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Perceived Exposure and Vulnerability to Climate Risks in the Urban Centers of Zio Prefecture, Togo

Kodjo Kadévi Etse [1,2,*], Bilouktime Badjaré [3], Demirel Maza-esso Bawa [4], Fousséni Folega [2], Kperkouma Wala [2] and Komlan Batawila [2]

[1] Regional Center of Excellence on Sustainable Cities in Africa (CERViDA-DOUNEDON), Lome 1 BP 1515, Togo
[2] Laboratory of Botany and Plant Ecology, University of Lomé, Lome 1 BP 1515, Togo; ffolegamez@gmail.com (F.F.); kperkouma.wala@gmail.com (K.W.); batawilakomlan@gmail.com (K.B.)
[3] Institute for Biodiversity Research in the Nimba Mountains (IReB-MN), Lola Urban Commune of Lola BP 50, Guinea; hilairebb@gmail.com
[4] Institute for Botany and Botanical Garden, Faculty of Biology, University of Belgrade, Takovska 43, 11000 Belgrade, Serbia; e3006_2021@stud.bio.bg.ac.rs
* Correspondence: etse2kadevi@gmail.com

Abstract

Climate change and rapid urban expansion are increasing populations' exposure to climate risks, particularly in secondary cities of West Africa. An analysis of local perceptions of these risks is therefore essential for improving the understanding of urban vulnerability and strengthening local adaptation and resilience strategies. This study analyzes the perceptions of exposure and sensitivity to climate risks in nine urban centers of the Zio prefecture (Togo), as well as their determinants. A mixed-method approach was conducted with 423 households, combining quantitative surveys and statistical analyses, including principal component analysis (PCA) and chi-square (χ^2) tests. The results show that extreme heat (80.6%) and drought (66.7%) are the most perceived hazards, with significant spatial variations: drought is more frequently cited in small rural localities (90.2%), while floods and storms predominate in peri-urban areas. Women (up to 89.5%) and residents of risk-prone areas are identified as the most vulnerable groups. Factor analysis reveals two dimensions structuring perceptions: a chronic and economic component (income loss, migration, drought) and an acute hydrometeorological component (river flooding, human losses, storms). Remote rural municipalities (Zio 4) exhibit higher perceptions of chronic risks, while the peri-urban area (Zio 2) combines both chronic and acute risks. Housing and roads are perceived as the most vulnerable infrastructures. External support remained limited, with 67.6% of households reporting none; government assistance was the leading source overall (14.7%), while non-governmental organizations NGOs predominated in large settlements (30.0%). These findings confirm the intra-territorial heterogeneity of perceptions and highlight the need for differentiated, gender-sensitive adaptation policies that strengthen institutional alert and assistance mechanisms.

Keywords: climate risk perception; exposure; sensitivity; urban vulnerability; Zio prefecture; Togo

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1. Introduction

Climate change is one of the major challenges of the twenty-first century, affecting territories and populations in different ways. Discussions surrounding this global phenomenon have largely focused on extreme weather events and their management [1]. According to

the Intergovernmental Panel on Climate Change (IPCC) [2], climate risks result from the interaction between hazards, exposure, and the vulnerability of both human and natural systems. Vulnerability is, in turn, determined by the sensitivity of these systems and their adaptive capacity, which is strongly influenced by socio-economic and institutional factors. The main drivers of these changes include global population growth, the increasing concentration of populations in coastal areas and large cities, growing dependence of economies on technology, rapid environmental degradation, and the widening gap between developed and developing countries [3].

In urban areas, these dynamics take on a particular significance. Rapid urbanization, often poorly managed in developing countries, increases the exposure of populations to climate hazards such as floods, heatwaves, and droughts [4]. Furthermore, social inequalities among residents based on their place of residence, inadequate infrastructure, and precarious livelihoods contribute to increasing the sensitivity of urban populations, particularly the most vulnerable groups [5,6]. In this regard, vulnerability is not limited to a biophysical dimension but also encompasses social and institutional factors [7]. Risk perception plays a critical role in understanding and managing climate vulnerabilities. Such perceptions are shaped by socio-economic and cultural factors [8] and influence the adaptation strategies adopted by populations to enhance their resilience [9]. Consequently, analyzing risk perceptions is essential for improving the effectiveness of climate change adaptation policies.

Research on urban climate vulnerability in Africa has expanded considerably over the past decade, developing along several complementary lines. A first strand comprises continental and sub-regional syntheses that have consolidated conceptual and empirical knowledge on the drivers of urban vulnerability across Sub-Saharan Africa [10–13] and highlighted the disproportionate exposure of African cities to climate hazards relative to their adaptive capacity [14]. A second strand consists of West African urban case studies, concentrated primarily in Ghana, spanning Accra [15–18], Kumasi [19], and the northern savannah zone [20–22], as well as in Nigeria, with studies on Lagos [23,24] and on gendered vulnerability among women and children in northern Nigeria [25], and in Central Africa, notably N'Djamena, Chad [26]. A third strand extends this empirical base to East and Southern African cities, including Kampala [27,28], Nairobi [29], Kigali [30], Addis Ababa [31], and several South African metropolitan areas [32–35]. Of particular relevance to the present study, a smaller but methodologically important set of works has focused specifically on risk perception as a determinant of adaptive behavior, showing that perceptions of exposure and sensitivity are shaped by gender, livelihood, and spatial location [15,20,36,37] and vary systematically across countries with differing exposure levels [38]. Taken together, this body of work confirms both the conceptual relevance of a perception-based approach to urban climate vulnerability and the near-total absence of comparable evidence for Togolese or other Francophone West African urban contexts a gap this study seeks to address by focusing on Zio Prefecture.

In Togo, secondary cities are experiencing rapid growth accompanied by increasing climate-related risks [39]. Zio Prefecture, characterized by sustained urban expansion, exemplifies the rapid and poorly regulated urban transformations increasingly observed in West African secondary cities [40]. Its urban centers are exposed to a variety of climate hazards, whose impacts vary according to the socio-economic conditions of populations, their spatial location, and their access to resources [41]. Its peri-urban position adjacent to Lomé, combined with the heterogeneous socio-economic conditions observed across its urban centers, makes Zio Prefecture a relevant case for examining how exposure and sensitivity to climate hazards are locally perceived and differentiated. These characteristics are consistent with structural drivers of urban climate vulnerability documented in other West

African contexts, including rapid demographic growth, informal settlement expansion, and limited adaptive infrastructure [42–44], as well as in comparable peri-urban settings in Nigeria [23] and Chad [26]. However, despite the growing body of research on urban climate vulnerability in Africa, public adaptation policies remain insufficiently informed by local perceptions of climate risks. A review of the Web of Science-indexed literature reveals a marked geographical imbalance: while substantial empirical research has been conducted in Ghana, Nigeria, Kenya, Uganda, Rwanda, Ethiopia, Tanzania, Zimbabwe, and South Africa, few studies have examined climate risk perception in Togolese or, more broadly, Francophone West African secondary urban centers. Previous research has nevertheless demonstrated the importance of risk perception in understanding adaptive behavior, showing that perceptions of exposure and sensitivity may vary according to gender, livelihoods, socio-economic conditions, and spatial location [15,20,36,37]. Thus, although significant conceptual advances have been made in the study of climate vulnerability, empirical understanding of how urban populations perceive their exposure and sensitivity to climate risks remains limited in the Togolese context. Understanding how populations in the urban centers of Zio Prefecture perceive their exposure and sensitivity to climate risks, as well as the socio-economic, environmental, and institutional factors shaping these perceptions, is therefore essential for addressing this research gap and providing evidence to support more context-specific urban resilience planning and climate risk management.

