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Article

Applying Integrated Climate and Disaster Risk Assessment to Land Use Planning and Development Policy in Benin

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Abstract: Benin is increasingly exposed to climate-related and geophysical hazards whose frequency and intensity are amplified by climate change, rapid urbanisation, environmental degradation, and limited institutional capacity. This study presents an integrated assessment of the disaster risk landscape in Benin, with a particular focus on sectoral vulnerabilities and the role of urban and territorial planning in disaster risk reduction. A mixed-methods approach was employed, combining qualitative policy analysis and quantitative spatial and statistical techniques. Data were collected from national strategic frameworks, including Benin's National Disaster Risk Reduction Strategy, National Adaptation Plan, National Action Plan for Sustainable Land Management (PAN-GDT 2018–2027), nationally determined contribution documents, spatial planning schemes, and post-disaster needs assessments. Spatial analysis of land use, infrastructure, and hazard exposure was integrated with statistical analysis of historical disaster data, climate trends, and socioeconomic indicators. Vulnerability, adaptive capacity, and institutional readiness were evaluated using the World Bank Climate and Disaster Risk Screening Tools based on an exposure-sensitivity-adaptive capacity framework. Results reveal a highly heterogeneous risk profile across the country. Southern coastal zones are predominantly exposed to flooding and coastal erosion; central plateau areas face recurrent bushfires and drought; while northern regions are characterised by severe drought and seasonal flooding along major river systems. Agriculture, energy, natural resource management/forestry, and water and sanitation emerge as the most vulnerable sectors, facing high levels of both current and future risk. Institutional assessments indicate disparities in preparedness, with relatively stronger capacities in agriculture and natural resource management, but gaps in awareness, adaptation implementation, and early warning infrastructure in other sectors. The study highlights the critical need to mainstream disaster risk reduction into urban and territorial planning, strengthen governance coordination, modernise meteorological and hydrological observation systems, and enhance community-centred resilience strategies. Integrating risk considerations into land use planning and sectoral policies is essential to reduce vulnerability and support sustainable development in Benin under increasing climate pressure. In addition, this work advances disaster risk research in Benin by integrating multiple dimensions hazard exposure, sectoral vulnerability, institutional capacity, and policy frameworks into a cohesive analysis. It offers actionable insights for policymakers, providing an evidence-based foundation to support integrated disaster risk reduction and climate adaptation strategies at both national and local levels.

Keywords: climate change; disaster risk reduction; vulnerability assessment; climate resilience; Benin

1. Introduction

Disaster vulnerability and exposure are rising as more people and assets located in high-risk areas. Since 1970, the world's population has expanded by 87%. During the same time period, the proportion of people living in flood-prone river basins climbed by 114% and on cyclone-prone coasts by 192% [1]. More than half of the world's largest cities, with populations ranging from 2 to 15 million, are in earthquake-prone zones. Aside from catastrophe susceptibility, the key risk factors include poorly planned and managed urbanisation, environmental degradation, poverty, and bad governance. Disaster risk decreases as a direct result of sound development [2].

Benin is exposed to extreme meteorological and climatic impacts. The country is increasingly characterised by ongoing environmental degradation, marked by the emergence of new threats, particularly in terms of security, with the resurgence of natural and anthropogenic disasters [3]. These upheavals have led Benin to engage, since 2010, in a policy of crisis and disaster prevention and management in support of its economic emergence. In this context, the government has made the strengthening of good governance one of its major concerns, with the aim of increasing efficiency and effectiveness in public affairs management and disaster risk reduction [4]. To effectively accomplish this mission, all the involved stakeholders must have access to a strategic framework of reference and receive the necessary guidance for action. This will enable the country to address the pressing challenges posed by evolving climate-related risks and environmental degradation and to enhance its resilience and sustainable development.

Like many countries around the world, Benin is frequently affected by disasters, notably floods, fires, epidemics, coastal erosion, and others (BENIN-Stratégie Nationale de Réduction Des Risques de Catastrophe, n.d.-a). Flooding, drought, late and intense rainfall, violent winds, excessive heat and Sea level rise are the climate-related risks that impact livelihoods and means of subsistence within particularly vulnerable sectors such as agriculture, water resources, and the coastal region [5]. These climate-induced hazards have significant impacts on key economic and social sectors within the country, threatening the wellbeing and resilience of local communities and ecosystems. Addressing these climate-related risks is crucial for safeguarding sustainable development and improving the adaptive capacity of Benin's most vulnerable populations and economic activities [6].

Over the past decade, Benin has experienced a series of disasters, including the deadly floods of 2010 which resulted in 46 fatalities and 127 billion FCFA in losses to the gross domestic product, as well as the fire at the Dantokpa international market, the losses from which were estimated at nearly 5 billion FCFA. In 2018, 49 deaths were recorded, and 15,466 hectares of crops were destroyed. Similarly, several individuals have lost their lives in river accidents [7].

Reducing catastrophe risks (for example, prevention, preparedness, mitigation, and early warning systems) for predictable occurrences such as heavy rains, floods, and avalanches helps to safeguard both people and economic assets. The level and quality of development and planning have a significant influence on how risks affect people, buildings, and economies. There is mounting evidence that the severity and frequency of hazard-related severe events are disproportionately affecting vulnerable cities. It is also vital that catastrophes be seen through the perspective of lowering risk and creating resilience during the planning process of a city, rather than as a response to a single catastrophic occurrence [8]. Planning a city without a strong catastrophe resilience strategy is a waste of money that puts people, infrastructure, assets, and the economy at risk. Disaster resilience is thus a desirable characteristic that cities should include in their urban development and management methods. Cities can resist shocks from manmade and natural calamities thanks to systems that develop and incorporate resilience.

Working with many stakeholders throughout the planning process to identify known risks, requirements, and viable solutions, and recognising communities' capacity to contribute to risk reduction. All urban development designs, master plans, and development plans must include risk assessment and vulnerability studies that take into account exposure, vulnerability, and hazards, as well as urban settlements development and services.

Urban planning is crucial for building resilience in cities and settlements. It involves risk assessment, vulnerability studies, and ensuring safe land for development. Public spaces are protected, and informal settlements are upgraded. Critical infrastructure is allocated in safe areas, and plans for post-disaster reconstruction are developed. Urban planning helps analyze and plan towns, cities, and settlements as a system, coping with interdependencies in disaster situations. It also prevents secondary disasters and delays in rehabilitation and recovery. Involving multiple stakeholders in disaster risk assessment can help achieve resilience [1].

Despite increasing exposure to climate-related and geophysical hazards, Benin lacks comprehensive and integrated studies that provide a spatiotemporal analysis of disaster risk profiles and their impacts. Existing research remains fragmented, with limited evidence on the characterisation of hazards, their potential impacts across key sectors, and the rate and distribution of these impacts over time and space.

Moreover, there is a significant gap in the systematic assessment of risk levels across sectors, as well as in understanding the linkages between urban and territorial planning and disaster risk reduction. While national frameworks exist, the operationalisation of the guiding principles of Benin's Disaster Risk Reduction Strategy and the identification of key challenges related to sustainable disaster risk management remain insufficiently explored.

This study addresses these gaps by providing an integrated analysis of hazard dynamics, sectoral vulnerabilities, and planning frameworks to support evidence-based and climate-resilient decision-making in Benin.

