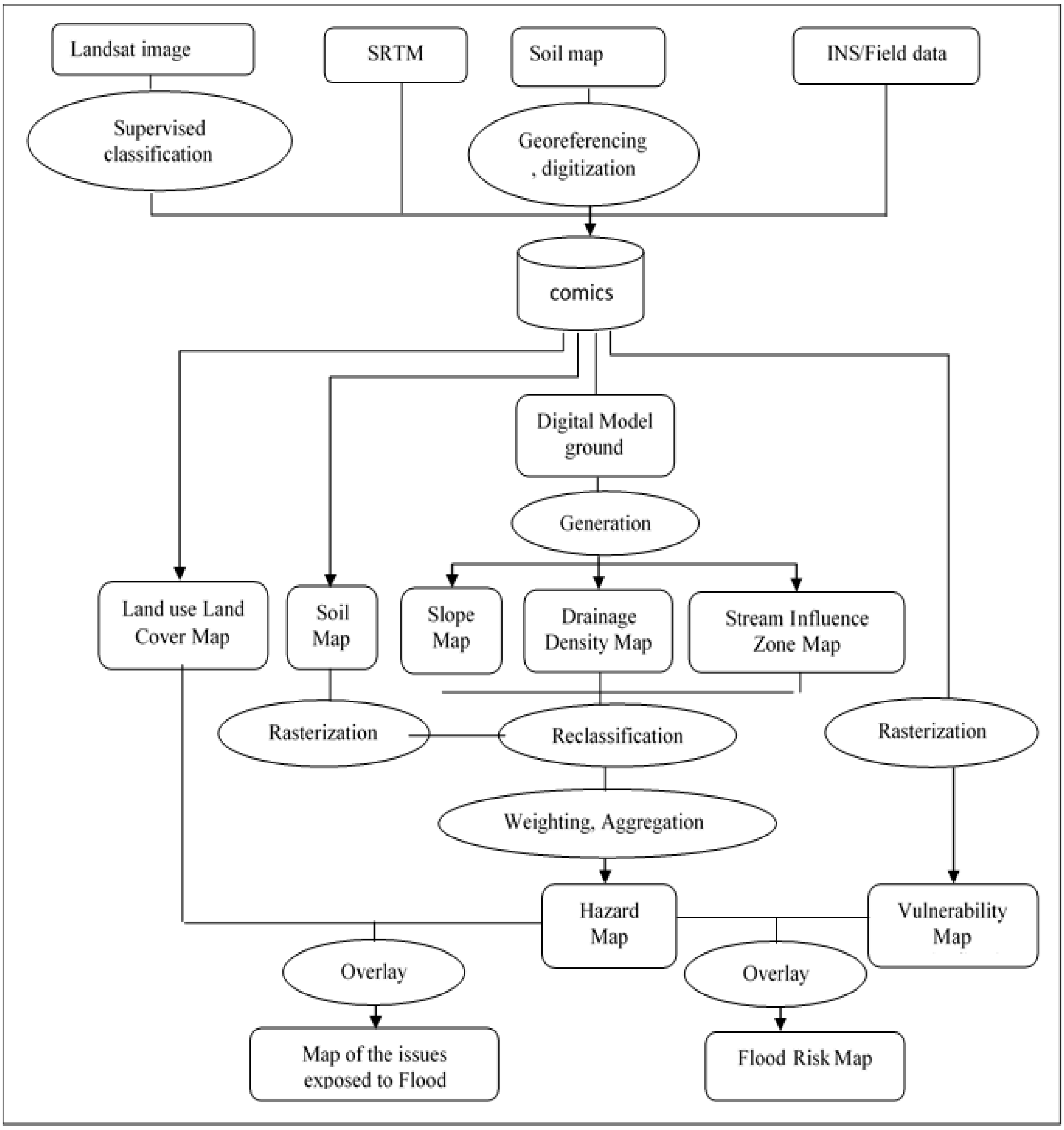

Figure 42: Steps in flood risk mapping

4.4 Results

4.4.1 Pedology

Figure 43 shows the map of the different soil layers and their ability to promote flooding. It shows that a large part of the Municipality of Niamey is covered by soils with moderate, low and very low sensitivity to flooding. The soils with very high and high sensitivity are located in the southern part of the Municipality, more precisely in the valley of the Niger River and the localities of Tondigamey, Airport Road Tchanga

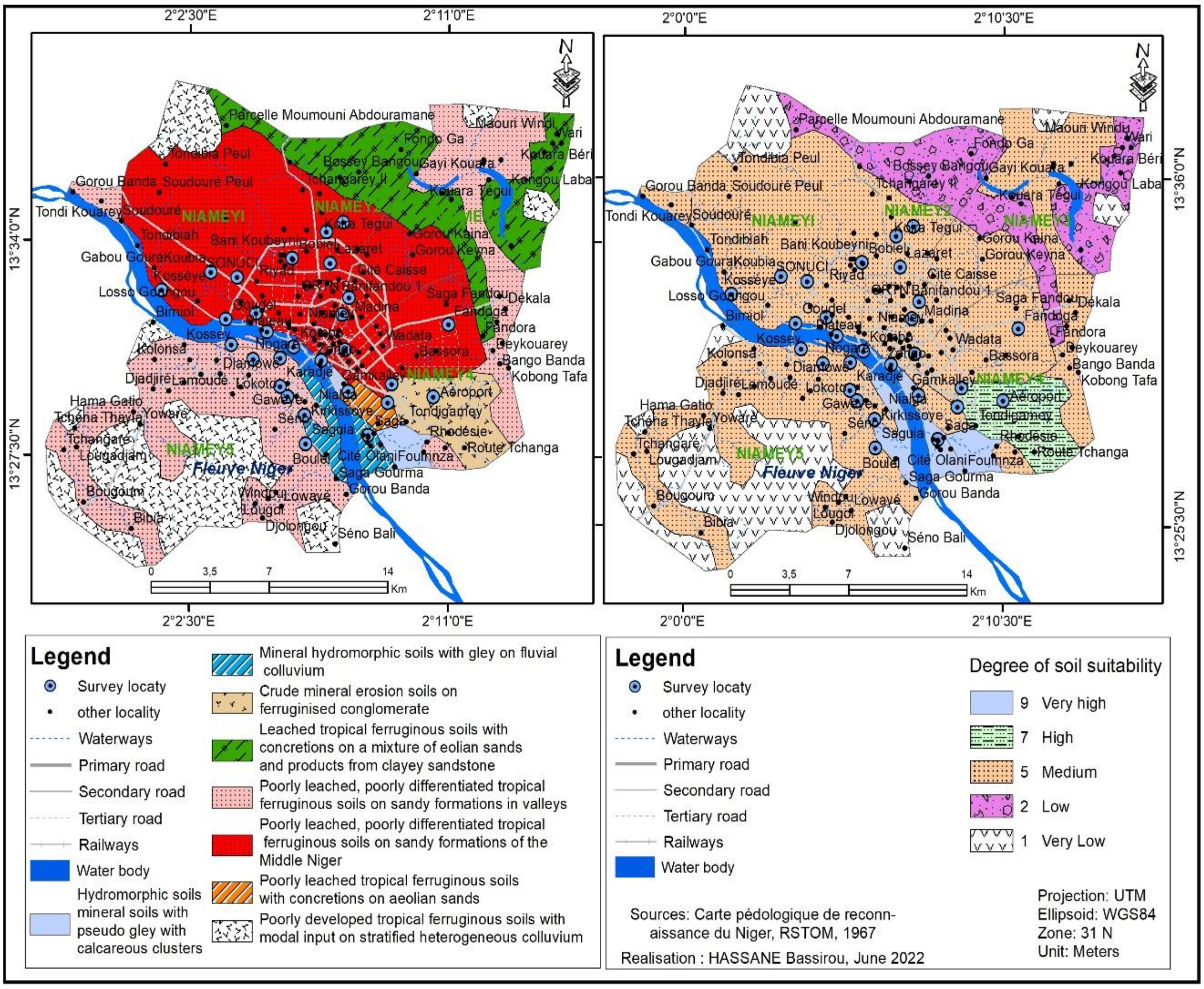

Figure 43: Pedologic map of Niamey

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4.4.2 Drainage Density

Figure 44 shows the drainage density map in the Municipality of Niamey. It indicates that areas with very high and high drainage density are located along the Niger River and its various tributaries. Moderate, low and very low drainage densities are observed in areas where the level of service in the hydrographic network is low. A high drainage density presents a high sensitivity to the risk of flooding

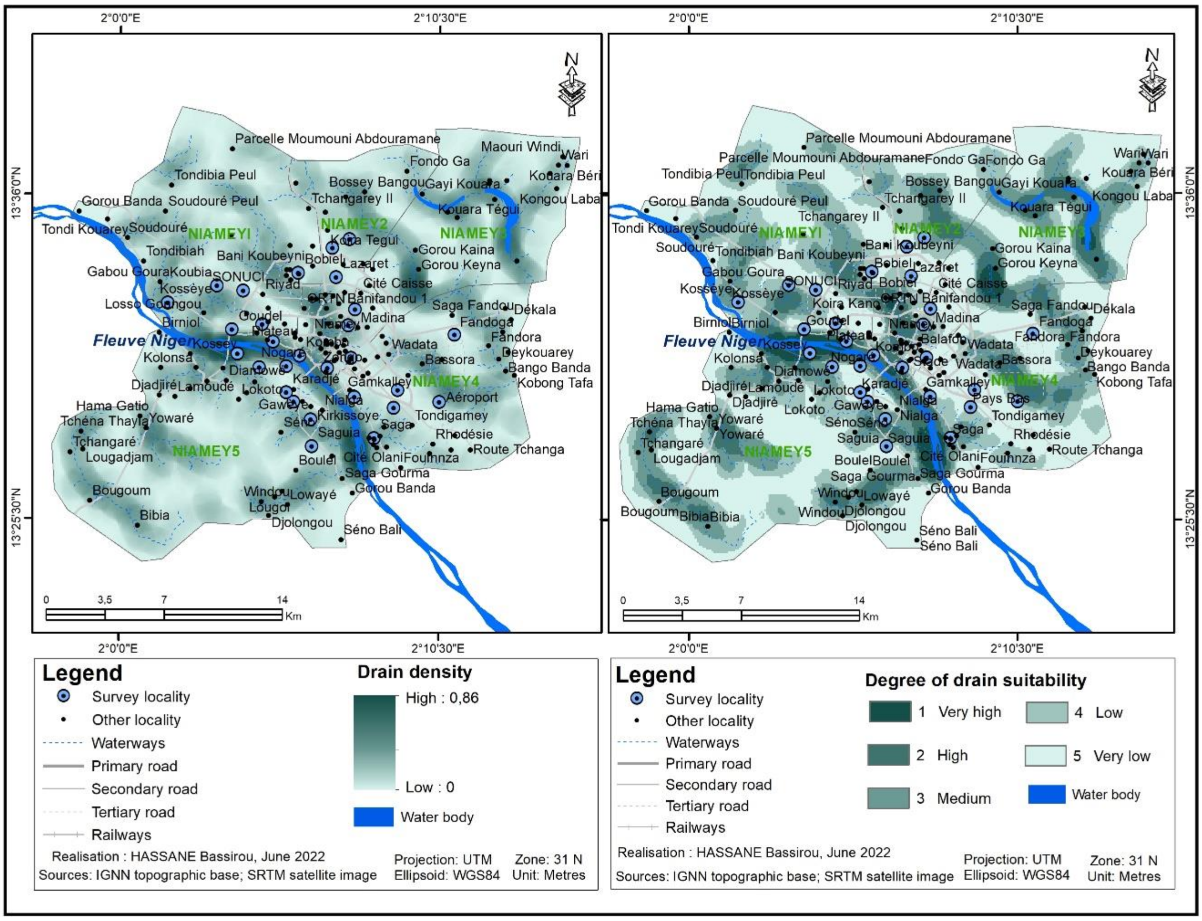


Figure 44: Drainage density map of Niamey.

4.4.3 Zone of Influence of River

The River Niger is a significant waterway that passes through Niamey. The lands, towns, and infrastructure in its immediate vicinity that are subject to the effects of the river's hydrological cycles and the dangers that come with them are included in its zone of influence. Numerous elements, such as the flow patterns of the river, floodplains, and tributaries, affect the zone of effect. Topography, local climate, ecological dynamics, and local human activities are all significantly influenced by the River Niger and its tributaries. In terms of flood danger, Niamey's River Niger influence zone is highly susceptible to flooding incidents. The river can overrun its banks and inundate the surrounding areas during times of extreme rainfall or increased water output, inflicting substantial harm on infrastructure, properties, and livelihoods. The social and economic characteristics of the communities residing near the river are also included in the zone of influence. The river provides an essential water source for transportation, agriculture, and home use. It supports numerous economic activities directly impacted by its existence, including fishing, trading, and tourism. To promote resilient and sustainable growth, the River Niger's influence zone must be considered throughout urban design and development. The hazards brought on by the river's influence can be reduced, and the potential effects of floods can be minimized, with the help of measures like floodplain zoning, sensible land use planning, and infrastructure design. Additionally, it is essential for preserving biodiversity, preserving ecological balance, and maintaining the services the river offers to manage and safeguard the environment of the river within its influence zone. Overall, for building flood resilience, safeguarding populations and infrastructure, and encouraging sustainable development in the area, it is essential to comprehend and manage the River Niger's zone of impact in Niamey. The map of the zones of influence of the rivers is presented in Figure 45.

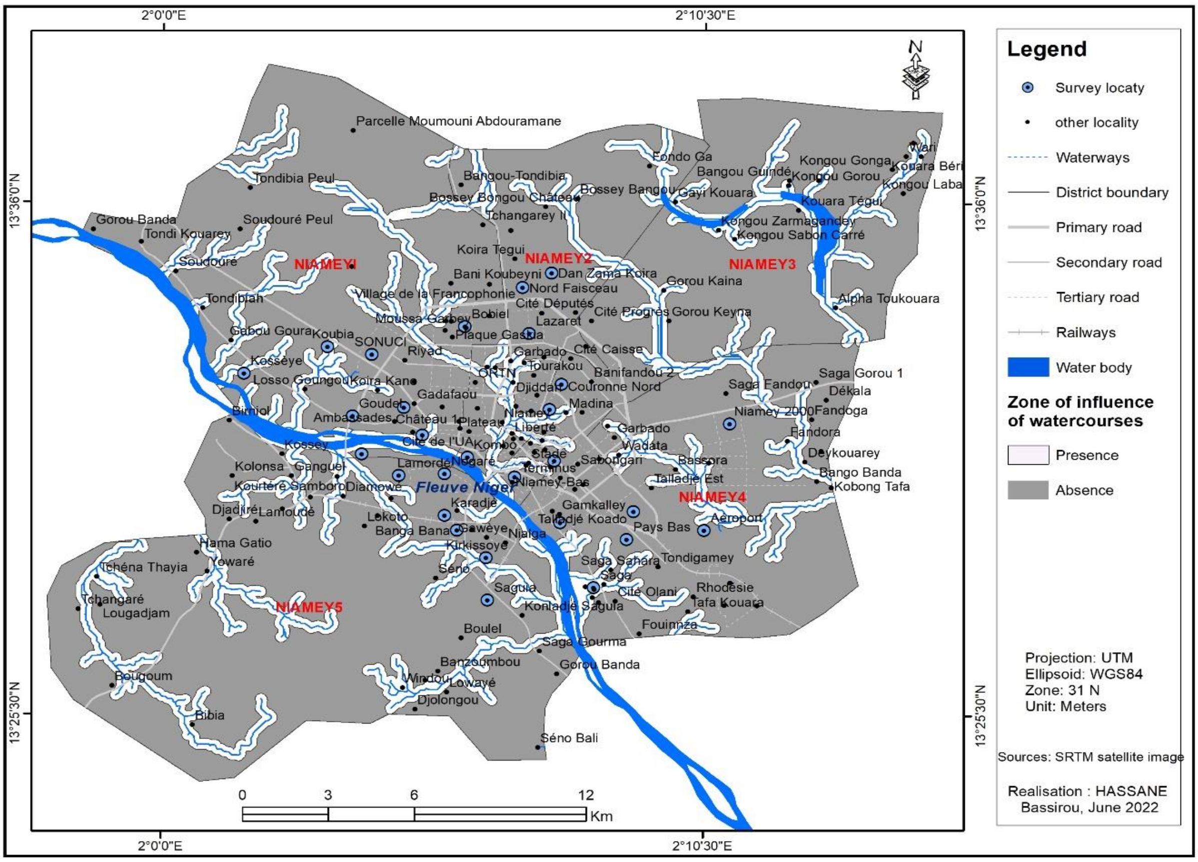


Figure 45: Minor and major beds of the Niger River

This figure indicates that the minor and major beds of the Niger River and its tributaries correspond to the zones of influence of the rivers. These areas are highly sensitive to flooding.

4.4.4 Slope

Figure 46 presents the map of the slopes of the Municipality of Niamey. It shows that a large part of the municipality of Niamey has slopes of between 2.5% and 10%. The areas where the slope is less than 2.5% correspond, in large part, to the Niger valley and to a few plateaus scattered throughout the Municipality. The areas with the steepest slopes (>20%) coincide with rocky outcrops that are weakly prone to flooding.

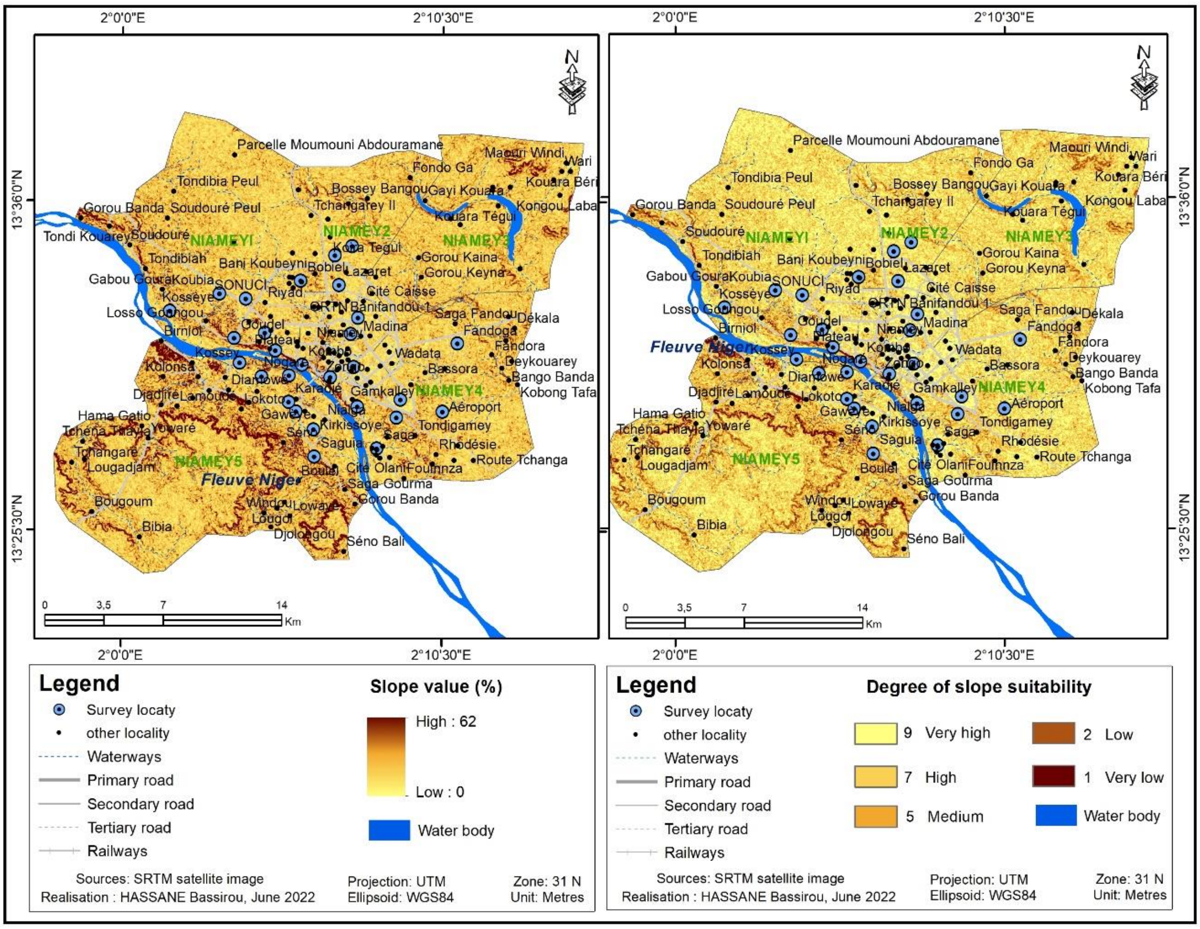


Figure 46: Slope map of Niamey

4.4.5 Hazard

Figure 47 illustrates the flood hazard map in the Municipality of Niamey obtained from the various criteria maps drawn up (soil map, slope map, drainage density map and map of the zone of influence of the watercourse). In this figure, it is shown that 26% of the area of the Municipality of Niamey is subject to a strong hazard, 33% to a moderate hazard and 41% to a weak hazard. The strong hazard covers the alluvial plain of the Niger River and the surroundings of the main tributaries are the areas concerned.

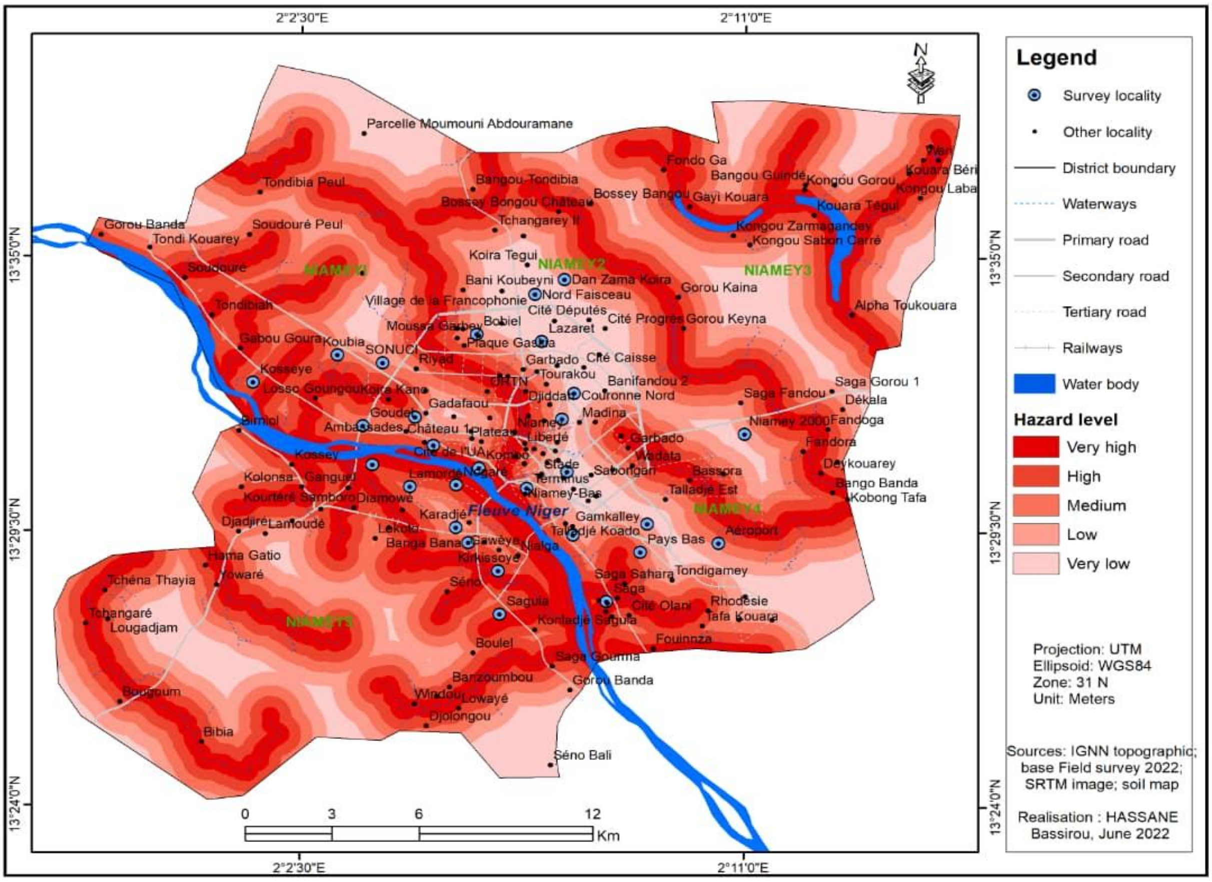


Figure 47: Flood hazard map of Niamey

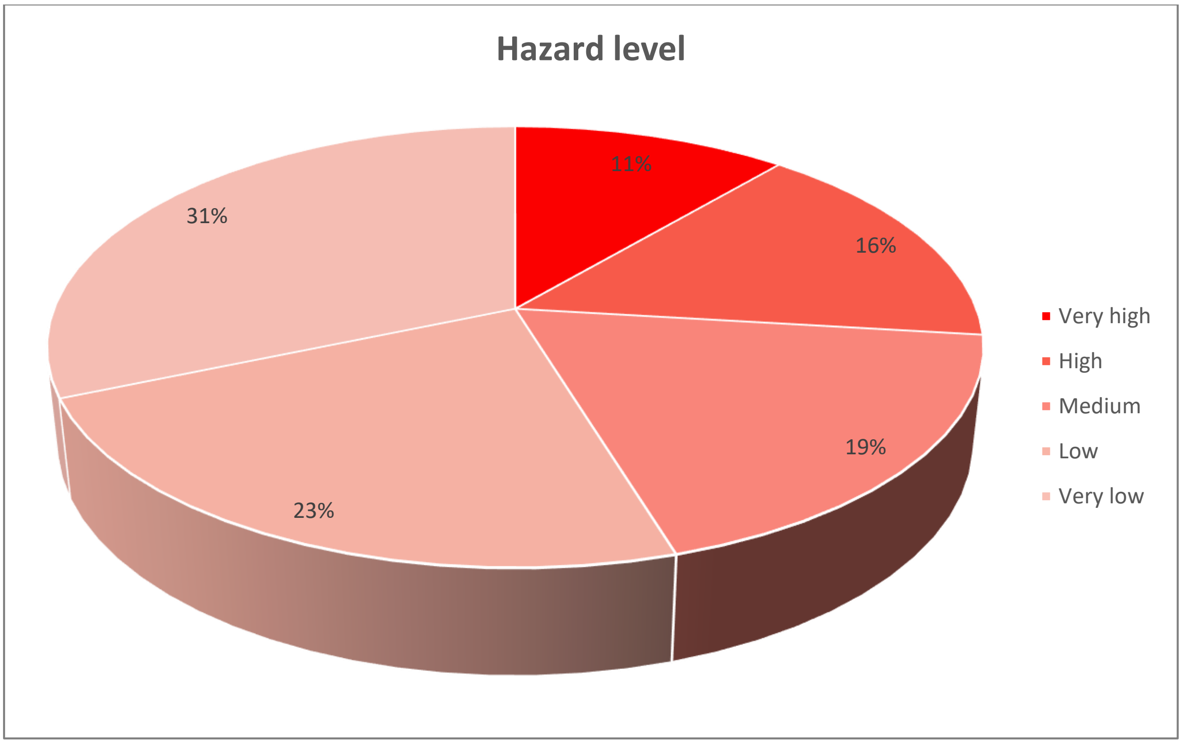


Figure 48 : Percentage of Flood hazard

4.4.6 Exposure

Exposure identifies the individuals, the value of infrastructures and economic activities that may encounter a natural hazard and may be negatively influenced by it. Broadly, exposure refers to an inventory of materials in an area where a hazard occurrence may occupy.