The central research question guiding this study is: How are perceptions of exposure and sensitivity to climate risks structured in the urban centers of Zio Prefecture? This overarching question gives rise to three specific research questions: (i) How do urban populations perceive their level of exposure to different climate hazards? (ii) Which urban systems and social groups are perceived as being the most sensitive to climate risks? (iii) What socio-economic, environmental, and institutional factors determine these perceptions? The overall objective of this study is to analyze perceptions of exposure and sensitivity to climate risks in the urban centers of Zio Prefecture and to identify their determinants. Specifically, the study aims to: (i) analyze perceptions of exposure to climate risks according to socio-demographic and spatial characteristics; (ii) assess the perceived sensitivity of urban systems (infrastructure, social groups, and livelihoods) to climate risks; and (iii) model the socio-economic, environmental, and institutional determinants influencing these perceptions.

2. Materials and Methods

2.1. Geographic Location of the Study Area

The study was conducted in Zio Prefecture, one of the eight prefectures in the Maritime Region of Togo (Figure 1). Its administrative center is the city of Tsévié, located approximately 35 km north of the capital, Lomé. Tsévié serves as the capital of both Zio Prefecture and the Maritime Region. Zio Prefecture is bordered to the north by the Haho Prefecture (Plateaux Region), to the south by the prefectures of Agoè-Nyivé, Golfe, and Lacs, to the east by the prefectures of Yoto and Vo, and to the west by Avé Prefecture. It lies between 0°53′ and 1°25′ E longitude and 6°11′ and 6°50′ N latitude, covering an area of approximately 2054 km^2. According to the Fifth General Population and Housing Census, the prefecture has an estimated population of 500,032 inhabitants [45]. It is administratively divided into four municipalities: Zio 1, Zio 2, Zio 3, and Zio 4. The study area experiences a Guinean-type tropical climate, characterized by four distinct seasons comprising two rainy seasons and two dry seasons each year. Annual rainfall ranges from 424 mm to 1417 mm, with a mean annual precipitation of 826 mm. Mean annual temperatures vary between 26.24 °C and 29.93 °C. Located within Ecological Zone V (the Southern Coastal Plain) [46], the study area is dominated by cultivated land (31.98%), open forests and wooded savan-

nas (20.01%), and tree and shrub savannas (19.61%), according to the results of the First National Forest Inventory (NFI-1) and Akpegnon et al. [47]. The main traditional economic and livelihood activities include agriculture, traditional livestock farming, hunting, trade, and agro-food processing.

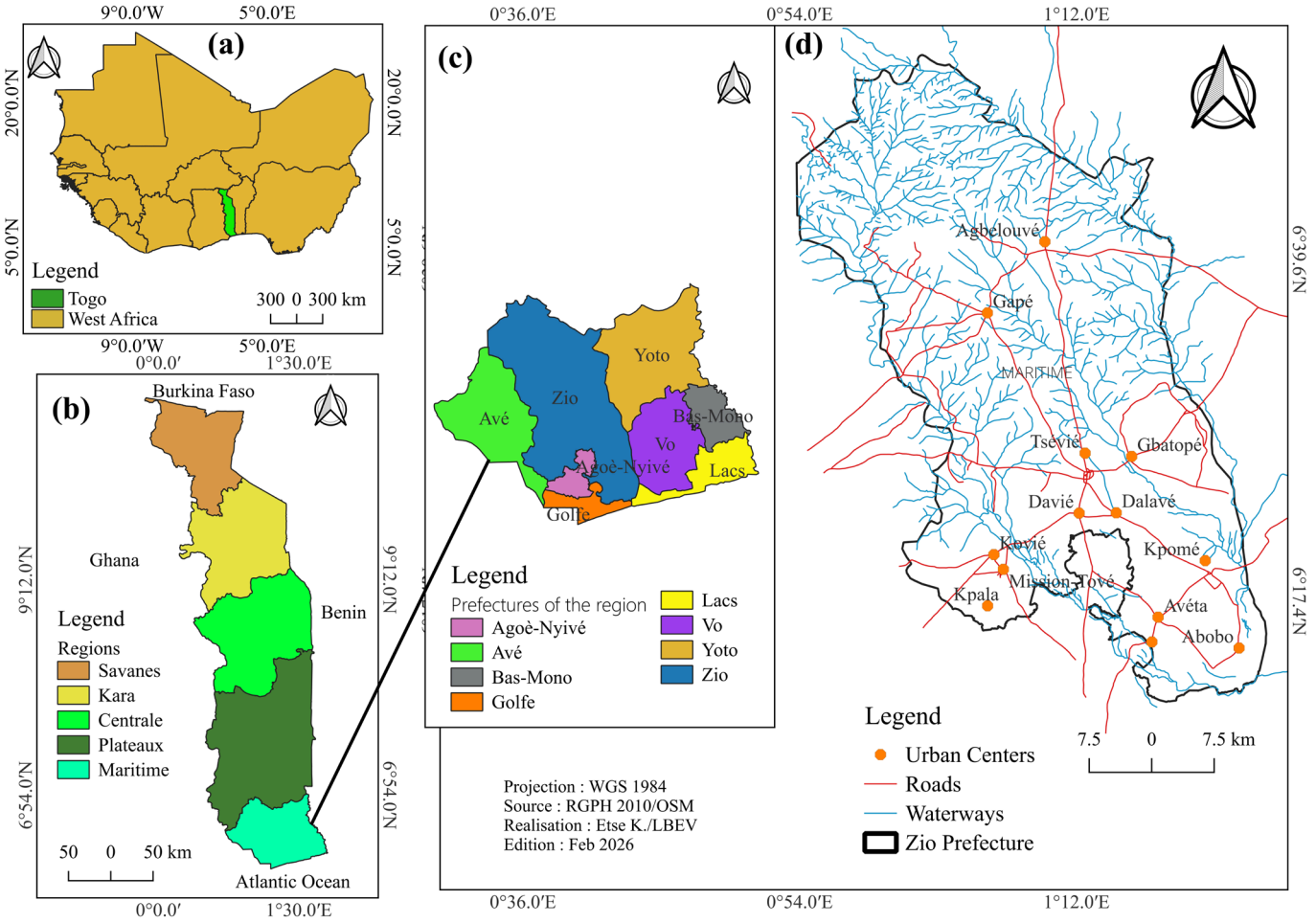


Figure 1. Location and geographical context of the study area. (**a**) Location of Togo in West Africa; (**b**) administrative regions of Togo; (**c**) Maritime Region and its prefectures; (**d**) Zio Prefecture, representing the study area.