Recent studies emphasize the importance of embedding climate adaptation and disaster risk reduction within urban and regional planning. For instance, Paul et al. [9] highlight strategies to mitigate climate change impacts on the built environment, including vulnerability assessments, resilient design principles, and the integration of hazard mapping into construction and urban planning processes. Similarly, Effiong et al. [10] demonstrate that in river-dependent communities in Nigeria, land use planning that incorporates climate risk data can enhance community resilience, reduce exposure to flooding and erosion, and guide sustainable development practices.

These studies support our approach in Benin, where spatial and statistical analyses were integrated with policy reviews to identify vulnerable areas and sectors, guiding disaster risk-informed land use and urban planning decisions. By considering both structural and policy dimensions of disaster risk, our work aligns with emerging best practices for climate-resilient development planning in West Africa.

In this study, we identified the different climate disaster risk events in Benin, described the urban planning for disaster risk reduction and the institutional readiness to reduce disasters in Benin.

2. Methods

2.1. Study Area

Benin is situated in West Africa, bordered by Togo to the west, Nigeria to the east, and Burkina Faso and Niger to the north. To the south, it has a coastline of approximately 121 km along the Gulf of Guinea (Figure 1). The country lies at approximately 9.31° N latitude and 2.32° E longitude, placing it firmly within the tropical belt of West Africa [11].

The physical geography of Benin is characterised by a combination of low-lying coastal plains and gently undulating savannah landscapes. The terrain is predominantly flat, although elevations increase towards the north, where the Atacora Mountains reach altitudes of up to approximately 1000 m. The country is traversed by several important river systems, notably the Ouémé River and the Mono River, which play a critical role in transportation, irrigation, and fisheries.

Benin experiences a tropical regime characterised by a rainy season extending from April to October and a dry season from November to March. Mean annual temperatures generally range between 25 and 30 °C, with higher humidity levels observed during the wet season (Figure 2) [11]. Spatial variability in rainfall is pronounced, with the southern coastal zone receiving substantially greater precipitation than the northern regions, where drier conditions prevail. This climatic gradient exerts a strong influence on agricultural systems, water resource availability, and broader livelihood patterns.

Like many countries around the world, Benin is frequently affected by disasters, notably floods, fires, epidemics, coastal erosion, and others [12]. Flooding, drought, late and intense rainfall, violent winds, excessive heat and Sea level rise are the climate-related risks that impact livelihoods and means of subsistence within particularly vulnerable sectors such as agriculture, water resources, and the coastal region [5]. Over the period 1982–2022, Benin experienced 20 major flood events, affecting approximately 3.3 million people, alongside a single severe drought impacting an estimated 2.1 million individuals [13]. The frequency and intensity of these events have been increasingly influenced by climate variability and long-term warming trends [11].

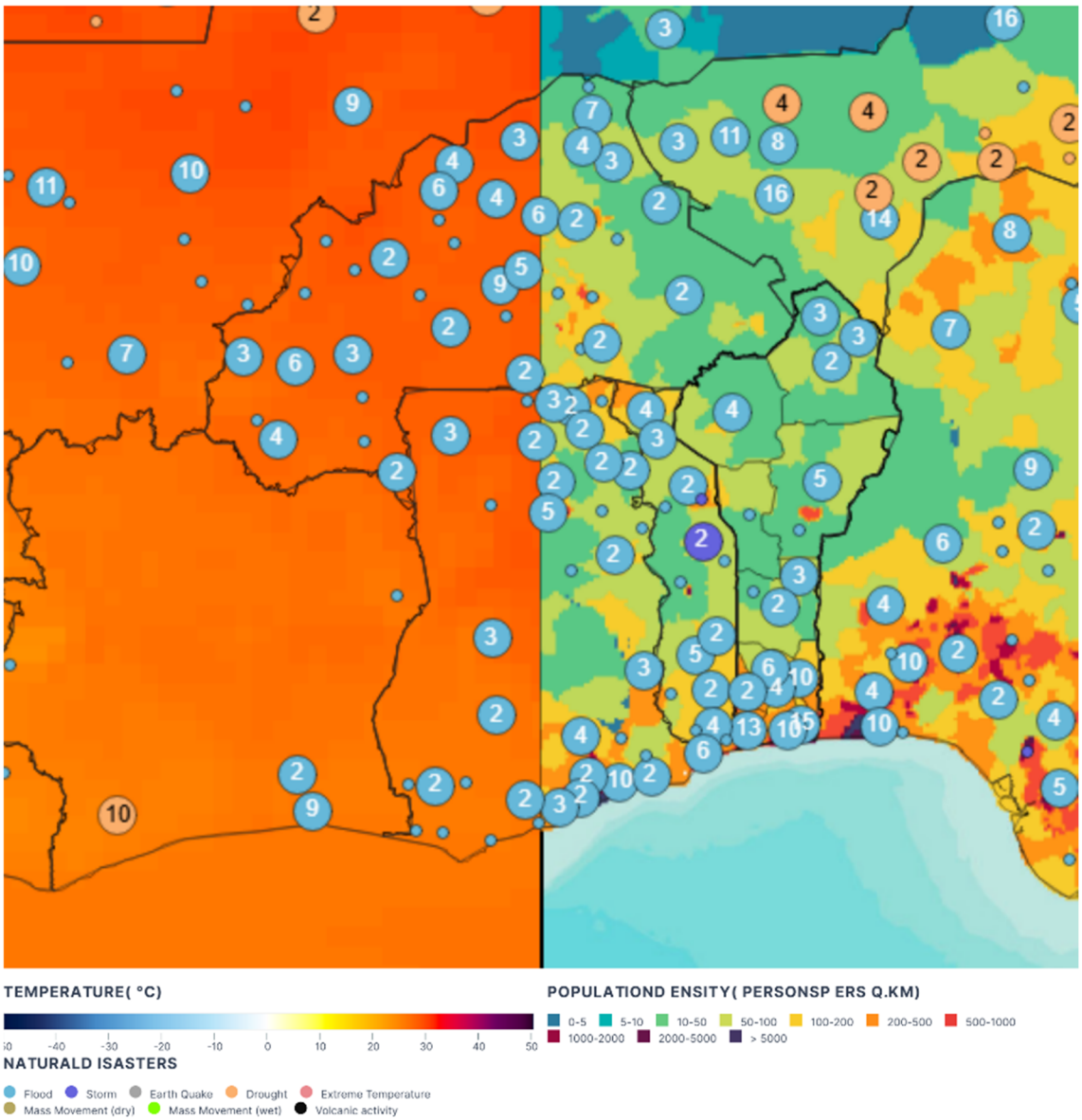

Figure 1. Situation of Benin, Population density, Natural disasters.

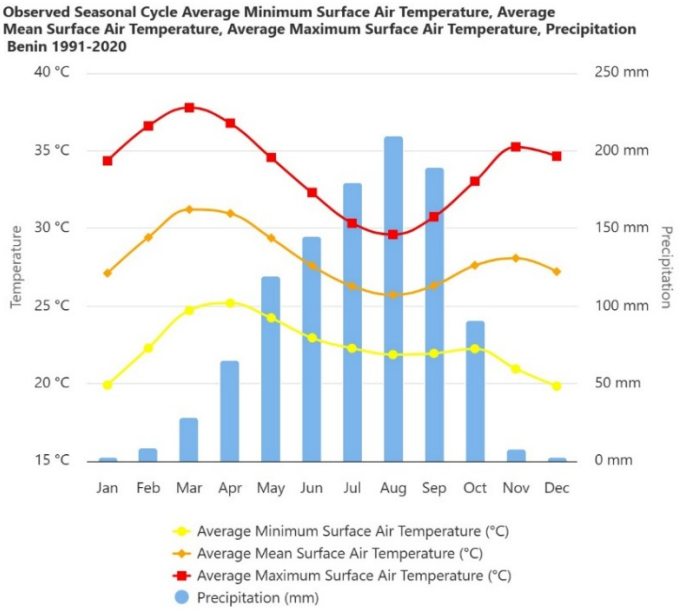

Figure 2. Characteristics of the climate of Benin, Precipitation and Temperature from 1991–2020 [11]. Source: World Bank Group. Climate Change Knowledge Portal (CCKP): Benin. Available at: View Benin climate data.