The land use units exposed to the flood hazard are represented in Figure 49. This figure shows that land use units (dwellings, cropping areas, infrastructure, etc.) located in the alluvial plain of the Niger River and around the main tributaries are the units most exposed to flood hazards. In addition, the level of vulnerability is a function of the degree of loss of assets.

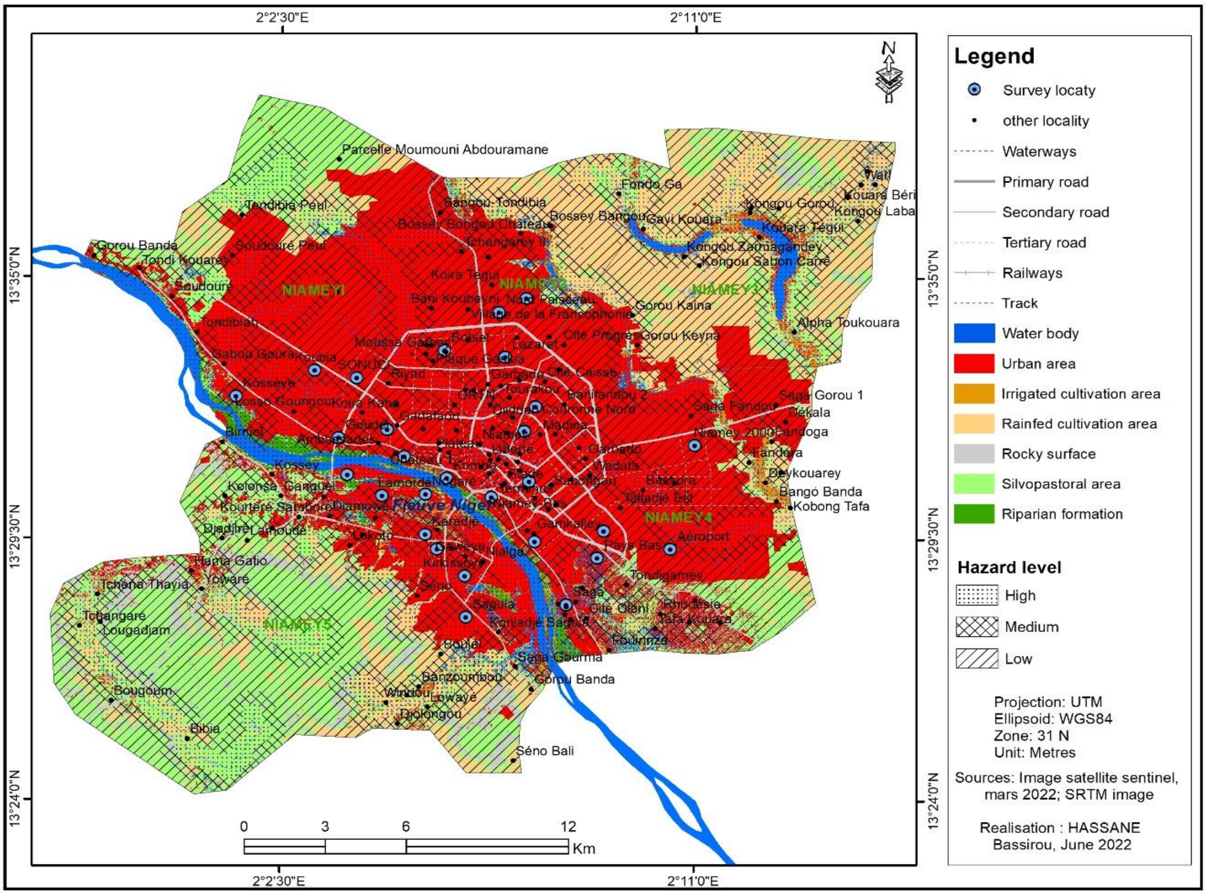


Figure 49: Land use units exposed to the flood hazard

4.4.7 Vulnerability

vulnerability is defined in terms of exposure, capacity, and potentiality. The latter definition states that interventions to lessen susceptibility should also increase coping skills, lessen negative outcomes, and limit exposure.

The degree of flooding vulnerability in the Niamey Municipality is shown in the following graph figure 50 and 51. The vulnerability to flooding varies from area to area as can be seen in

Figure 50. The figure 51 was extracted from Figure 50 for clarity purposes. Thus 11% of the municipality of Niamey presents a very high vulnerability to flooding which is considered part of Niamey5. 34% present a high vulnerability and cover a good part of Niamey 1, 2, 3 and 4. 23% present a moderate vulnerability which takes only part of Niamey 2, 3 and 4. 12% present a low vulnerability and cover only a part of Niamey 1 and 2. 20% has a very low vulnerability only covers part of Niamey 5.

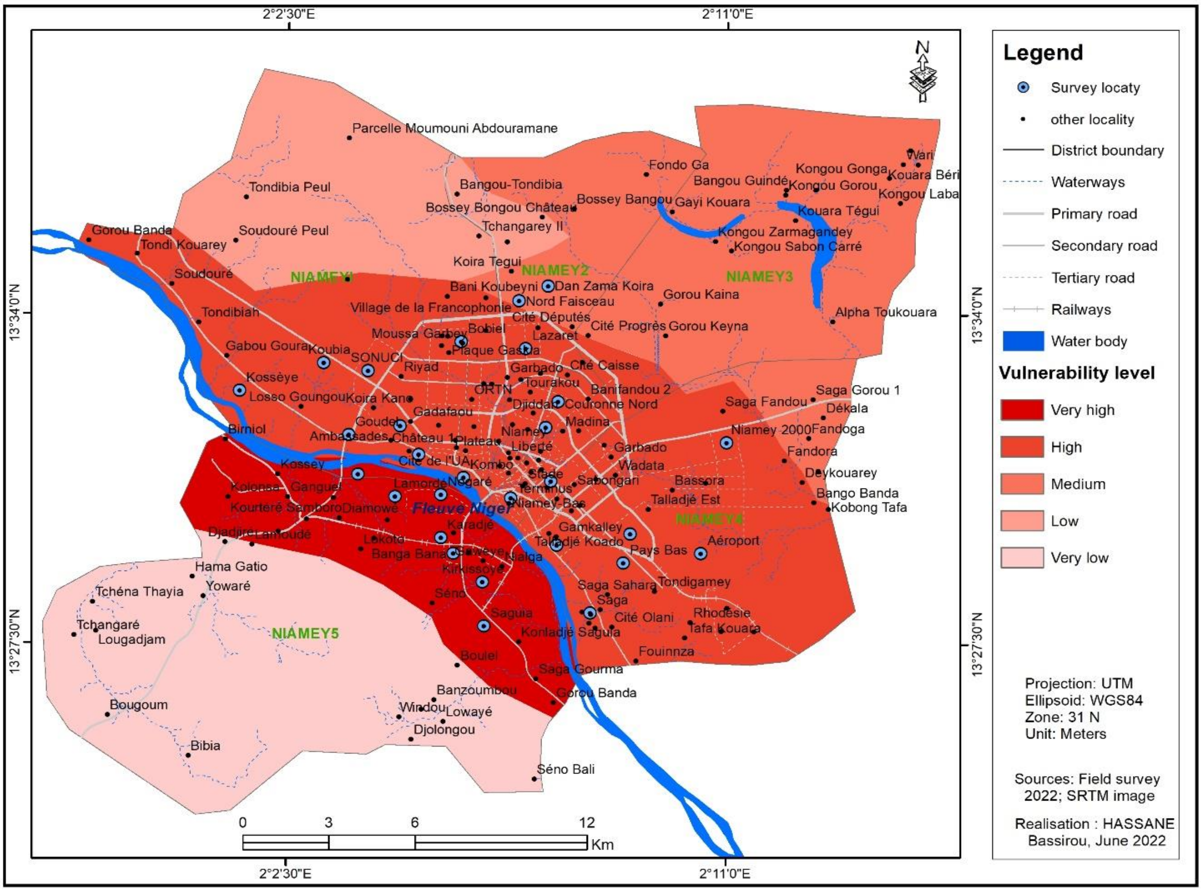


Figure 50: Level of vulnerability of areas to flooding of Niamey

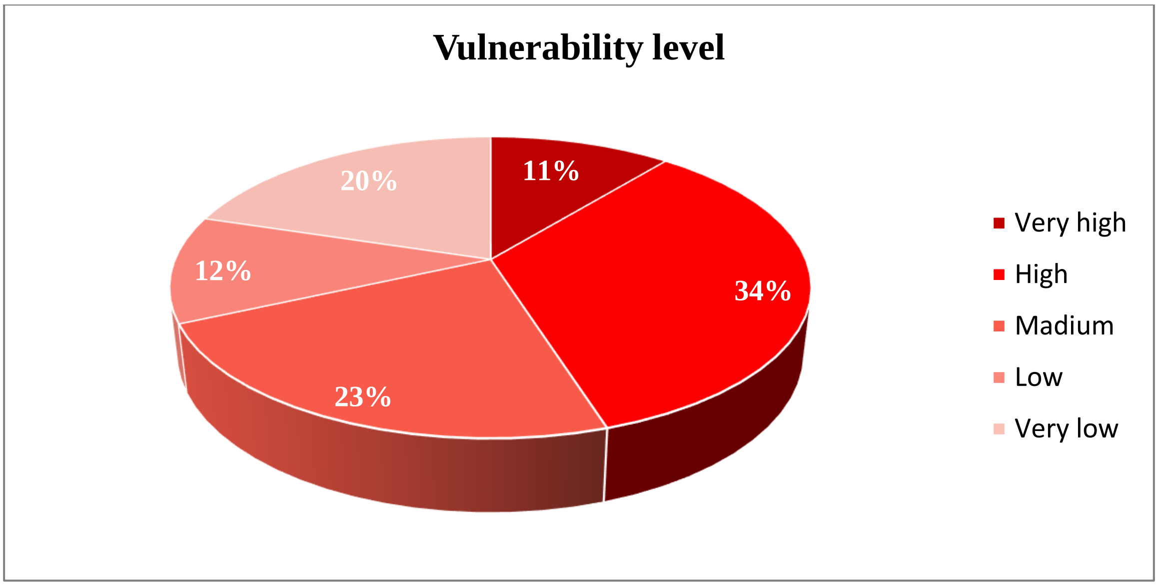


Figure 51: Circular diagram of the level of vulnerability of areas to flooding of Niamey

4.4.8 Risk

Figure 52 presents the flood risk map in the Municipality of Niamey. Figures 52 and 53 distinguished five levels of risk: very low, low, moderate, high and very high. The very low and low flood risk areas cover the largest area of the study area, 22% and 36% respectively. The probability of flooding can be considered negligible. Moderate-risk areas cover 23% of the area of the Municipality. The consequences of a possible flood are quite significant due to the proximity to high-risk areas that can be located at low altitudes. High and very high-risk areas occupy the smallest area, ie respectively 11% and 8% of the area of the Municipality, with however very significant damage in the event of flooding. These areas are located in the alluvial plains of the Niger River and its surroundings. The effects of flooding diminish as one moves away from the river. The localities of Saga, fouinza, talaladjé Saguia, Nogaré, Néini Goungou, Kossey, Kourtéré, Kombo, Kosseyé, Lamordé Zarmagandey, etc. are some of the most affected by this phenomenon.

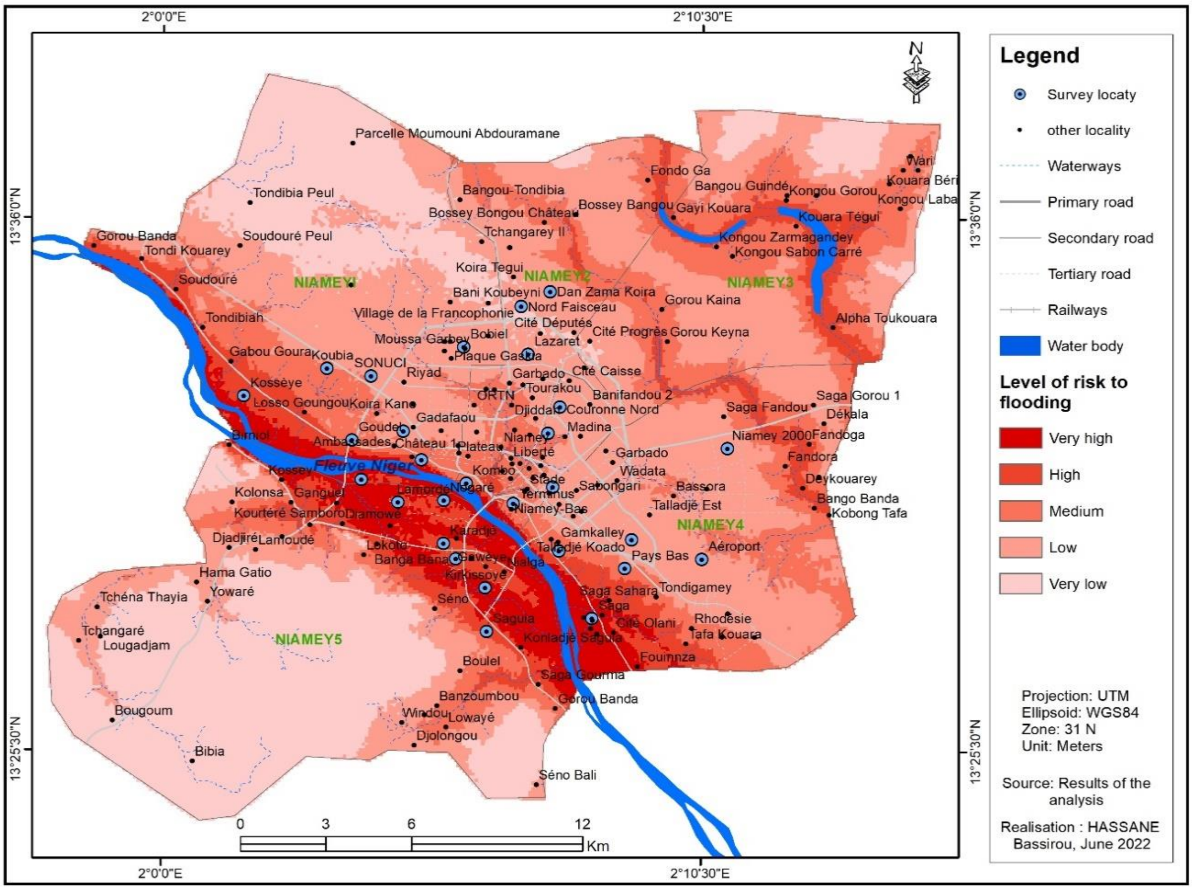


Figure 52: Flood risk map of Niamey

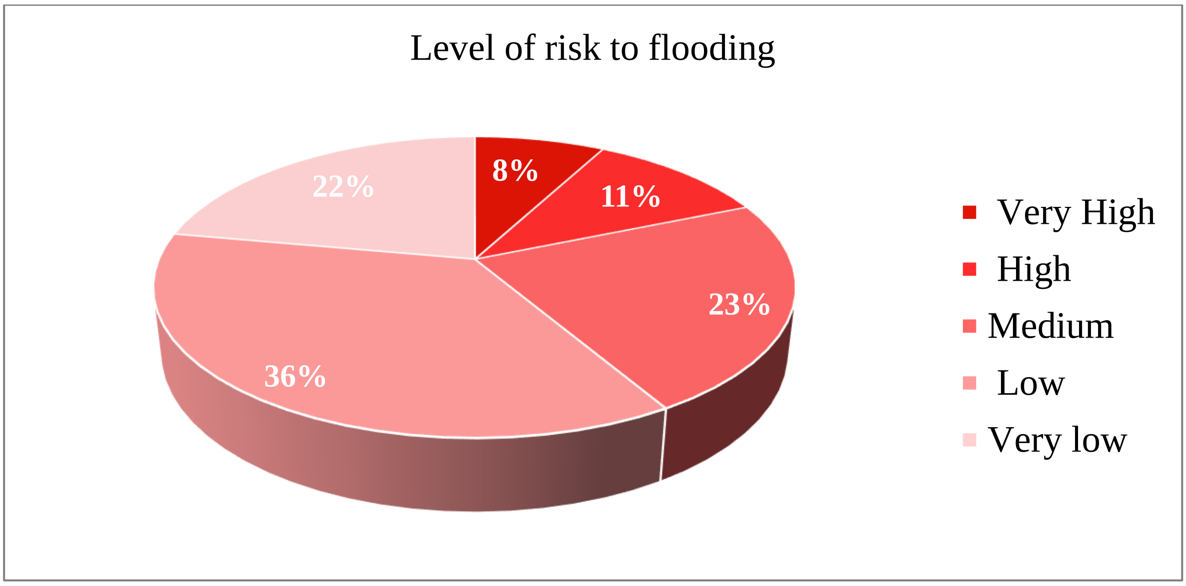


Figure 53: Circular diagram of flood risk map of Niamey

4.5 Discussion

The distribution of soils that are more or less sensitive to flooding indicates that a large part of the Municipality of Niamey has a moderate to very low sensitivity. However, areas of high and very high sensitivity are concentrated in the southern part of the Municipality, particularly in the Niger River valley and in localities such as Tondigamey and the Tchanga airport road. This highlights the need for special attention and appropriate measures in these vulnerable areas to minimize the impact of flooding. The analysis of the drainage density reveals that the areas with high drainage density are mainly located along the River Niger and its tributaries. These areas are more likely to be flooded because of the greater volume of water flowing through them. On the other hand, areas with moderate, low, and very low drainage density are less prone to flooding, which underlines the importance of maintaining and improving the drainage network in order to effectively manage floods and mitigate their effects. The identification of the minor and major beds of the Niger River and its tributaries as zones of influence confirms their high sensitivity to flooding. These areas are particularly prone to flooding and should be prioritized in flood risk management and resilience-building efforts. The implementation of protection and mitigation measures in these areas will be crucial for building resilience to climate change in the municipality. The slope analysis indicates that the majority of Niamey Municipality has slopes between 2.5% and 10%. Areas with slopes below 2.5% are mainly found in the Niger valley and on scattered plateaus. In addition, areas with steeper slopes (>20%) correspond to rocky outcrops that are less prone to flooding. Understanding slope characteristics is essential to identify areas where floodwaters are likely to accumulate and to design appropriate drainage and flood control measures. The flood risk map provides an overview of the level of flood risk in the municipality. It shows that 26% of the area is at high risk, 33% at moderate risk, and 41% at low risk. The alluvial plain of the River Niger and the surrounding areas of the main tributaries are particularly prone to flooding. These results highlight the urgent need for a comprehensive flood risk assessment and the implementation of targeted mitigation strategies in high-risk areas. The exposure assessment considers the vulnerability of people, infrastructure, and economic activities to flood risks. The figure shows that the land use units located in the alluvial plain of the River Niger and around the main tributaries are the most exposed to flood risks. In addition, the level of vulnerability is influenced by the degree of property loss. Understanding patterns of exposure allows prioritization of protection and mitigation measures for vulnerable communities, infrastructure, and livelihoods. Vulnerability, which encompasses physical, social, economic, and environmental factors, plays a crucial role in determining the sensitivity of a community to the effects of hazards. The assessment reveals different types of vulnerabilities in the municipality of Niamey, including social, physical, economic, and environmental vulnerabilities. Addressing these vulnerabilities through targeted interventions, such as improving housing conditions, strengthening livelihood resilience, and promoting environmental conservation, is essential to reducing flood risk and building resilience to climate change. The risk assessment classifies the level of flood risk into five categories: very low, low, moderate, high, and very high. The results indicate that a large part of the study area falls into the very low and low-risk categories, covering 22% and 36% of the area respectively. These areas have a relatively low probability of flooding and the potential consequences of flooding are considered minimal. However, it is important to note that the moderate-risk areas cover 23% of the municipality, indicating a significant potential for flooding and consequent impacts due to their proximity to high-risk areas at lower elevations.

The high and very high-risk areas, although occupying a small part of the municipality (11% and 8% respectively), present significant risks in case of flooding. These areas are mainly located on the alluvial plains of the River Niger and its surroundings. Localities such as Saga, Fouinza, Konladjé Saguia, Nogaré, Néini Goungou, Kossey, Kourtéré, Kombo, Kosseyé, Lamordé Zarmagandey, and others are particularly vulnerable to flooding. Efforts should be directed towards the implementation of robust and context-specific measures to mitigate risks and minimize potential damage in these high-risk areas.

Overall, the results highlight the complex interaction of various factors contributing to flood risk and climate change resilience in the municipality of Niamey. The results serve as a basis for informed decision-making, enabling stakeholders to prioritize mitigation strategies and allocate resources effectively. It is essential to consider a multi-dimensional approach that combines interventions on physical infrastructure, community engagement, capacity building, and policy measures to improve flood resilience and protect vulnerable communities. Furthermore, integrating these outcomes into broader urban planning and development frameworks can promote sustainable growth while minimizing flood-related risks. Close collaboration between different stakeholders, including government agencies, local communities, non-governmental organizations, and international partners, is essential to ensure the successful implementation of mitigation strategies and Niamey's long-term resilience to flood-related disasters and climate change challenges.

Partial Conclusions

The assessment of flood risk and resilience to climate change in the municipality of Niamey reveals essential information about the community's vulnerability to flooding. The results highlight highly sensitive areas, including the River Niger valley and specific localities, where targeted mitigation strategies should be implemented. Flood resilience can be improved by considering factors such as drainage density, river influence area, slope, hazard, exposure, vulnerability, and risk. The assessment highlights the importance of a multi-dimensional approach that combines interventions on physical infrastructure, community engagement, capacity building, and policy measures. Collaboration between government agencies, local communities, and other stakeholders is essential for successful implementation and long-term resilience. Promoting sustainable growth while minimizing flood risk requires integrating the results of the assessment into urban planning and development frameworks. Niamey can reduce its vulnerability to floods by improving infrastructure, strengthening livelihoods, and preserving the environment. The assessment also highlights the need to take social, economic, and environmental factors into account when addressing vulnerability. By improving housing conditions, livelihoods, and access to services, the municipality can strengthen the community's ability to withstand flooding. Ultimately, assessment is a valuable tool for informed decision-making, enabling stakeholders to allocate resources effectively and prioritize mitigation efforts. Niamey can better cope with flooding and climate change by building resilience and encouraging collaboration, ensuring the well-being and safety of its residents.

5 Chapter 5: Hydrography and Flood Modelling

Introduction

Understanding the dynamics of water resources and their effects on human activities requires knowledge about how precipitation has changed between 1990 and 2020, as well as the flow and height of the River Niger. Niamey, the nation's capital, is distinguished by the presence and behavior of water resources. Due to their proximity to the River Niger, these resources are of significant importance. Understanding the climatic factors that affect Niamey's water regime requires an evaluation of precipitation. Analyzing precipitation data collected over several decades allows us to discern long-term trends, seasonal variations, and prospective changes in rainfall patterns.

Furthermore, the hydrology of the area is substantially influenced by how the River Niger behaves as it passes through Niamey. To comprehend the hydrographic changes that have occurred in Niamey over the past three decades, this study will combine the analysis of precipitation patterns with measurements of the River Niger's flow and height. Understanding the connection between precipitation, river flow, and height offers a thorough understanding of Niamey's water system and can help with efforts to manage water resources and reduce flooding.

5.1 Hydrography of Niamey

Devastating floods have recently hit the Niamey area, resulting in significant losses and damages. Table 24 is about the data on the average flow and height of the Niger River and the precipitation from 1990 to 2020. The physical features of catchments, such as the topography, geomorphology, and land cover, have a significant impact on the rainfall-runoff process, making it challenging to identify the causes of floods.