2.2. Data Collection

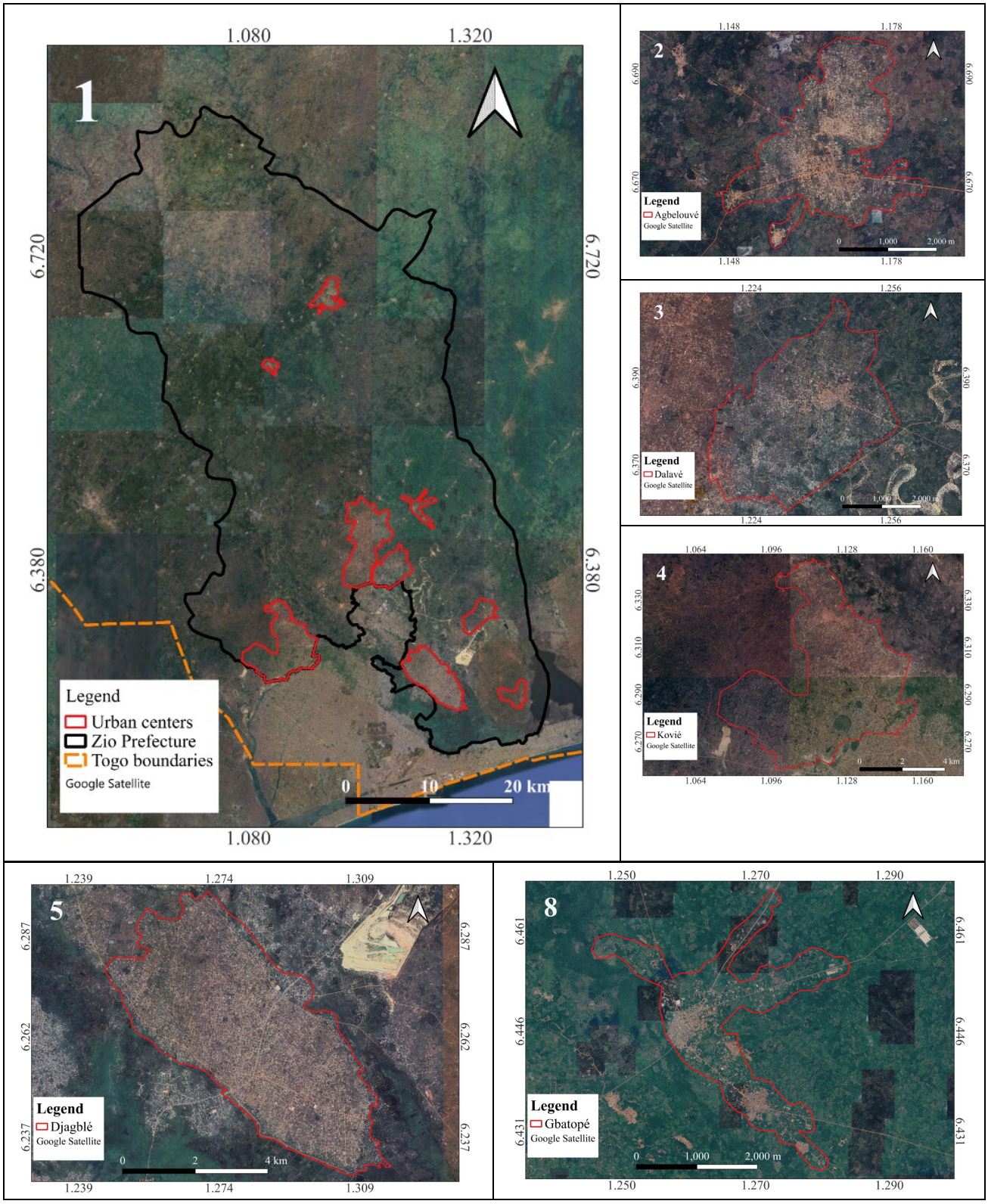
2.2.1. Delineation of Urban Centers

Urban centers were defined as areas characterized by a high concentration of population and economic activities, a continuous built-up morphology, and functional attractiveness to the surrounding areas. Based on these criteria, nine urban centers were delineated using Google Earth Pro imagery (Figure 2).

2.2.2. Data Collected

The study adopted a mixed-methods approach (quantitative and qualitative) to capture both the subjective perceptions of the population and the measurable determinants of these perceptions. It is based on the conceptual framework of climate vulnerability developed by the IPCC, in which vulnerability is considered a function of exposure, sensitivity, and adaptive capacity. A stratified sampling design was used for the collection of quantitative data. Spatial stratification was carried out (urban center, peri-urban areas, and high-risk zones) to account for intra-urban disparities. Households were then selected through random sampling within each stratum. Only individuals who voluntarily agreed

to participate were included in the survey. The survey sample size was determined using the Schwartz formula [48], based on a 95% confidence level and a 5% margin of error. The calculation yielded a minimum required sample of approximately 384 respondents. To improve the robustness of the survey and account for potential non-response, 423 respondents were ultimately surveyed.



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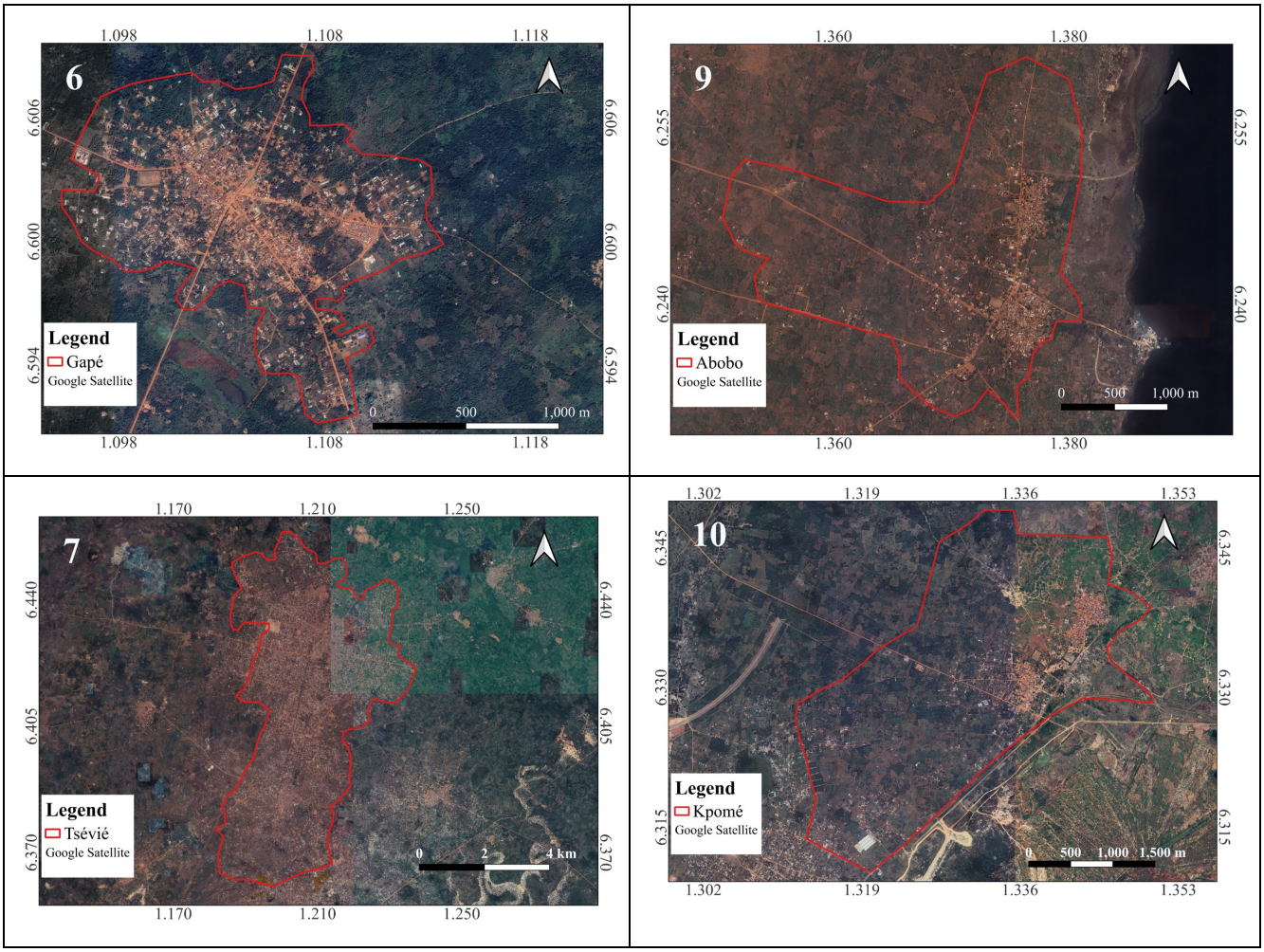

Figure 2. Urban centers in Zio Prefecture: (**1**) urban centers, (**2**) Agbélouvé, (**3**) Dalavé, (**4**) Kovié, (**5**) Djagblé, (**6**) Gapé, (**7**) Tsévié, (**8**) Gbatopé, (**9**) Abobo, and (**10**) Kpomé.

Data were collected using a structured questionnaire designed with the KoboCollect application v2025.3.3. The information gathered included respondents' general characteristics, their perceptions of exposure and sensitivity to climate hazards, the vulnerability of populations and infrastructure, adaptation capacity and risk management, climate change, governance and coordination, as well as priority needs [49]. Six climate hazards were predefined prior to data collection: river flooding, pluvial flooding, drought, extreme heat, storms, and vegetation fires [50]. Four frequency categories were used to assess the occurrence of these hazards: rare (less than one event every 10 years), occasional (1–2 events every 10 years), frequent (3–5 events every 10 years), and very frequent (more than five events every 10 years) [51]. In addition to the household surveys conducted in the urban centers, semi-structured interviews were held with representatives of NGOs operating in the prefecture. The information collected focused on the organizations' areas of intervention and perceptions of climate risks, the actions and initiatives they have implemented, partnerships, local coordination and governance, as well as institutional adaptation capacities and needs.