2.2. Data Collection

We collected data and information from various government sources in Benin, including Benin's updated nationally determined contribution to the Paris Agreement, National Action Plan on Sustainable Land Management (PAN-GDT) 2018–2027, Benin's National Strategy for Disaster Risk Reduction, Benin's National Climate Change Adaptation Plan, National Land Use/Spatial Planning Schemes, and Post-disaster needs assessment reports. This data provided information on the identified disaster risk events in Benin, such as flooding, drought, intense rainfall, violent winds, and sea level rise. Data on the existing urban planning policies, strategies, and capacities to address the challenges and threats to vulnerable sectors affected by these climate-related hazards were also gathered.

2.3. Data Processing

A combination of qualitative and quantitative analysis methods to assess the climate and disaster risks in Benin's secondary cities. A systematic review of policy documents, strategic frameworks, and stakeholder inputs was conducted to examine the institutional and governance context of disaster risk reduction in Benin. This allowed us to identify key principles, priorities, and gaps in national and local disaster management policies. The spatial analysis of land use, urban plans, and infrastructure data was used to identify vulnerable areas and exposure to climate-related hazards.

The World Bank Climate and Disaster Risk Screening Tool was applied in combination with the exposure–sensitivity–adaptive capacity (ESAC) framework to assess disaster risks across sectors and regions in Benin [14]. The screening tool integrates historical disaster and climate data, sectoral and socioeconomic information, policy and institutional assessments, and expert judgement to classify risk levels and identify priority areas for intervention. The ESAC framework provides the conceptual basis for understanding vulnerability, evaluating risk as a function of exposure, sensitivity, and adaptive capacity. Exposure captures the extent to which populations, infrastructure, and sectors are subject to hazards, sensitivity reflects their susceptibility to harm based on social, economic, environmental, and infrastructural factors, and adaptive capacity represents the ability of communities and institutions to anticipate, cope with, and recover from adverse events. In operational terms, geographic and sectoral exposure to floods, droughts, bushfires, and coastal erosion was assessed through spatial analysis, while sensitivity was evaluated using socioeconomic and sectoral indicators. Adaptive capacity was determined from policy review, governance assessments, and community-level coping mechanisms. Combining these dimensions allowed each sector to be assigned an overall risk level, highlighting vulnerabilities and supporting evidence-based planning for integrated climate and disaster risk reduction.

3. Result

3.1. Analysis of the Disaster Balance Sheet

Benin is exposed to a variety of disaster types, the frequency and magnitude of which are exacerbated by the effects of climate change, particularly extreme rainfall and hydrological phenomena. The priority risks to which the country is exposed are flooding, drought, epidemics, social conflicts (including transhumance), fire, radioactive accidents, and seismic shocks. Other no less important risks deserve to be highlighted, such as sea level rise, degradation of wetlands and coastal areas, soil erosion and degradation, violent winds, storms and tornadoes, landslides, and so on [4]. The probability of occurrence of these hazards differs according to their nature and the environmental context of each agroecological zone. Their manifestation has serious consequences on agriculture, education, energy, natural resource management/forestry, information and communications and water and sanitation [7].

3.2. Spatiotemporal Analysis of Disaster Risk Profiles and Impacts

Figure 3 presents the disaster risk distribution map of Benin. This map serves as a vital tool for understanding the vulnerability of various regions within the country to natural hazards. The analysis of this map offers an overview of the most susceptible areas, the frequency and intensity of disasters, and the specific risks to which Benin is exposed. The geographic location and climatic diversity of Benin make it susceptible to several types of natural disasters, including floods, coastal erosion, drought, and bushfires. The map highlights several critical regions:

- Coastal Vulnerability Zone (Southern Benin): The coastal region, encompassing cities such as Cotonou, Grand-Popo, and Ouidah, is particularly vulnerable to coastal erosion and flooding. The high population density and critical infrastructure located along the coastline amplify the impact of these disasters.
- Plateau and Hill Region (Central Benin): This area is primarily exposed to bushfires and drought. Intensive agricultural activities, combined with increasingly unpredictable climatic conditions, contribute to the frequency of these events.

❖ Northern Disaster Hotspot (Alibori and Atacora): Northern Benin is notably vulnerable to drought and seasonal flooding, especially along major river systems like the Niger River. Arid conditions and climate change have exacerbated the severity of droughts, severely impacting the livelihoods of local populations.

