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Climate induced flooding exposure among urban residents in Uganda

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Abstract

Climate prone cities' capacities to undertake effective adaptive actions are deeply shaped by how different actors are exposed to hazards. This cross-sectional mixed-methods study investigates exposure of urban residents to climate-induced flooding in Uganda, with GKMA and Kasese urban areas as study sites. Using household survey data from 939 respondents, consultations with municipal and local council leaders, and 12 focus group discussions, the study explores how exposure to flood hazards shape urban risk. Flood risk profiles differ, GKMA is primarily affected by rapid-onset flash and pluvial floods, whereas Kasese faces recurrent, longer-lasting riverine floods associated with more severe infrastructure damage, displacement, injury, and mortality. Geographical location and flood characteristics were the dominant predictors of reported flood severity, with households in Kira (APR = 1.53, p = 0.006) and Kasese (APR = 1.34, p = 0.050) reporting higher severity, instantaneous and rapid floods showing consistently elevated risks compared to slow on-set events (instantaneous: PRR = 1.60, 95% CI: 1.34–1.92, p < 0.001; APR = 1.34, 95% CI: 1.09–1.64, p = 0.005; rapid: PRR = 1.51, 95% CI: 1.26–1.82, p < 0.001; APR = 1.26, 95% CI: 1.02–1.54, p = 0.028), and moderate flooding frequency associated with lower severity (APR = 0.73, 95% CI: 0.54–0.99, p = 0.042). Flooding severity is shaped primarily by local spatial and hydrological conditions, calling for place-specific, community-centered adaptation. In GKMA, priority pathways include drainage expansion, wetlands restoration and informal settlements upgrading while in Kasese, effective adaptation hinges on upstream catchment management, river control flash-flood early warning systems and retreat management in highly active floodplains.

1. Introduction

Flooding is one of the greatest environmental challenges facing urban areas today, as cities increasingly experience more frequent and intense hydrometeorological extremes compounded by climate change. In cities worldwide, flood hazards are amplified by rising temperatures, altered precipitation patterns, sea-level rise and changing storm regimes. Yet, rapid urbanization, land use change and the expanding impervious surfaces accelerate runoff, overload ageing or undersized drainage systems and cause overflow of water resources [1], [2], [3]. Projections suggest that exposure to 1-in-100-year flood hazard could rise from 1.6 to 1.9 billion people by 2100, with the largest rises in low-GDP regions, already vulnerable urban areas [4], [5]. Evidence from Europe, Asia and beyond indicates climate change and urban development jointly drive compounding pluvial, fluvial and coastal flood risk [6], [7], [8], resulting in health, social and economic impacts that disproportionately affect marginalized groups [9], [10], [11]. Although research on modelling, low-impact development, nature-based solutions and vulnerability is expanding, major gaps remain in documenting lived experiences and translation of such knowledge into effective, equitable and climate-resilient urban governance [1], [12], [13].

Rapid and often unplanned urbanization, combined with climate change has made urban flooding one of the most pressing environmental and socio-economic challenges in Sub-Saharan Africa (SSA). Floods are the most frequent disaster in the region and have increased in both number and affected population over recent decades [14], [15], [16]. Studies closely attribute this trend to changes in extreme rainfall associated with climate change, together with expansion of impervious surfaces, encroachment on waterways and wetlands and inadequate drainage infrastructure in cities [14], [17], [18]. Consequently, urban residents in African cities face recurrent flood events that disrupt everyday life, damage assets and infrastructure and escalate pre-existing social inequalities [3], [19], [20]. For East and West African cities, climate change is already altering rainfall regimes, with more intense and sometimes more frequent heavy episodes that trigger flash floods in densely built environments [17], [21], [22]. Hydrometeorological trends create particular risks in cities like Kampala and secondary urban centers such as Kasese, where drainage systems, land use planning and basic services have not kept pace with rapid demographic and spatial growth [3], [23], [24].

Urban flood risk in African cities is not only from climate and hydrological factors but is produced through urbanization processes and uneven development. Expansion of built-up areas into low-lying and flood-prone zones without adequate drainage increases exposure of housing, roads, and public infrastructure to inundation [15], [19]. In Antananarivo, 32% of the city's population and nearly a quarter of buildings now lie in flood-prone zones [22]. Similar encroachment on wetlands, riverbanks, and retention areas in Accra and Lagos has expanded flood risk across central and peri-urban neighborhoods, compounded by fragmented, weak governance [25], [26]. These dynamics create vulnerability hotspots, particularly in low-income settlements marked by insecure tenure, poor housing, degraded ecosystems and lack of basic services [3], [27], [28]. Studies highlight how poverty, marginalization, weak regulation and limited adaptive capacity drive vulnerability [29], with poorer residents disproportionately settled in hazardous locations and lacking resources to cope, reinforcing environmental injustice [15], [25], [26]. Evidence from Kampala's informal settlements links flood exposure and sensitivity to income, education, informal employment, insecure housing and degraded local ecosystems [3]. Across African cities, inadequate drainage, poor solid waste management and weak institutional coordination further intensify localized flood impacts [30].

A growing body of work highlights the importance of characterizing flood events by severity, frequency, duration and spatial extent to better understand risk and inform planning. Recent assessments show that urban floods in Africa are becoming more frequent and severe, increasing the number of affected people and the scale of economic losses [16], [17], [31]. In Kano, frequency-based flood mapping identified extensive areas exposed to 2-100 year floods, implying large populations at risk [31]. Hydrological and spatial analyses in West African Coastal cities like Abidjan and Saint-Louis reveal that key infrastructure and residential neighborhoods often fall within inundation zones, with up to 64% of flooded regions in Abidjan located in such communities [32], [33]. In the Accra city region, over 80% of roads in some Areas flood regularly, disrupting mobility and access [33]. Flood duration further shapes the impacts i.e., in Ouagadougo, even short-storms can cause long-lasting inundation due to inadequate drainage (Miller et al., 2022). While flood severity is typically linked to water depth, velocity and damage, moderate rainfall can lead to destructive floods where drainage is inadequate and ecological buffers are encroached. Over half of flood events occur under normal rainfall conditions, underscoring the critical role of urban design [17], while residents report severe impacts such as rapid water rise, structural collapses and asset losses.

Urban floods in SSA deeply affect health, livelihoods, housing and social well-being. Evidence highlights extensive property destructions, loss of goods, land erosion, and reduced economic productivity as people struggle to work, live and trade during flood events [29], [34]. In cities such as Kumasi, recurrent floods drive major asset losses and declining output, prompting temporary migration and dependence on family support, while residents of Ibadan and Lagos

frequently loose belongings, triggering localized humanitarian crises [16], [35]. Health effects, including injuries, respiratory and diarrheal diseases and psychological distress are increasingly recognized yet remain under-researched. Studies from Accra, Mombasa and Kampala link stagnant waters to water pollution and vector-borne diseases with disproportionate burdens in low-income communities [14], [21], [29], [36], [37], [38], [39], [40]. Lived experiences research further shows that, despite awareness of flood causes and impacts, residents largely depend on small-scale coping strategies because of weak institutional support, limited early warning, low trust and poor information access constrain effective response [3], [28], [35].