2.3. Data Processing

The data collected through the KoboCollect application were exported to Microsoft Excel for processing. The analysis of these data provided insights into perceived exposure to climate hazards and the perceived sensitivity of urban systems and social groups.

To analyze the multidimensional structure of perceptions of exposure and sensitivity to climate risks, a PCA was performed using the FactoMineR package in R, with graphical visualizations generated using factoextra, ggplot2, and data preprocessing handled with dplyr and readxl. The analysis included 15 active variables describing perceptions of climate hazards, their frequency, recent trends, and observed socioeconomic impacts [50]. Qualitative variables including municipality, area type, economic activity, existence of a management plan, and external support were incorporated as supplementary variables. The dataset was cleaned, recoded into numerical categories, and standardized prior to analysis [52]. The results indicate that the first two principal components capture most of the overall variability. The first principal component represents a gradient of perceived exposure to climate risks, contrasting highly affected localities with less exposed areas. The second principal component reflects sensitivity to climate impacts, primarily distinguishing economic losses, migration, and service disruptions. The choice of PCA for this analysis is justified by the presence of binary and ordinal variables recoded numerically, as well as by our exploratory objective of identifying continuous dimensions underlying the structure of perceptions. The ordinal variables were included as active variables after numerical recoding, while acknowledging the interval-scale assumption implied by this approach.

3. Results

3.1. Perception of Exposure to Climate Hazards

The analysis of climate risk perception revealed that extreme heat and drought were the most frequently reported climate hazards across Zio Prefecture, as indicated by 80.6% and 66.7% of respondents, respectively (Table 1). Extreme heat was reported by 83.3% of respondents in the central zone, 85.0% in the intermediate zone, and 75.6% in the peripheral zone according to the urbanization-based stratification. When the urban centers were classified according to the size of settlements, drought was perceived by 90.2% of respondents in small settlements (peripheral areas), compared with only 10.0% in medium-sized settlements and 59.3% in large urban centers. This difference was statistically significant ($\chi^2 = 8.13$, $p = 0.017$). Storms were reported more frequently in the intermediate (45.0%) and central (21.5%) zones than in small settlements (12.0%). The vast majority of respondents (more than 95% in all strata) considered that climate hazards occur very frequently (more than five events over a ten-year period). However, perceptions of increasing hazard occurrence varied across the study area. Under the center–periphery stratification, 37.5% of respondents in the central zone perceived a marked increase in climate hazards, compared with 40.2% in the intermediate zone and only 29.7% in the peripheral zone. According to the urban-size stratification, respondents from small and medium-sized settlements more frequently reported a marked increase in climate hazards (48.1% and 50.0%, respectively) than those from the large urban centers (27.4%) (Figure 3).

3.2. Factor Analysis of Perceptions

A PCA was performed using all active variables related to hazard perception, perceived hazard frequency, perceived increase in hazards, and experienced impacts. The first two dimensions explained 20.3% and 11.8% of the total inertia, respectively (Figure 4).

3.2.1. Contribution of Variables to Dimension 1

Table 2 presents the ten variables with the highest contributions to the construction of Dimension 1, which accounts for 20.3% of the total inertia.

As shown in Table 2, Dimension 1 is primarily structured by the overall perception of impacts (18.83%), migration (17.13%), and drought (11.30%). It contrasts respondents reporting strong perceptions of climate-related impacts (multiple impacts, drought, income

loss, and migration) with those reporting lower levels of concern. Therefore, this dimension represents a gradient of perceived climate risk intensity that is strongly associated with socioeconomic consequences.

Table 1. Distribution of natural hazard indicators by spatial category and urbanization level in Zio Prefecture (%).

Indicator	Center (Spatial, n = 144)	Large Settlements (Urbaniza-tion, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbaniza-tion, n = 133)	Zio Prefecture (n = 423)
Pluvial flooding	18.1	18.5	12.1	25	16.9	9.8	16.1
River flooding	32.6	41.5	26.2	65	37.2	10.5	32.9
Drought	67.4	59.3	76.6	10	59.9	90.2	66.7
Extreme heat	83.3	73.0	85.0	85	75.6	95.5	80.6
Storms	17.4	21.5	15.0	45	24.4	12.0	19.6
Vegetation fires	7.6	13.3	15.9	30	19.8	15.0	14.7
Other	0.7	1.9	1.9	0	1.7	0.8	1.4

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

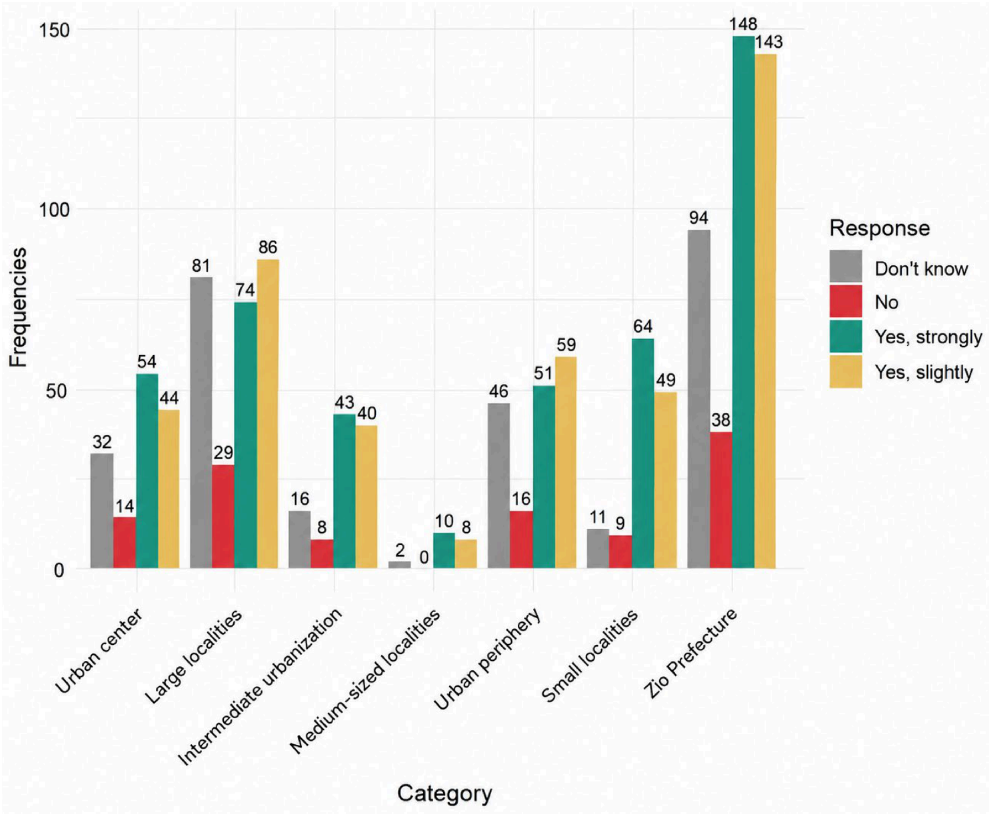

Figure 3. Distribution of respondents' perceptions of the increase in climate hazards.

3.2.2. Contribution of Variables to Dimension 2

Table 3 presents the ten variables with the highest contributions to the construction of dimension 2, which accounts for 11.8% of the total inertia.