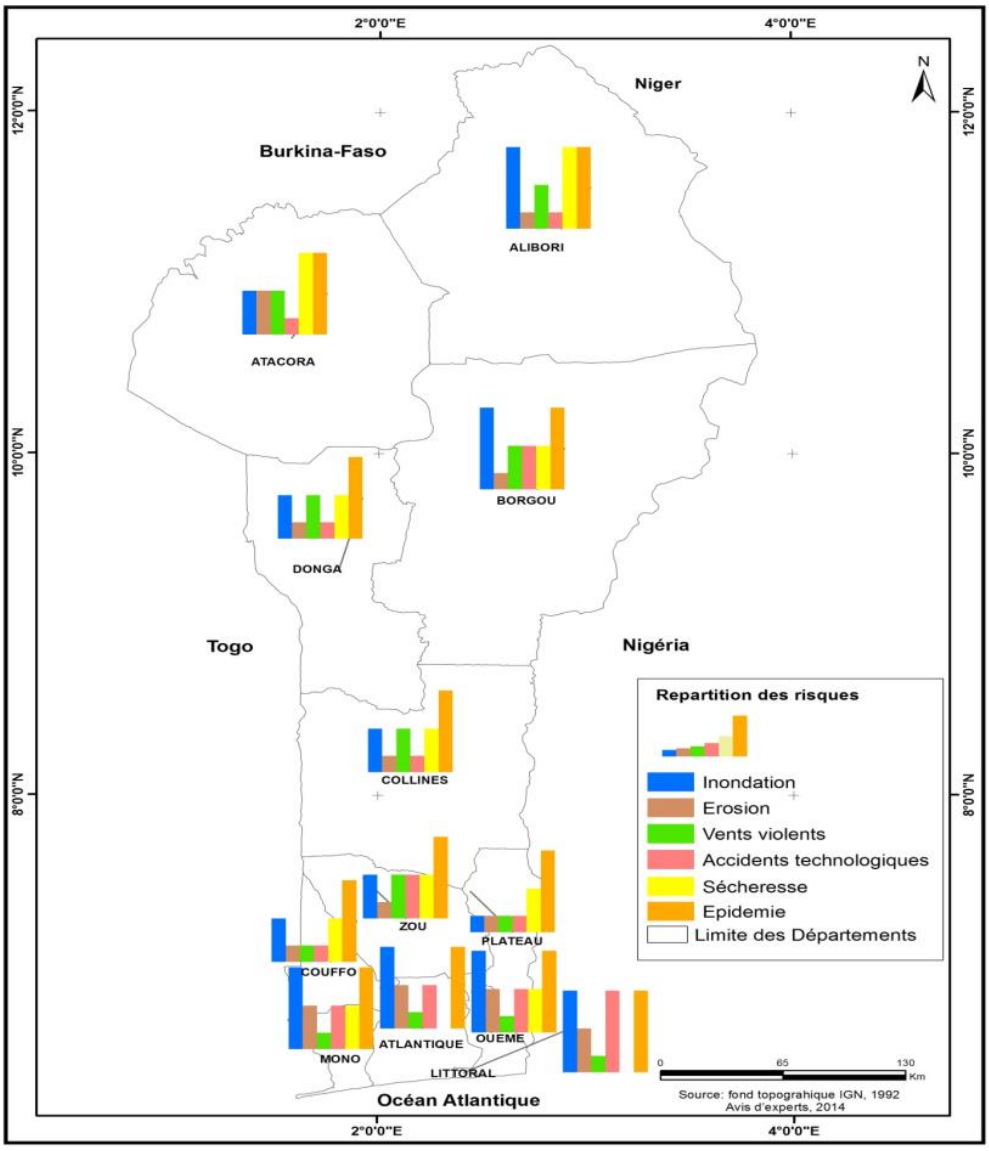

Figure 3. Distribution of risks in Benin (Source: Government of Benin (2019), *National Strategy for Disaster Risk Reduction 2019–2030*, Figure 7 (ORSEC, 2018), p. 31.).

On the others hands, the analysis of the map reveals distinct patterns in the frequency and intensity of disasters across different regions of the country.

- Flood Risk: Frequent in the coastal regions and river basins of southern Benin, the intensity of flooding has increased in recent decades due to climate change and unplanned urbanization.
- Drought Vulnerability: Particularly prevalent in the northern regions, droughts are becoming increasingly severe as rainy seasons become more irregular. The intensity of droughts varies annually but tends to be more pronounced during periods of low precipitation.
- Coastal Erosion Hotspots: This phenomenon is primarily concentrated in the southern coastal zone. Rising sea levels and unsustainable construction practices have intensified erosion, threatening critical infrastructure and residential areas.
- Bushfire Prevalence: Widespread in the plateau and hill regions, bushfires are often triggered by human activities such as slash-and-burn agriculture. Their intensity fluctuates seasonally but poses a persistent threat to the environment and local settlements.

The areas identified as most vulnerable on the map are also those where the impact of disasters is most significant, both in terms of human casualties and material destruction:

- Southern Coastal Zone: The high population density and the importance of coastal infrastructure, including ports and roads, make this region particularly sensitive to flooding and erosion. The economic impact of disasters in this area is substantial.
- Central Benin: Although less densely populated than the south, this region is vulnerable to bushfires, which regularly destroy hectares of agricultural land, affecting food security.
- Northern Benin: Recurrent drought conditions have a direct impact on agriculture, the primary source of livelihood. Seasonal floods add another layer of vulnerability, exacerbating the precarious conditions of rural populations.

3.3. Hazards Potential Impacts on the Potential Sectors in Benin

Figure 4 provides a clear assessment of the potential impacts various climatic hazards pose to the overall sector, both in the present and the future. The analysis reveals that some of the most significant threats, such as shifts in temperature, altered precipitation patterns, flooding, as well as drought and water scarcity, are currently exerting a high level of impact. Concerningly, these high-risk hazards are projected to retain their substantial potential to disrupt multiple sectors in the years ahead.

Figure 4. Impacts of climatic risks on overall sectors.

- **Agriculture**

Figure 5 presents a clear assessment of the potential impacts that various hazards pose to the agricultural sector, both in the present and the future. The analysis reveals that some of the most significant threats, such as shifts in temperature, altered precipitation and flooding, as well as drought and water scarcity, are currently exerting a high-level impact on agriculture. Concerningly, these high-risk hazards are expected to maintain their substantial potential to disrupt agricultural production and productivity in the years to come.

Figure 5. Impacts of climatic risks on agriculture.

- **Energy**

Figure 6 assesses potential impacts on the education sector, revealing significant threats like temperature shifts, precipitation changes, flooding, drought, and water scarcity on agriculture, which are expected to disrupt production and productivity in the future.

Figure 6. Impacts of climatic risks on energy.

- **Education**

Figure 7 assesses the potential impacts of climate hazards on education. The assessment reveals that education is currently facing high-level impacts from shifts in temperature, altered precipitation and flooding, as well as drought and water scarcity. These high-risk hazards are also expected to maintain their substantial potential to disrupt the sector in the future. This requires the sector to prepare for and address these risks for long-term sustainability.

Figure 7. Impacts of climatic risks on education.

- **Natural resources management/Forestery**

The analysis of Figure 8 presenting the impacts of climate hazards on natural resources management suggests that the sector is facing significant climate-related risks, particularly from hazards like shifts in temperature, altered precipitation and flooding, and drought and water scarcity. These high-impact risks are expected to persist or even intensify in the future, underscoring the need for comprehensive mitigation and adaptation strategies to address the sector's vulnerabilities.

Figure 8. Impacts of climatic risks on natural resources management.

- **Water and sanitation**

Figure 9 displays the potential impacts of climate hazards on water and sanitation. The analysis reveals that the water and sanitation sector is facing substantial climate-related risks that threaten to disrupt its operations and service delivery both in the present and the future.

Shifts in temperature, currently and projected to have a high potential impact, could significantly disrupt water supply, infrastructure, and treatment processes. Similarly, altered precipitation patterns and flooding, also assessed as high-risk hazards, have the potential to overwhelm water and sanitation systems, leading to service interruptions and water quality issues.

Notably, drought and water scarcity emerge as paramount concerns, with both the current and future potential impacts assessed as high. These hazards directly threaten the sector's ability to ensure reliable water availability and supply, which is the foundation of effective water and sanitation services.

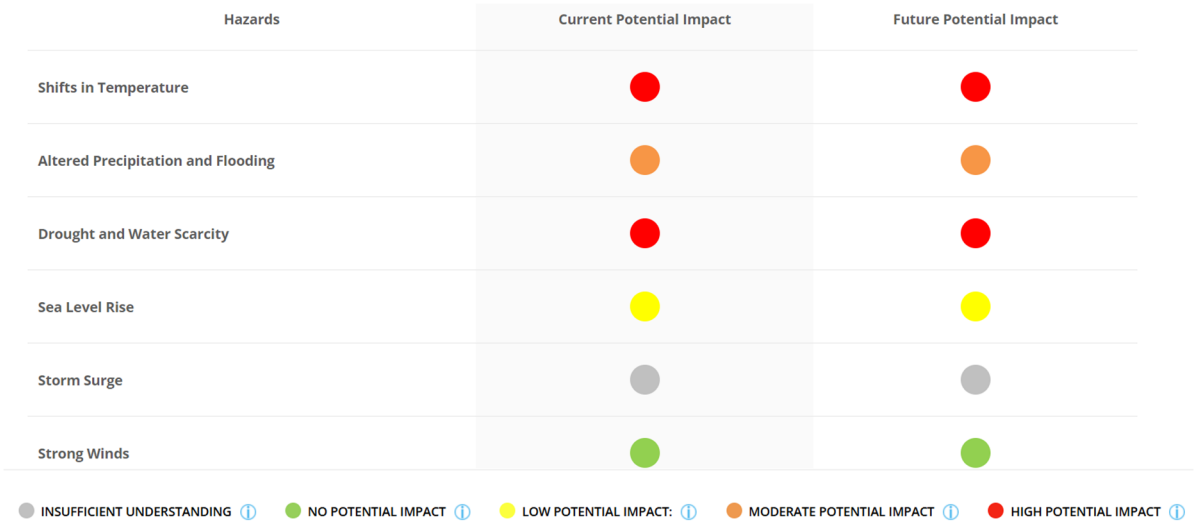

Figure 9. Impacts of climatic risks on water and sanitation.