Table 24. Average flow, P(mm) and Average height of Niamey from 1990 to 2020

Years	Average flow (m^3/s)	P(mm)	Average height (cm)
1990	525.7868	493.78	236.88
1991	604.2685	574.78	264.09
1992	645.0683	583.55	273.47
1993	566.9178	500.12	253.71
1994	747.1507	746.12	298.62
1995	893.5644	502.53	342.90
1996	766.776	515.92	315.86

Years	Average flow (m^3/s)	P(mm)	Average height (cm)
1997	698.0603	396.62	298.90
1998	835.4575	654.44	327.58
1999	872.9233	669.76	335.27
2000	940.6667	528.59	349.68
2001	895.137	531.17	338.89
2002	801.9479	501.9	321.52
2003	922.0493	741.77	336.80
2004	890.0328	462.14	341.10
2005	855.2658	688.03	333.75
2006	852.8521	550.12	327
2007	944.0767	607.08	351.33
2008	995.7459	587.59	356.23
2009	955.6082	530.44	349.55
2010	1200.337	556.69	393.58
2011	1075.438	475.8	377.73
2012	942.0792	595.17	365.87
2013	963.3808	570.96	393.14
2014	797.6082	566.45	361.02
2015	826.2192	591.54	361.16
2016	959.7077	603.28	412.92
2017	879.7808	634.81	395.24
2018	806.7288	598.35	263.71
2019	1007.047	541.47	342.74
2020	1144.377	784.95	435.91

5.2 Evolution of Precipitation from 1990 to 2020

In Table 25, long-term trends in precipitation patterns can be discerned by analyzing fluctuations over time. Positive and negative deviations reflect natural climate variability, influenced by regional and planetary climatic processes. Negative deviations signify years in which Niamey's annual rainfall has fallen below the average. The most significant negative deviation, at -31.16% in 1997, indicated a substantial rainfall deficit compared to the average. These negative deviations highlight dry spells and below-average precipitation. Several years, including 1990, 1993, 1995, 2004, and 2011, exhibited notable negative departures, suggesting relatively dry conditions. Consequences of negative deviations may encompass water scarcity, reduced agricultural yields, and impacts on ecosystems and natural resources.

Table 25. Annual Percentage Deviation in P(mm) of Niamey from 1990 to 2020

Years	P(mm)	Percentage	Annual Percentage Deviation in P(mm)
1990	493.78	85.70783864	-14.29216136
1991	574.78	99.76740957	-0.232590433
1992	583.55	101.2896619	1.289661876
1993	500.12	86.80830383	-13.19169617
1994	746.12	129.5077414	29.50774144
1995	502.53	87.22661945	-12.77338055
1996	515.92	89.55078803	-10.44921197
1997	396.62	68.84329654	-31.15670346
1998	654.44	113.5943901	13.59439006
1999	669.76	116.2535583	16.25355829
2000	528.59	91.74998264	-8.250017357
2001	531.17	92.19780601	-7.802193987
2002	501.9	87.11726724	-12.88273276
2003	741.77	128.7526904	28.75269041
2004	462.14	80.21592724	-19.78407276
2005	688.03	119.4247726	19.42477262
2006	550.12	95.48705131	-4.512948691
2007	607.08	105.3738804	5.373880442
2008	587.59	101.9909047	1.990904673
2009	530.44	92.0710963	-7.928903701
2010	556.69	96.62743873	-3.372561272
2011	475.8	82.58696105	-17.41303895
2012	595.17	103.3066028	3.306602791
2013	570.96	99.10435326	-0.89564674
2014	566.45	98.32153024	-1.678469763
2015	591.54	102.6765257	2.676525724
2016	603.28	104.7142956	4.714295633
2017	634.81	110.1871138	10.1871138
2018	598.35	103.8585711	3.858571131
2019	541.47	93.98562799	-6.014372006
2020	784.95	136.2476567	36.24765674
2021	549.79	95.42977158	-4.570228425

On the other hand, positive deviations represent years with above-average rainfall, indicating that Niamey received more rainfall than the norm figure 54. In 2020, there was a remarkable positive deviation of 36.25%, signifying a significant surplus of rainfall compared to the average. These positive deviations can have implications such as abundant water resources, increased agricultural productivity, and effects on ecosystems and natural resources.

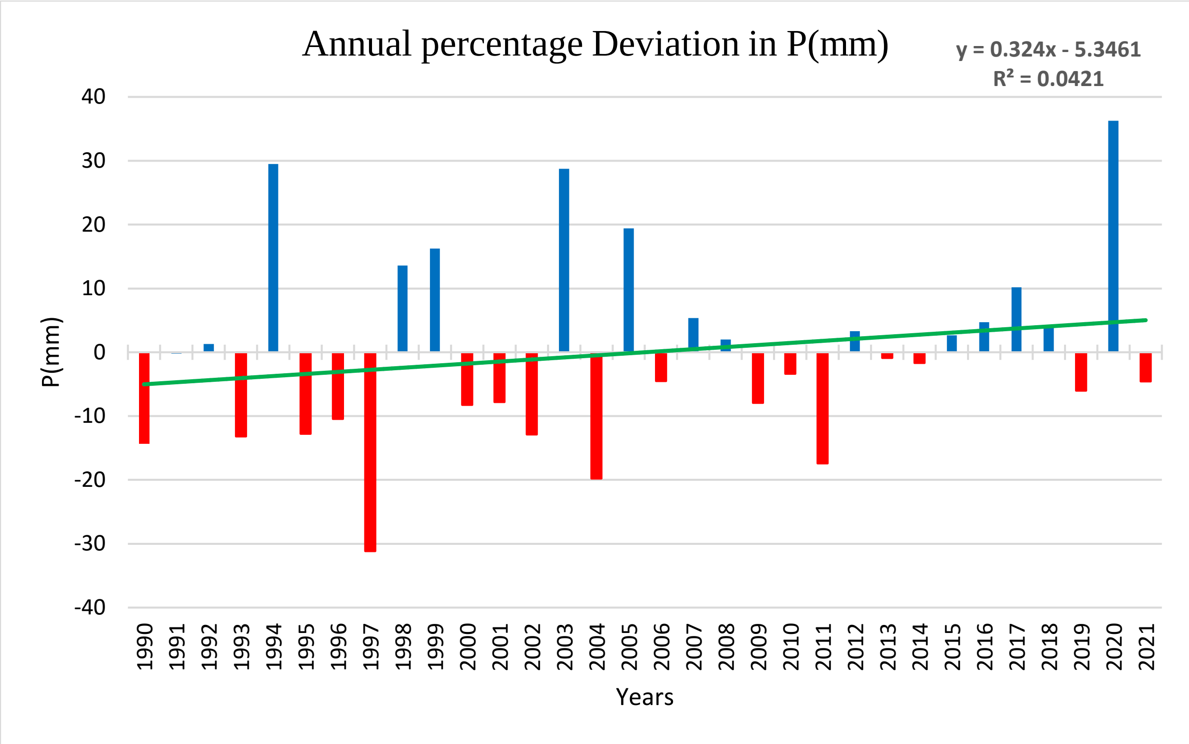


Figure 54: Annual percentage Deviation in P(mm) of the Niger River

The positive deviations in precipitation data draw attention to periods of increased rainfall and wetter conditions. Notably, several years, including 1994, 2003, 2005, 2017, and 2018, exhibit significant positive deviations, indicating relatively rainy years (as depicted in Figure 45). These positive deviations can bring advantages such as improved water availability, higher agricultural yields, and potential ecological benefits. However, they can also present challenges like flooding or difficulties in water management.

In contrast, certain years, such as 1992, 1999, 2008, 2012, and 2015, show near-zero or average deviations, suggesting rainfall levels in line with the long-term average. In other years, minor variations in annual rainfall occurred, with both unfavorable and positive outcomes. This table effectively highlights periods of both below-average and above-average rainfall, providing valuable insights into the annual rainfall fluctuations in Niamey.

Understanding these variations is crucial for the development of regional strategies for effective water resource management, agricultural planning, and the enhancement of resilience to climate-related changes.

Figure 55 visually presents the annual and monthly average rainfall evolution from 1990 to 2020, offering a comprehensive overview of the overall precipitation trend during this period.

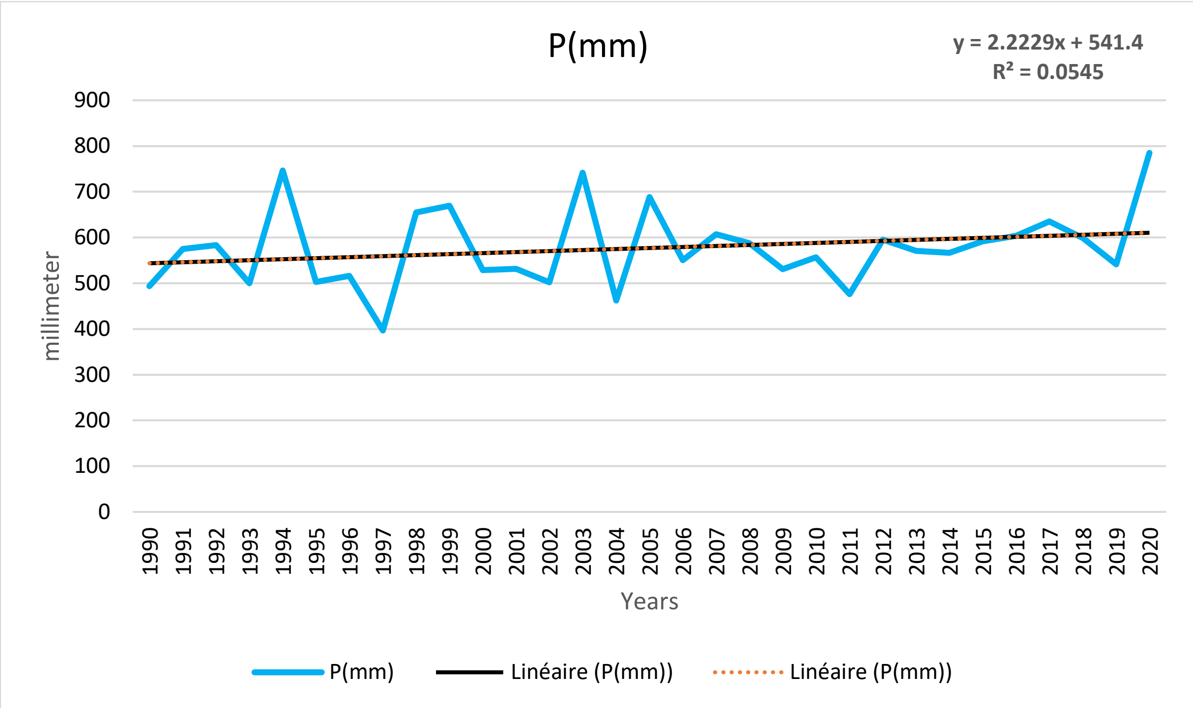


Figure 55: Trend of precipitation in Niamey from 1990 to 2020

Situated within the sub-Saharan region, the Niamey area undergoes two distinct seasons: the dry season and the rainy season. The dry season, spanning from June to September, is defined by its limited rainfall, which intermittently leads to occasional flash floods.

5.3 Niger river

The Niger River flows through Mali, Niger, runs along the border with Benin, and eventually empties into the Gulf of Guinea in the Atlantic Ocean, forming a vast delta known as the Niger Delta, also sometimes referred to as the Oil Rivers.

As the largest river in West Africa, the Niger River stretches approximately 4,180 kilometers (2,600 miles), making it the third-longest river in Africa, trailing only the Nile and the Congo River. It is surrounded by a vast drainage basin covering an impressive 2,117,700 square kilometers.

5.3.1 The Flow of The River Niger from 1990 to 2020

Figure 56 provides valuable data on the annual fluctuations in the typical flow of the River Niger. The River Niger's typical flow varies from year to year, and this information is crucial for comprehending its hydrological dynamics.

The highest recorded average flow, at 1200.337 m^3/s, was observed in 2010, indicating a significant volume of water passing through the river during that year. Conversely, the lowest average flow was documented in 1990, measuring only 525.7868 m^3/s.

Several years experienced above-average flows, including 1994, 1995, 1998, 1999, 2000, 2001, 2003, 2004, 2007, 2008, 2009, 2010, 2011, 2019, and 2020. These periods likely signify enhanced water availability, possibly due to above-average rainfall or other factors contributing to improved river flow.

Conversely, below-average flows were observed in the years 1990, 1992, 1993, 1997, 2002, 2014, 2015, 2017, and 2018. These instances indicate reduced water availability, which may be attributed to below-average rainfall or other factors leading to a decrease in river flow. Understanding these flow variations is essential for effective water resource management and for anticipating potential impacts on sectors reliant on the River Niger's water supply.

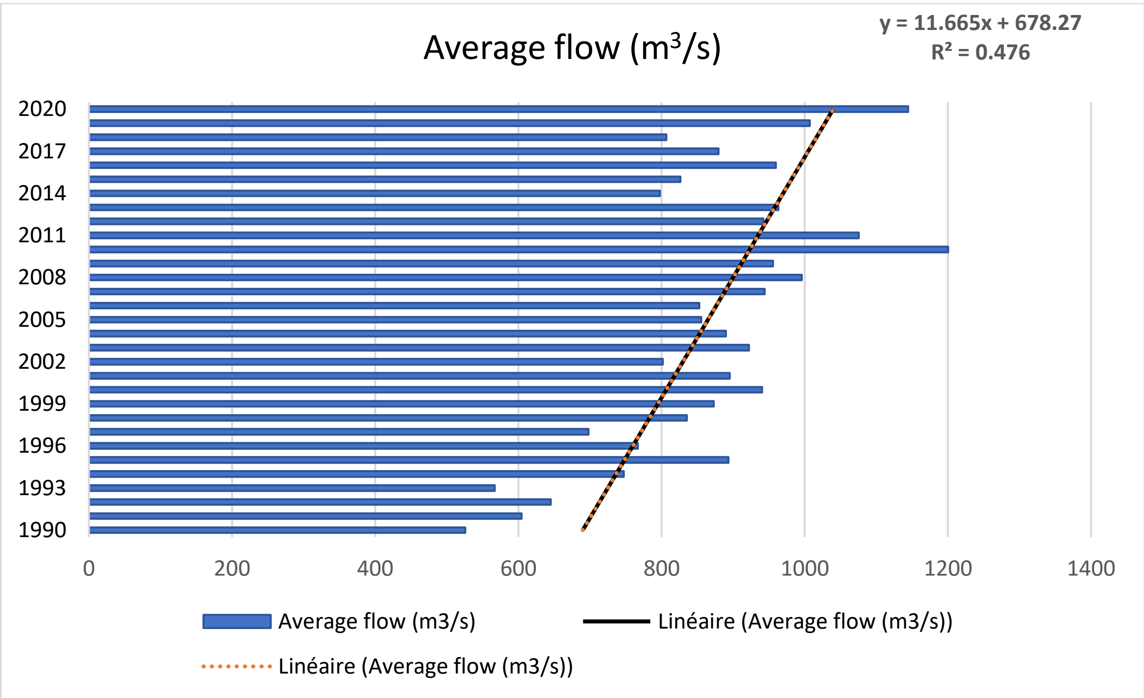


Figure 56: Average flow of the Niger river from 1990 to 2020

The flow of the River Niger naturally fluctuates from year to year, as illustrated in the table. Various factors, including weather patterns, variability in rainfall, changes in land use, and water management practices, contribute to these fluctuations in mean flow. Understanding a river's hydrological characteristics and its ecological significance relies on a thorough comprehension of its mean flow, which has far-reaching implications.

The availability of mean flow data is essential for the preservation of ecosystems, providing water for irrigation, generating hydroelectric power, and sustaining the livelihoods of communities residing along the riverbanks. To discern long-term trends in river behavior, it is imperative to analyze the mean flow data collected over an extended period. Detecting significant patterns or variations in the River Niger's flow requires additional research and data assessment.

Figure 56 presented offers a succinct summary of the inter-annual fluctuations in the mean discharge of the River Niger. It is vital to grasp these variations for purposes such as protecting the region's ecosystems, making accurate flood predictions, and effectively managing water resources.

5.3.2 Height of the River Niger

Figure 57 presents data detailing the annual mean flow of the River Niger for each respective year. The average gross flow of the River Niger varies from year to year, indicating fluctuations in the river's water flow or volume. Notably, the river appears to carry a substantial amount of water, as evidenced by the highest mean gross value of 435.91 cm^3 recorded in 2020. Conversely, the lowest-ever average gross value, at 236.88 cm^3, was recorded in 1990.

In certain years, including 2010, 2013, and 2016, there were gross values that exceeded the typical range. These instances likely signify an increase in water flow, potentially influenced by above-average rainfall or other factors that contribute to enhanced river flow.

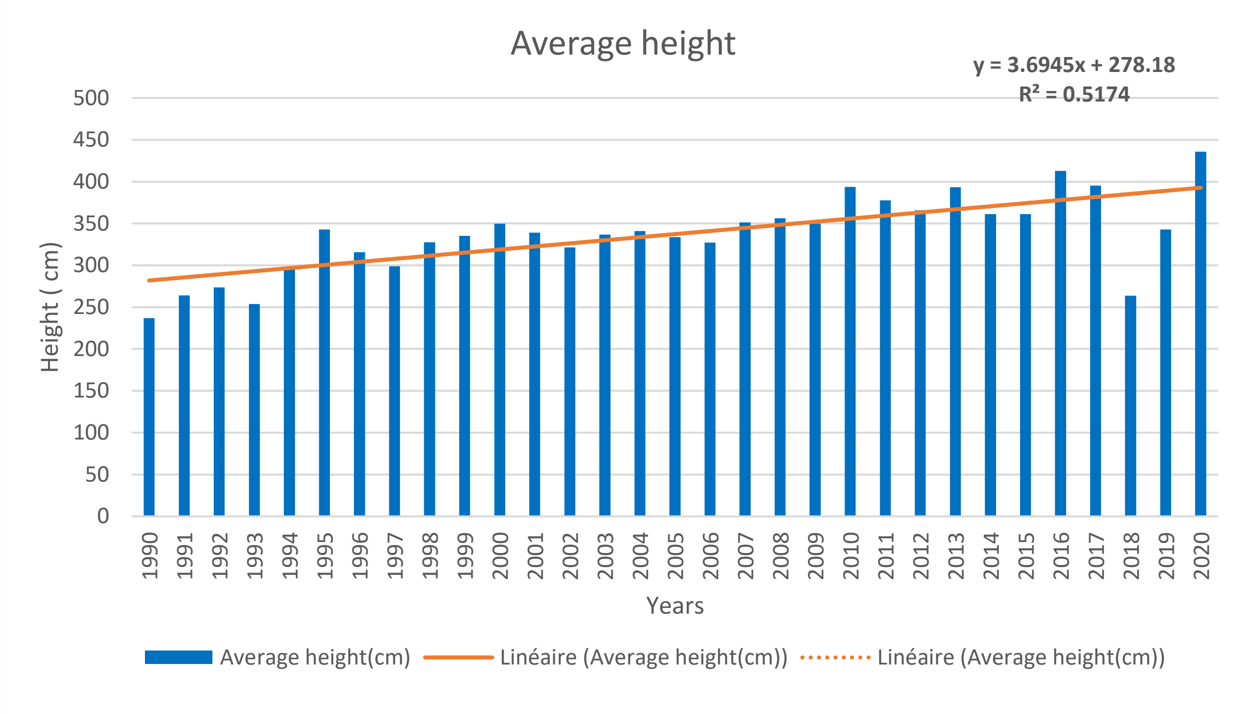


Figure 57: Average height of the Niamey River from 1990 to 2020

In both 2018 and 1990, the raw values of the River Niger were below the normal range. These periods indicate a decrease in water flow, which may be attributed to factors such as below-average rainfall or other influences affecting river flow.

The table illustrates the yearly fluctuations in the River Niger's raw values, driven by natural factors. Variables like rainfall patterns, changes in land use, and practices in upstream water management can all contribute to variations in mean raw discharge. Mean raw discharge provides a general insight into the river's flow and water volume. It is essential to understand the river's hydrological characteristics, water availability, and potential impacts on ecosystems and human activities.

To identify long-term trends in the river's behavior, it is necessary to analyze raw data averaged over an extended period. To uncover significant trends or changes in the raw data for the River Niger, additional information and further research are essential.

The figure 57 offers a summary of the year-to-year variability in the average Hight data for the River Niger. Understanding these variations is crucial for purposes such as preserving the region's ecosystems, making accurate flood predictions, and effectively managing water resources.

5.4 Influence of Precipitation on the Flow and Height of the River Niger

The inter-annual mean discharge in Niamey, a typical station for the Middle Basin, is around 875 $m^3 s^{-1}$ (1946–1992). Extremely low water levels may even cause the river to cease flowing, which happened in June 1986 (typically below 10 $m^3 s^{-1}$).

A characterisation of severe rainfall under climate change and land-use/land-cover (LULC) changes is required to enhance the forecast of rainfalls that cause catastrophe since the number of fatalities and economic losses is quickly rising, particularly in urban areas. Understanding the features of severe rainfall events as well as the role of LULC changes in the escalation of floods under current and future circumstances is essential. However, the definition of excessive rainfall varies from place to region, or even seasonally or between rural and urban regions. The influence of climate change on the spatiotemporal variability of rainfall across various locations is making it increasingly difficult to define severe rainfall. For decision-makers and stakeholders, an objectively oriented definition of excessive rainfall, such as flood analysis may be more beneficial.

In linear regression, the formula for the regression statistic of precipitation (or any independent variable) can be expressed as follows in formula:

Formula 9

$$\mathbf{Y = \beta_0 + \beta_1 X + \varepsilon} \qquad \mathbf{9}$$

Where:

- **Y** represents the dependent variable (in this case, the height or discharge of the River Niger).
- **X** represents the independent variable (precipitation).
- $\boldsymbol{\beta_0}$ is the intercept, which represents the predicted value of Y when X is equal to 0.
- $\boldsymbol{\beta_1}$ is the regression coefficient, which represents the change in Y for a one-unit change in X.
- $\boldsymbol{\varepsilon}$ represents the error term, which accounts for the variability in Y that is not explained by the linear relationship with X.

In the context, this formula is used for the height or discharge of the River Niger based on the amount of precipitation. The regression statistics such as R Square, Multiple R, and the coefficients (β_0 and β_1) are derived from the analysis of the data to describe the strength and characteristics of the relationship between precipitation and the river's height or discharge. These statistics help determine how well the linear regression model fits the data and how much of the variation in the dependent variable can be explained by the independent variable.

5.4.1 Influence of Precipitation on the flow of the River Niger

Table 26 presents the findings of a straightforward linear regression analysis conducted to explore the relationship between rainfall and River Niger discharge. efforts to define the excessive precipitation that caused a pluvial flood in Niamey.

Table 26: Regression statistic of precipitation on the flow of the River Niger

Regression Statistics	
Multiple R	0.239889
R Square	0.057547
Adjusted R Square	0.025048
Standard Error	85.49175
Observations	31

In order to reveal a better understanding of the data presented in the aforementioned table, Here's a revised and clearer summary of the results:

Correlation (Multiple R-value): The multiple R-value, which stands at 0.239889106, indicates a moderately favorable association between river discharge and rainfall. This suggests that there is a noticeable relationship between these two variables.

R-Squared Value: The R-squared value is 0.057546783, implying that approximately 5.75 per cent of the variability in River Niger flow can be attributed to rainfall. However, this signifies a relatively weak connection between the two variables.

Adjusted R-Squared Value: The adjusted R-squared value, which considers both the number of predictors and the data size, is 0.025048396. After accounting for sample size and predictors, this number, similar to the R-squared value, indicates that precipitation explains approximately 2.5% of the variation in river flow.

Standard Error: The standard error, measuring the average difference between observed and predicted values by the regression model, is 85.49175198. A lower standard error suggests that the projected values closely align with actual observations, while a higher standard error implies greater variability in the anticipated values.

Sample Size: This analysis is based on 31 observations, representing the number of data points used in the regression analysis.

In summary, the analysis reveals a moderately positive association between rainfall and River Niger discharge, as indicated by the presented regression statistics. However, it's important to note that only a small percentage (approximately 5.75% and 2.5%, respectively) of the variability in river discharge can be attributed to rainfall, according to the R-squared and adjusted R-squared values. Additionally, the relatively high standard error of 85.49175198 implies variability in the predicted values compared to the actual observations.

5.4.2 Influence of Precipitation on the height of the River Niger

Table 27 presents the results of a straightforward linear regression analysis examining the relationship between rainfall and the assumed gross discharge of the River Niger. Here's a revised and more coherent version of the paragraph:

Table 27 Regression statistic of precipitation on the height of the River Niger

Regression Statistics	
Multiple R	0.279604
R Square	0.078178
Adjusted R Square	0.046391
Standard Error	84.55081
Observations	31

Correlation (Multiple R-value): The multiple R-value, which is 0.279604, indicates a modestly favorable association between rainfall and River Niger discharge. This suggests that there is a noticeable relationship between these two variables.

R-Squared Value: The R-squared value is 0.078178, implying that roughly 7.82 percent of the variation in River Niger flow can be attributed to rainfall. However, this signifies a relatively weak connection between the two variables.

Adjusted R-Squared Value: The adjusted R-squared value, which considers both the number of predictors and the data size, is 0.046391. After accounting for sample size and predictors, this figure, similar to the R-squared value, suggests that precipitation may account for approximately 4.64% of the variation in river flow.

Standard Error: The standard error, measuring the average difference between observed and predicted values by the regression model, is 84.55081. A lower standard error implies that the projected values closely align with actual observations, while a higher standard error denotes greater variability in the anticipated values.

To recapitulate, the research reveals a modest positive association between rainfall and River Niger discharge based on the presented regression statistics. However, it's essential to note that only a small percentage (approximately 7.82% and 4.64%, respectively) of the fluctuation in river discharge can be explained by rainfall, according to the R-squared and adjusted R-squared values. Additionally, the standard error of 84.55081 highlights variability in the predicted values compared to the actual observations.

5.5 Extreme Rainfall and Streamflow in Niamey: Trends and Relationships Between Higher Streamflow and Rainfall.

Introduction

In recent decades, West African cities, including Niamey, have experienced a growing recurrence of floods. Starting in 2020, the city of Niamey witnessed a series of severe floods due to extreme rainfall events. These floods left millions of residents homeless, inflicted extensive damage to homes, resulted in significant livestock losses, and tragically claimed lives (*EM-DAT - The International Disaster Database*, 2023; OCHA, 2018). Given this context, analyzing the frequency of extreme rainfall and flooding in Niamey is of paramount importance for effective flood risk management.

Many regional studies on extreme precipitation and flooding have been carried out in the Western Sahel region (Bigi et al., 2018; Panthou et al., 2014; Ta et al., 2016). These studies revealed that the intensity and frequency of extreme rainfall have increased in the Sahel. While local studies have increasingly revealed that rainfall extremes trends in many West African countries are spatially heterogeneous (Fofana et al., 2022; Klassou & Komi, 2021; Sougué et al., 2023; Tazen et al., 2019). Local studies have indicated that the rise in flood frequency is more likely attributed to alterations in land use, land cover, and rapid population growth rather than solely to extreme rainfall events.