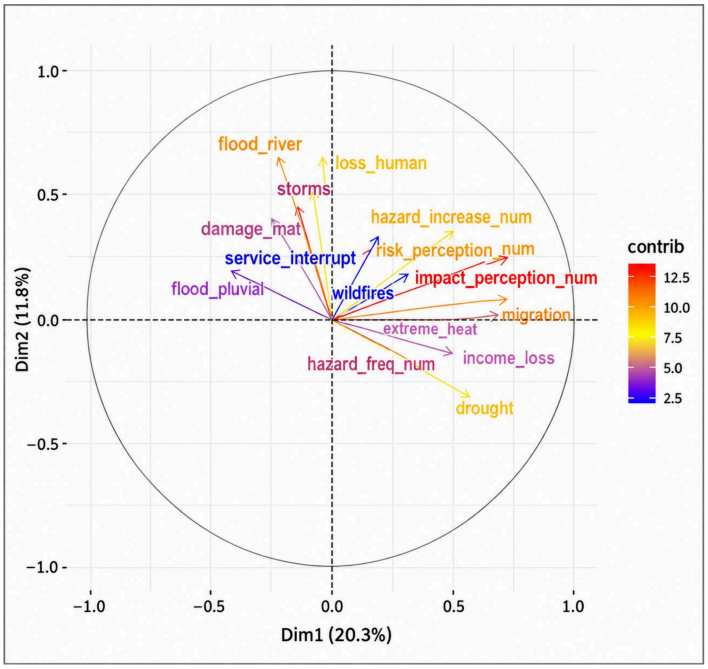

Figure 4. Projection of hazard and impact variables on the first two dimensions of a PCA.

Table 2. Contribution of active variables to dimension 1 (20.3%) of the PCA.

Rank	Variable	Contribution (%)
1	Overall perception of impacts	18.83
2	Migration	17.13
3	Drought	11.30
4	Risk perception	9.63
5	Extreme heat	8.02
6	Income loss	7.38
7	Perceived increase in hazards	7.15
8	Perceived hazard frequency	7.05
9	Pluvial flooding	5.73
10	Wildfires	2.51

Table 3. Contribution of active variables to dimension 2 (11.8%) of the PCA.

Rank	Variable	Contribution (%)
1	River flooding	23.59
2	Human losses	21.14
3	Storms	11.94
4	Material damage	10.09
5	Perceived increase in hazards	6.84
6	Risk perception	6.22
7	Service interruption	4.81
8	Overall perception of impacts	4.33
9	Drought	4.30
10	Perceived hazard frequency	2.32

Table 3 shows that dimension 2 is mainly driven by river flooding (23.59%), human losses (21.14%), storms (11.94%), and material damage (10.09%). This dimension distinguishes respondents who associate climate risks with sudden and destructive events from those who do not. It therefore reflects an acute severity component of climate hazards, distinct from the more chronic and socioeconomic dimension represented by dimension 1.

3.2.3. Projection of Variables and Overall Interpretation

The graphical projection in Figure 4 shows a clear differentiation between the two dimensions. Dimension 1 is positively associated with drought, income losses, migration, and extreme heat, indicating a common perception structure centered on longer-term climate impacts and associated economic and social consequences. In contrast, river flooding, human losses, storms, and material damage are more strongly associated with dimension 2, reflecting a perception structure focused on acute hydrometeorological hazards and their immediate consequences. Perceived increase in climate hazard intensity or frequency and overall climate risk perception contribute to both dimensions, with contributions of 9.63% and 7.15% to Dimension 1 and 7.15% and 6.84% to dimension 2, respectively. Their contribution to both dimensions suggests that perceptions of increasing climate risks and overall risk perception constitute cross-cutting concerns that are not limited to a specific type or temporal dimension of climate hazard. Overall, the projection indicates that respondents' perceptions of climate risk are structured around two complementary dimensions: one associated primarily with longer-term socioeconomic impacts and another with acute hazard events and their immediate consequences.

3.3. Perception of Exposure by Municipality (Dimension 1)

Figure 5 presents the coordinates of the four municipalities of Zio Prefecture on dimension 1 of the factor analysis, which summarizes the perceived intensity of climate risks, income losses, and migration, in accordance with the high contributions of these variables shown in Table 2.

The results reveal a clear gradient among the municipalities along Dimension 1. Zio 4 Municipality has the highest coordinate on Dimension 1, indicating a particularly strong perception of income losses, drought, and climate-related migration. This pattern may be related to the municipality's predominantly rural context and the importance of rain-fed agricultural activities, although these mechanisms were not directly assessed in the present study. Zio 2 Municipality also displays a relatively high positive coordinate, suggesting a strong perception of chronic climate risks. Its peri-urban context and continuing association with agricultural activities may contribute to this pattern, although this interpretation should be considered as a plausible explanation rather than an objectively established determinant of perceived sensitivity. Zio 3 Municipality exhibits a moderate coordinate on Dimension 1, while respondents tend to associate climate risks more strongly with acute events, particularly flooding, storms, and human losses, as reflected by the contributions of these variables to dimension 2 (Table 3). In contrast, Zio 1 Municipality, corresponding to the main urban center, has the lowest and slightly negative coordinate on Dimension 1, indicating comparatively weaker perceptions of income losses and climate-related migration. This pattern may be associated with greater economic diversification and access to services and social support mechanisms, although these factors were not directly measured in the present study. Overall, the municipal gradient suggests that perceptions of chronic climate impacts vary across the territory, with stronger associations with socioeconomic consequences in Zio 4 and Zio 2 and a greater emphasis on acute climate events in Zio 3.

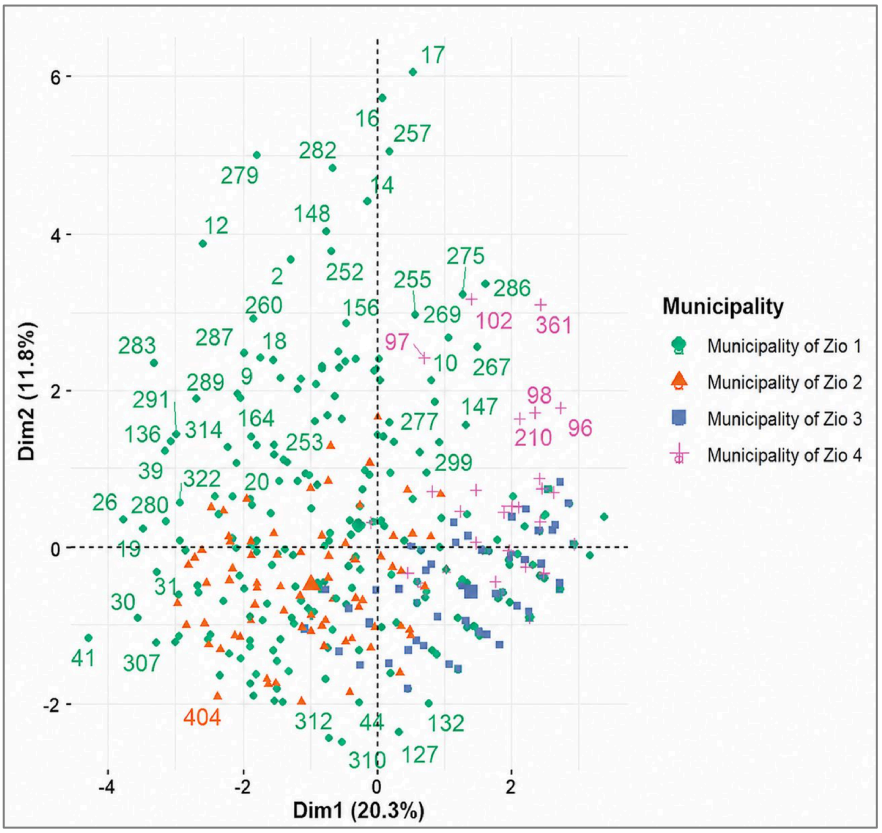

Figure 5. Perceptions of Municipal Exposure Along the First Principal Component of the PCA.

Overall, dimension 1 clearly differentiates the municipalities along a rural–urban gradient: the more rural and remote a municipality is from the urban center, the stronger the perceived chronic climate risks and associated economic losses.

3.4. Perceived Sensitivity of Urban Systems and Social Groups

3.4.1. Vulnerable Populations

Women were identified as the social group most vulnerable to climate risks across all areas, with proportions ranging from 66.9% in the peripheral zone to 74.3% in the central zone. According to the second spatial classification based on the level of urbanization, the perceived vulnerability of women reached 89.5% in small settlements, compared with only 25.0% in medium-sized settlements (Table 4).