3.4. Characterization of Hazards and Rate Impacts

Climate and geophysical hazards are causing significant challenges in various sectors, including agriculture, education, energy, natural resource management and forestry, information and communications, and water and sanitation. The agriculture sector is currently experiencing high impacts, while the education sector is experiencing moderate disruptions. The energy sector is also facing high impacts, while the natural resource management and forestry sector is facing high-level challenges (Table 1). The information and communications sector is experiencing moderate impacts, while the water and sanitation sector is facing high impacts. The education and

information/communications sectors are expected to face moderate-level impacts. Overall, these sectors are expected to continue facing high-level impacts from climate and geophysical hazards.

Table 1. Score of the impacts of climate and geophysical hazards.

	Current Impact	Future Potential Impact
Agriculture		
Education		
Energy		
Natural Resource Management/Forestry		
Information and Communications		
Water and Sanitation		

Legend: INSUFFICIENT UNDERSTANDING ⓘ NO POTENTIAL IMPACT ⓘ LOW POTENTIAL IMPACT: ⓘ MODERATE POTENTIAL IMPACT ⓘ HIGH POTENTIAL IMPACT ⓘ.

3.5. Assessment of the Risk Levels

Table 2 assesses the risk levels faced by different sectors due to climate and geophysical hazards in Benin. The agriculture sector faces high risks, while the education sector is moderate. The energy sector faces high risks, while natural resource management and forestry face high risks. Information and communications face low risks, while water and sanitation face high risks. The agriculture, energy, natural resource management/forestry, and water/sanitation sectors are the most vulnerable, while the education sector faces moderate risk. The information and communications sector appears to have a low risk level.

In addition to these risks, rising temperatures are an emerging and underexplored climate risk in Benin, particularly in rapidly urbanising areas. The urban heat island effect, characterised by higher temperatures in urban environments compared to surrounding rural areas, significantly amplifies heat exposure in cities, especially in tropical regions where baseline temperatures are already high [15,16]. Heat exposure poses a major and growing public health threat, increasing the risk of heat stress, cardiovascular and respiratory diseases, and premature mortality [17,18]. Urban populations are particularly vulnerable, with the elderly, children, low-income communities, and individuals with limited adaptive capacity experiencing disproportionately higher health risks [15,16].

Furthermore, heat exposure affects productivity, wellbeing, and overall societal resilience [19]. These findings emphasize the importance of integrating heat-related risks into disaster risk reduction and urban planning strategies, including strengthening heat-health early warning systems, promoting nature-based solutions such as urban greening, and improving housing and infrastructure design to enhance climate resilience and protect public health in Benin's urban areas [15].

Table 2. Risk levels faced by different sectors due to climate and geophysical hazards.

Priority Sector	Overall Risk
Agriculture	
Education	
Energy	
Natural Resource Management/Forestry	
Information and Communications	
Water and Sanitation	

Legend: INSUFFICIENT UNDERSTANDING ⓘ NO RISK ⓘ LOW RISK: ⓘ MODERATE RISK ⓘ HIGH RISK ⓘ.

3.6. Institutional Readiness

Figure 10 presents an assessment of various sectors and their capacities to address climate and geophysical hazards. It covers six key sectors: Agriculture, Education, Energy, Natural Resource Management/Forestry, Information and Communications, and Water and Sanitation.

The agriculture and natural resource management/forestry sectors show relatively stronger capacities across the board, with higher ratings for awareness of hazards, risk assessment abilities, and adaptation measures. In contrast, the education, energy, information/communications, and water/sanitation sectors exhibit more room for improvement, with lower ratings in several areas like hazard awareness and adaptation implementation.

In terms of awareness of hazards, agriculture and natural resource management/forestry have the highest levels (rated 3), while education, energy, and information/communications show relatively lower awareness (rated 1). Water and sanitation is in the middle, with a moderate awareness level (rated 2).

Regarding risk assessment capabilities, agriculture, energy, natural resource management/forestry, and water/sanitation have strong abilities (rated 3), while education and information/communications have some capacity but can be enhanced further (rated 2).

When it comes to adaptation and adaptive management, all sectors exhibit room for improvement in their ability to implement adaptation measures and develop adaptive management capabilities, with most receiving a rating of 2 in these areas. Information/communications shows the weakest adaptation implementation (rated 1).

The summary highlights the disparities in capacities across different sectors to address climate and geophysical hazards, with the agricultural and natural resource management domains appearing more prepared, while others like education, energy, and information/communications may require targeted efforts to build up their awareness, assessment, adaptation, and adaptive management capabilities.

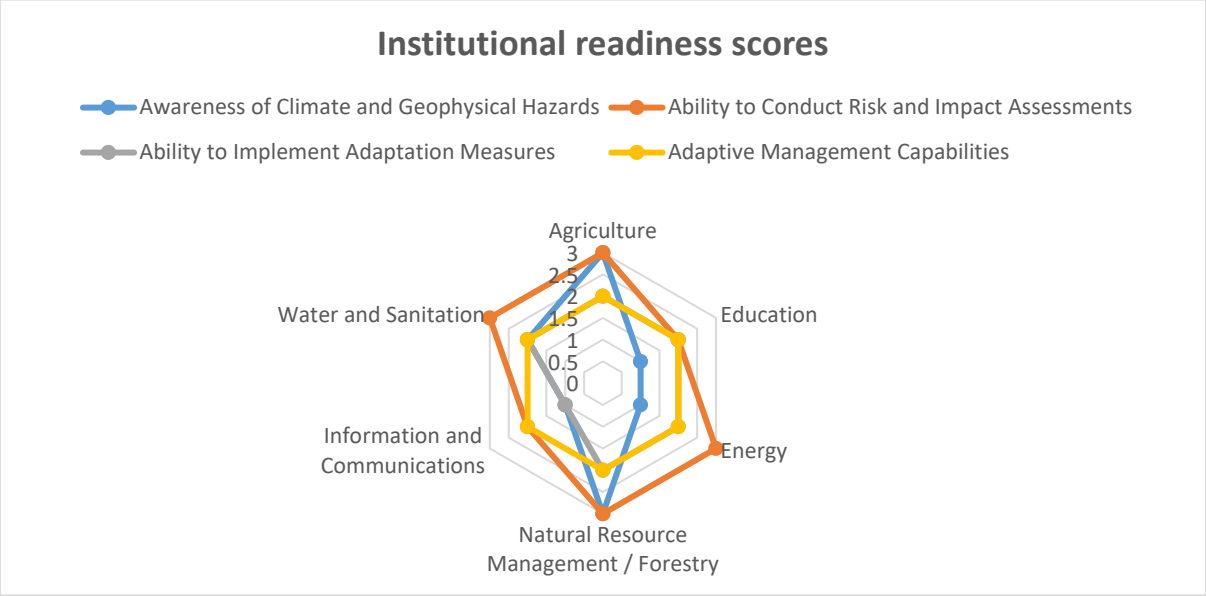

Figure 10. Institutional readiness scores.