5.5.1 Data Description

Data used in this work are daily rainfall and streamflow data obtained from the National Direction of Meteorology Centre in Niger. Rainfall data covers the period 1990-2020 for the rainy season only, while river flow data, which is slightly longer, covers the period 1990-2020. Both precipitation and streamflow time series had no missing data.

5.5.2 Methods

5.5.2.1 Trend analysis

To evaluate trends in rainfall indices, streamflow, and streamflow height at the meteorological and hydrological station in Niamey City, six precipitation indicators were chosen from the set of 27 precipitation and temperature indicators recommended by the team of climate change detection and indices experts (ETCCDI) (Sillmann *et al.*, 2013), and three streamflow indicators from (Amichiatchi *et al*., 2023). Therefore, Table 28 describes the indicators used in this work to characterize rainfall and streamflow behavior, including their extremes.

Table 28: Indicators used in this study to characterize rainfall and discharge behavior.

Index	Name	Unit	Description
R1day	Wet days	Days	Annual number of wet days (day with rainfall ≥ 1 mm)
PRCPTOT	Total wet days rainfall	mm	Annual total rainfall from wet days
R95p	Very wet day	Days	Annual number of days with rainfall ≥ 95^{th} percentile of wet days
R99p	Extreme wet day	days	Annual number of days with rainfall ≥ 99^{th} percentile of wet days
RX1day	Maximum 1-day rainfall	mm	Annual maximum of 1-day rainfall
RX5day	Maximum 5-days rainfall	mm	Annual maximum of consecutive 5-days rainfall
QMin	Annual minimum discharge	m^3/s	The lowest discharge value of the year
QMax	Peak discharge	m^3/s	Annual maximum discharge
QX5day	5-days maximum flow	m^3/s	Moving average of maximum discharge rate over five days

Trends in meteorological and hydrological time series were widely assessed using the modified Mann-Kendall test (Amichiatchi et al., 2023; Li et al., 2017; Sa'adi et al., 2019), which is a non-parametric test used in several studies. It is worthy of note that this method takes into account the effect of data autocorrelation (Amichiatchi *et al*., 2023). The original Mann-Kendall test was modified to consider the case of autocorrelation time series. In the new version of the Mann-Kendall test, the variance of the statistic is modified to account for autocorrelation in the series. Hence, the variance is expressed as follows through Eq. (10) (Amichiatchi et al., 2023) as

Formula 10

$$VAR(s) = \frac{1}{18}\left(n(n-1)(2n+5)\right)\frac{n}{ns^*} \tag{10}$$

Where, ns^* is the effective number of observations to account for autocorrelation in the data, Also, to put more emphasis on the variable ns^*, Eq. (11) is presented.

Formula 11:

$$\frac{n}{ns^*} = 1 + \frac{2}{n(n-1)(n-2)}\sum_{s=1}^{n}(n-1) \tag{11}$$

At 5% significance level, the test is such that the null hypothesis H_0 corresponds to "no linear trend" and the alternative hypothesis H_1 corresponds to the presence of a linear trend in the series.

5.5.2.2 Extreme rainfall and flood frequency analysis

Numerous studies have highlighted changes in climate and hydrological parameters, such as rainfall, temperature, and streamflow, over recent decades. Consequently, when modelling variables like daily maximum precipitation and annual maximum discharge, it becomes imperative to incorporate these trends. In this instance, the Generalized Extreme Value (GEV) model is employed, utilizing a nonstationary approach. Equation (12) expresses the GEV model as follows (Coles, 2001a):

Formula (12)

$$GEV(x,\mu(t),\sigma(t),\varepsilon)=\begin{cases} exp\left\{-\left[1+\ \varepsilon\left(\frac{x-\mu(t)}{\sigma(t)}\right)\right]^{-\frac{1}{\varepsilon}}\right\},\ for\ \varepsilon \neq 0 \\ exp\left\{exp\left[\frac{x-\mu(t)}{\sigma(t)}\right]\right\} \qquad ,\ for\ \varepsilon = 0 \end{cases} \tag{12}$$

In the nonstationary framework, the location and scale parameters become functions of the time parameter 't,' denoted as μ(t) and σ(t), respectively. It is important to note that estimating the shape parameter, denoted as ε, carries a high level of uncertainty. Therefore, it is not advisable to represent this parameter as a function dependent on covariates. The parameters are expressed by the set of variables presented in Eq. (13) as follows:

Formula 13

$$\begin{cases} \mu(t) = \mu_0 + \mu_1 t \\ \sigma(t) = \sigma_0 + \sigma_1 t \\ \varepsilon(t) = \varepsilon_0 \end{cases} \tag{13}$$

Where, $\mu(t)$ and $\sigma(t)$ are location and scale parameters expressed as a function of covariable time t. $\varepsilon(t)$, the shape parameter, was considered constant because of its uncertainty when viewed as a function of covariates.

The likelihood ratio test, conducted at a 5% significance level, was used to ascertain the preferred GEV model (either stationary or nonstationary) based on the sample of daily maximum rainfall (Coles, 2001b). After selecting a fitted model, the return levels of streamflow were calculated and plotted. The return level Z_p associated with the return period $1/p$ is expressed through the use of Eq. (14) as

Formula 14

$$Z_p = \begin{cases} \mu(t) - \frac{\sigma(t)}{\varepsilon}[1 - \{-log(1-p)\}^{-\varepsilon}], & for\ \varepsilon \neq 0 \\ \mu(t) - \sigma(t) log\{-log(1-p)\}, & for\ \varepsilon = 0 \end{cases} \tag{14}$$

Where, $\mu(t), \sigma(t), and\ \varepsilon(t)$ are parameters of location, scale, and shape, respectively.

5.5.2.3 Relationship between extreme rainfall and flood occurrences

Table 29 shows the model parameters used. This section involves the analysis of the influence of extreme rainfall on flood frequency. The initial step involves assessing the correlation between extreme rainfall and streamflow, while the second step entails evaluating the impact of extreme rainfall on streamflow. To achieve this, extreme rainfall will be considered as a covariate in the location and scale parameters of the flood frequency mode.

Table 29: Model parameters

Model	Parameters
M0	$\mu(t) = \mu_0$ $\sigma(t) = \sigma_0$ $\varepsilon(t) = \varepsilon_0$
M1	$\mu(t) = \mu_0 + \mu_1 X_1 + \mu_2 X_2$ $\sigma(t) = \sigma_0 + \sigma_1 X_1 + \sigma_2 X_2$ $\varepsilon(t) = \varepsilon_0$
M2	$\mu(t) \quad \mu_0 + \mu_1 X_1$ $\sigma(t) = \sigma_0 + \sigma_1 X_1$ $\varepsilon(t) = \varepsilon_0$
M3	$\mu(t) = \mu_0 + \mu_2 X_2$ $\sigma(t) = \sigma_0 + \sigma_2 X_2$ $\varepsilon(t) = \varepsilon_0$

5.5.2.4 Returning Period

The maximum daily rainfall with return periods of 5, 10, 50, and 100 years was computed in this research using the best fitting distribution. Extreme rain events may be classified into five types, according to Vandiepenbeeck (1997), as quoted by (Hounvou et al., 2023),(Sene & Ozer, 2002) (Table 30). The return period values of severe rain occurrences in Niamey are classified into five categories. The classification information reveals if severe rainfall events are often the primary causes of unexpected and catastrophic floods in Niamey and its surrounds

Table 30 :Classification of extremes rain events by using return period values

Return period (in year)	Attributed classes to extreme events
T ≥ 100	Very exceptional
50≤ T < 100	Exceptional
10≤ T < 50	Severely abnormal
50≤ T < 10	Abnormal
T < 5	Normal

Source: Adapted from Vandiepenbeeck (1997).

5.5.3 Results

5.5.3.1 Climatology characteristics of rainfall and streamflow

In Table 31, it becomes evident that over the past three decades, the city of Niamey has experienced an average of 36 wet days in just under two months. The typical wet-day interval ranged from 32 to 41 days. However, a noteworthy observation is that 9.7% of the years within the study period (specifically 1990, 1991, and 1997) reported a total number of rainy days fewer than 32. Similarly, another 9.7% of the years (including 1994, 1999, and 2006) witnessed a total number of wet days exceeding 41. Over the period from 1990 to 2020, the PRCPTOT ranged between 340.2 and 753.3 mm, with an average value of 514.4 mm, deviating by approximately 101.3 mm. The count of very or extremely wet days was less than one and two weeks, respectively.

Despite the total number of rainy days spanning less than two months over the last three decades, the city of Niamey encountered extreme rainfall events resulting in localized flooding during the study period. Notable instances include 1994, 2012, and 2017, where RX1day reached 129, 119.2, and 120.5 mm, respectively. The RX1day indicator exhibited a range between 31.6 and 129 mm, with an average value of 64.6 mm. Additionally, the annual maximum of consecutive 5-day rainfall ranged from 42.5 to 150 mm, with an average of 88.3 mm.

Turning to streamflow, the analysis indicates that the annual maximum of 1-day discharge varied between 1182 and 2757 m^3/s from 1985 to 2020, with an average of 1825.9 m^3/s. Similarly, the annual maximum of consecutive 5-day discharge ranged between 5910 and 13215 m^3/s, with an average value of 8806.6 m^3/s.

Table 31: Preliminary statistics of rainfall and streamflow

Rainfall and streamflow indices	Min	Mean ($\pm SD$)	Max
R1day	27	36 ($\pm$4.9)	48
PRCPTOT	340.2	514.4 ($\pm$101.3)	753.3
R95p	3	7.7 ($\pm$2.3)	11
R99p	0	1.5 ($\pm$1.3)	6
R1Xday	31.6	64.6 ($\pm$23.2)	129
R5Xday	42.5	88.3 ($\pm$ 29)	150
QMin	0	39.5 ($\pm$28)	137
QMax	1182	1825.9 ($\pm$ 364.3)	2757
QX5days	5910	8806.6 ($\pm$1612)	13215

5.5.3.2 Autocorrelation test assessment

We observe that all the time series of discharge indices, such as QMin, Qmax, and QX5days, exhibit noticeable autocorrelation. Among the precipitation indices, PRCPTOT and R1Xday display pronounced autocorrelation patterns, whereas R1day, R95p, and R99p precipitation indices demonstrate relatively acceptable levels of autocorrelation (as illustrated in Figure58).

To mitigate the impact of autocorrelation in the rainfall and streamflow indices, it is necessary to deseasonalize the time series.

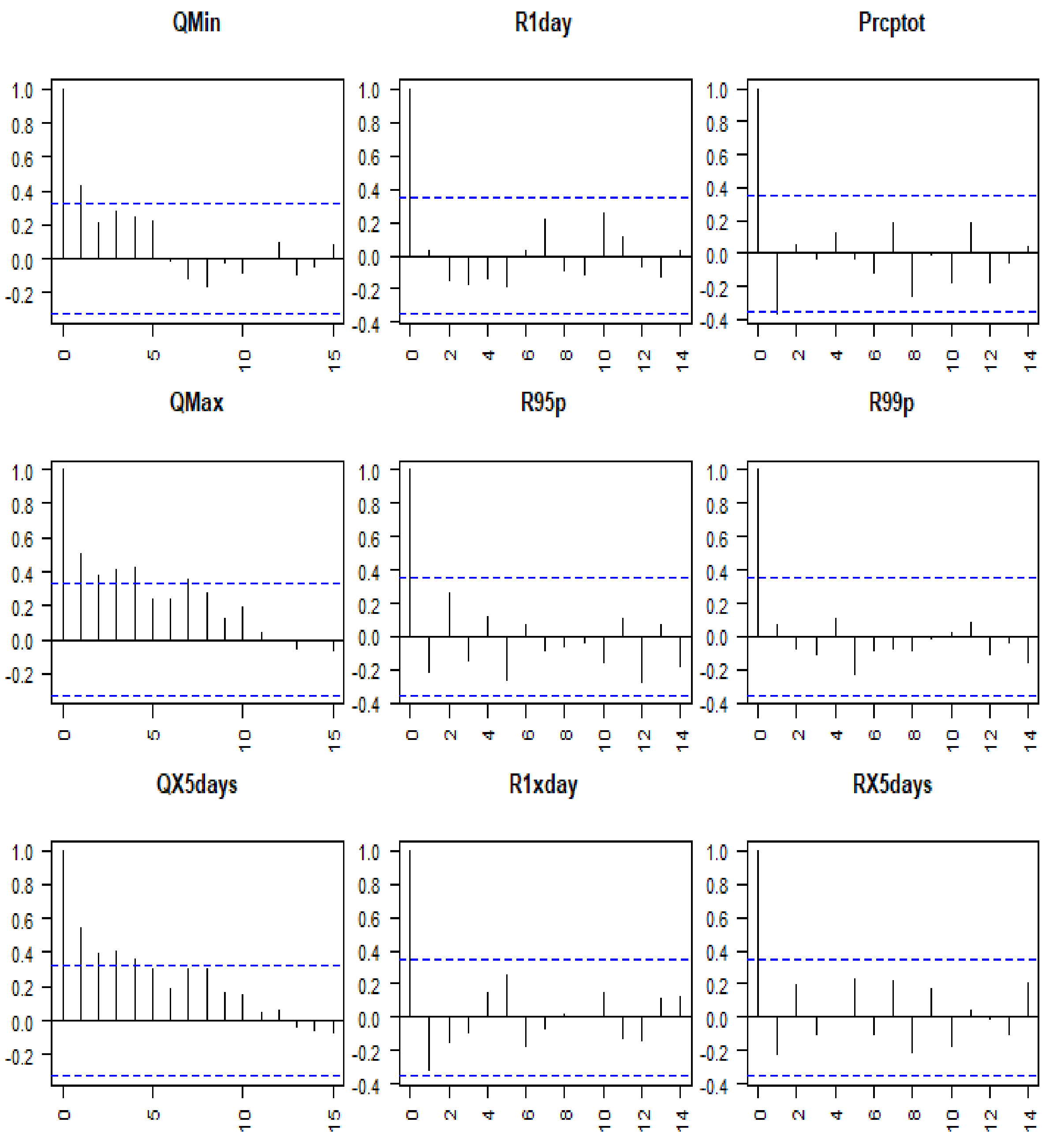


Figure 58: Column 1: The plots denote the autocorrelation of streamflow. **Columns 2 & 3:** plots corresponding to autocorrelation of rainfall indices.

5.5.3.3 Trends analysis

Precipitation indicators, namely wet days (R1day), very wet days (R95p), and extremely wet days (R99p), exhibit no significant linear trends, with slope values consistently hovering around zero (see Fig. 59-b, e, f). Notably, both R95p and R99p, which represent the frequency of extreme precipitation, indicate a stable frequency of extreme precipitation events over time.

When focusing on the intensity of extreme rainfall indices, we identify upward trends in the annual maximum of 1-day rainfall (RX1day) and the annual maximum of consecutive 5-days rainfall (RX5day) with trends amounting to 6.2% and 13.9% per decade, respectively (as depicted in Fig. 59-h, i). Additionally, we observe an upward trend in the total wet-day precipitation, showing an increase of 3% per decade (refer to Fig. 59-c).

Turning to streamflow, all the discharge indices derived in this study exhibit upward trends. Specifically, we find that peak flow (QMax) has increased by 27.9% per decade (Figure 59-d). Furthermore, the lowest flow and the annual maximum of consecutive 5-day discharge (QX5day) have witnessed increases of 1.7% and 0.9%, respectively (in Figure 59.-a, g).

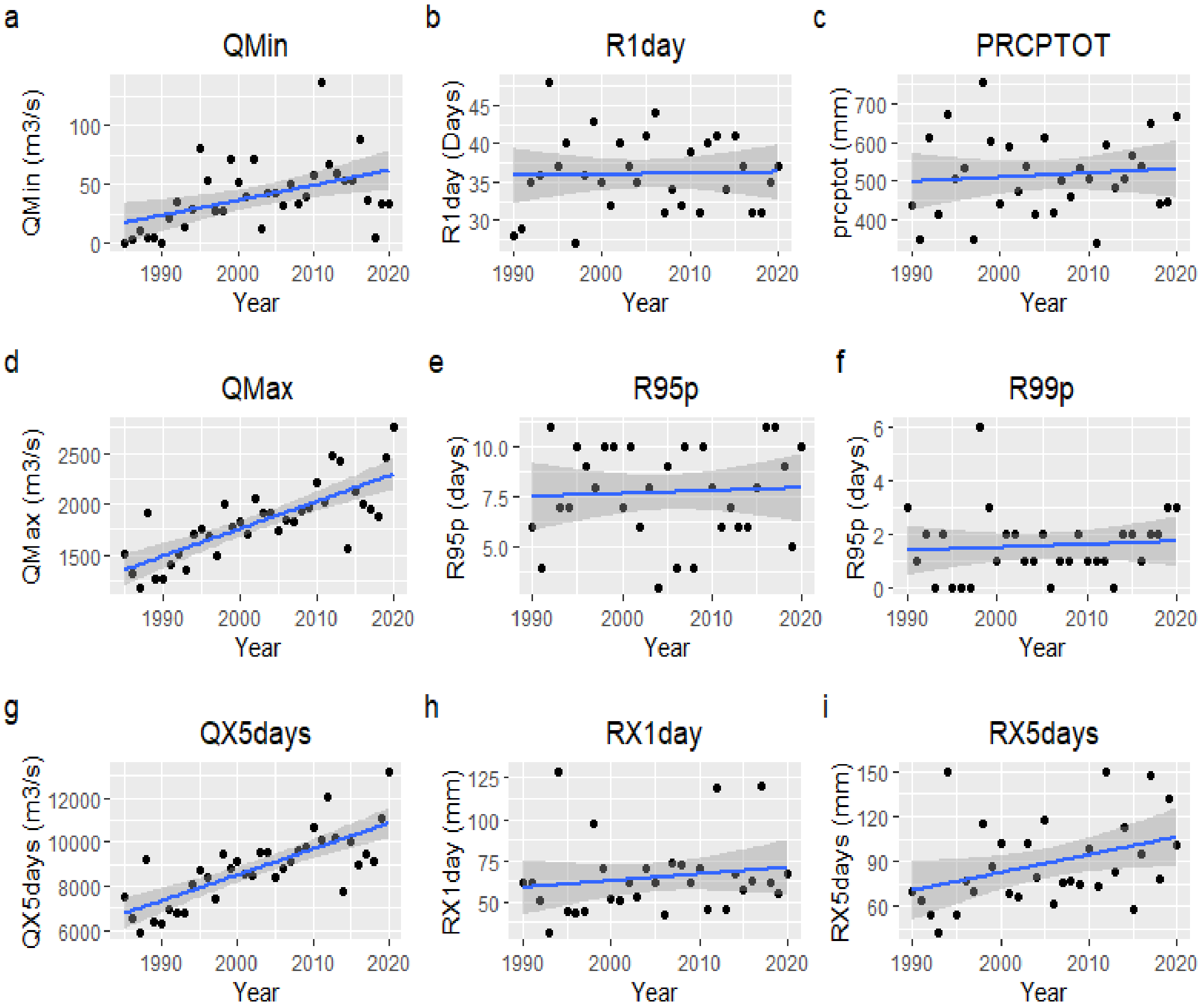


Figure 59: Trends in rainfall and discharge indices given as changes per year in QMin (a), R1day (b), PRCPTOT (c), QMax (d), R95p (e), R99p (f), QX5days (g), RX1day, RX5days (i). **First column:** plots (a, d, g) represent trends in discharge indices. **First and second columns:** plots (b, c, d, f, h, i) represent the trends in rainfall indices.

5.5.3.4 Rainfall and Streamflow Anomalies

In figure 60, from 1990 to 2020, we found that 1991, 1997, and 2011 were droughts years, while 1994, 1998, 2017, and 2020 were wet years in Niamey. Apart from these years, the other years are marked by alternations of slight drought and humidity considered to be neutral years. Regarding the standard flow index, we found that the flow is characterized by two hydrological periods (drought and wet) divided into four phases. A period of negative anomalies, during which there were years of meteorological and hydrological droughts that occurred concomitantly. This period corresponds to a single phase of hydrological drought over the period 1990-2020 and occurred between 1990 and 1999. A second period of positive flow anomalies was characterized by three moisture phases: The first phase corresponds to the resumption of the wet period from 2000 to 2005, reaching a peak in 2010. Between 2006 and 2013, there was a second phase, with higher humidity over the study period, during which a meteorological drought occurred in 2011. From 2016 onwards, a final phase of moisture has been resumed until 2020, with some years considered wet weather years.

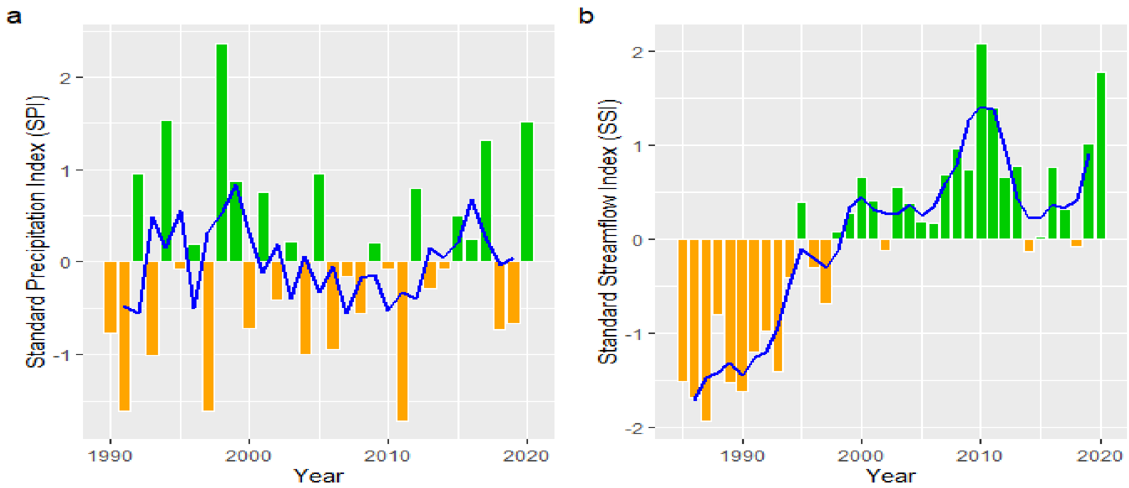


Figure 60: Plot-a represents the standard precipitation index and plot-b denotes the standard streamflow index. The blue line denotes the 3 years moving average of SPI and SSI in plot-a and plot-b respectively.

5.5.3.5 Modelling of Extreme Rainfall and Higher Discharge

5.5.3.5.1 Estimation of parameters

Table 32 indicates that the p-values of the deviance are less than 5%, suggesting that the nonstationary models for rainfall and streamflow exhibit superior performance when compared to their respective stationary models. In the case of RX1day and RX5day models, the location parameter is expressed as a function of time, while the scale and shape parameters remain constant. Conversely, for QMax and QX5day models, the shape parameter remains constant, while both the location and scale parameters are c*ontingent on the time parameter*.

Table 32: Estimation parameters of rainfall and streamflow models

Variable	Model	Model parameters	Log-likelihood
RX1day	Stationary	$\mu(t)$ = 54.1 $\sigma(t)$ = 14.8 $\varepsilon(t)$ = 0.12	134.5
	Nonstationary	$\mu(t)$ = 43.7 + 0.6t $\sigma(t)$ = 12.5 $\varepsilon(t)$ = 0.25	131.8
	Deviance 5.43		
	P-value of deviance 0.01		
RX5day	Stationary	$\mu(t)$ = 74.7 $\sigma(t)$ = 21.8 $\varepsilon(t)$ = 0.04	145.3
	Nonstationary	$\mu(t)$ = 59.9 + 0.97t $\sigma(t)$ = 19.2 $\varepsilon(t)$ = 0.08	142
	Deviance		6.61
	P-value of deviance 0.01		
QMax	Stationary	$\mu(t)$ = 61.9 $\sigma(t)$ = 43.4 $\varepsilon(t)$ = 0.11	262.4
	Nonstationary	$\mu(t)$ = 1615 + 11.9t $\sigma(t)$ = 5.7 - 6.6$\times 10^{-4}t$ $\varepsilon(t)$ = 0.16	255.6
	Deviance 13.5		
	P-value of deviance 0.001		
QX5day	Stationary	$\mu(t)$ = 8217 $\sigma(t)$ = 1496.1 $\varepsilon(t)$ = - 0.17	316.2
	Nonstationary	$\mu(t)$ = 8201.7 + 34.7t $\sigma(t)$ = 7.5 – 0.02t $\varepsilon(t)$ = - 0.04	311.7
	Deviance 8.9		
	P-value of deviance 0.011		

5.5.3.5.2 Return levels of daily maxima streamflow

Table 33 reveals that over the course of 100 years from 2020, the daily maximum of 1-day rainfall and daily maxima of consecutive 5-days rainfall could potentially reach 163 mm and 182.2 mm, respectively. Additionally, for QMax and QX5day, the peak discharge and the daily maximum of 5-days discharge might reach levels of 2722.2 m^3/s and 14287 m^3/s, *respectively*.

Table 33: Return period and associated return level of daily maxima streamflow.

Return period (Year)	RX1day (mm)	RX5day (mm)	QMax (m^3/s)	QX5day (m^3/s)
5	76.4	106.1	2198.6	10743.4
10	91.5	122.8	2350.2	11646.8
25	115.3	145.4	2517.3	12745.6
50	137.1	163.4	2625.9	13531.3
100	163	182.2	2722.2	14287.0

Figure 61 illustrates the relationship between return level and return period. The first column presents return level plots for the annual maximum rainfall for a single day and the annual maximum rainfall for five consecutive days. Meanwhile, the second column displays the return level plot for the annual maximum 1-day discharge and the annual maximum continuous 5-day discharge concerning return periods.