Urban flooding and climate risk research in Africa cities has expanded rapidly but still largely focuses on physical hazard dimensions. Most studies privilege hydrological and coupled hydrologic-hydraulic models to analyse floodplain dynamics, streamflow and inundation under climate change [41], [42]. Remote sensing and satellite products such as Sentinel, Landsat, MODIS, and drones, integrated with Geographic Information Systems (GIS) are widely applied to delineate flood extent, map hotspots and generate hydrologic inputs where in situ data are scarce [43], [44], [45], [46], [47], [48]. In parallel, numerous assessments adopt high-level vulnerability and risk frameworks that combine hazard, exposure and vulnerability through indicator-based indices, impact chains, AHP/fuzzy logic and multi-criteria evaluation at basin, regional or community scales [45], [49], [50], [51], [52], [53], [54]. The existing literature on urban flooding in African cities is dominated by biophysical and model-driven analyses, with comparatively little attention to local experiences and lived realities of affected communities. Yet, urban residents possess detailed knowledge of flood pathways, hotspots and impacts, revealing inequalities that remain invisible in standard technical assessments. To depart from dominant methodologies, this paper assesses climate change exposure, with a focus on flood hazards and their impacts in the Kampala city region and Kasese. It documents residents' experiences of flood hazards, characterizing flood events, identifying impact hotspots, and evaluating the associated socio-economic and health consequences.

Moving beyond dominant, technocratic approaches [16], [55], [56], this paper foregrounds urban residents' lived experiences, reported interpretations and qualitative perceptions of flood risks. While emerging work highlights local narratives, storytelling, gendered experiences and indigenous knowledge in cities such as Lusaka, Nairobi, Kigali and Cape Town [56], [57], [58], [59], [60], there is still limited empirical evidence on how city dwellers describe flood types and characteristics (including severity, frequency, timing, duration) as well as which spaces are most affected and how impact patterns vary across neighborhoods and city types [28], [40], [61], [62]. In general, research shows that vulnerability in African cities is shaped by socio-economic status, informality, land governance and everyday practices, and emphasize participatory approaches that socially construct vulnerability with "risk bearers" rather than deriving it solely from biophysical indicators [3], [19], [27], [62]. However, localized ways of knowing remain weakly integrated in formal planning, disaster risk reduction and climate agenda, leading to top-down interventions that often fail to address the lived realities of vulnerable communities.

Although studies in Kasese and Kampala identifies floods as frequent and severe risks for the urban poor [3], [34], [63], there is no empirical evidence on how residents articulate flood events characteristics, hazard hotspots and multi-dimensional impacts. Resident-centered studies are particularly scarce for the expanding urban councils in Greater Kampala Metropolitan Area (GKMA) and secondary municipalities such as Kasese. This gap constrains planners' and policymakers' ability to co-produce adaptation strategies with communities, tailor interventions to neighborhood-level risk patterns and address questions of justice and recognition in climate-resilient urban development [26], [64], [65], [66]. Against this backdrop, this study aims to; (1) determine the climate hazards experienced by residents in GKMA and Kasese municipality, (2) characterize and examine flood events based on people's perceived severity, frequency, speed of onset and duration, (3) identify flood impacts hotspots and assess the socio-economic and health consequences associated with floods.

3. Materials and Methods

3.1 Study design and area context

The study employed a cross-sectional descriptive and analytical design, combining quantitative and qualitative approaches to determine climate change impacts on urban populations. It focused on identifying the various climate hazards experienced, characterizing floods and associated consequences in past 10 years in two Uganda urban contexts i.e., the Greater Kampala Metropolitan Area (GKMA) and Kasese municipality (Fig. 1), both highly vulnerable to climate change [23], [67], [68], [69].

GKMA, situated on the northern shores of Lake Victoria, covers about 1,000 km^2 and hosts over 6.4 million people. It comprises Kampala capital city, three districts (Mukono, Wakiso and Mpigi) and five municipalities (Entebbe, Kira, Makindye-Ssabagabo) [69], [70]. Rapid population growth, unplanned expansion, extensive impervious surfaces and settlement in low-lying wetlands increase surface runoff and flash flooding [3]. Informality is widespread i.e., around 60% of settlements and 80% businesses [71], with dense slums in flood-prone areas, an outdated drainage system and frequent drain blockages by solid waste further heightening flood risk [3], [72].

Kasese municipality, north of Lake George in western Uganda, has expanded from fewer than 20,000 residents in 1991 to approximately 132,184 [70]. Typical of many small and mid-sized African cities, it faces housing, infrastructure and services deficits alongside high poverty. While most households have piped water and generally dispose of waste appropriately, access to health facilities remains limited and a small fraction still lack toilets [24]. According to Nedala et al., (2025), the municipality is highly exposed to riverine and flash floods driven by intense rainfall and steep catchments. Since 2012, recurrent flooding along River Nyamwamba has destroyed settlements, livelihoods and critical infrastructure including health facilities, schools and roads and has been linked to cholera and malaria outbreaks, as well as psychosocial and mental-health impacts among affected residents [73].

3.3 Data collection

3.3.1 Sampling procedure for household surveys

The study applied a multi-stage sampling strategy to obtain representative samples across the study area and to capture variation in climate vulnerability. First, potential urban study centers were identified using existing information on climate vulnerability and hazards/risks from the Office of the Prime Minister (OPM), published literature on climate change, vulnerability assessments and hazard and risk profiles. Second, divisions and parishes/wards that are disproportionately affected by climate-related hazards were identified through consultations that occurred between May 2024 and June 2025, with municipal urban councils in the two selected study cities. In each city, officers from the physical planning, environment, community development and health departments were engaged to identify specific parishes where data should be collected (See Table 1). The reviews and consultations led to the selection of urban councils like Kampala, Makindye-Ssabagabo, Nansana, Kira, and Kasese as study sites (See Table 1). In Kasese, a disaster-displaced camp located outside the municipality was also included to capture the experiences of urban residents displaced by the 2020 floods.

The sample size was determined using the household statistics from the latest UBOS census data [70], estimating N = 139,429 for GKMA and N = 33,663 for Kasese (See Table 1). Using the [74] equation, produced a total of 939 surveys, distributed as 481 for GKMA and 458 for Kasese. Within each urban council, a proportionate sampling strategy was then applied at the parish/ward level, with allocation also adjusted to account for varying climate risk exposures (See Table 1).