3.7. Disaster Impacts Across Benin's Sectors: A Comprehensive Assessment

The floods of 2022 did not spare any sector in Benin. In the agricultural sector, more than 61,761 hectares of crops were flooded, of which 28,397 hectares of flooded areas were unrecoverable [20]. As for the social sectors, the 2022 floods impacted 197,182 people in around forty communes, with 60 deaths, including 10 due to the floods, 47 due to water-related accidents, and 3 missing persons. Similarly, 30 health centres, 178 nursery and primary schools, and 16 colleges were flooded, unroofed, or inaccessible in 2022, compared to 75 classroom modules affected by the floods in 2019 [21]. At the infrastructure level, 1922.88 km of rural roads and tracks, as well as 12 bridges, 48 culverts, and 30 submersible fords (box culverts) were damaged. The floods of 2022 had overall effects (damages and losses) of the order of 190,440,578,371 CFA francs [20].

The Table 3 displays a detailed picture of the multifaceted impacts of disasters across Benin's various sectors. In the health domain, the table paint a concerning picture. With over 2200 cases of hospitalisation and 109 affected health facilities registered, the strain on the country's medical infrastructure is evident [12]. Furthermore, the 25 health centres impacted underscore the disruption to vital healthcare services, particularly in the most vulnerable communities. Turning to the water, hygiene, and sanitation sector, the table highlights 20 instances of interruption to the drinking water supply, as well as 24 cases of disruption to sanitation and hygiene systems. These disruptions not only jeopardise public health but also undermine the overall wellbeing of affected populations. The security and food sector has borne the brunt of devastating impacts. The staggering 140,287 hectares of destroyed crops paint a grim picture of the threat to food security, while the 259 affected food stores and 37,339 damaged commercial establishments illustrate the far-reaching economic consequences. Infrastructure, too, has been significantly impacted, with 24 affected desert roads, 5 damaged roads, and 4 compromised electrical and telecommunication networks. These disruptions to critical infrastructure can severely hinder relief and recovery efforts, further exacerbating the challenges faced by affected communities. The education sector has also suffered, with 163 schools reported as affected. The disruption to educational services not only impacts the academic progress of students but also undermines the long-term resilience and development Nationalof Benin's

communities. The widespread impacts across health, water, food security, infrastructure, and education sectors underline the need for a comprehensive and coordinated approach to disaster risk management.

Table 3. Summary of disasters in Benin from 2011 to 2015 (Source: Benin's National Contingency Plan for 2024).

Sectors	Indicateurs D'impacts en Nombre	Impact des Catastrophes par Secteurs	Flood		Violent Winds		Busfires		Disease Outbreaks	
		Total Number	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Health	health centers affected	25	25	100	-	00	-	-	-	00
	deaths recorded	109	25	22.93	7	6.42	16	14.67	61	55.96
	cases hospitalized	2202	215	9.76	6	00.27	8	0.36	1973	89.60
Water, hygiene and sanitation drinking Food security	situation of drinking water	20	20	100	-	-	-	-	-	-
	hygiene and sanitation concerns raised	24	24	100	-	-	-	-	-	-
	hectare of crops destroyed	140,287	139,582	99.49	-	-	705	0.50	-	-
	affected stores	259	257	99.22	-	-	2	0.77	-	-
	head of livestock lost	37,339	37,189	99.59	-	-	150	0.40	-	-
Shelter	victims	63,203	47,051	74.44	436	00.68	15,716	9.93	-	--
	affected dwelling	17,817	11,654	65.40	135	0.75	6028	33.83	-	-
Education	affected school	163	120	73.67	27	00.16	16	9.81	-	-
Social and community infrastructure	=number of affected desert tracks	24	19	79.16	-	-	-	-	-	-
	Affected markets	5	4	80.00	1	20	-	-	-	-
	damaged power networks	4	4	100	-	-	-	-	-	-
	damaged telephone networks	0	-	-	-	-	-	-	-	-

3.8. Urban Planning and Disaster Risk Reduction

In today's world of quickly changing environments, increased urbanisation, and vulnerability, it is critical to include the notion of resilience into our cities' development planning in order to achieve sustainable development. Planning a city without a thorough catastrophe resilience strategy is a waste of resources that endangers people, infrastructure, assets, and the economy. Disaster resilience is thus a desirable trait that cities should include into their urban design and management practices. Cities can endure shocks from man made and natural disasters by implementing systems that improve and include resilience. The floods of 2010 and 2022 spared no sector in Benin (Schemes 1 and 2).

Scheme 1. flooded City in Benin (Flooding event in 2010).

Scheme 2. Flood in 2022.

Disaster resilience and management in urban areas has been a challenge for town planners. The huge loss of lives, property, economy and society in Benin can be minimized by making our cities resilient to disasters and calamities. It is very crucial to incorporate or embed resilience in planning and development of city's infrastructure as disasters usually occur very abruptly giving no time to react or to take immediate mitigation actions, therefore resilience should be mainstreamed at the very early stages of development to make the final product strong, robust and flexible to withstand shocks and stresses [22]. Resilient cities are able to cope with disaster situations as they are robust and prepared for any such situation beforehand only. It bounces back to normal functioning once disaster passes away. In Benin, we face floodings because we are setting cities dangerously close to a natural phenomenon due to rapid urbanization, and we cannot handle its impact with available resources and arrangements [23]. A focus on disaster resilience in the process of urban planning forms a basic backbone structure for a resilient and safe city [20].

The hydrographic network of Benin comprises 3048 km of rivers and 333 km^2 of water bodies (lakes and lagoons), situated in the southern region of the country (Figure 11). These form the boundaries of several major hydrographic units: the Niger basin (the Mékrou, Alibori and Sota rivers), the Volta basin (the Pendjari), the Mono and Couffo basins, and the Ouémé-Yéwa basin (Figure 11). This hydrographic network feeds a series of water bodies in the coastal sedimentary basin, including the Porto-Novo lagoon (35 km^2), Lake Nokoué (150 km^2), Lake Ahémé (78 km^2), the Ouidah lagoon (40 km^2), Lake Toho (15 km^2), and the Grand-Popo lagoon (15 km^2) (Figure 7). These lakes and lagoons contribute large quantities of water to the Atlantic Ocean, accounting for approximately 2.6% of the volume of the coastal sediment basin (BENIN-Stratégie Nationale de Réduction Des Risques de Catastrophe, n.d.-b). The risk of flooding in river basins is greatest in areas bordering the minor and major river beds and their main tributaries. The sensitivity thresholds of river basins to flooding vary from around 10 m to 500 m, depending on the size of the hydrographical unit. As a result, the ecological functions of natural ecosystems are altered, rendering populations more vulnerable from an economic and health perspective.

The national meteorological institution, METEO-Benin, is responsible for observing, analysing, studying, and forecasting the weather, climate, and atmospheric constituents of the environment, with the aim of ensuring the safety of people and property. However, this institution is hampered by outdated and obsolete observation and dissemination infrastructures. Additionally, there is a lack of observation infrastructure throughout the country and insufficient human resources.

The national meteorological observation network consists of the following components:

- 6 conventional synoptic stations
- 20 conventional agro-climatic stations
- 70 conventional rain gauge stations
- 19 automatic rain gauge stations
- 11 automatic synoptic stations, 8 of which are teletransmitted
- 19 teletransmitted automatic agri-climatological stations
- 20 Thermo automatic agro-climatological stations installed in GLOBE BENIN schools, with more intended for educational purposes.