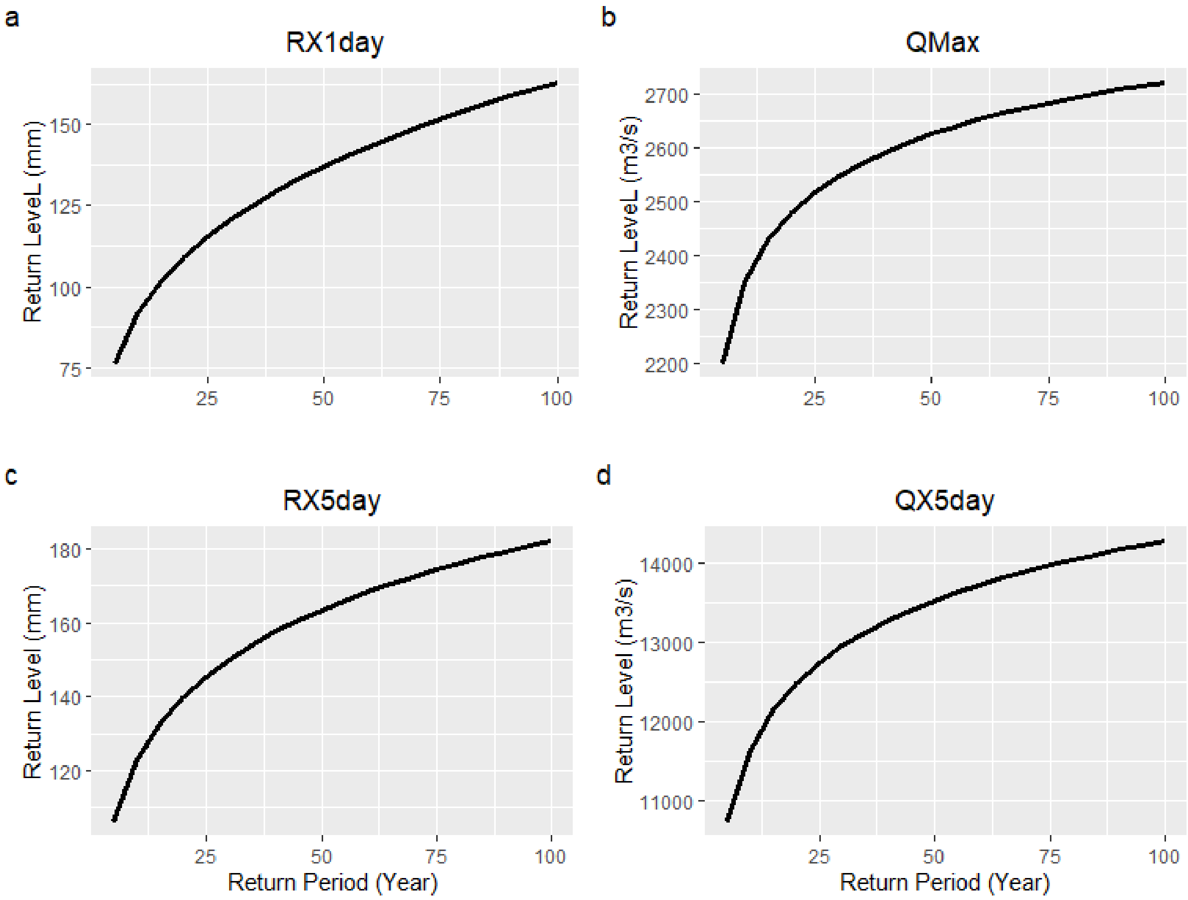


Figure 61: Return period graphs.

5.5.3.5.3 Impact of extreme rainfall upon flood frequency

Figure 62 shows that the correlation between the frequency of the annual maximum of 1-day discharge and an annual maximum of consecutive 5-days discharge and an annual maximum of 1-day rainfall and an annual maximum of consecutive 5-days rainfall are not strong, ranging from 0 to 0.4. In addition to correlation analysis, we modelled QMax and QX5day as functions of RX1day and RX5day. We found that the stationary models of QMax and QX5day outperformed the nonstationary models, implying that the upward trends in past flood frequency could not be due to extreme rainfall variability.

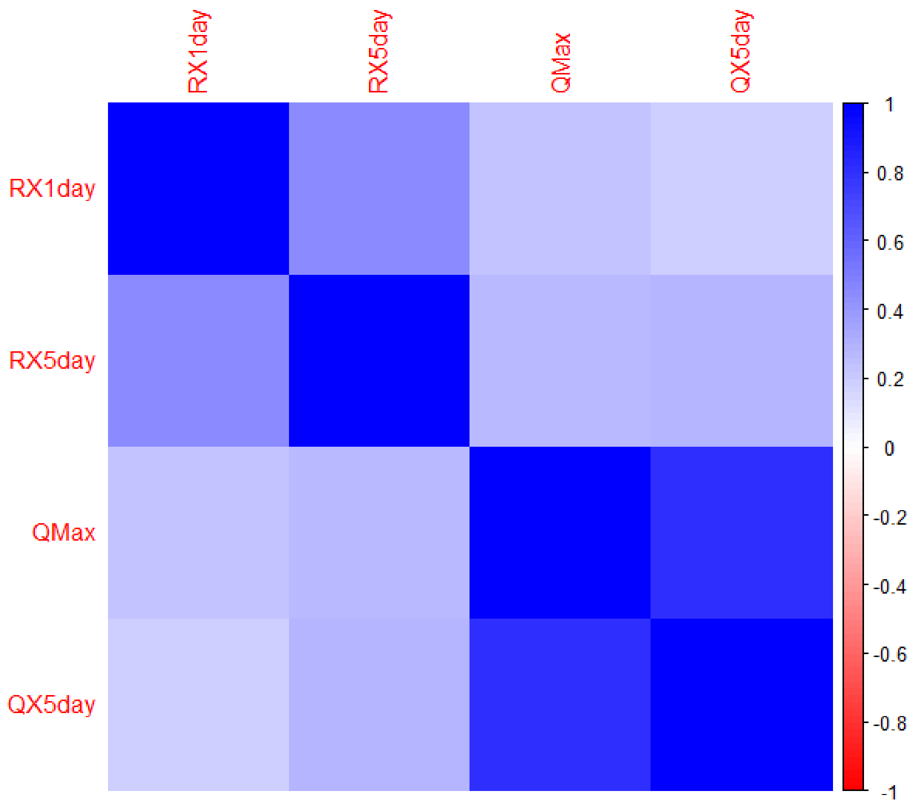


Figure 62: Correlation plot between Rainfall and discharge indices, including RX1day, RX5day, QMax and QX5day.

5.6 Discussions

Understanding the evolving trends in flooding and extreme events holds crucial importance for effective natural disaster management, particularly in the case of floods. An analysis of the frequency and intensity of extreme precipitation reveals an increased frequency of extreme precipitation events, although no discernible trend is observed in the intensity of these events. Interestingly, local studies, such as those conducted by (Klassou & Komi, 2021; Sougué et al., 2023), have indicated that downward trends in rainfall indices surpass upward trends.

Furthermore, our research reveals an elevated frequency of flooding in Niamey. These findings align with the observations made by (Cheng et al., 2017), who noted that annual maximum flow patterns do not exhibit a monotonic trend but rather global downward trends before 1980, followed by upward trends, particularly in West and South Africa. These results substantiate our own findings regarding trends in the annual maximum of peak discharge and the annual maximum of consecutive 5-day discharge in Niamey.

Moreover, while it is acknowledged that extreme precipitation events can influence floods, it is noteworthy that the relationship between flood frequency and extreme precipitation frequency is not notably strong. Our investigation, employing a non-stationary generalized extreme value model with location and scale parameters as functions of extreme precipitation, indicates that extreme precipitation does not significantly contribute to the recent upward trends in flood frequency.

In the context of Burkina Faso, research by (Sougué et al., 2023; Tazen et al., 2019) revealed that the recent surge in floods is primarily attributed to factors such as changes in land use, land cover, and rapid population growth, rather than solely being a consequence of extreme rainfall. Similarly, in Mali, (Fofana *et al.,* 2022) found that over 50% of floods were not directly attributable to extreme rainfall events. Instead, changes in land use, land cover, and the expansion of impervious surfaces emerged as significant factors amplifying the frequency of floods.

However, a study by (Aich *et al*., 2015)introduces a more nuanced perspective, suggesting that climate change and alterations in land use and land cover contribute to increased flooding, although their respective contributions remain challenging to quantify. Consequently, a comprehensive and intricate model is essential to assess the combined impact of land use, land cover changes, and extreme precipitation on both flood frequency and intensity.

This research underscores the importance of employing a non-stationary generalized extreme value model, incorporating a time parameter as a covariate, over a stationary generalized extreme value model. It emphasizes that caution should be exercised when relying solely on the stationarity assumption when modelling the frequency of extreme precipitation events and peak discharge.

A notable limitation of this study pertains to the absence of long-term data. Given the influence of changes in land use and land cover on flood occurrences, it is imperative to acknowledge the role these changes play in the prevalence of flash floods within our study locations. The observed upward trend in floods may be attributed to several factors, including the marginal increase in precipitation between 1990 and 2020, or the expansion of exposed soil resulting from urbanization. Similar conclusions have been drawn from a study of floods in Ouagadougou, where the frequency of floods increased from 1961 to 2015, despite the precipitation that triggered these floods not being exceptionally high. Consequently, it is essential to consider changes in land use, although this falls beyond the scope of our current work, as an additional contributing factor alongside rainfall in flood occurrences.

For developing countries like Niger, where reliable rainfall data may be limited, investigating climate change impacts using CHIRPS satellite data could serve as a viable alternative. Recent studies utilizing CHIRPS data and research conducted in the Vea catchment in Ghana by Larbi et al. (2018) between 2016 and 2018 provide supporting evidence. It is evident that rainfall is becoming more intense and frequent in West Africa. The escalating values of extreme rainfall indices, such as RX1Day, RX5Day, and R99P, corroborate this trend. It is crucial to inform the public about the increasing intensity of rainfall and its potential consequences, including flooding.

Moreover, increased precipitation contributes to soil erosion, exacerbating the risk of flooding, as illustrated by historical flood statistics from the Civil Protection Directorate and the EM-DAT database. This paper not only provides details regarding the age of dams but also outlines immediate steps that must be taken to mitigate the impact of flood disasters. The flood in the Niamey area serves as an example of how even relatively modest rainfall within the orange alert level (580-619 cm) can lead to flooding. Recognizing the pivotal role of rainfall in causing floods, it is essential to take proactive measures whenever it rains to alleviate potential issues.

Decision-makers should remain informed and prepared to implement effective flood mitigation measures for anticipated and future flood events, ultimately benefiting the public. Proper maintenance of gutters and drainage systems is imperative, as any obstruction caused by faulty drainage or poorly constructed properties can redirect water flow, exacerbating flood-related problems.

Partial Conclusion

This study delves into the temporal variability of rainfall and discharge characteristics while examining the influence of extreme rainfall events on flood frequency in Niger. In contrast to comprehensive large-scale studies that have concluded that extreme rainfall has become more frequent and intense in West Africa, our findings present a more nuanced perspective. Specifically, we observe that only the frequency of extreme precipitation exhibits upward trends, with no significant trend observed in their intensity within Niamey. Interestingly, our results reveal upward trends in flood frequency, and these trends are not solely attributed to extreme precipitation events.

This study can serve as a valuable resource for decision-makers, equipping them with critical information to prepare for potential flooding events. Armed with this knowledge, swift and effective actions can be taken to mitigate the potential damage caused by flash floods. One notable challenge throughout this study has been the limitations of currently available data, especially regarding historical flood information in Niamey, where limited prior research has been conducted. Given that rainfall has not been identified as the primary cause of flooding in Niamey, it is imperative to conduct further investigations into the substantial influence of land-use changes in future flood studies.

6 Chapter 6: Flood mitigation, resilience and adaptation measures

Introduction

Disaster management entails the seamless coordination and integration of diverse activities essential for establishing, sustaining, and enhancing the ability to prepare for, shield against, respond to, and recover from both potential and actual natural or human-induced disasters. It is a comprehensive initiative that spans multiple jurisdictions, sectors, disciplines, and resources. In recent years, the government of Niger has dedicated significant efforts to raise awareness about the challenges associated with preventing natural disasters, with a particular emphasis on addressing the country's predominant concern, drought. However, the nation's administrative capacity for disaster prevention is marked by notable weaknesses, both at the central and local levels. Consequently, the country often appears to be operating in a perpetual state of emergency response, especially in the realm of food insecurity. This operational mode is sometimes perceived as a means for the authorities to address their financial requirements for the annual state budget. Thus, the involvement of various stakeholders and actors in disaster management necessitates the establishment of a robust coordination and collaboration mechanism.

6.1 Methodology

A comprehensive strategy that takes into consideration both short-term emergency response and long-term resilience-building measures is required in order to develop a technique for adjusting tactics to food crises. Adapting strategies for food disasters requires a multi-dimensional and collaborative approach, involving various stakeholders at local, national, and international levels. Continuous learning, flexibility, and community involvement are essential components of an effective methodology. For this study, field survey and preview studies have been considered to analyse the coping capacities of the communities in Niamey.

The formula used is

Formula 14

$$P = \frac{f}{N} \times 100$$

where:

P = Percentage.

F = Frequency to be converted to percentage.

N = Numbers of frequencies.

Data obtained was analyzed via statistical and descriptive statistics such as percentages and tables.

6.2 Adaptation Strategies According to Local Communities

6.2.1 Flood Preparedness Activities

Flood preparedness procedures have been put in place. When asked if they were currently using adaptive approaches, the majority of respondents said 'yes'. The information included items such as sandbag track 69, sand encroachment 59 and pumping figure 63. However, some adaptive strategies, such as early warning systems, knowledge transfer and assurance through interaction and training, community institutions and forums, etc., are underdeveloped, insufficient and inappropriate.

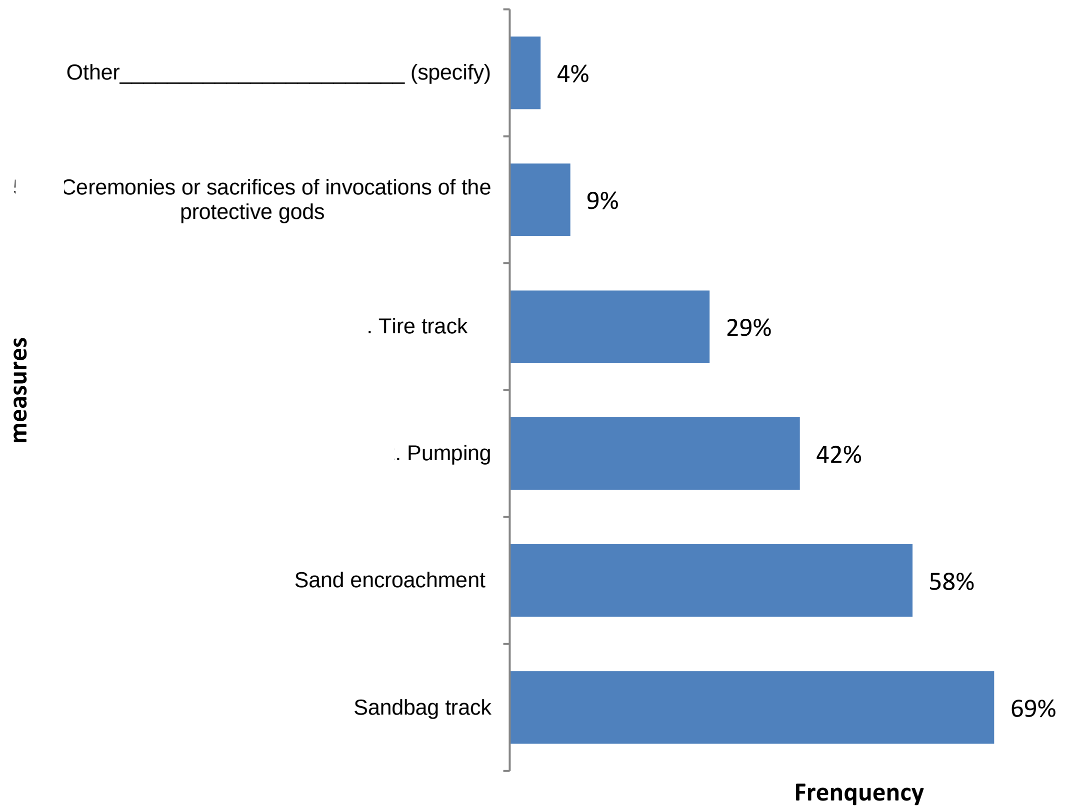


Figure 63: Employment of preventive strategies for flood mitigation according to local communities **(Source:** Field survey,2022)

Prevalence of Sandbagging figure 64: The data shows that sandbagging is the most prevalent flood preventive strategy, with a frequency of 69%. This indicates that communities heavily rely on this method, which is a conventional and widely recognized approach. Significance of Sand Encroachment:

Figure 64 sandbag use for flooding (Source https://www.rcinet.ca/es/2019/08/30/)

Sand encroachment, at 58%, is another prominent strategy. It suggests that communities might be using natural processes, such as the accumulation of sand, as a means of flood prevention. This method may be particularly relevant in regions with sandy terrains. Utilization of Pumping Systems: Pumping, with a frequency of 42%, is a common method, but it is employed to a lesser extent compared to sandbagging and sand encroachment. This could be due to factors such as the availability of pumping equipment and energy resources.Tire Tracks as a Strategy: The use of tire tracks, at 29%, implies that communities are experimenting with innovative methods, possibly using tires to create barriers or channels for redirecting water. Cultural Elements with Ceremonies or Sacrifices: The inclusion of ceremonies or sacrifices as flood preventive strategies, at 29%, suggests a cultural or traditional dimension to disaster risk reduction. This could involve community rituals aimed at seeking protection from floods. Diversity in Other Strategies: The "Others" category at 4% indicates that there are additional, less common strategies not explicitly specified in the data. Further details are needed to understand the nature of these strategies.

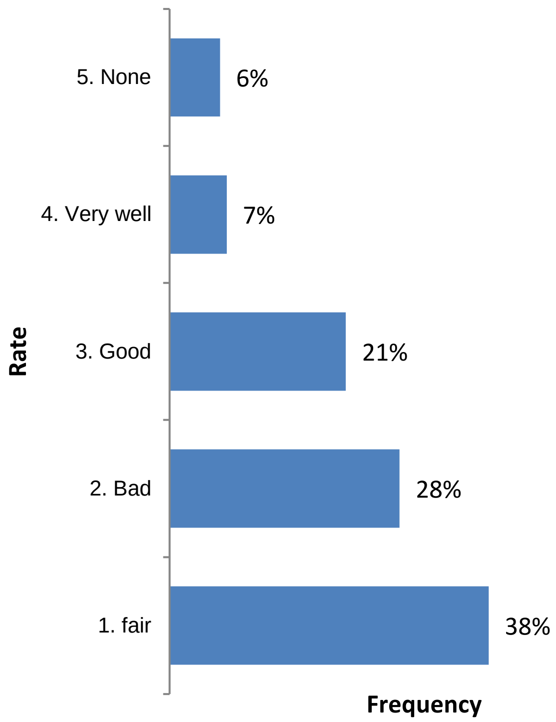
To conclude it can be said that the data highlights the diversity of flood preventive strategies employed by communities, reflecting a combination of traditional, innovative, and cultural approaches. The prevalence of sandbagging suggests its effectiveness and widespread acceptance. Additionally, the inclusion of cultural practices, such as ceremonies or sacrifices, emphasizes the importance of local beliefs in disaster risk reduction.

The variety of strategies underscores the need for tailored approaches based on local conditions, available resources, and cultural contexts. To enhance community resilience, it would be beneficial for policymakers, NGOs, and disaster management agencies to collaborate with communities, considering both traditional knowledge and modern techniques in developing comprehensive flood risk reduction plans. Moreover, further research into the strategies categorized as "Others" could unveil additional effective approaches not covered in the current analysis.

6.2.2 Assessment of The Government's Ability

The assessment of the government's ability to anticipate and prepare for flood disasters by stakeholders reveals a varied perception among respondents. The majority falls into the categories of "Fair" and "Bad," suggesting that there is a significant portion of stakeholders dissatisfied with the government's current approach to flood preparedness. On the positive side, there are respondents who view the government's efforts as "Good" or "Very well," indicating some level of satisfaction. As depicted in Figure 65, 38% perceive the situation as fair, while 28% rate it as bad. The assessment of the government's ability to anticipate and prepare for flood disasters by stakeholders reveals a diverse range of opinions. Let's analyse the data based on the provided percentages:

Fair (38%), Stakeholders who rated the government's ability as "Fair" might perceive some efforts in flood preparedness but likely believe there is room for improvement. This suggests a moderate level of satisfaction but with identified shortcomings. Bad (28%): A significant portion of stakeholders expressing a "Bad" assessment indicates a substantial dissatisfaction with the government's ability to anticipate and prepare for flood disasters. This could signify perceived inefficiencies, lack of resources, or inadequate planning. Good (21%), Stakeholders providing a "Good" assessment likely acknowledge positive steps taken by the government in flood preparedness. However, there may still be areas where improvement is desired, as "Good" does not necessarily mean optimal or flawless. Very well (7%), The minority of stakeholders who rated the government's performance as "Very well" indicates a relatively high level of satisfaction. These stakeholders likely perceive the government's efforts as comprehensive, effective, and successful in flood disaster anticipation and preparation. None (6%), The respondents who selected "None" may imply that they have no opinion or are not well-informed about the government's efforts in flood preparedness. This could be due to a lack of engagement, awareness, or information on the subject.



Source: Field survey,2022

Figure 65: Assessment of the government's ability to anticipate and prepare flooding

Their longstanding and traditional coping strategies, once employed effectively and uniquely to address familiar climate-related challenges, are now shrouded in uncertainty. The critical question at hand pertains to the adequacy of their existing coping mechanisms and other capabilities in facilitating adaptation to climate change. Do they possess the resilience required to sustain their way of life and livelihoods in the face of climate change?

The assessment underscores the importance of a comprehensive review of the government's flood preparedness strategies. it suggests a mixed perception among stakeholders regarding the government's ability to anticipate and prepare for flood disasters. The significant percentage of respondents expressing dissatisfaction ("Bad") indicates a need for the government to address perceived shortcomings and enhance its flood preparedness measures. The relatively lower percentage of respondents expressing high satisfaction ("Very well") suggests that there is room for improvement in the government's communication and transparency about its flood preparedness initiatives. It would be valuable for the government to engage with stakeholders, especially those who provided negative assessments, to identify specific concerns and areas for improvement. Continuous monitoring and evaluation of flood preparedness measures, along with effective communication with stakeholders, can contribute to building trust and improving the overall effectiveness of the government's efforts in this regard.

6.2.3 Rating of the Difficulties of Coping with Flood by the Local Communities

Figure 66 provides insight into the challenges of dealing with flood hazards. It illustrates that 53% of respondents find coping with flood hazards to be highly challenging, while 39% perceive it as moderately challenging (Figure 66). The assessment of the government's ability to anticipate and prepare for flood disasters by stakeholders reveals a diverse range of opinions. Let's analyze the data based on the provided percentages

High Difficulty (53%): The majority of communities perceive coping with floods as highly challenging. This could be indicative of frequent or severe flood events, inadequate infrastructure, or limited community preparedness. Further investigation is warranted to identify specific challenges faced by communities with a high difficulty rating. This may involve assessing the effectiveness of existing flood management strategies and understanding the impact of recent flood events on these communities.

Medium Difficulty (39%): A substantial portion of communities considers coping with floods as moderately difficult. This suggests a nuanced perspective on flood challenges, possibly influenced by local factors such as geography, infrastructure, or community resilience. Qualitative research could delve into the reasons behind the medium difficulty rating, allowing for a more comprehensive understanding of the challenges faced by these communities.

Low Difficulty (8%): A minority of communities perceives coping with floods as having low difficulty. This might be attributed to effective flood management measures, strategic community planning, or residing in areas less prone to flooding. Studying these communities can offer insights into successful mitigation strategies that could be shared with others facing higher difficulty levels.