2.3.3 Household surveys

A total of 939 household (HH) surveys were administered in Kampala city region/GKMA and Kasese municipality between August 2025 and November 2025 to capture quantitative data on socio-demographic and economic characteristics, and self-reported experiences of climate change-related extreme weather events, reported flood characteristics, spaces most affected by floods and main effects of floods in neighborhoods. For climate extremes, the survey initially focused on three including floods, heatwaves and drought as shown in nation and Inter-Governmental Panel on Climate Change (IPCC). However, after consultations and piloting, consistent distinction between short ‘rainstorms’ from medium-length ‘dry spells and prolonged ‘drought’. Such differences were locally meaningful and observed across urban councils hence, adding ‘rainstorm’ and ‘dry spell’ were added as separate, interviewer-defined response options, with open-ended answers later mapped onto them. Since these two categories are more subjective than the others, they are interpreted mainly as indicators of perceived weather anomalies rather than strict meteorological events.

Flood characteristics were specified in advance using standard flood-risk terminology, refined by insights from literature and consultations. Four standard dimensions including severity, frequency, onset and duration were organised and ordered into survey-friendly categories that mirrored 4–5-points Likert-type scales and using descriptive wording instead of numbers. To match local ways of speaking, each dimensions combined several near-synonymous terms explored in literature and consultations (such as ‘severe/acute/serious for severity). Enumerators read the full descriptors and could paraphrase them in local language to preserve the intended ordering, which response categories were coded numerically to facilitate analysis.

Vulnerable spaces were derived from standard land-use/elements-at-risk classifications widely used in flood vulnerability and economic loss assessments, alongside consultations with urban councils. Studies routinely distinguish residential, commercial, infrastructure/transport, public facilities and green/agricultural areas because these land uses have systematically different patterns of exposure, damage and risk [75], [76], [77]. Infrastructure and public facilities like roads, schools, health centers, government buildings are treated as separate classes since their failure amplifies community-level vulnerability [78], [79]. In line with this literature, six hotspot types were defined prior data collection i.e., residential areas, commercial areas/corridors. Infrastructure, public buildings, recreation areas, and gardens/farms, adapting generic land-use schemes used in urban flood risk mapping to the Ugandan context. Although data were collected through a HH survey, questions on hotspots explicitly asked respondents to report places in their neighbourhoods where they personally experienced or regularly observed flooding, not only inside their dwelling. Similar HH-based approaches are used to capture local knowledge of flood-prone roads, schools, markets and farms and to link household vulnerability with spatial exposure patterns. Respondents’ reports therefore reflect user-centered exposure to different land-use types rather than a full physical inventory.

An ArcGIS spatially generated 50*50-meter grid squares with centroids on the street map of study settlements was used to select households for survey administration. A nearest household was preferred in contexts where a centroid was situated on an open space, parking lot or swampy area without habitable structures. Data was collected by trained enumerators, using Kobo Collect and Open Data Kit (ODK) applications, allowing for efficient and systematic gathering of field data through mobile devices, reducing entry errors and facilitating real-time data synchronization for timely analysis.

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Table 1
Population and sample size for administering household surveys.

(Adapted from [70] census)

Urban Councils	Population	Household Population	Division/s	Population	Household population	Parishes/Wards	Population	Household population**	Sample size
Kampala	1,509,750	529,059	Kawempe	300,663	102,319	Bwaise I	16,441	6,345	101
						Bwaise III	7,153	2,897	
			Nakawa	386,536	134,015	Mbuya II	48,913	16,530	98
						Banda	28,813	12,185	
			Makindye	425,888	149,805	Bukasa	8,162	2,467	90
						Salaama	34,182	11,535	
Makindye Ssabagabo	393,319	114,527	Masajja	181,699	53,343	Masajja	35,861	10,831	91
						Namasuba	61,353	18,946	
Nansana	609,021	195,699	Nabweru	205,679	64,091	Nabweru-North	33,064	11,416	53
						Nabweru-South	21,273	7,673	
Kira	396,189	134,369	Namugongo	164,833	59,302	Kireka	104,341	38,604	48
Sub-Total	**2,908,279**	**973,654**	**Sub-Total**	**1,665,298**	**562,875**	**Sub-Total**	**339,556**	**139,429**	**481**
Kasese	132,184	34,697	Nyamwamba	70,189	19,207	Nyakasanga II, Nyakasanga III, Kanyangeya, Nyakasanga I, Kisanga, Kihara	54,139	20,058	226
			Central	47,942	12,031	Base Camp, Kirembe, Nyakabingo II, Railway	39,760	9,768	118
			Bulembia	14,053	3,459	Kyanjuki, Katiri, Namuhuga, Nyakabinjo III	14,053	3,549	65
Muhokya Town Council*	Approx. 1000	288	Muhokya IDP camp	Approx. 1000	288	IDP Camp	1000	288	48
Sub-Total	133,184	34,985	Sub-Total	133,184	34,985	Sub-Total	108,952	33,663	458
Overall Total	3,041,463	1,008,639	Overall Total	1,798,482	597,860	Overall Total	448,508	173,092	939

Note: * Population statistics captured through consultations; **Parish/Ward household population used to calculate sample size proportionately

3.3.4 Focus Group Discussions

Focus group discussions (FGDs) were conducted in both the GKMA and Kasese municipality. In total, twelve (12) FGDs were held, six (6) in each study site, comprising of between 8–10 participants selected purposively to capture a range of flood related experiences. The criteria for participant selection based on being a resident with direct flood experience and/or roles in disaster preparedness, health, social support, local governance, youth representation, social action groups or as refugees, flood-displaced or differently abled persons. In Kasese, FGDs were conducted separately with members of Village Disaster Preparedness Committees (VDPCs), Village Health Teams (VHTs), Para-Social Workers, local leaders, youth representatives and flood displaced persons. In GKMA, FGDs involved local residents (including refugees), Local Council 1 (LC1) leaders, climate change champions, VHTs, social action groups (SAGs) and differently abled persons (DAPs). The FGDs in GKMA were held at a community centre in one of the wards/parishes in each division (See Table 1), while in Kasese, these were conducted at the urban council's central division hall. Discussions were predominantly conducted in local languages for example "Luganda" in GKMA and "Rukonzo" and "Luganda" with only youths and VHTs in Kasese, except for LC1s interactions that used both English and a local language. Author One facilitated all the FGDs, although an experienced translator supported engagements in Kasese. Each discussion lasted between 1 hour 30 minutes and 2 hours 15 minutes, and was audio-recorded using a Sony digital voice recorder, with participants' written and oral consent. The FGDs explored community experiences of the different flood types, their perceived characteristics (severity, frequency, speed of onset and duration), neighborhoods and spaces disproportionately affected and associated outcomes over the past 10 years.