Residents living in high-risk areas (flood-prone zones and unstable slopes) were also perceived as highly vulnerable, particularly in the intermediate zone and medium-sized settlements, with reported proportions of 55.1% and 90.0%, respectively. Although the differences among zones were not statistically significant for this indicator ($p = 0.1358$), the observed trends suggest a higher perceived vulnerability in the less urbanized areas.

3.4.2. Vulnerable Infrastructure

Housing is perceived as the most vulnerable infrastructure, particularly across the center–periphery gradient (72.2% in the center, 65.4% in the intermediate zone, and 58.7% in the periphery). Under the urban-size classification, this perception reaches 91.0% in small settlements. Roads rank second, with 63.2%, 57.9%, and 64.5% of respondents in the center, intermediate, and peripheral zones, respectively, considering them vulnerable according to the first classification. Under the second classification, 100% of respondents in medium-sized settlements perceive roads as vulnerable. Electricity infrastructure is

mentioned less frequently, with perceived vulnerability ranging from 37.2% to 55.0% across the different strata (Table 5).

Table 4. Distribution of Vulnerable Groups in Zio Prefecture (%).

Group	Center (Spatial, n = 144)	Large Settlements (Urbanization, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbanization, n = 133)	Zio Prefecture (n = 423)
Women	74.3	65.6	73.8	25	66.9	89.5	71.2
Children	70.8	56.3	72.9	40	56.4	88.0	65.5
Older Adults	67.4	52.6	63.6	50	53.5	78.9	60.8
Persons with Disabilities	59.0	40.4	51.4	45	43.0	72.2	50.6
Households with low incomes	66.0	47.8	60.7	45	48.3	78.9	57.4
Residents of risk-prone areas	56.3	35.6	55.1	90	45.9	78.9	51.8

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

Table 5. Perceived vulnerability of infrastructure in Zio Prefecture (%).

Infrastructure	Center (Spatial, n = 144)	Large Settlements (Urbanization, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbanization, n = 133)	Zio Prefecture (n = 423)
Water	50.0	45.9	64.5	35	51.2	73.7	54.1
Electricity	40.3	41.5	49.5	55	37.2	39.1	41.4
Roads	63.2	63.3	57.9	100	64.5	54.9	62.4
Schools	54.9	39.6	38.3	60	40.7	53.4	44.9
Settlements	72.2	53.0	65.4	55	58.7	91.0	65.0
Others	13.2	4.1	9.3	10	5.8	19.5	9.2

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

3.5. Sensitivity to Impacts by Area Type (Dimension 2)

Figure 6 presents the coordinates on dimension 2 according to area type (urban, peri-urban, and rural). This dimension captures the perception of extreme hydrometeorological hazards (river flooding, storms, human losses, and material damage), whose contributions are detailed in Table 3. The results reveal a clear differentiation among the three area types. Peri-urban areas display the highest coordinate on Dimension 2. Respondents in these areas report stronger perceptions of acute hazards, particularly flash floods and storms. This pattern may be related to the transitional character of peri-urban environments, where agricultural activities coexist with ongoing urban expansion and where respondents may perceive drainage and other protective measures as insufficient. Urban areas (city centers) also exhibit a positive coordinate on Dimension 2, although lower than that of peri-urban areas. Residents of urban centers report acute hazards, particularly pluvial flooding and service disruptions, but their perceptions may be influenced by differences in access to infrastructure and services. Overall, these results suggest that perceived sensitivity to acute climate impacts varies not only with the degree of urbanization but also with geographical context and respondents' assessments of infrastructure and protective measures. However,

because the study did not objectively assess drainage capacity, infrastructure quality, land-use planning, or physical hazard exposure, these interpretations should be considered hypotheses requiring further empirical validation.

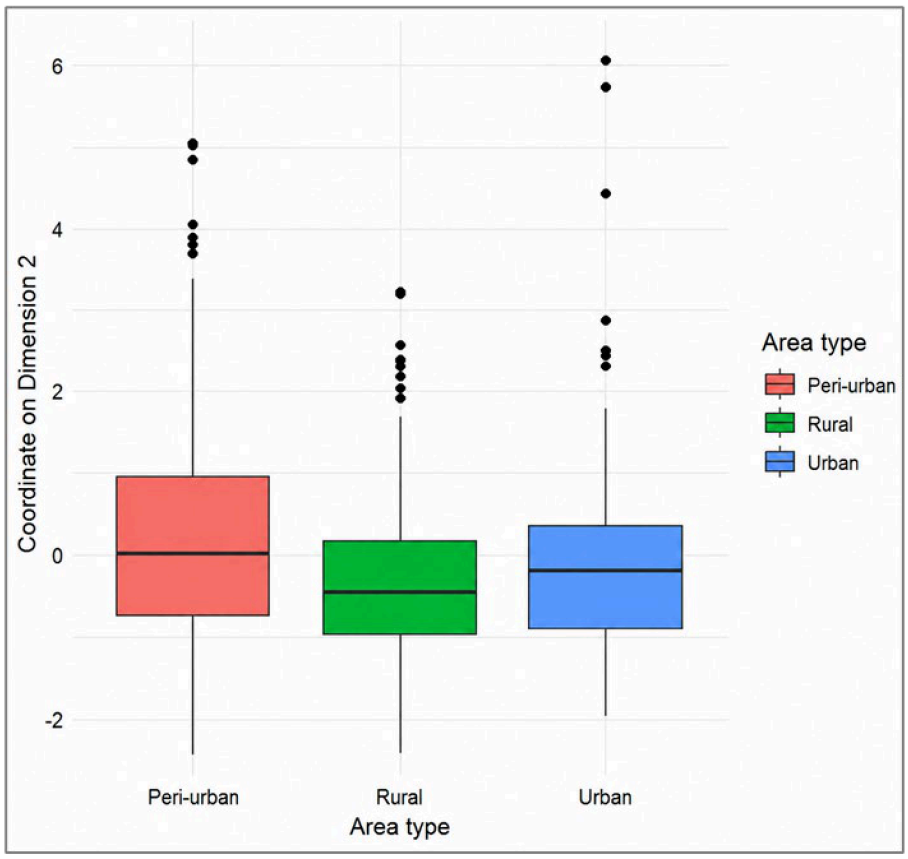

Figure 6. Sensitivity to Climate Impacts by Area Type Along the Second Dimension.

3.6. Synthesis of Determinants by Municipality and Area Type

A comparison of the results presented in Figures 4 and 5 with the socioeconomic data allows the identification of a cross-classified typology (Table 6).

Table 6. Typology of Perceptions by Municipality and Area Type.

Municipality	Position on Dimension 1 (Chronic Risks)	Position on Dimension 2 (Acute Risks)	Dominant Profile
Zio 1 Municipality	Low	Moderate	Moderate/diverse perception
Zio 2 Municipality	High	High	Mixed perception (chronic and acute risks)
Zio 3 Municipality	Moderate	Very high	Acute (hydrometeorological) risk perception
Zio 4 Municipality	Very high	Moderate	Chronic (agricultural) risk perception

The χ^2 tests revealed a significant association between municipality of residence and the perception of drought ($p < 0.001$). The factor analyses, whose variable contributions are presented in Tables 2 and 3, confirm that risk perception jointly depends on: the type of hazard (chronic versus extreme); the municipality of residence, which may capture differences in perceived exposure, infrastructure conditions, and economic structure; and

the type of area (urban, peri-urban, or rural), which is associated with differences in perceived exposure and adaptive capacity; and perceptions of exposure and sensitivity vary significantly according to both municipality and area type within Zio Prefecture, confirming the hypothesis of intra-territorial heterogeneity in representations of climate risks.

3.7. Recent Impacts and Determinants of Risk Perceptions

3.7.1. Experienced Impacts

Income loss was the most frequently reported impact, affecting between 70% and 80% of households depending on the area. Migration rates were higher in intermediate (46.7%) and central (43.8%) areas than in peripheral areas (32.0%) according to the first classification, whereas the opposite pattern was observed in the second classification, with migration reaching 78.2% in small settlements compared with 20.7% in large settlements (Table 7). Material damage was more common in intermediate areas (42.1% and 85.0%, depending on the classification). Human losses were relatively rare but occurred more frequently in peripheral areas (10.5%) and medium-sized settlements (40.0%).