The survey results reflect a diverse range of perceptions among local communities regarding the difficulties of coping with floods. Communities with high difficulty ratings may require targeted interventions, such as improved infrastructure, early warning systems, or community training programs to enhance resilience. Medium difficulty ratings call for a nuanced approach, considering local factors that contribute to the community's perception. This could involve tailored educational initiatives and community-based adaptation strategies. Communities with low difficulty ratings present an opportunity for knowledge exchange and the identification of best practices that could benefit neighboring areas:

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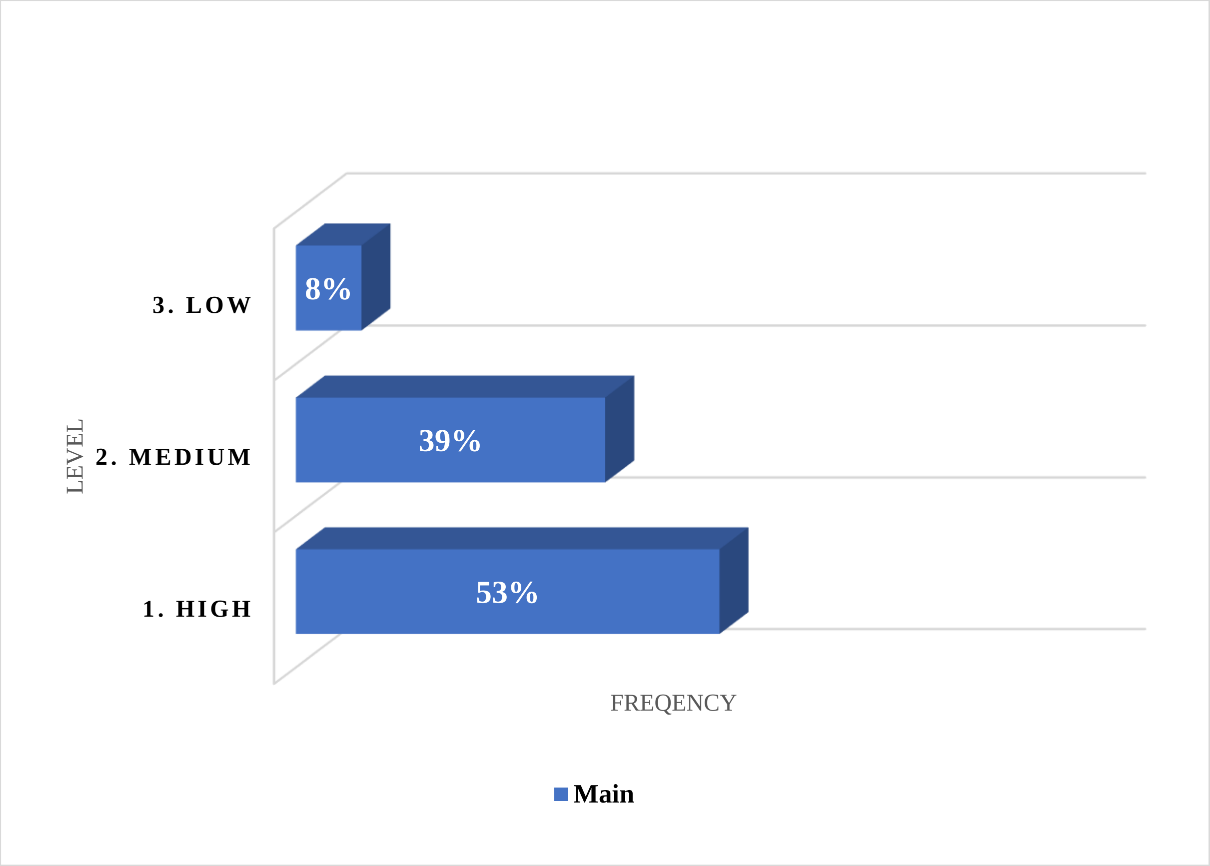


Figure 66: Rating of the difficulties of coping with flood by the local communities

The cornerstone of disaster risk reduction practices and policies lies in the reduction of vulnerability and the enhancement of resilience. Therefore, by addressing all forms of vulnerability and bolstering adaptive capacity, disaster risk reduction serves as a gateway and a platform for climate change adaptation. In recent decades, a multitude of ecological, demographic, economic, social, political, and climatic factors have posed challenges to the sustainability of livelihoods and coping mechanisms for rural residents. Consequently, they grapple with both chronic and acute crises, leading to increased impoverishment, marginalization, and vulnerability. These transformations and their impacts have been witnessed and expressed by communities and individuals of all ages

6.3 Discussion and Assessment of the work of the Institutions

6.3.1 Legislation

As of now, Niger lacks specific national legislation dedicated to Disaster Risk Reduction (DRR). Nevertheless, it's essential to highlight the existence of various decrees that establish different structures, including those within the Disaster Prevention and Management System (DNPGCCA). Additionally, there are sector-specific laws governing various areas such as agriculture, water and sanitation, health, and more. These laws, while not explicitly focused on DRR, contribute both directly and indirectly to the reduction of vulnerabilities and risks associated with natural disasters, particularly concerning food security.

However, it's crucial to recognize the absence of comprehensive, integrated legislation that addresses the multifaceted challenges posed by Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA). Currently, there is no overarching legal framework that specifically addresses these interconnected issues comprehensively in Niger.

6.3.2 Politics

Until 2021, Niger did not have a specific national policy dedicated solely to Disaster Risk Reduction (DRR). Instead, DRR efforts were primarily encompassed within the broader framework of Climate Change Adaptation (CCA), with CCA taking precedence in national policy discussions. This situation has led to an overshadowing of DRR concerns by the CCA agenda, where the CCA has held a dominant position in policy considerations.

However, it's worth noting that several sectoral policies have contributed to DRR in Niger. For example, the National Social Protection Policy, which plays a crucial role in poverty reduction in low-income countries like Niger, serves as one of these significant policy instruments. Additionally, there are other noteworthy policies, such as the National Environmental Policy (which includes a CCA component), the National Health Policy (which addresses epidemic prevention and management), and policies related to water and sanitation strategies, among others.

Nevertheless, many policymakers and officials within various ministries and technical institutions responsible for implementing these policies acknowledge that the systematic integration of natural disaster risks into the development of these policies has been somewhat lacking.

Efforts to enhance the incorporation of DRR considerations into sectoral policies, alongside CCA efforts, can strengthen overall disaster resilience and preparedness in N**iger** (République du Niger, 2014)**.**

6.3.3 Challenges and gaps

Several challenges exist in the realms of Disaster Risk Reduction (DRR) and Adaptation to Climate Change (ACC). These challenges include:

Insufficient Trained Professionals: There is a shortage of professionals within government ministries who are adequately trained in both DRR and ACC. This lack of expertise hampers the integration of these critical issues into planning processes.

Limited Awareness of Linkages: The connections between DRR and ACC have not been adequately emphasized or recognized, leading to missed opportunities for coordinated efforts.

Resource Constraints: Sectoral services responsible for addressing underlying risk factors, such as environmental management, regional planning, and water and sanitation management, often lack the necessary resources to fulfil their mandates effectively.

Lack of Norms and Standards: The absence of established norms, indicators, and standards poses a challenge to the integration of DRR and CCA. This is exacerbated by gaps in fundamental knowledge, such as local climate data, seasonal weather forecasts, and trends in extreme weather events.

Inadequate Spatial Planning: Authorities encounter difficulties in both having the necessary planning tools for development and enforcing them effectively. These hampers organized spatial development, which is crucial for risk reduction.

Underdeveloped Social Protection: Social protection mechanisms remain underdeveloped, despite their potential to mitigate the vulnerability of the most marginalized segments of the population.

Addressing these challenges will require a concerted effort to enhance expertise, promote awareness, allocate resources, establish norms and standards, improve spatial planning, and strengthen social protection mechanisms.

6.4 Strategies and Government Actions

Flood disaster management, like other forms of disaster management, can be categorized into distinct phases:

Preparedness Phase: This phase involves proactive activities conducted well in advance of an event. It encompasses activities such as prediction, risk zone identification, and vulnerability mapping.

Prevention Phase: Activities in this phase are focused on minimizing the impact of an impending disaster. This includes activities like forecasting, early warning systems, ongoing monitoring, and the preparation of contingency plans. These actions may occur before or during the event.

Response and Mitigation Phase: This phase entails actions taken after the disaster has occurred. Activities include damage assessment and relief management.

The saying "A dollar invested in prevention equals ten dollars saved in response" underscores the importance of prioritizing prevention measures over-reactive responses.

The Government of Niger, in collaboration with its partners, is actively seeking sustainable solutions to address recurring flood disasters. One notable initiative involved the inauguration of a protective dike in Goudal, Niamey commune1, in early November 2017. This dike is designed to safeguard approximately 30,000 residents living in several neighborhoods of the city from the threat of floods.

Furthermore, in April 2017, the government issued a decree prohibiting construction in high-risk flood-prone areas. However, despite the decree, many families still reside in these vulnerable communities.

Idé Harouna, the Permanent Secretary of the National Disaster Prevention and Management System for the Niamey region, emphasized the urgent need to enforce this ban effectively. Doing so would facilitate the unimpeded flow of water through appropriate channels and ultimately reduce the number of flood victims.

6.4.1 The Communities' rating of government response during and after flood

Figure 67 offers valuable insights into how communities in Niamey, Niger, perceive the effectiveness of the government's response during and after the floods. These perceptions shed light on the community's level of satisfaction with the government's response and provide insights into areas for improvement in disaster management and response strategies.

The most common assessment of the government's response was 'fair,' with 38% of respondents describing it as such. This suggests a mixed sentiment within communities, where government efforts are viewed as moderate and fair, but possibly falling short of expectations in some aspects. This rating may indicate a response that is deemed acceptable but not entirely adequate, highlighting the need for enhancements in disaster preparedness, response coordination, and aid distribution.

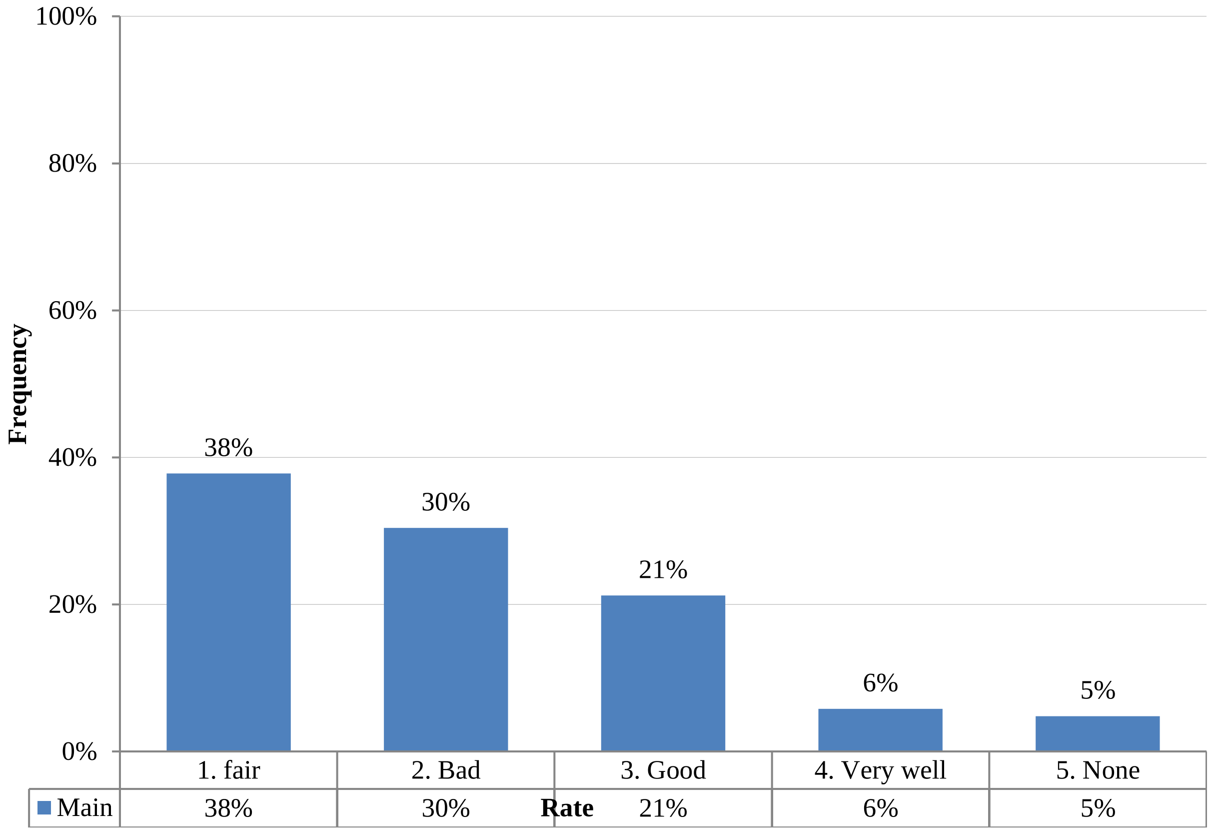


Figure 67: Rating of the government's response during and after flood events by the local communities (**Source:** Field survey,2022)

The perception of the government's response to the floods in Niamey, Niger varies among communities, as indicated by the different ratings provided.

A noteworthy perception is the 'poor' rating, with 30% of communities expressing dissatisfaction with the government's response. This signifies that a significant portion of the surveyed population felt that the government's actions during and after the floods were inadequate or ineffective. The 'poor' rating underscores the necessity for a critical evaluation of existing disaster management plans, prompt remedial action, and improved communication between government agencies and affected communities.

On the other hand, 21% of communities rated the government's response as 'good,' indicating a positive assessment of the government's efforts. This suggests that a considerable number of respondents believe the government's actions have been commendable in addressing flood-related issues. The 'good' rating emphasizes the importance of building upon successful strategies, maintaining transparency, and enhancing collaboration between communities and the government to ensure sustained positive outcomes.

A smaller percentage, 6%, of respondents rated the government's response as 'very good,' indicating a higher level of satisfaction. This group likely believes that the government's actions during and after the floods were not only effective but also exemplary. This rating suggests that some communities benefited from well-coordinated relief efforts and effective measures that mitigated the impact of the floods.

Surprisingly, 5% of communities indicated that they have "no" appreciation of the government's response. This could suggest a perception that the government's efforts have been negligible or non-existent. Nonetheless, this low percentage highlights a group of respondents who feel they have not witnessed a significant government response to the floods.

In summary, the table reveals a range of perceptions regarding the government's response to the floods in Niamey, Niger. The diversity of ratings, spanning from 'Poor' to 'Very Good,' reflects a nuanced understanding of the challenges faced during the floods and the effectiveness of the government's actions in response. The significant percentage of 'Fair' ratings suggests an intermediate perspective that can be leveraged to refine disaster management strategies, enhance accountability, and establish mechanisms for continuous improvement. By addressing the concerns expressed by the "Poor" ratings and building on the positive feedback from the "Good" and "Very Good" ratings, the government can enhance its disaster response capabilities and better meet the needs of affected communities.

6.4.2 Existing Capacities

✓ For non-structural measures of environmental factors, Niger has already signed international conventions (UNCBD, UNFCCC, UNCCD) and has developed strategic and planning frameworks (PNEDD, PANA, programs for sustainable land management, protection of biodiversity, energy and sustainable development…). The country also subscribes to the ACC.

✓ There is a National Strategy in DRR dating from 2013. National authorities are increasingly aware of the need to invest in DRR (3N). Sectoral strategic frameworks that participate in DRR: PICAG, PDES 2017-2021, SDDCI. 2035, UNDAF 2014-2018, other support staff for TFPs**.**

✓ For socio-economic factors, there are a number of operational initiatives (3N, free distribution of food and sales at moderate prices from the DNPGCCA, etc.) as well as programs and planning (Health development plan, Sustainable development strategy of the (Protection of the most vulnerable groups, TFP programs, etc.).

✓ For territorial planning, Niger has a national regional development policy (2014), in Niamey, the "Niamey Niala" project for the development of the river is developing. Finally, and this goes beyond the only aspects of territorial planning, the World Bank granted a loan of US $ 106.65 million for disaster risk management and urban development.

6.4.3 Challenges and gaps

In general, only weak links exist between the different types of knowledge, data and work applied by climate and risk scientists and practitioners, which hinders straightforward communication, collaboration and joint programming. The failure to communicate scientifically acquainted knowledge of climate change in a practical way, and the lack of substantial guidance on how to deal with the aspect of uncertainty, provide substantial challenges for practitioners (Barnett & Adger, 2007)(Barnett *et al.,*2007). Furthermore, several other researchers (Brinkmann et al., 2014; Smit & Wandel, 2006; Wisner, 2016)2004) affirmed that some important information, such as social and economic census data of dynamic areas with high fluctuations of people and economic instability, which would be essential in order to assess changing vulnerabilities and develop appropriate adaptation strategies, is not available at all. This data has not been sufficiently developed due to costs, as well as due to the lack of appropriate methodologies to forecast societal development at meso and micro-scales. These are some of the challenges:

✓ There are not enough professionals trained in DRR as well as in ACC in the ministries, capable of integrating these problems in their planning.

✓ The links between DRR and Adaptation to Climate Change (ACC) are not yet sufficiently highlighted.

✓ The sectoral services which deal with underlying risk factors (environment, regional planning, water and sanitation management, etc.) lack of means to accomplish the mission entrusted to them.

✓ The lack of norms, indicators and standards that could help the integration of DRR and CCA has been outlined and can be derived from the lack of basic knowledge in certain areas (e.g. data of local climate effects, seasonal weather forecasts, trends of extreme weather events).

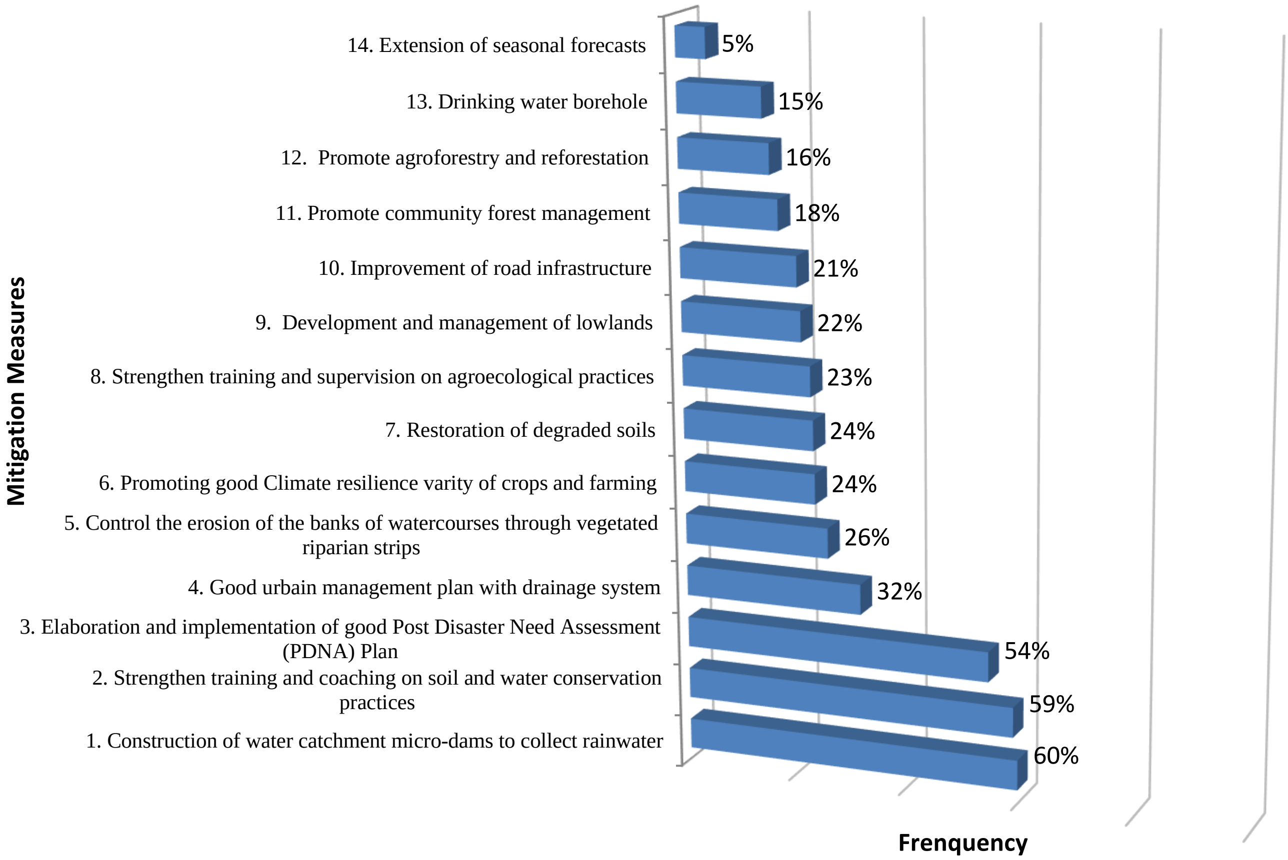
✓ In terms of spatial planning, the authorities lack the tools to plan and control development. On the other hand, even when planning tools exist, it is difficult to enforce them.

✓ Social protection is still too underdeveloped, and yet it would help reduce the vulnerability of the most vulnerable groups of the population.

✓ We do not know the real share of the state budget devoted to DRR and therefore, there is no specific budget allocated to DRR**.**

6.5 Niamey flood mitigation Technics and measures

Flood management can indeed be effective and successful, drawing on strategies employed by developed nations in addressing climate change and heavy rainfall. These approaches can be adapted for use in Niger. The table provides valuable insights into how people in Niamey, Niger, assess the effectiveness of various adaptation strategies that government and other organizations may employ to reduce floods. These opinions shed light on how communities perceive solutions that can effectively mitigate the impacts of floods and contribute to resilience-building. The most widely recognized adaptation measure is the "construction of micro-dams to collect rainwater," with 60% of respondents endorsing this strategy (Figure 68).



Source: Field survey, 2022

Figure 68: Flood mitigation tactics and measures in Niamey

. This adaptation measure underscores the importance of capturing and regulating rainfall through infrastructure like micro-dams. Rainwater harvesting can help prevent excessive runoff, replenish groundwater, and provide water for agricultural and other purposes during dry periods.

"Strengthening training and support for soil and water conservation practices" was mentioned by 59% of respondents. This indicates recognition of the crucial role played by sustainable land management methods in flood control. Training and support can empower communities to implement measures that prevent soil erosion, enhance water retention, and improve overall soil health.

Approximately 54% of respondents selected "developing and implementing a robust post-disaster needs assessment plan" as a key adaptation step. This highlights the recognition of the significance of comprehensive post-disaster assessment and planning for effective recovery and reconstruction.

The perception of a "sound urban management plan with a drainage system" as an adaptation strategy is indicated by 32% of respondents. This underscores the necessity of urban planning that incorporates well-designed drainage systems to channel and control excess water during floods, reducing flood risks in urban areas.

"Controlling riverbank erosion with riparian vegetation strips" was noted by 26% of communities. This method promotes the use of vegetation along watercourses to prevent bank erosion, stabilize the soil, and maintain healthy water bodies.

"Promoting a diverse range of climate-resilient crops and farms" and "Restoring degraded soils" were both mentioned by 24% of communities. These adaptation measures underscore the need for agricultural practices that can withstand climate fluctuations and enhance soil health for sustainable production.

Approximately 23% of respondents suggested "strengthening and monitoring agroecological practices," highlighting the importance of farming methods aligned with local ecosystems that promote sustainability.

"Developing and managing low-lying terrain" was mentioned by 22% of communities, emphasizing the need for planned development in low-lying areas to minimize worsening flood risks.

"Improving road infrastructure" was proposed by 21% of respondents, emphasizing the importance of well-maintained roads that can help manage water runoff and reduce obstructions during floods.

"Promoting community forest management" and "Promoting agroforestry and reforestation" were recognized by 18% and 16% of communities, respectively. These indicators underscore the benefits of conserving and restoring forests and supporting sustainable land use practices that benefit both communities and the environment.

"Drilling for drinking water" was suggested by 15% of communities, highlighting the importance of having clean and accessible sources of drinking water even in the event of floods.

Finally, "Extension of seasonal forecasts" was cited by 5% of communities, underscoring the potential importance of accurate and timely weather predictions for community education and preparedness.

In conclusion, the table presents a range of adaptation strategies that residents in Niamey, Niger believe can effectively manage floods. These opinions demonstrate an understanding of the interconnectedness of various tactics and the need for a comprehensive approach to flood control. By incorporating the suggestions put forward by communities into comprehensive disaster management plans, the government and relevant institutions can enhance their capacity to address the challenges posed by floods and build a more resilient future for communities.

6.6 Recommendations for Disaster Risk Reduction

In general, disaster risk reduction aims to promote sustainable development by preventing societies from regressing in their development due to catastrophic events and by supporting their growth on a more secure and sustainable foundation (Begum et al., 2014). This entails considering strategies to mitigate the risk of natural or man-made hazards. Disaster risk reduction initiatives are inherently long-term in focus, although this may not always be the case. Vulnerability factors and associated intermediate impacts play a crucial role in understanding cause-and-effect relationships. For example, the intermediate impact of "erosion" in the catchment is directly related to "deforestation" and the degradation of the ecosystem's "erosion protection." This is in addition to being a consequence of excessively high-water levels and increased flow velocity.

Both climate change adaptation (CCA) and sustainable risk reduction initiatives require long-term perspectives that extend beyond individual election cycles. Existing funding mechanisms must account for the present situation and uncertainty surrounding the impact of climate change on future extreme events. As per findings by (Birkmann et al., 2014), it is common for humanitarian donors to allocate short-term funding for disaster response, and nations frequently grant temporary work visas to relevant relief organizations, often neglecting the imperative for long-term financial support for adaptation efforts. When formulating adaptation and risk reduction programs, it is vital to embed them within a broader framework that can serve as guidance for entities such as development organizations and disaster assistance agencies. These programs should undergo assessment in the context of the specific regional or local environment where they will be applied, considering the existing risks. The quality and assessment standards outlined below may prove invaluable in this regard.

The following quality and assessment standards may be useful:

1. **Develop a Comprehensive Strategy**: Create a practical approach for risk reduction and disaster management, complemented by orientation legislation to streamline operational processes, necessitating appropriate legal backing. This strategy must gain approval from the Council of Ministers and subsequent approval from the National Assembly. The legislation should be accompanied by implementing documents, such as decrees and orders, when it passes the National Assembly stage. This strategy establishes the minimal requirements for its operationalization.

2. **Review of International Cooperation Initiatives**: Examine various initiatives and programs supported by international cooperation partners in areas such as resilience, food security, environmental protection, risk reduction, and climate change adaptation. This assessment should provide insight into intervention regions, targeted activities, participants, and allocated funding.

3. **Screening of Other Programs and Projects**: Integrate the screening of other programs and projects in target countries, identifying potential thematic linkages and opportunities for cooperation to enhance coordination between humanitarian and development organizations for greater effectiveness and efficiency.

4. **Capacity Building**: Strengthen the capacity of national planning institutions by establishing a training program and creating methodological tools for integrating climate-related risks and disaster risk reduction into sectoral development programs and action plans.

5. **Enhancing Local Community Resilience**: Incorporate disaster risk reduction, including climate-related risks, into development programs for Convergence Municipalities. Address the adverse impacts of climate change and natural disasters on vulnerable communities, fostering their adaptive capabilities and contributing to peacebuilding and recovery efforts.

6. **Poverty Reduction and Risk Mitigation**: Recognize that climate change and disaster risk disproportionately affect the poor, as they lack access to the resources needed to enhance resilience across economic, social, physical, and environmental dimensions. Integrating disaster risk reduction and climate change adaptation at all levels can reduce vulnerability, contribute to poverty reduction, and promote sustainable natural resource management.

This connection underscores the importance of including disaster risk reduction and climate change adaptation in development strategies and planning (Begum et al., 2014).

It also highlights the need to establish a link between disaster risk reduction and climate change adaptation at the local level, where collaboration and coordination between Districts s and communities are essential (Figures 69 and 70).