3.4 Data Analysis

Stata Version 15 was used for all quantitative analyses. Descriptive statistics in form of frequencies and percentages were generated to summarise socio-demographic and economic characteristics, climate change impacts experiences and perceived flood characteristics including severity, frequency, speed of onset and duration, flood hot spots and impacts. Descriptive statistics and chi-square tests were applied for variables with sufficiently large expected counts,

while Fisher's exact test was used for variables with small expected cell counts to ensure accurate p-values. Chi-square analysis was conducted across all data collected. To examine associations between categorical variables, the Pearson's chi-square tests were applied when expected cell counts were sufficiently large (all expected counts ≥ 5) and Fisher's exact test when any expected cell count was < 5, in order to obtain accurate p-values. Chi-square analyses were conducted across all relevant variables to assess associations between socio-demographic/economic characteristics, reported climate change events, and flood-related characteristics and experiences. All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant.

Further, the analysis also centered on exposure to flood severity as an outcome variable defined through respondents' self-reported experiences. This variable was recorded into a binary format, with 79% of the respondents reporting severe flooding (coded as 1) and 21% indicating less severe flooding (coded as 0). Key household and demographic, and exposure as well as flood characteristics variables were considered in the analysis, with assumed relationship to flood severity drawn from literature (See Appendix I). Such variables included; household size, duration of residence, migration status (born in the area or not), monthly income, municipality of residence, education level, sex of household head, productive assets and flood event characteristics such as frequency, speed of onset and duration (See Table 2). To analyze the data, a modified Poisson regression model was selected within a generalized linear model (GLM) framework due to the high prevalence of severe flooding, which can lead to the overestimation of odds ratios in logistic models.

The model assumes that the expected value of the outcome Y_i for the i^{th}observation, denoted $\mu_{i} = E\left[\frac{Y_i}{X_i}\right]$ is related to the predictors through a log link function:

$$\log(\mu_{i}) = \beta_0 + \beta_1 X_{j1} + \beta_2 X_{j2} + \ldots + \beta_p X_{jp}$$

Where: β_0 is the intercept, β_j represents the effect of the j^{th} predictor X_j, and p is the total number of predictors included in the model. Exponentiating the coefficients (e^{β_j}), provides the risk ratio associated with a one-unit increase in the corresponding predictor, adjusting for all other variables in the model. This approach facilitated direct estimation of prevalence ratios for better interpretability.

The strengths of the modified Poisson model include its ability to provide relative risk estimates free from the limitations of the odds ratio and its resistance to convergence issues seen in log-binomial regression. The model has been found to be reliable in risk estimation studies [80], [81] and currently deployed in flood impact assessments [82], [83], [84]. The model-building strategy comprised fitting bivariate modified Poisson models to evaluate unadjusted associations and utilizing Wald tests for assessing joint significance of categorical variables. A stepwise refinement process was implemented to address confounding factors, culminating in a final model that included all variables under consideration (Supplementary file I) while avoiding overfitting. This comprehensive approach ensured that the analysis effectively captures the nuances of flood severity within the study population.

FGDs recordings were transcribed verbatim and imported into using Nvivo 15 for systematic organisation and coding, with the main author leading the analysis, assisted by a junior researcher. Data gathered in local language were translated during transcribing and later subjected to validation by two enumerators, fluent in respective languages and who participated in the data collection process. The coding followed a predominantly inductive approach, beginning with independent line-by-line open coding on a subset of transcripts to identify recurring ideas about flood types, frequency, onset and duration, perceived severity, affected locations as well as socio-economic and health impacts These were then reconciled and refined into a shared coding framework. Subsequently, a more deductive approach was applied across all transcripts, with flexibility to add new codes where needed put into consideration. Higher-level themes were shaped by the study objectives and literature on urban flood risk and social vulnerability. NVivo supported data organisation and pattern querying, while interpretive analysis drew on manual review of exported code reports, analytic memos and cross-group comparisons. Qualitative findings were very limitedly used to triangulate and contextualize survey results, with illustrative quotations selectively included to highlight key statistical patterns rather than provide an exhaustive narrative.

4. Results

4.1 Socio-demographics and economic characteristics of respondents

Table 2 shows the socio-demographic and economic characteristics of the respondents across urban councils in GKMA and Kasese municipality.

Table 2
Socio-demographic and economic characteristics of respondents in urban councils of GKMA and Kasese (n = 939)

Respondent characteristics	Category	Overall (Freq; %)	Kampala (Freq; %)	Makindye-Ssabagabo (Freq; %)	Kira (Freq; %)	Nansana (Freq; %)	Kasese (Freq; %)	p-value
Sex	Female	659(70)	213 (74)	69 (76)	25 (52)	30 (57)	320(70)	**0.004***
	Male	280(30)	76 (26)	22 (24)	23 (48)	23 (43)	136(30)	
Age	18–35	435(47)	154 (54)	41 (46)	29 (60)	23 (43)	188(42)	**0.001***
	36–60	438(47)	122 (43)	48 (53)	19 (40)	24 (45)	223(50)	
	> 60	298(32)	10 (4)	1 (1)	0 (0)	6 (11)	36(8)	
Migration status	Migrant	464(49)	192 (66)	38 (42)	30 (63)	17 (32)	186(41)	**< 0.001***
	Non-migrant	475(51)	97 (34)	53 (58)	18 (38)	36 (68)	270(59)	
Head of household	No	426(46)	139 (48)	40 (44)	23 (48)	20 (38)	204(45)	0.666
	Yes	513(54)	150 (52)	51 (56)	25 (52)	33 (62)	252(55)	
Sex of household head	Female	298(32)	96 (33)	32 (35)	7 (15)	13 (25)	148 (32)	0.069
	Male	641(68)	193 (67)	59 (65)	41 (85)	40 (75)	308 (68)	
Marital status	Divorced	15(2)	3 (1)	1 (1)	0 (0)	2 (4)	9 (2)	**< 0.001***
	Living together	362(39))	120 (42)	43 (47)	23 (48)	21 (40)	155 (34)	
	Married	256(27)	47 (16)	18 (20)	8 (17)	14 (26)	169 (37)	
	Never married	105(11)	41 (14)	3 (3)	6 (13)	6 (11)	47 (10)	
	Separated	124(13)	47 (16)	21 (23)	8 (17)	6 (11)	42 (9)	
	Widowed	77(8)	31 (11)	5 (5)	3 (6)	4 (8)	34 (7)	
Highest education level	None	134(14)	40 (14)	5 (5)	3 (6)	6 (11)	80 (18)	**0.010***
	Primary	342(36)	108 (37)	27 (30)	15 (31)	17 (32)	174 (38)	
	Secondary (A)	61(6)	24 (8)	6 (7)	3 (6)	5 (9)	23 (5)	
	Secondary (O)	287(31)	88 (30)	42 (46)	22 (46)	15 (28)	119 (26)	
	Diploma/Tertiary	82(9)	20 (7)	6 (7)	4 (8)	6 (11)	46 (10)	
	Vocational	33(4)	9 (3)	5 (5)	1 (2)	4 (8)	14 (3)	
Household monthly income	< 150,000	186(20)	185 (64)	63 (69)	37 (77)	33 (62)	244 (54)	**< 0.001***
	150,000–500,000	563(60)	45 (16)	21 (23)	5 (10)	11 (21)	59 (13)	
	500,001–1,500,000	142(15)	46 (16)	6 (7)	5 (10)	4 (8)	125 (27)	
	> 1,500,000	16(2)	6 (2)	0 (0)	0 (0)	0 (0)	10 (2)	
	Don't Know/Prefer not to say	32(3)	7 (2)	1 (1)	1 (2)	5 (9)	18 (4)	
Main income source	Business	452(48)	162 (56)	55 (60)	28 (58)	21 (40)	185 (41)	**0.001***
	Casual labor	334(36)	88 (30)	25 (27)	13 (27)	25 (47)	182 (40)	
	Formal employment	84(9)	24 (8)	8 (9)	47 (10)	4 (8)	47 (10)	
	Other	36(4)	6 (2)	3 (3)	24 (5)	1 (2)	24 (5)	
	Remittances	33(4)	9 (3)	0 (0)	18 (4)	2 (4)	18(4)	