Table 7. Distribution of Climate Hazard Impacts Reported by Respondents in Zio Prefecture (%).

Type of Impact	Center (Spatial, n = 144)	Large Settlements (Urbanization, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbanization, n = 133)	Zio Prefecture (n = 423)
Material damage	30.6	39.6	42.1	85	39.0	24.1	36.9
Human losses	6.3	7.0	4.7	40	10.5	3.8	7.6
Service interruption	30.6	30.0	31.8	0	23.3	27.8	27.9
Income loss	75.7	68.9	70.1	60	70.3	80.5	72.1
Migration	43.8	20.7	46.7	40	32.0	78.2	39.7
No impact	12.5	8.1	8.4	10	8.7	13.5	9.9

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

3.7.2. Socioeconomic and Institutional Determinants

The dominant economic activities differed across areas: trade was more common in central areas (70.8%), whereas agriculture and livestock farming predominated in peripheral areas (57.6% in the first classification and 60.2% in the second classification) (Table 8). The most frequently cited adaptation measures were awareness-raising (61.8% in central areas, 57.0% in intermediate areas, and 45.3% in peripheral areas) and drainage (32.6–39.0%) (Table 9). Retention basins were reported more frequently in peripheral areas (21.5%) according to the spatial classification, whereas under the urbanization-based classification, they were reported most frequently in medium-sized settlements (30.0%). Relocation remained marginal (<5%).

External support following climate hazards was generally limited across Zio prefecture. A majority of respondents reported receiving no assistance, with the proportion ranging from 54.9% in small settlements to 70.3% in peripheral areas (Table 10). Among those who received support, government assistance was the most frequently reported source in central areas (15.3%), intermediate areas (15.9%), medium-sized settlements (15.0%), peripheral areas (13.4%), and small settlements (21.1%). In contrast, NGOs were the dominant source of support in large settlements, where 30.0% of respondents reported receiving assistance. Inter-municipal cooperation and private-sector support were generally reported at much lower levels across all settlement categories.

Table 8. Main Economic Activities of Respondents (%).

Activity	Center (Spatial, n = 144)	Large Settlements (Urbanization, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbanization, n = 133)	Zio Prefecture (n = 423)
Agriculture/livestock farming	53.5	50.0	43.9	40	57.6	60.2	52.7
Fishing	0.7	5.6	9.3	0	4.1	2.3	4.3
Trade	70.8	55.2	56.1	40	52.9	72.2	59.8
Industry	19.4	18.1	23.4	10	12.2	17.3	17.5
Other activity	21.5	13.7	18.7	35	13.4	22.6	17.5

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

Table 9. Adaptation Measures Reported by Respondents Against Climate Hazards (%).

Adaptation Measure	Center (Spatial, n = 144)	Large Settlements (Urbanization, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbanization, n = 133)	Zio Prefecture (n = 423)
Drainage	32.6	47.8	33.6	60	39.0	6.8	35.5
Revegetation	31.3	28.9	35.5	25	38.4	49.6	35.2
Retention basins	13.9	18.1	8.4	30	21.5	8.3	15.6
Early warning systems	6.3	6.3	3.7	45	9.9	3.0	7.1
Relocalization	4.2	3.7	3.7	0	3.5	4.5	3.8
Awareness-raising	61.8	34.4	57.0	80	45.3	89.5	53.9
Economic diversification	18.1	11.1	16.8	10	12.8	25.6	15.6

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

Table 10. External Support Received by Populations in Response to Climate Hazards in Zio Prefecture (%).

Entity	Center (Spatial, n = 144)	Large Settlements (Urbanization, n = 270)	Intermediate (Spatial, n = 107)	Medium-Sized Settlements (Urbanization, n = 20)	Periphery (Spatial, n = 172)	Small Settlements (Urbanization, n = 133)	Zio Prefecture (n = 423)
None	68.1	60.4	62.6	65.0	70.3	54.9	67.6
Inter-municipal cooperation	9.0	0.7	5.6	0.0	2.3	13.5	5.4
Government	15.3	8.1	15.9	15.0	13.4	21.1	14.7
NGOs	6.9	30.0	12.1	15.0	12.2	7.5	10.4
Private sector	0.7	0.7	3.7	5.0	1.7	3.0	1.9

Note: Values are percentages of respondents within each subgroup. n denotes the number of valid respondents contributing to the corresponding estimate.

3.7.3. Factors Influencing Risk Perceptions

The χ^2 tests revealed a significant association between residential area and the perception of drought ($p < 0.001$), but no significant association with the perception of living

in a risk-prone area (p = 0.1358). Although not measured directly, access to information appears to play an important role: respondents from central areas, which are generally better served by communication infrastructure, more frequently reported a strong increase in climate hazards. Conversely, residents of less urbanized settlements, who are more heavily dependent on agriculture, exhibited higher perceived sensitivity regarding housing damage and income loss.

4. Discussion

4.1. Spatial Variation in the Perception of Climate Hazards

The results show that drought is the most frequently perceived climate hazard, particularly in rural and peri-urban settlements, reaching up to 90.2% in small settlements. This predominance of drought in local perceptions is consistent with the findings of Tschakert et al. [53] in Senegal and Ghana, where rural communities identified water scarcity as the most visible manifestation of climate change. Similarly, Zougmoré et al. [54] reported that rainfall variability and recurrent droughts constitute the principal climate stresses perceived by farmers across West Africa because of their direct impacts on agricultural productivity and livelihoods.

In contrast, storms and river flooding are more frequently perceived in intermediate and peri-urban areas. This pattern is consistent with the literature showing that rapid and poorly planned urbanization can increase flood exposure through mechanisms such as soil sealing, obstruction of natural drainage systems, and settlement in flood-prone areas [55]. In Togo, a study conducted by researchers at the University of Lomé; ref. [56] showed that the occurrence of droughts and floods negatively affects household resilience to climate change, highlighting the importance of economic diversification as a means of reducing vulnerability.

The near unanimity of respondents (more than 95%) in describing climate hazards as "very frequent" reflects widespread awareness of the accelerating pace of climate-related events. This finding is consistent with the projections of the IPCC [2], which indicate an intensification of extreme events across West Africa, and with the perceptions documented by Niang et al. [57] in the coastal regions of Benin and Togo.

4.2. Perceived Sensitivity: Women, Residents of High-Risk Areas, and Housing

The identification of women as the most vulnerable social group (reaching 89.5% in small settlements) is a robust finding that is strongly supported by the literature. Rao et al. [58] demonstrated that gender inequalities in access to resources, information, and decision-making processes exacerbate women's vulnerability to climate hazards. More recently, Njuki et al. [59] showed that climate change increases women's domestic and agricultural workloads, thereby reducing their adaptive capacity. In Togo, a study examining the determinants of climate change perception found that gender significantly influences risk perception, with men being more engaged in climate-dependent activities such as agriculture.

The high perceived vulnerability of residents living in areas identified by respondents as high-risk reflects strong awareness of perceived exposure to flooding and other potentially hazardous environmental conditions. Satterthwaite [60] argued that poor urban populations in developing countries are often compelled to settle in hazardous areas because affordable land alternatives are unavailable. Likewise, Adger et al. [61] demonstrated that perceptions of residential vulnerability are strongly associated with previous exposure to damaging events, a finding that is supported by the material damage reported in the intermediate areas of the present study.

Housing and road infrastructure were perceived as the most vulnerable types of infrastructure, particularly in small settlements. These findings are consistent with those of Cutter et al. [62], who emphasized that housing quality— including the use of fragile construction materials and inadequate foundations, as well as the condition of road networks—are major determinants of vulnerability to floods and storms.