Figure 69: Conceptual framework I: Linkages between DRR and CCA (**Source:** Begum *et al.*, (2014))

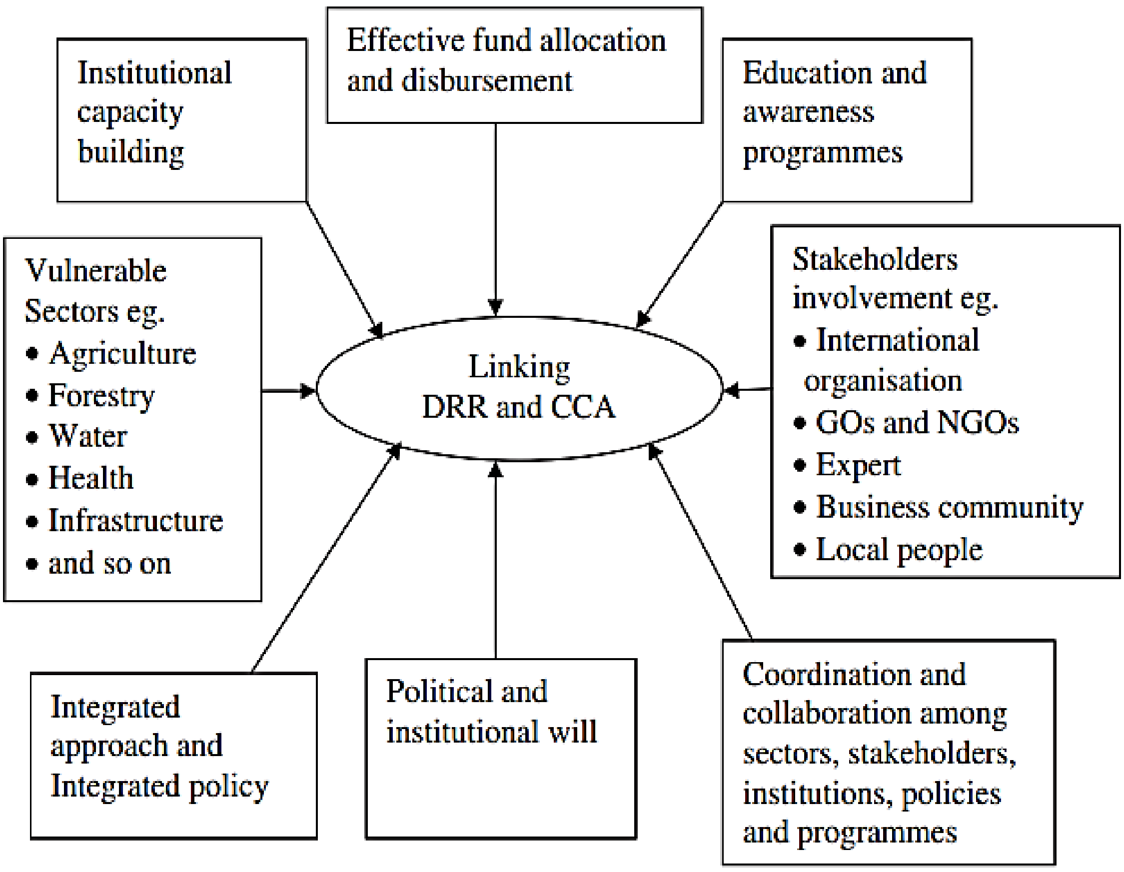


Figure 70: Conceptual framework II: Factors involvements to linking DRR and CCA

Figure 61 has been drawn to provide a conceptual framework for better understanding the linkages of DRR and CCA at the local and national level. The factors involved to linking DRR and CCA have been discussed in the Flowchart. It also highlights a summary of reviews on experiences of integrating DRR and CCA from several international organizations and compares how integration has been approached and implemented.

6.7 SWOT analysis as support for measures to reduce the risk of Flood

SWOT analysis is conducted by examining and categorising the several elements that impact the four aspects (Strengths, Weaknesses, Opportunities, Threats). Strengths and weaknesses pertain to internal attributes, while opportunities and threats refer to external circumstances affecting individuals within the society. Strengths and Opportunities have beneficial effects, but Weaknesses and Threats have adverse effects on individuals. The foundation of many activities and the analysis of materials (such as reports and social citations) rely on the capabilities of individuals in the field of study.

Strengths:

1. **Natural Features:** Niamey benefits from natural features such as rivers and wetlands, which can serve as natural buffers against floods if properly managed.
2. **Community Resilience:** The community's resilience and traditional knowledge can be leveraged for flood preparedness and response efforts.
3. **Government Commitment:** The government's commitment to disaster risk reduction and infrastructure development provides a foundation for implementing flood mitigation measures.
4. **International Support:** Niamey may receive support from international organizations and donors for implementing flood risk reduction projects.

Opportunities:

1. **Green Infrastructure:** Investing in green infrastructure presents an opportunity to enhance natural flood mitigation and improve urban resilience.
2. **Community Engagement:** Engaging local communities in flood risk reduction initiatives can foster ownership, resilience, and sustainable development practices.
3. **Technological Innovation:** Leveraging technology, such as early warning systems, remote sensing, and GIS mapping, can improve flood forecasting, monitoring, and response capabilities.
4. **Policy Integration:** Integrating flood risk reduction into urban planning, land use management, and climate change adaptation policies presents opportunities for mainstreaming resilience across sectors.

Weaknesses:

1. **Poor Drainage Infrastructure:** Inadequate drainage infrastructure exacerbates flood risks in urban areas, leading to property damage and disruptions.
2. **Informal Settlements:** Informal settlements in flood-prone areas lack proper infrastructure and are highly vulnerable to floods, posing challenges for disaster response and recovery.
3. **Limited Resources:** Limited financial and human resources constrain the implementation of comprehensive flood risk reduction measures.
4. **Lack of Awareness:** Low levels of awareness among the population about flood risks and preparedness measures hinder effective disaster management efforts.

Threats:

1. **Climate Change:** Climate change exacerbates flood risks through increased intensity and frequency of extreme weather events, posing challenges for adaptation and resilience-building efforts.
2. **Urbanization:** Rapid urbanization encroaches on floodplains, reduces natural drainage areas, and increases surface runoff, amplifying flood hazards and vulnerabilities.
3. **Resource Constraints:** Competition for limited resources and funding priorities may divert attention from flood risk reduction efforts, leaving communities exposed to recurring disasters.
4. **Social Vulnerability:** Social inequalities, including poverty, marginalization, and lack of access to basic services, exacerbate vulnerability to floods and hinder equitable disaster response and recovery efforts.

By aligning the strengths and opportunities of Niamey with targeted strategies to address weaknesses and threats, the city can develop comprehensive and sustainable approaches to reduce flood risks and build resilience to the impacts of climate change, urbanization, resource constraints, and social vulnerability.

Strategies:

1. **Leverage Natural Features and Community Resilience:** Capitalize on the strengths of natural features and community resilience by implementing nature-based solutions, such as wetland restoration and community-based flood management practices. Engage local communities in the design, implementation, and maintenance of green infrastructure projects to enhance flood resilience and reduce vulnerabilities in informal settlements.
2. **Maximize Government Commitment and International Support:** Strengthen government-led initiatives for flood risk reduction by mobilizing international support

and technical expertise. Advocate for increased investment in drainage infrastructure upgrades, informal settlement upgrading, and community-based disaster risk reduction programs. Align international funding with national priorities and community needs to address resource constraints and enhance flood resilience at the local level.

3. **Harness Technological Innovation and Enhance Awareness:** Utilize technological innovations, such as mobile apps, social media platforms, and community-based early warning systems, to enhance flood preparedness, response, and recovery efforts. Develop targeted awareness campaigns and educational programs to raise public awareness about flood risks and preparedness measures, particularly in vulnerable communities. Enhancing technological innovation and awareness reduces the threat of resource constraints and social vulnerability by empowering communities with timely information and tools for effective flood risk management.
4. **Promote Policy Integration and Community Engagement:** Advocate for policy integration across sectors to mainstream flood risk reduction measures into urban planning, land use management, and climate change adaptation policies. Foster multi-stakeholder partnerships and community engagement in decision-making processes to ensure inclusive and participatory approaches to flood resilience-building. Promoting policy integration and community engagement mitigates the threat of fragmented governance and urbanization-driven flood risks by fostering collective action and resilience at the local level.

6.8 Recommendation for Resilience Strategies on Reducing Flood Risks in Niamey

6.8.1 Mitigation Flooding

Flooding can have a devastating impact on communities, leading to the loss of homes, crops, livestock, life savings, and even potential loss of life. Therefore, it is essential to manage flooding effectively, which involves implementing a comprehensive flood mitigation plan. The River Niger Basin can benefit from several key mitigation measures, which can foster economic and personal development for the affected population. By considering these core elements and their interplay, stakeholders can develop more targeted and holistic strategies to mitigate flood risk in Niamey.

One critical approach is to prioritize resilient infrastructure and the preservation of natural drainage areas in urban design techniques. Investment in robust drainage infrastructure, such as the construction and maintenance of canals, stormwater retention ponds, and flood control structures, can significantly improve the city's capacity to manage heavy rainfall and mitigate flood risks.

Additionally, upstream regions' reforestation, sustainable land management practices, and erosion control measures can reduce sedimentation and soil erosion, which reduces the risk of downstream flooding.

Ongoing maintenance and effective implementation of flood risk reduction methods in Niamey require collaboration among government agencies, urban planners, environmental organizations, and local communities. Together, they can work towards a more resilient and flood-resistant city that safeguards its residents and supports sustainable development. Flooding can have a devastating impact on communities, leading to the loss of homes, crops, livestock, life savings, and even potential loss of life. Therefore, it is essential to manage flooding effectively, which involves implementing a comprehensive flood mitigation plan. The River Niger Basin can benefit from several key mitigation measures, which can foster economic and personal development for the affected population. By considering these core elements and their interplay, stakeholders can develop more targeted and holistic strategies to mitigate flood risk in Niamey.

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6.8.2 Dam construction

The flow of water or an underground stream may be halted or regulated by a dam. It is a proven means of avoiding floods. In developed countries, dams were first designed expressly to alleviate floods. The level of a reservoir must be maintained below a specified level ahead of the rainy season in flood control reserves, which are found in many big dams. Flood water is enabled to fill the dam during the rainy season, keeping them from damaging houses and lives. Imagine the dam as a water-filled open tank. To create space for rainwater during the rainy season and decrease flooding in the neighbourhood, the tank is emptied prior to the rainy season.

6.8.3 Flood Resilience

Resilience to flooding is the ability to recover after flooding. Compared to river defences, this strategy works better. Buildings and other urban infrastructures should be properly planned or maintained to facilitate flood recovery. Raising electrical outlets and waterproofing buildings are two examples. Employing green roofs is encouraged.

In this initiative, homes are being constructed with green roofs. Soil is found atop vegetative roofs, where it absorbs rainwater to lessen floods. The cost of construction and upkeep, however, is high.

6.8.4 Establish Flood Plains

Flood plains are lands having a high-water absorption capacity. Diverting water from flooded neighbourhoods lowers the flood. Since flood plains are utilised as a natural reservoir that people may use during droughts, this is a conservation approach. Other countries have created flood basins out of deserts and wild terrain. This has to be looked at in Niger. Flood plains are a natural home for aquatic animals.

In Niger, it's critical to encourage reforestation and the protection of wetlands. Reforestation, or the act of planting trees, minimises the consequences of floods. The trees' ability to absorb water reduces the rate at which rivers flood into surrounding settlements. Wetland areas that soak up rain and forested areas assist in lessening flooding when a river overflow. Both the creation of wetlands and reforestation are considered to be superior environmental practices.

6.8.5 Improving Drainage Systems

Regular maintenance of current canals, gutters, and drainage channels is necessary to maintain the free flow of water and improve drainage systems in Niamey. Additionally, it can need the development of additional drainage infrastructure, especially in regions that are rapidly urbanising. Drainage system upkeep and expansion will aid in efficient stormwater management and reduce the likelihood of localised floods. Drainages are crucial systems for reducing floods in a community, particularly in metropolitan areas. For free-flowing water during periods of severe rainfall, proper management and drainage system upgrades are required. Smaller drainages should be made larger to hold water in order to prevent flooding during periods of severe rainfall. Wastes should be collected and properly disposed of where sediment and trash dumping have clogged drainage.

6.8.6 Build Flood Control Infrastructure

The installation of flood control infrastructure, including dams, dykes, and flood barriers, may help Niamey. These buildings control or redirect floods, safeguarding vital infrastructure, populated regions, and agricultural land. In order to reduce negative environmental effects, such infrastructure must be designed and built taking into consideration local hydrological conditions and blending into the surrounding environment.

Flooding may be avoided by using rainwater for irrigation. Rainwater is gathered in what ways? In times of heavy precipitation, the procedure for collecting rainwater is simple. Flooding may be controlled or avoided by storing the rainfall once it has been collected.

6.8.7 Enforcement of Land Use Regulations

To stop building in flood-prone locations, land-use restrictions must be enforced. The municipality has the authority to enact zoning regulations and building regulations that sternly forbid new construction in high-risk regions, particularly those close to riverbanks, floodplains, and low-lying areas. To guarantee compliance with these rules, strong enforcement procedures and education efforts are required.

6.8.8 Environmental Sanitation

Even though it can seem like an obvious step, sanitation is one of the requirements on this list. Sewage and garbage hinder water movement in drainage systems and canals, making them inefficient. Regularly cleaning debris from drains and canals, etc. Reminding people not to dump waste and sewage carelessly in the area and canal is necessary. This is the cheapest means of avoiding floods in Niger.

Acting is the costliest thing to do, I can say after reading this. Your desire to live in a society that resembles paradise on earth cannot be realised unless you shed that attitude of helplessness and exercise initiative.

6.8.9 Promote Sustainable Urban Planning

The utilization of sustainable urban design techniques can significantly reduce the risk of flooding in Niamey. Prioritizing the integration of green spaces, permeable surfaces, and retention basins into the city's urban layout is crucial. This approach promotes natural infiltration and drainage, effectively managing stormwater. Additionally, enhancing water absorption and retention can be achieved by incorporating green infrastructure elements like green roofs and rain gardens.

Another vital strategy for flood prevention within neighborhoods is community planning. When buildings are situated along waterways without proper planning, it can lead to either the creation of artificial alternatives or the natural diversion of water, potentially causing flooding. Hence, effective community planning is essential. Ministries like the "Urban and Regional Planning Development Authorities" have been established to oversee the positioning of businesses and housing developments in alignment with the intended urban layout. This ensures a vigilant approach to urban development, reducing flood risks in the process.

6.8.10 Improve Early Warning Systems

For efficient flood risk management, early warning systems must be created and improved. Niamey may spend money on systems for collecting real-time data, weather forecasting technology, and monitoring stations for river levels and rainfall. To provide citizens with early warnings and enable prompt evacuation, if required, these devices have to be connected to communication networks. Campaigns for public education are necessary to make sure that communities are aware of the warnings and react properly.

6.8.11 Public Wareness

Public awareness initiatives play a significant role in developing a culture of resilience. Niamey may conduct community workshops, disseminate educational materials and organise public meetings to enlighten citizens about flood hazards, preparatory measures and evacuation methods. These programmes should be customised to the local environment, including language preferences and cultural sensitivities, in order to successfully reach and incorporate all sectors of the population.

6.8.12 Strengthen Emergency Response Capacity

Niamey should increase the ability of emergency response services to efficiently handle flood-related situations. This involves educating emergency responders, supplying them with the required resources and equipment, and establishing up coordination procedures between the numerous authorities. In addition, constructing and maintaining emergency shelters, storing vital supplies and performing frequent exercises may enable a swift and coordinated response to floods.

6.8.13 Encourage Nature-Based Solutions

Nature-based solutions may complement established technological methods for flood risk control. Niamey may prioritise the conservation and restoration of natural habitats, such as wetlands, riverbanks and floodplains. The preservation of these places assists in flood management, water retention and erosion control. In addition, the promotion of sustainable agriculture methods that prioritise soil conservation and water retention may assist in minimising runoff and enhancing natural flood control.

6.8.14 Improving Data Collection and Modelling

Planning and assessing flood risk effectively depend on accurate and current data. Niamey needs to spend money on data-gathering projects including hydrological monitoring stations, rain gauges, and flood mapping activities. These data may be included in flood risk models to predict how climate change would affect flood patterns. The municipality will be better able to establish evidence-based initiatives thanks to ongoing monitoring and enhanced data-gathering techniques.

6.8.15 Strengthen International Cooperation

International partnerships and cooperation in flood risk reduction and climate resilience could offer significant benefits to Niamey. This involves collaborating with international agencies, neighboring cities, and regional projects that focus on similar challenges. Such collaboration can provide Niamey with access to valuable knowledge, technical support, and financing opportunities.

Examples of cooperation include sharing information, joint research initiatives, capacity-building programs, and the exchange of best practices and lessons learned. Through these collaborative efforts, Niamey can enhance its flood disaster risk assessment and climate change resilience measures by tapping into global expertise and resources.

6.8.16 Dredging of River

Another crucial method for mitigating floods is river dredging. Through the process of excavating and enlarging the river, it becomes possible to effectively manage the inflow of water from various tributaries, accommodate excess water from heavy rainfall, and absorb unexpected releases of water from dams. Dredging stands out as a paramount approach to preventing rivers from overflowing their banks.

In addition to flood mitigation, the construction of can have broader economic implications for the region. It has the potential to attract significant industries, boost commercial activities, and create employment opportunities, thus strengthening the local economy.

It's essential to emphasize that the application of these mitigation techniques in Niamey should be informed by local knowledge, involve stakeholder participation, and align with the specific context and goals of the municipality. Adopting an adaptive management approach will allow for adjustments and improvements over time through continuous monitoring and evaluation of the implemented measures. Furthermore, integrating these strategies into more comprehensive sustainability and climate action plans will enhance the long-term resilience and well-being of both the municipality and its residents.

6.8.17 National Flood Insurance Programme

Flood insurance is a specific type of insurance coverage designed to protect against property damage caused by flooding. Insurance companies often employ topographical maps that highlight low-lying areas, floodplains, and other flood-prone zones to assess the risk factors associated with specific properties. This information is crucial for identifying and promoting strategies to reduce losses in the face of climate-related events.

By leveraging the resources and expertise of both the public and private sectors, collaborative efforts aim to offer insurance solutions that are not only affordable but also share the responsibility for mitigating the consequences of floods and climate change. These partnerships work in tandem with existing programs and organizations to implement pilot projects focused on the utilization of insurance-related solutions. This includes identifying successful case studies and disseminating information regarding the essential components required to develop and implement effective climate insurance processes.

While these initiatives primarily target impoverished nations, they also involve evaluating insurance solutions that have proven effective in more affluent countries. This holistic approach aims to enhance global resilience to climate-related risks and foster sustainable practices across regions with varying levels of economic development.

Partial Conclusion

Decisions regarding disaster risk management are sometimes made without the direct involvement of various stakeholders, even though these decisions cannot effectively be put into action without the active participation of these stakeholders (Alipour, 2015). Therefore, an ideal approach to decision-making in disaster management is to adopt a participatory process where the expertise and preferences of all interested parties are incorporated from the outset. Evers et al. (2014) argue that this fosters trust among decision-makers and stakeholders, often resulting in the successful and complete implementation of selected measures aimed at mitigating risks and addressing the challenges posed by climate change while strengthening overall resilience.

In addition to disaster risk reduction (DRR) measures such as prevention, mitigation, preparedness, networking, local insurance, shelter protection, and water provision, poverty reduction initiatives like job creation, improved livelihoods, and social protection can also contribute significantly to reducing disaster risks and vulnerability. These DRR measures not only enhance resilience but also play a role in poverty reduction, leading to a mutually beneficial relationship.

Moreover, DRR prevention strategies can be instrumental in climate change adaptation and mitigation efforts. A comprehensive approach to climate change should encompass risk assessment, safety measures, and early warning systems. This holistic approach helps address the challenges posed by climate change while simultaneously reducing disaster risks and promoting overall sustainability.

General Conclusion, Recommendation and Perspectives

Conclusion

Flooding is a natural catastrophe that interacts with climate change, yielding severe consequences and inflicting substantial damage. Niger, in particular, faces vulnerability to a range of natural disasters, including floods, droughts, and locust invasions. Among these, floods are the most prevalent and recurrent natural disasters, posing the most severe threat in Niamey. The frequent, sudden onset of flood disasters, often unprepared for, poses substantial risks and damages to the socio-economic and environmental aspects of the study area, including loss of lives, property damage, displacement of people, disruptions of economic activities, and environmental degradation. The main objective of this study is to assess flood disaster risk and propose resilient methodologies for communities of Niamey and its vicinity. The specific objectives are:

- To identify the major factors contributing to flood disaster risk;
- (SO2) - To assess the impacts of flood events on the community living by River Niger in Niamey and its vicinity;
- (SO3) - To promote climate resilience measures for reducing the adverse impacts of floods and its likelihood; and
- (SO4) - To elaborate a model of flood forecasting mechanism to reduce the risks;

As a result, this study yields four major finding that are pertinent to each individual specific objective goal. This goal has been reached through the flowing outcomes:

For the specific objective one, the research findings that flood is the most devastating and most occurring environmental disasters in Niamey. Thus heavy rainfall is the acting factor of flooding. Contrary to the general assumption that heavy rainfall is the major cause of urban flooding, the study revealed that urbanization dynamics such as: location of residence (increasing informal settlements on flood prone areas), lack of good drainage facilities and distance of properties from drainage facilities, lack of a proper layout plan, indiscriminate dumping of refuse on drainage channels, indiscriminate building on water ways, plot sizes and lack of development control measures are among the major factors responsible for flood in Niamey. Additionally, factors such as soil conditions, vegetation, water channel contamination, and the local topography also play significant roles in the occurrence of flood disasters. The examination of the spatiotemporal dynamics of land use /land cover from 1991 to 2021 were also employed for the dynamic of land units to the flood hazards in Niamey

For the specific objective two, this thesis demonstrates the importance of remote sensing and GIS in assessing flood risk. The study effectively demonstrated the capabilities of GIS and remote sensing technologies in the field of disaster management, particularly in relation to flooding. To limit the consequences of flood it is necessary that all locations that are susceptible be recognised. Before this can be done, information is necessary on crucial indices of flood risk identification which include slope, distance to drainage, drainage density, soil and land use as utilised in this research study. We employed remote sensing and GIS tools to identify locations that are susceptible to flood. This study offers an empirical strategy for mapping susceptibility to flooding in metropolitan areas via the merging of AHP and GIS approaches. The suggested technique may enable decision and policy makers in the fast assessment and evaluation of flood. For the study region, a flood risk map has been developed using Analytical Hierarchy Process technique that incorporates physical and socio-economic elements The study's results define locations inside Niamey distinguished five levels of risk: very low, low, moderate, high and very high to flooding, accordingly.

The thirdly, in addition to investigating the impact of severe rainfall events on the frequency of floods in Niger, this research explores the temporal variability of rainfall and outflow characteristics. Our results provide a more nuanced view than many large-scale researches that have found that severe rainfall has increased in frequency and intensity in West Africa.The hydrological model of flood forecasting elaborated to reduce the impact of flood disaster risks. Furthermore, while the effect of severe precipitation events on floods is recognised, the correlation between the frequency of floods and the frequency of extreme precipitation events is not very high. Our analysis, which makes use of a non-stationary generalised extreme value model with location and scale parameters as functions of extreme precipitation, shows that the recent rising trends in flood frequency are not largely attributed to severe precipitation.

Finally, while it's acknowledged that flash floods caused by heavy rainfall cannot be entirely prevented, the study suggests that mitigation measures can reduce the frequency, hazards, adverse impacts, and overall threat of flood disasters in the study area. These measures aim to enable inhabitants in flood-prone regions to coexist with floods and harness their potential benefits. recognizing that flood knowledge is crucial for improving flood risk management and designing effective preventive and mitigation strategies, the study emphasizes the importance of flood statistics. Such data provide a comprehensive understanding of the region's susceptibility to hydro-climatic risks. Effective urban planning, especially concerning drainage systems in major urban centers, is crucial for flood regulation and prevention. The establishment of a national database dedicated to collecting information on flood events is particularly noteworthy, as it provides a valuable resource for quantifying the impacts on individuals and ecosystems in one of the world's most vulnerable nations. This initiative is especially remarkable given the nascent stage of data infrastructure development in the region. Climate resilience measures to reduce the adverse impact of floods and the likelihood of flood are promoted. It's important to note that flood disaster risk management should be an ongoing and adaptive process, with regular updates to plans and strategies based on changing conditions and new information.

The flowing hypothesis have been confirmed

- ✓ Climate change and the mode of land use in the floodplain are responsible for the increased flooding level in Niamey and its vicinity.
- ✓ In Niamey, floods threaten human security and land availability.
- ✓ The use of an appropriate model for flood forecasting can reduce flood-related risks in Niamey
- ✓ Communities in Niamey build resilience capacity but the adaptation and/or mitigation measures implemented by the government and local dwellers are not sufficient while the proposition to hence them.

Recommendations

Based on the findings of the investigation, the following recommendations are made to minimize the adverse impacts of recurrent floods in Niamey and provide practical solutions to the flood catastrophe:

Improving Drainage Infrastructure: The current inadequacy of drainage systems in the affected regions contributes significantly to the flood threat. It is crucial to establish and maintain a well-structured drainage infrastructure. Additionally, a risk assessment framework specific to Sahelian regions should be developed and implemented to identify vulnerable areas and plan accordingly.

Restricting Construction in Vulnerable Areas: Encourage residents to avoid building structures along waterways and strongly advise against settling near river banks and channels, especially during the peak rainy season. This will reduce the risk of inundation and safeguard lives and property.

Dredging River Channels: Government and relevant stakeholders, including management/response organizations, development partners, civil society groups, and affected communities, should collaborate to conduct regular dredging exercises in the river channels. This will help remove silt and aquatic weeds, such as typha grass, which obstruct the free flow of water and increase the risk of riverbank overflow.

Effective Operation and Maintenance of Dams: Ensure the proper operation and maintenance of hydraulic infrastructure, including controlled release of water from upstream dams and reservoirs. This proactive approach will help mitigate the threat of overflow and reduce the likelihood of flood disasters.

Enhance Flood Preparedness: Current disaster management strategies primarily focus on emergency responses, such as distributing relief supplies to victims. There is a critical need for all stakeholders, including government agencies, NGOs, and local communities, to prioritize flood preparedness and preventive measures. This includes early warning systems, evacuation plans, and public awareness campaigns.