This network faces challenges in terms of outdated infrastructure and insufficient coverage across the country, as well as a shortage of human resources to effectively operate and maintain the system. Benin still does not have a geospatial data infrastructure organisation.

An institutional coordination mechanism has been established to enable the production and dissemination of climate information from data-providing institutions to end-users (communities and populations). To this end, a network of observation activities has been set up for the main watercourses, rain gauges, and other measurement stations throughout the country. This was done as part of the implementation of the Benin Early Warning System (SAP Bénin). This framework allows the Directorate-General for Water (DG-Eau) to coordinate a hydrometric observation network across the most important river basins. This organisation has resulted in the establishment of a flood early warning system and has produced the following outcomes:

- Monitoring of floods in the most significant river basins;
- Collection and telemetry of hydrological data;
- Centralisation, processing, exploitation, and publication of alert bulletins;
- Monitoring of floods with hydrological information;
- Transmission of information to the National Agency for Civil Protection (ANPC), which is responsible for its dissemination.

This coordinated effort has enabled the relevant authorities to enhance their capacity for monitoring, analysing, and disseminating critical information related to flood risks, thereby strengthening the country's disaster risk management capabilities.

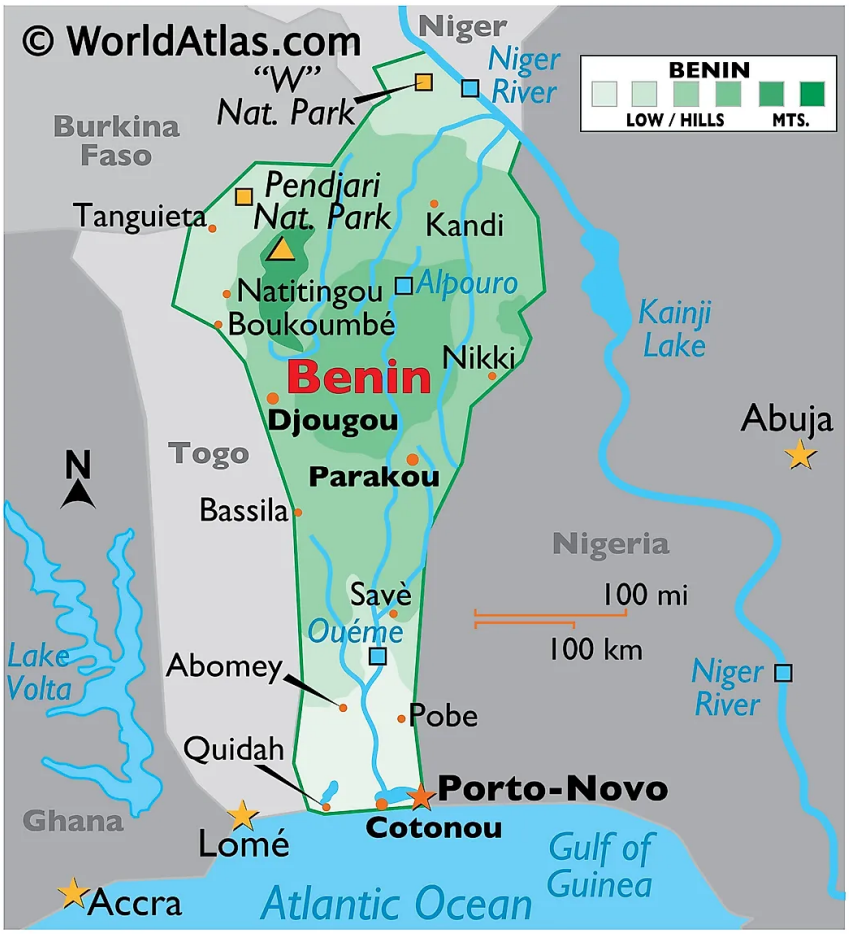

Figure 11. Hydrographic networks and the Benin river basins as a whole (https://www.worldatlas.com/maps/benin; accessed on 23 November 2025).

There are three main zones in Benin (Figure 12):

- the mountainous zone in the north-west of the country;
- the coastal zone, which extends along the coastline over an average width of 4 km;
- the plateau region, the third group, lies between the coastal plain and the Lonkli-Kétou transverse valley. There are also the sandstone plateaux of Kandi.

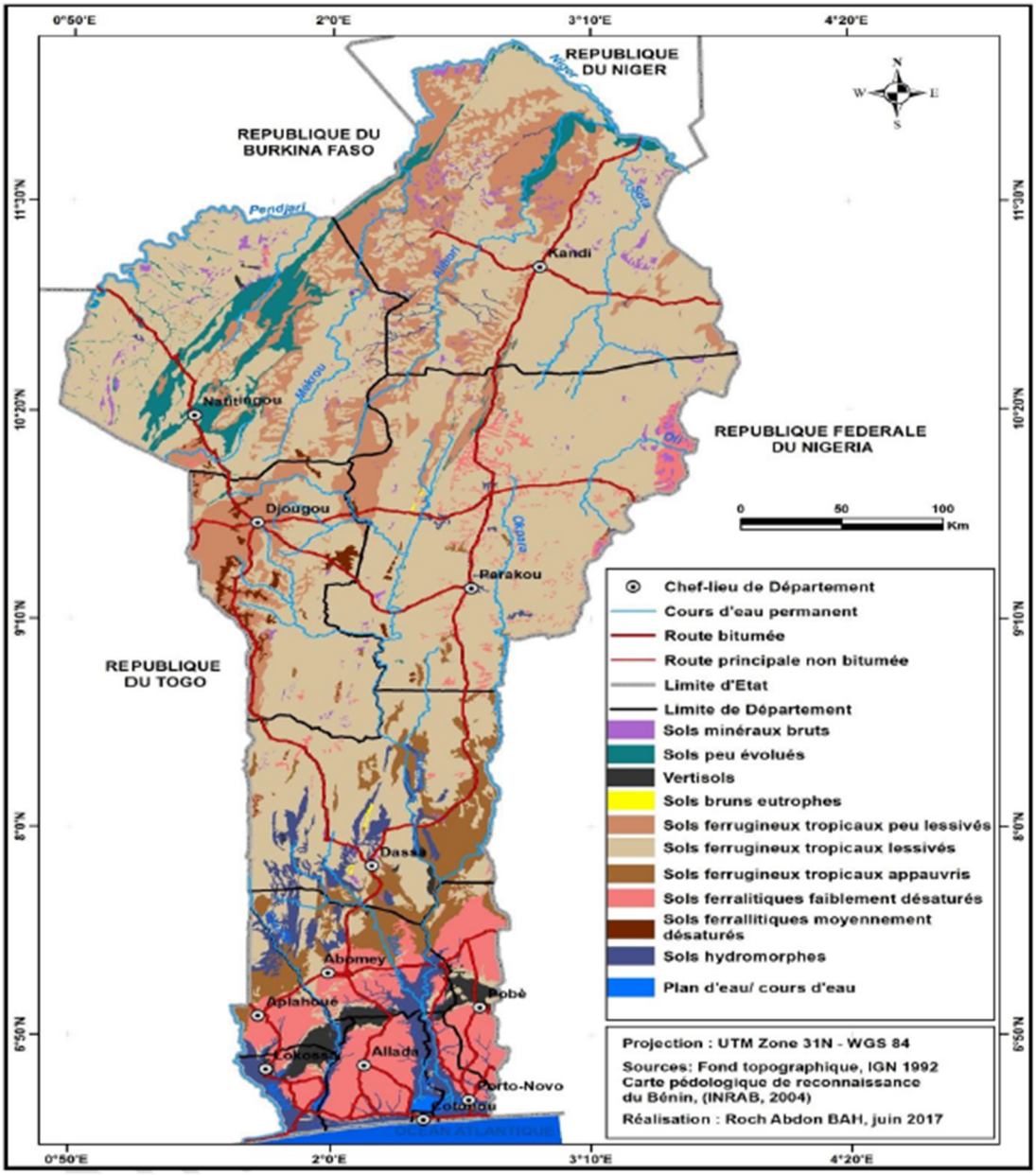

Figure 12. Pedological map of Benin.