A total of 939 respondents were analysed across five urban councils (Kampala, n = 289; Makindye-Ssabagabo, n = 91; Kira, n = 48; Nansana, n = 53; and Kasese, n = 458) (See Table 2). In general, 659 (70%) respondents were female. Three sites like Kampala, Makindye-Ssabagabo and Kasese had more strongly feminised samples (around 70–76% female), while the other two GKMA sites (Kira and Nansana) were more gender-balanced (52–57% female; p = 0.004). This pattern likely reflects the recruitment times and locations, which tended to find more women at home during daytime hours and a relatively high share of female-headed households in several sites.

Age distributions differed significantly across urban councils (p = 0.0001). Below half of respondents were 18–35 years overall (47%), with younger adults more common in Kira and Kampala, while Kasese had comparatively more respondents aged 36–60 and ≥ 60 years, indicating an older profile.

Migration status also varied ($p < 0.001$). About half of respondents were in-migrants (49%), but GKMA site such as Kampala and Kira had higher proportions of migrants (66% and 63% respectively), whereas Kasese (59%) and Nansana (68%) had more long-term or locally born residents, suggesting stronger place attachment and social networks in these latter areas.

Household roles were broadly similar across urban councils. Slightly above average respondents were household heads (54%), and around two-thirds of households were male-headed (68%), with only modest variation by urban council.

Marital status showed clear heterogeneity ($p < 0.001$). Across all sites, cohabiting and married respondents together formed the largest group, but Kasese had a relatively higher share of married respondents, while separation and never-married status were more concentrated in some GKMA sites.

Educational attainment differed significantly ($p = 0.010$). Secondary education (especially O-Level) was the most common level attained in general but Kasese had a noticeably higher proportion of respondents with only primary or no formal education, whereas Kampala-area municipalities had more respondents with secondary and post-secondary schooling.

Economic indicators also varied. Most households reported monthly incomes between 150,000 and 500,000 UGX (60%), but the distribution differed significantly across sites ($p < 0.001$), with Kasese having the largest share of very low-income households (< 150,000 UGX) and GKMA urban councils contributing a large proportion of middle-income and higher-income households.

Main income sources ($p = 0.001$) were split between business (48%) and casual labour (36%) overall. Business activities predominated in several GKMA sites and in parts of Kasese, whereas casual labour was particularly common in Kasese and Nansana, underscoring the more precarious livelihoods in these municipalities.

Conclusively, these patterns indicate substantial socio-demographic and economic diversity between the GKMA urban councils and Kasese, with implications for differential climate change hazards and more particularly flood exposure, sensitivity and severity explored in subsequent analyses.

4.2 Climate change-related extreme weather events experienced by urban residents in Kampala city region and Kasese municipality

Table 3 shows the self-reported climate-related extreme weather events experienced by residents in GKMA and Kasese municipality in the past 10 years.

Table 3
Climate-related extreme weather events experienced by residents in GKMA and Kasese municipality (n = 939)

Extreme weather events	Overall (Freq.; %)	Kampala (Freq.; %)	Makindye Ssabagabo (Freq.; %)	Kira (Freq.; %)	Nansana (Freq.; %)	Kasese (Freq.; %)	p-value
Floods	923	289	91	48	52	441	**0.007***
	(98)	(100)	(100)	(100)	(98)	(97)	
Rainstorms	438	164	42	26	20	184	**< 0.001***
	(47)	(57)	(46)	(54)	(38)	(40)	
Heatwaves	370	101	34	9	19	205	**0.002***
	(39)	(35)	(37)	(19)	(36)	(45)	
Dry spells	259	69	24	6	10	149	**0.004***
	(28)	(24)	(26)	(13)	(19)	(33)	
Drought	226	26	15	1	3	181	**< 0.001***
	(24)	(9)	(17)	(2)	(6)	(40)	

The findings in Table 3 showed that flooding is the predominant climate hazard, impacting 98% of households, indicating severe and recurrent risks in both the Kampala city region and Kasese municipality ($p = 0.007$). FGDs revealed that floods mainly arise from inadequate drainage, rapid urbanization which has increased impervious surfaces, degradation of wetlands and hillslopes as key water holding towers and intense rainfall patterns. Rainstorms reportedly affected 47% of households, indicating challenges faced by urban neighborhoods from severe storm events that can damage housing and infrastructure ($p < 0.001$). Further, heatwaves were reported by 39% households, particularly in Kasese where cases are slightly below average (45%), signaling emerging thermal stress concerns ($p = 0.002$). Notably, 28% of households experienced dry spells, with Kasese reporting the highest rate at 33% ($p = 0.004$), and 24% reported drought conditions. Households in Kasese also showed higher exposure to drought conditions at 40% compared to its minimal occurrences in Kampala city region sites (2% in Kira, $p < 0.001$). These findings reflect a situation where communities confront both water excess through flooding and water scarcity from droughts, revealing increasing climate variability and unpredictability that could significantly impact household food security, health, and community well-being. Given that floods were the most widely reported extreme weather event, we turn to a deeper consideration of how these were experienced and where the greatest vulnerabilities lie.