Support Climate Change Adaptation: Support local and national humanitarian efforts to adapt to climate change. While adaptation strategies are often poorly implemented in underdeveloped nations, it is essential to integrate and enhance these strategies to address the increasing threat of floods due to changing climatic patterns.

Strengthen Monitoring and Intervention: Enhance the capacity of organizations responsible for monitoring floods, disaster risk reduction, and humanitarian relief to respond effectively to flood emergencies. This includes improving the coordination and response mechanisms to ensure a rapid and efficient response to flood disasters.

By implementing these recommendations, Niamey and the surrounding regions can work towards reducing the impact of recurrent floods and better prepare for future flood events. Collaboration among government, stakeholders, and the community is essential to achieve these goals and enhance overall flood resilience.

Perspectives

To assess the risks and damages linked to a flood disaster in Niamey, a mixed-method approach was employed. To delve deeper into novel insights and critical aspects regarding the reduction and mitigation of flood disaster risks in the study area, it is recommended that further research be expanded to a broader scope using the SWAT methodology. Additionally, for the purpose of validating the findings of this study and facilitating broader applicability, additional research should be carried out across various flood-prone regions within Niger and its neighboring sub-regions.

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Appendices

Appendix 1: Research Questionnaire

QUESTIONNAIRE

PhD Research Thesis

FLOOD RISK ASSESSMENT AND CLIMATE CHANGE RESILIENCE IN THE CITY OF NIAMEY-NIGER

This study aims to evaluate the risks of flooding and to propose methods of resilience for the communities of Niamey the capital of Niger. It is part of the requirements for obtaining the PhD in Climate Change and Disaster Risk Management from the University of Lomé, Togo. The information obtained through this study is purely for academic purposes. You are reassured of the confidential treatment of the valuable information provided.

Thanks very much.

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Researcher's Name: Hassane Bassirou

SECTION 1 : LOCATION

1.0 Day/Month/Year of interview:	___ ___/ ___ ___/ 2022
1.1 Region: ___________________	1. 4. Name of respondent ____________
1.2. Municipal district ____________	1.5. File No.!____! !____ ! !____ !
1.3. District : ________________________	1. 6. Geographic coordinates Latitude : Longitude :

SECTION 2 : GENERAL INFORMATION			
2.1	Sex	1. Male 2. Female	|___|
2.2	How old are you ?	1. Teenagers (<20 years old) 2. Young adult (20-39 years old) 3. Adult (40-59 years old) 4. Adults (60 and over)	|___|
2.3	Marital status	1. Single 2. Married) 3. Divorced/Separated 4. widow/widower	|___|
2.4	Highest level of education in the household	1. No school education 2. Literacy (able to read and write) 3. Primary 4. Middle School 5. High school 6. University	|___|
2.5	What is the total number of household members?	Women Man Children (under 15) Seniors (55+)	|___||___| |___||___| |___||___|
2.6	Do you own your house?	1. Yes 2. No 3. Unspecified	|___|
2.7	How long did you stay in this locality?	1. ≤10 years 2. 11 -20 years old 3. 21- 30 years old 4. 31- 40 years old 5. > 40 years	|___|
SECTION 3 : SOCIO-ECONOMIC CHARACTERISTICS			
3.1	What is the main activity of the head of the household?	1. Salaried worker 2. Agriculture 3. Breeding 4. Hunt 5. Fishing/fish farming 6. Forestry 7. Arts and crafts 8. Palm oil production 9. Trade 10. Catering and accommodation 11. Sand/gravel extraction 12. Undeclared 13. Other________________________ (specify)	|___|
3.2	What is your secondary activity	1. Salaried worker 2. Agriculture 3. Breeding 4. Hunt 5. Fishing/fish farming 6. Forestry 7. Arts and crafts 8. Palm oil production 9. Trade 10. Catering and accommodation 11. Sand/gravel extraction 12. Undeclared 13. Other________________________ (specify)	|___| |___| |___| |___| |___| |___| |___| |___| |___| |___|
3.3	Does your household own arable land?	1. Yes 2. No	|___|
3.4	If yes, what is the total area of your household's fields?	1. < 1 ha 2. 1ha-2ha 3. 2ha-5ha 4. 5ha-10ha 5. > 10 hectares	|___|
3.5	Do you have access to credit?	1. Yes	|___|

		2. No	
3.6	How many people in your household depend on the head of household?	1. 1-5 2. 6-10 3. 10+	|___|

SECTION 4: KNOWLEDGE, EXPERIENCE AND PERCEPTION OF THE FLOOD HAZARD			
4.1	Have you ever experienced flooding in your locality in the last 10 years?	1. Yes 2. No	|___|
4.2	Do you think that the frequency of occurrence of floods has increased over the past 30 years?	1. Increase 2. Decreases 3. No change 4. Do not know	|___|
4.3	What were the characteristics of these floods in terms of precipitation?	1. Normal 2. Precipitation excess 3. Precipitation deficit	|___|
4.4	Please indicate the current frequency of flooding in the village (recurrence period in years)	1. Every year 2. Every two years 3. Every three years 4. Every four years 5. Every five years 6. Every six years 7. Every seven years 8. Every eight years 9. Every nine years 10. Every ten years 11. More frequently than every ten years 12. Don't Know	|___|
4.5	When was your locality last flooded (check one only)	1. Never 2. This year 3. Last year 4. In the last 2-3 years 5. In the last 5 years 6. I don't know / I don't remember	|___|
4.6	How large was the effect in terms of life and property?	1. None 2. Very Low 3. Low 4. Middle 5. High 6. Very High 7. Do not know	|___|
4.7	What do you think are the causes of flooding in your locality? Mention all that apply)	1. Extreme precipitation in a short time 2. Saturated or wet soil 3. Long period of rain 4. Lack of drainage infrastructure and dams 5. Climate Change 6. Deforestation 7. poor management of the dam 8. Construction of houses near the river 9. Siltation of the river and tributaries 10. River Overflow 11. God's Will 12. Lack of waste management 13. Rising groundwater level 14. Don't Know 15. Other (specify): ______________________	|___| |___| |___| |___| |___| |___| |___| |___| |___| |___| |___| |___| |___|
4.8	What negative effects does your district experience due to flooding	1. Property damage 2. Residence house damaged/flooded 3. Damaged/lost goods and merchandise 4. Roads, bridges, damaged electricity 5. Damage to public infrastructure (market; school, health center, institutions, religious buildings, cemeteries, etc.) 6. Flood-related illnesses 7. Death 8. Injuries 9. Loss of income 10. Polluted drinking water/no drinking water available for households 11. Lack of food	|___| |___| |___| |___| |___| |___| |___| |___| |___| |___| |___| |___| |___|

		12. Disruption of education/schools have been closed 13. Social life has been disrupted 14. Difficult trips 15. Environmental pollution 16. Loss of important plants/trees/ecosystems 17. Other (Please specify) :	|___| |___| |___| |___| |___| |___|
4.9	Please indicate in which months the floods usually occur nowadays (indicate the period(s))	1. Jan 2. Feb 3. Mar 4. Apr 5. May 6. June 7. Jul 8. August 9. Sep 10. Oct 11. Nov 12. Dec	|___|
4.10	What changes have you observed in the rainy seasons over the past 10 years? (List all that apply)	1. Shorter rainy seasons 2. Longer rainy seasons 3. Late rainy seasons 4. Earlier rainy seasons 5. More rain 6. Less rain 7. No change 8. Don't Know	|___|

SECTION 5: LOCAL FLOOD ALERT INDICATORS			
5.1	What are the indigenous warning signs that let you know that flooding is imminent? (Please specify the type (animal, plant, celestial body or meteorological parameter observed), behavior and the number of days it occurs before flooding	1. Animal behavior 2. The behavior of plants. 3. Celestial bodies (moon, strata, sun) 4. Meteorological (temperature, winds, precipitation, clouds 5. River behavior 6. Other (s) to be specified	|___| |___| |___| |___| |___| |___|
5.2	Are there any steps you are taking to prepare for flooding based on the local warning signs you explained to us earlier? Will you monitor the water level based on these local signs?	1. food storage 2. preparing and moving livestock 3. Evacuation 4. move to safer places/higher ground 1. yes 2. No	|___| |___| |___| |___| |___|
5.3	How do you monitor water levels	1. Using the reed or a tree branch) 2. Through the beacons implanted 3. Other specify	|___|
5.4	How often do you monitor the water level?	1. Daily 2. Weekly 3. Monthly 4. Quarterly 5. Other specify	|___|
5.5	How do you determine the water level that tells you it's time to evacuate?		
5.6	How do you share the early warning message based on pre-flood indigenous signs?		
5.7	How often do you share the message during this time?		
5.8	How long (days, hours) before the flood do you share the message?		
5.9	Can you tell, based on the native warning signs immediately before flooding, how severe the flooding is		

SECTION 6: EXPOSURE FACTOR			
6.1	Where is the place of residence of the household?	1. upland 2. floodplain 3. Between the dike and the bank	|___|
6.2	How far can you estimate the distance from your house to the Niger River?	1. < 500m 2. 500m - 1km 3. 1km-1.5km 4. 1-2km 5. > 2km	|___|
6.3	How far can you estimate the distance from your field to the Niger River?	1. < 500m 2. 500m - 1km 3. 1km-1.5km 4. 1-2km 5. > 2km	|___| |___|
6.4	Are your household fields often affected by floods	1. Yes 2. No	
6.5	Approximately how deep is the water in your house when there is flooding (m)	1. 0 to 0.5m 2. 0.5 to 1m 3. 1 to 2 m 4. > 2m	|___|
6.6	How long does water stay in your locality during floods?	1. ≤ 15 days 2. 16 – 30 days 3. 31-45 days 4. > 45 days	|___|
6.7	Number of existing public infrastructure in your locality at risk of flooding	1. School |___||___| 2. Hospital |___||___| 3. Market |___||___| 4. Drinking water point/mini water supply |___||___|	
6.8	Number of houses/houses existing in the flood zone of your locality?	1. <10 2. 10-50 3. >50	|___|
6.9	How many people per km2 in the flood zone of your locality?	1. <100 2. 100-500 3. >500	|___|

SECTION 7 : VULNERABILITY FACTORS			
7.1	Was your household affected by the last flood	Yes No	|___|
7.2	If yes, How are you affected?	1 Loss of a household member 2 Loss of crops 3 Loss of animals 4 Loss of reserves 5 Loss of material goods 6 House collapse 7 flooded house 8 Other specify)	|___| |___| |___| |___| |___| |___| |___| |___|
7.3	How many hectares of crop have been destroyed? how much can we assess the losses (monetary)		
7.4	How many animal heads have been lost? how much can we assess the losses (monetary)		
7.5	How many bags were destroyed? how much can we assess the losses (monetary)		
7.6	Which social groups are most vulnerable to flooding in your village?	1. women 2. Old people 3. children	|___| |___| |___|
7.7	Materials of construction of your house (directly observed by the interviewer):	1. Cement house with sheet metal roof 2. Banco house with sheet metal roof 3. Banco house with straw roof 4. Other specify…………………………	

7.8	House with a high foundation (Directly observed by the interviewer)	1. Yes 2. No	|___|
7.9	What is your average monthly household income?	1. <50,000 2. 50,000-100,000 3. >100,000 4. Not specified	|___|
7.10	Are the daily expenses of your household more than 500 CFA?	1. Yes 2. No	|___|
7.11	Do you have access to drinking water during floods?	1. Yes 2. No	|___|
7.12	Do you have access to health care during the floods?	1. Yes 2. No	|___|
7.13	Do floods degrade the natural resources from which you benefit (forest/forest products, fish products, fauna, river/river/pond, sand/gravel; agricultural land, etc.)	1. Yes 2. No	|___|
7.14	If yes What is the magnitude of the effect of floods on these resources during the last 10 years?	1. None 2. Very Low 3. Low 4. Middle 5. High 6. Very High	|___|
7.15	Do floods cause you to overexploit these natural resources?	1. Yes 2. No 3.I don't know	|___|

SECTION 8: FLOOD PROTECTION AND FLOOD WARNING SYSTEM (SAP) INFORMATION

8.1	Are you aware of the flood risks in your area?	1. Yes 2. No	|___|
8.2	Is there a flood management committee in your community?	1. Yes 2. No	|___|
8.3	Are you a member of the committee?	1. Yes 2. No	|___|
8.4	Can you anticipate the arrival of the floods?	1. Yes 2. No	|___|
8.5	How ? 'Or' What ?		
8.6	Are you and your family able to evacuate in the event of a flood?	1. Yes 2. No	|___|
8.7	Are you aware of the evacuation sites in your locality?	1. Yes 2. No	|___|
8.8	If yes, which ones		
8.9	Do you employ any preventive strategies to mitigate the effects of flooding?	1. Yes 2. No	|___|
8.10	If yes, which ones	1. Tire track 2. Pumping 3. Sandbag track 4. Sand encroachment 5. Ceremonies or sacrifices of invocations of the protective gods 6. Other__________________________ (specify)	
8.11	Are you personally prepared in your household against flooding?	1. Yes 2. No	

8.12	Which measures do you have?		
8.13	In the event of heavy to very heavy precipitation, do you receive an alert message?	1. Yes 2. No 3. I don't remember / I don't know	|___|
8.14	if so, from what source? from whom?	1. Media (TV/radio/newspaper) 2. Official government warning (siren/police announcements) 3. Rise of water at the beacons 4. Other specify	|___| |___| |___| |___|
8.15	Do you trust the warning received?	1. Yes 2. No	|___|
8.16	What is your perception of the accuracy of the warning?	1: 100% 2: 75% 3. 50%. 4= 25% 5= 0	|___|
8.17	What information do you collect from the source?	1: Timing 2: Intensity 3: Duration 4: How to answer	|___| |___| |___| |___|
8.18	How do you perceive the seriousness of flooding upon receipt of information?	1: Not serious 2: potentially serious 3: Serious 4: Very serious	|___|
8.19	What was the time between receipt of the warning and the occurrence of the event?	1. Less than two hours 2. two to four hours 3. More than four hours 4. A day or two in advance	|___|
8.20	Do you think these warnings are useful for the household and/or the community?	1. yes 2.no 3. don't know	|___|
8.21	Do you share the information you have received with other community members/neighbours?	1. yes 2.no 3. don't know	|___|
8.22	What actions do you think or have you taken in response to the early warning information?	1 move to safer locations/higher ground 2. discuss and validate information from the community 3. discuss things within the household 4. wait for outside help 5. Do Nothing 6. Moving of goods/livestock, protective goods 7. other	|___|
8.23	Who decides to take these measures? Is it an individual or group decision, ie who takes the risk?		
8.24	Please indicate in which situation your household/individual responds to early warning?	1. when someone dies in the community 2. when people observe property damage 3. when danger comes to the area 4. in case of panic situation 5. When the information is widely disseminated in the community 6. If the early warning is heard 7. Other	|___|

SECTION 9: GOVERNMENT ACTION AGAINST FLOODS

9.1. Are there prevention and protection measures or actions implemented by the government against flooding in the village? Yes___ / No____ (if no, skip 9.1.1.)

9.1.1. If yes, please name them (Check the respondent's answers and ask them how they are useful in relation to risk management by filling in the table below)

Measures taken by the government	**Yes or no**	**Is it useful? (Yes No)** **Classify them with:** 1 = Very Satisfactory, 2 = Satisfactory and 3 = Less Satisfactory
Awareness campaigns (on risk culture) / community capacity building		
Setting up an (early) warning system		
Reforestation (mangroves) as a means of limiting the effects		
Community mapping of risk areas		
Construction of protective dykes		
Development plan		
Reservoirs for water storage		
Improvement of road infrastructure		
Building resilient homes		
Selection of varieties / seeds with high resilience to climate change		
Resettlement / displacement of the population		
Flood Preparedness Activity		
Identification and training of focal points		
Construction of drinking water boreholes in host sites		
Soil remediation works and periodic dredging		
Extension of seasonal forecasts		
Training of peer educators and first aiders		
Farm subsidy programs		
Fertilizer subsidy		
Equipment (e.g. machine) for agricultural production		
Other specify		
Other specify		

9.1.2. How do you assess the government's ability to anticipate and prepare for floods?

1. Very good; 2. Good; 3. Indifferent 4. Bad; 5. Very bad; 6 None

Are there prevention and protection measures or actions implemented by an NGO against flooding in the village? Yes No____ (if no, skip 9.1.3. and 9.1.4.)

9.1.3. If yes, please name them: ……..………………………………………………………………………………

……… …………………………………
…………………………………………………

9.1.4. Were these actions useful? ....

1) very helpful 2) helpful 3) indifferent 4) not really helpful 5) not helpful at all ☐ ☐

9.2. Do you receive help from the government during and after the floods? No (if no, skip 9.3.)

Yes ☐ no ☐

9.3. If so, what type of assistance do you receive? ....

Measures taken by the government	**Yes or no**	**Is it useful? (Yes No) Classify them with: 1 = Very Satisfactory, 2 = Satisfactory and 3 = Less Satisfactory**
Mosquito net and medicine donation		
Displacement of populations in places on		
Gift of tent and live		
Financial allocation to cover losses (agricultural, materials, etc.) due to flooding		
Other specify		
Other specify		

9.4. How do you rate the government's response during and after the floods? …………………

(*1*. Very well; 2. Good; 3. Indifferent 4. Bad; 5. Very bad; 6 None)

9.5. do you receive help from NGOs / structures during and after the floods? Yes No

yes ☐ no ☐

9.6. If so, what type of assistance do you receive? …………………………………… ………………………………… ……………… ………… ……………………………………………………… ………………………………………………………………………… ……………………

9.7. How do you rate the NGO's response during and after the floods? :…………………………………………

(*1*. Very well; 2. Good; 3. Indifferent 4. Bad; 5. Very bad; 6 None)

9.8. What do you think should be done to deal with the risk of flooding? ………………

Measures	Will you accept and participate in this type of project? (Yes or no)
Engineering (such as a levee, levee, drain, bridge, etc.)	
Hydro-agricultural development (drainage system, irrigation, etc.)	
Grant for resilient house buildings	
Donation of land in another locality (Permanent displacement)	
Other :	
Other :	

9.9. What are your expectations of the government? ………………………………………… ………………………………………… ………………………………………… ………………………………………… …… ……………………………………… …… …… ……………………………………………………………………………………………

What do you think the community needs to do to adapt to future floods? …………………….. ….. ……………………………………………………………………………………………… ……………………… ………………………………………………………………………………………… ………………………………………

Appendix 2: Guide Focus Group Discussions

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

Federal Ministry of Education and Research

Université de Lomé

Guide to Focus Group Discussions (FGDs)

1. What factors contribute to flooding in Niger? and in the city of Niamey in particular?
2. What impact did the flood have specifically on communities, activities, livelihoods, , etc.? Do you benefit in any way from the flood?
3. Considering the regular floods, why did you choose to stay here?
4. What do you do to prevent future flood events before, during, and after them?
5. Do women play a role in the case of flooding? What are the responsibilities ?
6. How did you find out that a certain year will have flooding?
7. How do you handle, deal with, or adjust to flooding?
8. Which organisations are assisting communities in dealing with flooding? Please identify them and explain what they did to assist you.
9. What steps have the authorities taken to mitigate the consequences of flooding? What can the government do, in your view, to help you get beyond this flooding problem?
10. What can the community do to mitigate the consequences of flooding

Appendix 3: Logic Framework

Table: logic framework of the project

Objectives	**Research questions**	**Hypotheses**	**Data collection**	**Data analysis**
To Identify the major factors that contribute to flood disaster risk; **(SO1)**	To what extent has climate change been responsible for flooding in Niamey?	Climate change and the mode of land use in flood plain are responsible for the increased level of flooding in Niamey.	Participatory Rural Appraisal (PRA) techniques	to compare frequencies in SPSS statistical software. To analyze and establish correlations if any among vulnerability variables
To assess the flood disaster risks area along the River Niger in Niamey and its vicinity; ; (**SO2)**	What are the flood disaster areas in Niamey and how can the risks be assessed?	Flood disaster is a threat to human security in the Flood prone areas in Niamey	Flood inventory Environmental data (permanent factors) Triggering data both primary and secondary data will be collected	The linear model of household vulnerability Remote Sensing Data Risk Assessment Using GIS Spatial Multi-Criteria Evaluation (SMCE) using GIS
To elaborate a model of flood forecasting to reduce the risk**; (SO3)**	How is the model used necessary for flood forecasting in Niamey?	Using an appropriate model for flood forecasting can reduce flood-related risks in Niamey.	Geospatial Data rainfall, temperature, and streamflow	the Generalized Extreme Value (GEV) model is used considering a nonstationary approach. The GEV model is expressed as (Coles, 2001a): Using R
To promote climate resilience measures for reducing the adverse impact of floods and the likelihood of floods; **(SO4)**	Which resilience measures have been taken by the communities and the government?	The resilience capacity of communities in Niamey is built by effective adaptation/and or mitigation measures implemented by the government and local dwellers	the survey and Focus Group Discussion	Analyze livelihood of resilience indicators matrix approach of risks

Appendix 4: Confusion Matrix

Table A: Confusion matrix of the classified TM 1981 image

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	190	0	4	0	0	0	0	0	194	0.99	0.01
PE	0	235	0	0	0	0	0	0	235	1	0
CZ	0	0	200	0	5	0	0	0	205	0.96	0.03
BF	7	0	0	330	0	0	0	0	337	0.99	0.02
H.A.B.	0	0	8	0	357	0	0	0	365	0.98	0.02
THIS	0	0	1	0	2	260	0	0	263	0.99	0.01
TR	2	0	0	10	10	0	236	0	260	0.90	0.1
SS	0	0	2	0	0	0	0	216	217	0.99	0.01
Total	197	235	214	340	374	260	236	216	2072		
LCI	0.96	1	0.96	0.95	0.95	1	1	1			
EO	0.03	0	0.05	0.03	0.05	0	0	0			
Kappa index											
IPT	96.04										

Legend: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah.

EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index

Table B: Confusion matrix of the classified TM 1991 image

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	195	0	1	0	0	0	0	0	196	0.99	0.01
PE	0	230	0	0	0	0	0	0	230	1	0
CZ	0	0	210	0	5	0	0	0	215	0.97	0.03
BF	3	0	0	339	0	0	0	0	342	0.99	0.01
H.A.B.	0	0	7	0	357	0	0	0	364	0.98	0.02
THIS	0	0	2	0	2	264	0	0	268	0.98	0.02
TR	2	0	0	12	10	0	236	0	260	0.90	0.1
SS	0	0	1	0	0	0	0	216	217	0.99	0.01
Total	200	230	221	351	374	264	236	216	2092		
LCI	0.97	1	0.95	0.96	0.95	1	1	1			
EO	0.03	0	0.05	0.04	0.05	0	0	0			
Kappa index											
IPT	97.84										

Legend: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah.

EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index

Table C : Confusion matrix of the classified Landsat ETM+ 2001 images

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	195	0	1	0	0	1	0	0	197	0.98	0.01
PE	0	230	0	0	0	0	0	0	230	1	0
CZ	0	0	210	0	10	0	0	0	220	0.95	0.03
BF	3	0	0	339	0	0	0	0	342	0.99	0.01
H.A.B.	0	0	7	0	357	0	10	0	374	0.97	0.02
THIS	0	0	2	0	2	264	0	0	268	0.98	0.02
TR	2	0	0	12	20	0	236	0	260	0.90	0.1
SS	0	0	1	0	0	0	0	216	217	0.99	0.01
Total	200	230	221	351	389	265	246	216	2118		
LCI	0.97	1	0.95	0.96	0.95	0.99	0.99	1			
EO	0.03	0	0.05	0.04	0.05	0	0	0			
Kappa index											
IPT	97.02										

Legend: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah.

EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index

Table D : Confusion matrix of the classified Landsat ETM+ 2011 images

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	EC
Steppe	284	0	15	0	0	0	1	0	300	0.94	0.06
PE	0	683	0	0	0	0	0	0	683	1	0
CZ	15	0	331	0	0	0	0	0	346	0.95	0.05
BF	0	0	0	373	0	0	0	0	373	1	0
H.A.B.	0	0	0	0	533	0	0	0	533	1	0
THIS	0	0	0	45	21	237	0	0	303	0.78	0.22
TR	0	0	0	0	0	0	185	0	185	1	0
SS	2	0	0	0	0	0	0	122	124	0.98	0.02
Total	301	683	346	418	554	237	186	122	2847		
LCI	0.94	1	0.95	0.89	0.96	1	0.99	1			
EO	0.06	0	0.05	0.11	0.04	0	0.01	0			
Kappa index											
IPT	96.52										

Legend: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah.

EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index

Table E : Confusion matrix of the classified Landsat OLI-TIRS 2021 image

Classes	Steppe	PE	CZ	BF	H.A.B.	THIS	TR	SS	Total	CPI	OC
Steppe	386	0	0	0	0	0	1	0	387	0.99	0.01
PE	0	459	0	0	0	0	0	12	471	0.97	0.03
CZ	9	0	223	0	28	0	0	0	260	0.85	0.15
BF	0	0	0	757	0	2	0	0	759	0.99	0.01
H.A.B.	0	0	40	0	997	0	0	0	1037	0.96	0.04
THIS	0	0	149	0	4	253	0	0	406	0.62	0.38
TR	239	0	0	0	0	0	233	0	472	0.49	0.51
SS	0	0	5	0	0	0	0	196	201	0.97	0.03
Total	634	459	417	757	1029	255	234	208	3993		
LCI	0.60	1	0.53	1	0.96	0.99	0.99	0.94			
EO	0.40	0	0.47	0	0.04	0.01	0.01	0.06			
Kappa index											
IPT	87.75										

Legend: PE: Body of water; ZC: Cultivation area; BF: Lowland; HAB: Dwellings; CI: Irrigated crops; TR: Rocky terrain; SS: Sahelian savannah.

EC: Commission errors; EO: Errors of Omission; TPI: Total Classification Accuracy Index; CPI: Purity classes; IVC: Cartographic Validation Index.

Appendix 5 : Some pictures from the Survey

Figure 71: View of Flooded neighbourhood in Niamey

Figure 72 : View of the flooded compound

Figure 73 : Collapsing bacon house

Figure 74 : Meeting with dwellers

Figure 75 : Visit to the levee of Niamey

Figure 76 : Meeting with Professionals