4.3. Multidimensional Structure of Risk Perceptions: A Dual Chronic and Acute Component

The PCA identified two main dimensions structuring respondents' perceptions. Dimension 1 (20.3% of the total inertia), dominated by the overall perception of impacts, migration, drought, and income loss, represents the chronic and socioeconomic component of climate risks. This dimension reflects concerns about slow-onset processes whose cumulative effects undermine livelihoods. Barnett and O'Neill [63] previously emphasized that climate-induced migration is more often a delayed response to chronic stresses (declining agricultural productivity and resource depletion) than to isolated extreme events.

Dimension 2 (11.8% of the total inertia), dominated by river flooding, human losses, storms, and material damage, represents the acute and hydrometeorological component of climate risks. This duality of risk perceptions has been documented by Howe et al. [64] in a meta-analysis covering 33 countries, showing that populations clearly distinguish between chronic stresses and extreme shocks, with different implications for adaptation strategies. Similarly, Van Valkengoed and Steg [65] demonstrated that the perception of acute risks (e.g., flash floods) is more strongly associated with individual adaptation behaviors, such as elevating houses or constructing embankments, whereas the perception of chronic risks (e.g., drought and rising temperatures) tends to stimulate collective and institutional adaptation measures, including water resource management and agricultural diversification.

4.4. Municipal and Area-Type Disparities: Evidence of Intra-Territorial Heterogeneity

The projection of municipalities on Dimension 1 revealed a rural–urban gradient: the more rural and remote a municipality is from the urban center, the stronger the perception of chronic climate risks, as illustrated by Zio 4 Municipality. This finding is consistent with the territorial vulnerability framework proposed by Birkmann et al. [66], which argues that isolated rural areas combine high dependence on natural resources, limited economic diversification, and restricted access to adaptation services, thereby intensifying perceptions of chronic climate risks. Zio 3 Municipality is characterized by a particularly strong perception of acute risks, notably flooding and storms, which may be related to its geographical context and respondents' perceptions of exposure to coastal and fluvial hazards. Reference [67] highlights that the coastal areas of West Africa, particularly the Togolese coastline, are recognized as vulnerability hotspots because of sea-level rise and severe storm events, leading to significant human and material losses. The peri-urban area (Zio 2 Municipality) exhibits high scores on both Dimensions 1 and 2, indicating a mixed perception of chronic and acute climate risks. This pattern may be explained by the transitional nature of these areas, which remain partly agricultural and therefore may be perceived as sensitive to drought, while simultaneously undergoing urbanization. Respondents' stronger perception of flooding in these areas may also reflect concerns about the adequacy of drainage and other protective infrastructure. Allen [68] describes African urban peripheries as "zones of vulnerability", where inherited rural risks overlap with emerging urban hazards. By contrast, the central urban area (Zio 1 Municipality) displays relatively moderate perceptions on both dimensions. This pattern may be associated with greater access to services and infrastructure, as well as greater economic diversification, although these mechanisms were not directly assessed in the present study. Nevertheless, service interruptions (30.0%) and the perceived strong increase in climate hazards (37.5%)

remain major concerns, consistent with the findings of Lwasa et al. [69], who highlighted the hidden vulnerabilities of African urban centers, including fragile electricity networks and inadequate drainage systems.

4.5. Socioeconomic and Institutional Drivers of Risk Perceptions

Climate risk perceptions are significantly shaped by both socioeconomic and institutional factors. Agriculture remains the dominant livelihood activity (52.7% of households) and is associated with stronger perceptions of drought and income loss, particularly in small settlements, where 80.5% of respondents reported income losses owing to climate hazards. This reflects the direct dependence of agricultural production on rainfall patterns [54]. Previous studies conducted in Togo have similarly shown that households affected by droughts or floods perceive climate change as having a greater impact on their livelihoods. In contrast, households primarily engaged in trade tend to perceive flooding and service disruptions as more significant threats.

From an institutional perspective, external support following climate hazards remains limited across Zio Prefecture, with 67.6% of respondents reporting that they received no assistance. Government assistance was the most frequently reported source overall (14.7%) and was particularly prominent in small settlements (21.1%), as well as in central (15.3%), intermediate (15.9%), medium-sized (15.0%), and peripheral areas (13.4%). NGOs constituted an important source of support in large settlements, where 30.0% of respondents reported receiving assistance, substantially higher than the pre-fectural average of 10.4%. Inter-municipal cooperation and private-sector support remained comparatively limited, although inter-municipal cooperation was relatively more common in small settlements (13.5%). These findings indicate that institutional support is not only limited in overall coverage but also varies considerably according to settlement characteristics. The high proportion of households receiving no assistance suggests gaps in the reach and territorial distribution of post-hazard support, while the concentration of NGO assistance in large settlements may reflect differences in the presence or accessibility of non-governmental interventions.

5. Conclusions

This study examined perceptions of climate-risk exposure, sensitivity, and vulnerability across the urban centers of Zio Prefecture, Togo, using a household survey of 423 respondents. The findings demonstrate substantial spatial and socioeconomic differentiation in the perception of climate risks across municipalities and settlement types. Extreme heat (80.6%) and drought (66.7%) were the most widely perceived hazards, while drought perception was particularly high in small settlements (90.2%). In contrast, storms and river flooding were more frequently perceived in intermediate and peri-urban areas. The principal component analysis identified two complementary dimensions of climate-risk perception: a chronic socioeconomic dimension associated mainly with drought, income loss, and migration, and an acute hydrometeorological dimension associated with flooding, storms, and human losses. Zio 4 and Zio 2 showed stronger perceptions of chronic climate risks, whereas Zio 3 was more strongly associated with acute hazards.

The results further indicate that perceived vulnerability is strongly linked to social and livelihood conditions. Women were consistently identified as the most vulnerable social group, while residents living in risk-prone areas were also perceived as particularly vulnerable. Housing and roads were identified as the most vulnerable infrastructure, and income loss was the most frequently reported climate-related impact. The importance of agriculture and livestock as major livelihood activities further highlights the sensitivity of local households to climate variability, particularly drought and its associated socioeco-

nomic consequences. At the institutional level, the large proportion of households reporting no external assistance indicates gaps in the coverage and territorial distribution of climate-risk support, while the involvement of government institutions and NGOs varied across settlement types.

These findings have important implications for climate-risk management and urban resilience planning in Zio Prefecture. The observed spatial heterogeneity indicates that adaptation strategies should be territorially differentiated rather than implemented through a uniform prefecture-wide approach. Responses to chronic risks such as drought and income loss should include livelihood diversification, social protection, and measures that strengthen the resilience of climate-sensitive economic activities. Acute risks such as flooding and storms require complementary structural and non-structural measures, including improved drainage and flood-management infrastructure, early-warning systems, and accessible climate-risk information. Given the high perceived vulnerability of women, adaptation interventions should also incorporate gender-responsive measures and strengthen women's access to resources, capacity building, and participation in decision-making. Furthermore, stronger coordination among government institutions, municipalities, NGOs, and other stakeholders could improve the reach and territorial equity of climate-risk assistance, particularly in less-served settlements.

Several limitations should nevertheless be considered when interpreting these findings. The cross-sectional design captures perceptions at a specific point in time and therefore cannot account for temporal changes in risk perception. The reliance on self-reported perceptions may also introduce reporting and perception-related biases. In addition, the study did not incorporate objective measures of hazard exposure, such as rainfall records, flood hazard maps, or detailed infrastructure assessments, which limits direct validation of the reported perceptions. Although the sample provides evidence for households within Zio Prefecture, the findings should not be generalized to the whole of Togo.

Future research should therefore combine perception-based assessments with objective climatic, environmental, and spatial data to provide a more comprehensive assessment of climate vulnerability. Integrating rainfall and flood records, hazard mapping, land-use information, infrastructure assessments, and longitudinal household data would help distinguish perceived vulnerability from objectively measured exposure and examine how risk perceptions evolve over time. Overall, this study provides empirical evidence of the spatial and social heterogeneity of climate-risk perceptions in Zio Prefecture and demonstrates the importance of incorporating local perceptions into territorially differentiated, socially responsive, and evidence-based climate adaptation planning.

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