4.2.1 Types of floods experienced in Kampala city region and Kasese municipality

Qualitative data illuminate ways how people make sense of floods through shedding light on understandings and description of flood events that almost all households in the survey reported experiencing. FGDs and consultations across the GKMA and Kasese municipality showed that residents distinguish floods

by source (rainfall, river bank overflow, or lake level rise), location/terrain and speed of onset, aligning with findings that communities in Africa describe floods through their own experiences and local categories rather than formal typologies [15], [27].

It was established that Kampala city has and continues to grapple with recurrent flooding patterns which respondents primarily characterised as flash floods and pluvial (urban) floods, especially during the rainy seasons from March to May and September to November. Technical officers across urban councils indicated that the flood occurrence is becoming difficult to ascertain due to variability in rainfall and temperature throughout the year, which has led to the development of floods even after a single downpour.

Local leaders in Makindye Ssabagabo, Bwaise, Nabweru and Kireka emphasized that rapid-onset flash floods caused by intense rainfall, steep slopes and concentrated runoff from hilly neighborhoods (for example; Banda, Mbuya II, Salaama, Bwaise II and Namasuba). Similar combinations of steep terrain, intense rain and undersized or clogged drains have been shown to trigger flash and pluvial flooding in other African cities [15], [85], [86].

Residents attributed pluvial/urban flooding to rainfall exceeding drainage capacity, wetland and hilltop degradation and indiscriminate dumping of solid waste in drains and channels. Such narratives are consistent with studies highlighting wetland encroachment, inadequate drainage and waste blocking waterways as central drivers of Kampala's and Other SSA cities' floods [37], [86], [87].

Though less frequent, some respondents also recognized riverine flooding along major channels such as Lubigi, Nakivubo, Nakamiro, Kawooya/Kinawataka, Nalukolongo, Kansanga, Lufuka Nyanama-Walufumbe and tributaries to connect to River Mayanja (Nansana and parts of Mpigi town council), Kame valley and channels around Namanve industrial areas (Mukono municipality), Nalubaaga, Lwajali and Nakalele (Kira). Besides, lake-level rise driven flooding along Lake Victoria were also reported in neighborhoods surrounding the lake. Such findings reflect literature that suggests that African cities often face overlapping fluvial, pluvial and lake/coastal flood hazards [27], [86], [88]. The quote below illustrates that, during an FGD with residents in Banda, participants identified pluvial flood conditions:

"We are at a steep slope, and when it rains heavily, the water flows rapidly to the lower side where Kawooya channel is located…… there is a lot of bottles and other wastes, and sand which make the channel to overflow into people's homes"

In Kasese, communities and officials primarily identified fluvial (riverine) floods from major rivers such as Nyamwamba, Mubuku, Nyamugasani and Lhubiriha, driven by heavy rainfall in the Rwenzori mountains, ice melt and landscape degradation. It was also indicated that flash floods are common, occurring due high intensity and short duration rainfall in the mountains that result in rapid and often destructive rises in water levels. Urban/pluvial floods were presented by residents/communities and officials as a persistently localized issue mainly in Nyamwamba division. Further, they also reported mudflows at the Muhokya IDP camp to be triggered by heavy rainfall that saturates soil, prompting rapid move downslope as a mixture of water, mud, and debris. These findings correspond with existing descriptions of riverine floods as gradual overbank flows after prolonged or intense rainfall and yet localized urban/pluvial floods mirror distinctions made elsewhere between flash floods from small steep catchments and riverine floods from larger rivers [59], [85]. The Environment Officer of Kasese described floods as follows;

"For the past 12 years, River Nyamwamba has been flooding yearly…… in some moments, water come rushing down at a high speed…… the channel cannot absorb all of it…. It overflows into people's home and around the town… the small and poor drainage cannot redirect the water elsewhere, making almost the entire town flooded…at times, we might be sitting here at the council offices, and we just see water flowing from up".

The findings show that flood exposure in GKMA and Kasese cannot be understood through single-hazard, mainly fluvial lenses but instead emerges from interacting pluvial, fluvial, flash and lake-related processes. Residents' accounts reveal how different sources of water, terrains and drainage conditions combine to generate compound flood situations, implying that exposure is co-produced by natural dynamics., informal urbanisation, weak planning and inadequate waste management rather than rainfall alone. Community narratives help trace how everyday decisions about settlement, land use and infrastructure intersect with topography, wetlands and waterways/drainage to shape who and what is at risk.

4.3 Understanding flood characteristics: Severity, frequency, speed of onset, and duration of floods

Table 4 shows the reported characteristics of flood events from the respondents' perspectives including severity, frequency, speed of onset and duration over the past 10 years in GKMA metropolitan area and Kasese municipality.

Table 4
Reported flood characteristics experienced by residents in GKMA and Kasese municipality over the last 10 years

Flood characteristics	Urban councils					P-value	Comparison		P-value
	Kampala (Freq.; %)	Makindye Ssbagabo (Freq.; %)	Nansana (Freq.; %)	Kira (Freq.; %)	Kasese (Freq.; %)		GKMA (Freq.; %)	Kasese (Freq.; %)	
Flood severity									
Catastrophic	132 (46)	5 (5)	9 (17)	7 (15)	168 (37)	**< 0.001***	153 (32)	168 (37)	0.376
Severe	105 (36)	56 (62)	21 (40)	36 (75)	196 (43)		218 (45)	196 (43)	
Moderate	45 (16)	18 (20)	13 (25)	4 (8)	70 (15)		80 (17)	70 (15)	
Minor	7 (2)	12 (13)	10 (19)	1 (2)	22 (5)		30 (6)	22 (5)	
Flood frequency									
Frequent	277 (96)	87 (96)	53 (100)	48 (100)	392 (86)	**< 0.001***	465 (97)	392 (86)	**< 0.001***
Occasional	10 (3)	3 (3)	0 (0)	0 (0)	51 (11)		13 (3)	51 (11)	
Infrequent	2 (1)	1 (1)	0 (0)	0 (0)	8 (2)		3 (1)	8 (2)	
Very rare	0 (0)	0 (0)	0 (0)	0 (0)	5 (1)		0 (0)	5 (1)	
Speed of onset									
Instantaneous (minutes)	144 (50)	32 (35)	14 (26)	20 (42)	193 (42)	**0.009***	210 (44)	193 (42)	**0.032***
Rapid (hours)	115 (40)	43 (47)	29 (55)	25 (52)	198 (43)		212 (44)	198 (43)	
Gradual (days)	29 (10)	15 (16)	10 (19)	3 (6)	52 (11)		57 (12)	52 (11)	
Other	1 (0)	1 (1)	0 (0)	0 (0)	13 (3)		2 (0)	13 (3)	
Flood duration									
< 24 hours	141 (49)	56 (62)	43 (81)	25 (52)	115 (25)	**< 0.001***	265 (55)	115 (25)	**< 0.001***
1 day – 1 week	132 (46)	33 (36)	10 (19)	20 (42)	289 (63)		195 (41)	289 (63)	
> 1 week	14 (5)	1 (1)	0 (0)	3 (6)	36 (8)		18 (4)	36 (8)	
Several weeks to months	2 (1)	1 (1)	0 (0)	0 (0)	16 (4)		3 (1)	16 (4)	

Table 4 manifest significant differences across sites in experiences of flood severity, frequency, rapidity and duration. In terms of flood severity, households in the two big urban councils of Kampala city and Kasese municipality reported the highest rate of catastrophic or disastrous flooding (46% and 37% respectively), while the other sites ranged from only 5–17% ($p < 0.001$). Reports of severe or acute levels of flooding were highest in Kira (75%) and Makindye Ssabagabo (62%), with other sites between 36–43%.