3.9. Application in Territorial Planning or Land Use Planning

The process of urban expansion has led to the functional reclassification of space. As a result, certain rural areas have transitioned from "agricultural land" to "urbanisable land". However, this reclassification has not always been accompanied by an analysis of the vulnerability of these areas to disasters, nor the establishment of land use regulations in several communes.

The rapid pace of urban expansion has generated significant challenges, including a shortage of potable water, poor public hygiene, unsanitary conditions, the proliferation of slums, and the development of precarious housing in flood-prone and submersible areas. In these zones, dwellings, often constructed with local materials (mud bricks, planks, wattle), offer little resistance to floodwaters and are frequently destroyed during inundation periods.

To address this problem, the Government has developed a National Land Use Planning Scheme and guidelines for the elaboration and approval of Urban Development Master Plans (SDAC), which some communes have used to develop their own SDAC with the support of technical and financial partners. Other urban planning instruments, such as Urban Master Plans and Land Use Plans, have also been implemented to define various zones (agricultural, residential, industrial, tourism, etc.) [22]. Furthermore, a National Urban Observatory has been established, and around thirty Master Plans and Development Plans have been produced [24]. However, the reality on the ground shows a lack of respect for the planning options adopted during the implementation of urban planning and land use allocation initiatives.

The mitigation and attenuation of the aforementioned risks necessitates the integration of these risks into sectoral policies spanning a range of domains, including land use planning, environmental management, agriculture, fisheries and livestock, water resource management, infrastructure development, urban planning and housing, population and social protection, sanitation of human settlements, and security considerations [25]. It is imperative that state budget projections account for and incorporate provisions to address these identified risks. Furthermore, it is essential to ensure the effective implementation of these policies and the rigorous application and compliance with the relevant legal frameworks.

3.10. Key Principles of Benin's Disaster Risk Reduction Strategy

The National Disaster Risk Reduction Strategy (2019–2030) is based on principles that must be taken into account in the interpretation, implementation of strategic orientations and the realisation of the planned actions to achieve the desired results (BENIN-Stratégie Nationale de Réduction Des Risques de Catastrophe, n.d.-b).

The principles guiding the strategy are:

1. People-centred approach: Communities who are victims of disasters are at the centre of the paradigm advocated in this strategy. For any intervention, targeting efforts will be made to reach the most vulnerable communities and areas. Within these communities, it is crucial to prioritise women, girls, children, people with disabilities, and the elderly. The approach also values traditional knowledge and local know-how, local learning methods, and involves strengthening community mechanisms to prevent risks, manage disasters and ensure resilient recovery.
2. "All-hazards" (natural and man-made), "integrated" (all operations) and "holistic" approach. It focuses on the systematic identification, analysis, control and treatment of all disaster risks to which the Beninese population is exposed.
3. Targeting multidimensional vulnerability and treating it as a priority: DRR actions aim to reduce social, physical, environmental and economic vulnerabilities. It optimises national and local planning to ensure the priority of reducing the vulnerabilities of people with disabilities, women, girls, children, the elderly, and uses risk analysis/assessment methodologies in planning for long-term development and emergency response.
4. Integration of DRR actions into the implementation plan of the National Development Plan and other sectoral policies and plans.
5. Linking disaster risk reduction actions to the policy of decentralisation and deconcentration to help strengthen capacities at the level of departments, communes, districts and villages or city neighbourhoods.
6. Supporting disaster risk reduction actions through regional and international cooperation. Benin must work to strengthen technical and financial partnerships to seize all opportunities at the sub-regional and international level in terms of DRR.

3.11. Challenges and Lessons Learned

The major challenges associated with risk management can be summed up in four main points: Firstly, improving the level of education and risk culture at both the local and national level by engaging all relevant stakeholders is of paramount importance. Secondly, strengthening governance mechanisms is essential to ensure that the bodies involved in disaster risk reduction (DRR) operate in a cohesive and coordinated manner. Thirdly, increasing investment in disaster risk reduction initiatives is crucial for building resilience within communities. And fourthly, strengthening disaster preparedness is key for enabling effective response and facilitating the 'building back better' approach during the recovery, rehabilitation, and reconstruction phases. The overarching aim is to significantly reduce disaster risks in line with national guidelines and Benin's international commitments, with the ultimate goal of improving the living conditions of the people (BENIN-Stratégie Nationale de Réduction Des Risques de Catastrophe, n.d.-b).

4. Conclusions

In light of the findings above, the study provides the first comprehensive, integrated assessment of disaster risk in Benin that combines sectoral vulnerability, spatial exposure, institutional capacity, and policy analysis within a unified analytical framework. Findings highlight critical vulnerabilities in key sectors such as agriculture, energy, and water/sanitation, which are vital to the country's development and population well-being. The analysis also reveals substantial disparities in institutional preparedness, demonstrating that while some sectors possess relative capacity, others require urgent intervention to enhance resilience. By operationalising the World Bank Climate and Disaster Risk Screening Tool alongside the exposure–sensitivity–adaptive capacity framework, the

study not only evaluates risk levels but also identifies priority areas for action. The work contributes original empirical evidence to support integrated, evidence-based planning and informs strategies for mainstreaming disaster risk reduction into national and local development policies. The National Disaster Risk Reduction Strategy (2019–2030) further reinforces a people-centered approach, emphasizing vulnerable communities, local knowledge, and participatory mechanisms in disaster prevention and recovery.

Recommendations:

- Strengthen Education and Awareness: Implement targeted educational programs to improve risk culture and awareness at both local and national levels. Engaging communities, especially vulnerable groups, in DRR initiatives will foster a culture of preparedness and resilience.
- Enhance Governance Mechanisms: Establish cohesive governance frameworks that facilitate coordination among various stakeholders involved in DRR. This includes enhancing the roles of local governments and community organizations in disaster management processes.
- Increase Investment in DRR Initiatives: Allocate more financial resources towards disaster risk reduction projects, particularly in high-risk sectors such as agriculture and water/sanitation. This investment should focus on building infrastructure that can withstand climate impacts and support sustainable development.
- Promote Regional and International Cooperation: Foster partnerships with regional and international organizations to share knowledge, resources, and best practices in DRR. Collaborative efforts can enhance technical and financial support for local initiatives.
- Focus on Adaptive Management: Encourage the implementation of adaptive management practices across all sectors, particularly in education, energy, and information/communications, to improve their capacity to respond to and recover from disasters effectively.

Author Contributions

G.J.G.: conceptualization, methodology, software; data curation, writing—original draft preparation, visualization, investigation; W.L.F. and N.T.: supervision; W.L.F. and N.T.: software, validation; N.P.I.D.: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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This study used secondary data which is available online.

Conflicts of Interest

The authors declare no conflicts of interest.

Use of AI and AI-Assisted Technologies

No AI were used for this manuscript.

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