Frequent floods were generally very high, reported by 96–100% households across all sites except Kasese where it was 86% ($p < 0.001$). The reported speed of flood onset where floods instantly appear in minutes following a downpour was highest in Kampala city (50%), compared to only 26–42% in the other sites ($p = 0.009$). Rapid flooding (within hours) was also reported by 20–55% respondents across all sites. Experiences of flood duration showed the most differentiation, with only 25% in Kasese reporting floods lasting less than 24 hours while all other sites reported much higher proportions of short floods, with Nansana at the other end of the spectrum reporting 81% floods lasting less than 24 hours ($p < 0.001$). There were almost no reports, in any site, of floods lasting more than 1 week.

Flood patterns across GKMA as a whole with Kasese municipality shows that the p-values correspond to χ^2 tests of difference between the aggregated GKMA percentages and Kasese for each category (e.g. catastrophic flooding: 32% GKMA vs 37% Kasese, $p = 0.376$; frequent flooding: 97% vs 86%, $p < 0.001$; instantaneous onset: 44% vs 42%, $p = 0.032$; floods < 24 hours: 55% vs 25%, $p < 0.001$). These results indicate that, although nearly all sites experience frequent flooding, the GKMA typically faces rapid-onset floods that recede quickly, whereas floods in Kasese are more likely to be longer-lasting.

4.4 Flood severity, hotspots and vulnerability

4.4.1 Predicted flood severity in GKMA and Kasese

Table 5 indicates the PRRs for reported flood severity as determined by socio-demographics, economic and flood characteristics in GKMA and Kasese municipality. Socio-demographic and economic characteristics showed limited independent effects. Household size, productive asset ownership, sex of respondent, migration status, sex of household head, and duration of residence were not significantly associated with flood severity in either the unadjusted or adjusted models, ($p > 0.05$), suggesting that these demographic factors may not independently shape reporting on severity patterns of flooding. In the unadjusted analysis, higher household income was associated with lower flood severity reporting, with households earning between UGX 150,000–500,000 and UGX 500,000–1,500,000 experiencing 11% and 13% less severe floods compared to the lowest income group that are more likely to be exposed to acute and moderate levels of flood severity (PRR = 0.89, 95% CI: 0.83–0.96, p = 0.002; PRR = 0.87, 95% CI: 0.78–0.97, p = 0.013). However, these associations became non-significant after adjustment (p = 0.226 and p = 0.752, respectively), suggesting that the apparent protective effect of income is largely explained by spatial and environmental factors. It is worth noting that households earning more than UGX 1,500,000 showed a strong but borderline reduction in flood severity exposure patterns post-adjustment (unadjusted PRR = 0.65, 95% CI: 0.42–1.01, p = 0.056; adjusted APR = 0.56, 95% CI: 0.31–1.04, p = 0.066).By contrast, respondents who were unsure of their income tended to reported acute/catastrophic severity of flood exposure, with borderline evidence of increased risk after adjustment (APR = 1.20, 95% CI: 0.99–1.44, p = 0.060).

Geographical location and flood characteristics remained strong predictors of flood severity after adjustment. Compared to the reference urban council (Makindye-Ssabagabo), households in Kira were around 50% more likely to experience severe flooding (APR ≈ 1.53, p = 0.006), and residents of Kasese had about one-third higher severity with borderline significance (APR ≈ 1.34, p = 0.050). Associations for Kampala and Nansana were weaker and did not remain statistically significant in adjusted models, although point estimates suggested higher severity in Kampala and lower severity in Nansana.

Flood characteristics were the strongest predictors and most consistent predictors of flood severity. Instantaneous floods (occurring within minutes) and rapid floods (within hours) were associated with substantially higher severity compared to slow-onset events, both before and after adjustment (instantaneous: PRR = 1.60, 95% CI: 1.34–1.92, p < 0.001; APR = 1.34, 95% CI: 1.09–1.64, p = 0.005; rapid: PRR = 1.51, 95% CI: 1.26–1.82, p < 0.001; APR = 1.26, 95% CI: 1.02–1.54, p = 0.028). Short-term floods lasting less than 24 hours were associated with lower severity (PRR = 0.78, 95% CI: 0.72–0.84, p < 0.001; APR = 0.81, 95% CI: 0.72–0.91, p < 0.001), whereas persistent floods lasting several weeks to months showed higher severity in the unadjusted model (PRR = 1.17, 95% CI: 1.12–1.21, p < 0.001), although this association attenuated and became non-significant after adjustment (APR = 1.13, 95% CI: 0.97–1.32, p = 0.118). Areas with moderate flooding frequency had lower severity than those with frequent flooding in both models (unadjusted PPR = 0.74, 95% CI: 0.61–0.91, p = 0.005; APR = 0.73, 95% CI: 0.54–0.99, p = 0.042), suggesting that communities exposed to regular but moderate events may have developed adaptive measures that reduce prevalence of severe impacts.

These findings indicate that once spatial and exposure conditions are accounted for, socio-demographic characteristics have relatively modest independent effects on reported flood severity. Instead, where people live and the specific characteristics of the floods, they experience especially frequency, rapidity and duration are the dominant drivers of severe flood impacts in Uganda's urban centers.

Table 5
PRRs for predicted flood severity in GKMA and Kasese

Variable	Category	Unadjusted PPR (95% CI)	p-value	Adjusted PRR (95% CI)	p-value
Household size	4–6 members	1.00 (0.92–1.09)	0.992	1.04 (0.92–1.17)	0.523
	≥ 7 members	0.99 (0.91–1.08)	0.851	1.07 (0.93–1.23)	0.341
Productive assets category	Medium	1.06 (0.98–1.14)	0.176	1.00 (0.89–1.13)	0.961
	High	0.97 (0.89–1.06)	0.478	0.97 (0.85–1.11)	0.628
Sex of respondent	Male	0.99 (0.92–1.06)	0.761	0.98 (0.87–1.11)	0.733
Migration status	Non-migrant	1.05 (0.98–1.12)	0.146	-	
Duration of stay	4–10 years	0.96 (0.83–1.11)	0.569	0.94 (0.81–1.08)	0.367
	> 10 years	0.99 (0.86–1.13)	0.825	0.95 (0.82–1.10)	0.475
Monthly income (UGX.)	150,000–500,000	0.89 (0.83–0.96)	0.002	0.93 (0.83–1.04)	0.226
	500,000–1,500,000	0.87 (0.78–0.97)	0.013	0.97 (0.81–1.16)	0.752
	> 1,500,000	0.65 (0.42–1.01)	0.056	0.56 (0.31–1.04)	0.066
	Don't know	1.09 (0.98–1.21)	0.114	1.20 (0.99–1.44)	0.06
Municipality/	Kampala	1.22 (1.05–1.43)	0.01	1.29 (0.97–1.71)	0.085
Urban council	Kasese	1.19 (1.02–1.39)	0.024	1.34 (1.00–1.79)	0.05
	Kira	1.34 (1.12–1.59)	0.001	1.53 (1.13–2.06)	0.006
	Nansana	0.84 (0.64–1.11)	0.231	0.53 (0.27–1.07)	0.076
Education level	Primary	0.92 (0.84–1.00)	0.063	0.95 (0.85–1.06)	0.388
	Secondary (A-Level)	0.73 (0.59–0.89)	0.002	0.87 (0.68–1.12)	0.274
	Secondary (O-Level)	0.91 (0.83–1.00)	0.044	0.88 (0.77–1.00)	0.057
	Tertiary/Diploma	0.92 (0.81–1.05)	0.233	0.81 (0.64–1.02)	0.079
	Vocational	0.88 (0.72–1.08)	0.233	1.13 (0.88–1.45)	0.345
Sex of household head	Male	0.97 (0.90–1.04)	0.374	1.01 (0.90–1.13)	0.895
Flood occurrence frequency	Infrequent flooding	1.02 (0.77–1.36)	0.866	1.12 (0.75–1.67)	0.583
	Moderate flooding	0.74 (0.61–0.91)	0.005	0.73 (0.54–0.99)	0.042
	Very rare flooding	1.00 (0.65–1.56)	0.994	1.08 (0.90–1.31)	0.403
Speed of flood occurrence	Instantaneous	1.60 (1.34–1.92)	< 0.001	1.34 (1.09–1.64)	0.005
	Other	0.50 (0.21–1.18)	0.115	0.70 (0.33–1.47)	0.347
	Rapid (hours)	1.51 (1.26–1.82)	< 0.001	1.26 (1.02–1.54)	0.028
Average flood duration	Long term	1.04 (0.94–1.15)	0.454	1.04 (0.89–1.22)	0.601
	Short term	0.78 (0.72–0.84)	< 0.001	0.81 (0.72–0.91)	< 0.001
	Persistent floods	1.17 (1.12–1.21)	< 0.001	1.13 (0.97–1.32)	0.118

4.4.2 Flood vulnerability hotspots and outcomes

Table 6 illustrates the spaces/hotspots vulnerable to and outcomes of flooding in GKMA and Kasese municipality. As shown in Table 10, residential areas were found to be disproportionately vulnerable to floods over 95% responses across all urban councils, and registering a p-value of 0.008 at municipal specific focus and p-value of < 0.001 when comparing GKMA with Kasese. Infrastructure vulnerabilities were highest in Kasese at 61% ($p < 0.001$), while public buildings exposures showed similar trends with 61% in Kasese compared to 48% in Kampala, also statistically significant ($p < 0.001$). During the FGD with VHTs in Bwaise, the following was revealed about residential spaces being vulnerable;

When there is a lot of water, it floods and people's property is destroyed… water enters inside their homes, some houses collapse, rooftops are blown off during heavy storms, causing a lot of destruction.

In Kasese, the outcomes of floods included loss of life, reported by 77% of respondents with a p-value of < 0.001, compared to lower figures in the GKMA. Further, injury rates and displacement followed similar trends, highlighting considerably higher impacts in Kasese. FGDs in all study areas revealed rise in disease incidences such as malaria and typhoid during floods, yet the economic outcomes embed damages and losses for local businesses which escalates poverty. Infrastructure challenges were also noted especially for many road networks along channels that are cut off during floods in Kampala, Nansana,

Mukono and Kasese which compromise mobility, while damage to healthcare facilities and equipment like Kilembe mines hospital in Kasese was reported to inhibit access to health services. The VHTs at Kambukamabwe in Kasese reported on disease outbreaks as follows;

Floods destroy toilet facilities…. feaces get into our water wells which makes us sick after collecting water for use at home…. We mainly get diarrhea… the children get diarrhea and also begin vomiting…... Also, mosquitos breed from the bushes and in stagnant water. Once they come out into our homes, they bring us malaria.

Table 7
Spaces of vulnerability to flooding

Variable (Yes only)	Municipalities					P-value	Comparison		P-value
	Kampala (Freq.; %)	Makindye Ssabagabo (Freq.; %)	Nansana (Freq.; %)	Kira (Freq.; %)	Kasese (Freq.; %)		GKMA (Freq.; %)	Kasese (Freq.; %)	
Spaces most vulnerable									
Residential areas	289 (100)	90 (99)	53 (100)	48 (100)	441 (97)	**0.008***	480 (100)	441 (97)	**< 0.001***
Commercial areas	209 (72)	60 (66)	25 (47)	16 (33)	313 (69)	**< 0.001***	310 (64)	313 (69)	0.174
Infrastructure	149 (52)	44 (48)	15 (28)	8 (17)	276 (61)	**< 0.001***	216 (45)	276 (61)	**< 0.001***
Public buildings	138 (48)	37 (41)	16 (30)	11 (23)	277 (61)	**< 0.001***	202 (42)	277 (61)	**< 0.001***
Recreation areas	63 (22)	22 (24)	9 (17)	3 (6)	169 (37)	**< 0.001***	97 (20)	169 (37)	**< 0.001***
Gardens/farms	43 (15)	4 (4)	3 (6)	1 (2)	211 (46)	**< 0.001***	51 (11)	211 (46)	**< 0.001***
Flooding outcomes									
Damage to property	288 (99)	88 (97)	52 (98)	44 (92)	440 (96)	**0.009***	472 (98)	440 (96)	0.12
Loss of life	198 (69)	44 (48)	18 (34)	7 (15)	352 (77)	**< 0.001***	267 (56)	352 (77)	**< 0.001***
Injury	171 (59)	43 (47)	24 (45)	9 (19)	330 (72)	**< 0.001***	247 (51)	330 (72)	**< 0.001***
Displacement	235 (81)	59 (65)	31 (58)	21 (44)	360 (79)	**< 0.001***	346 (72)	360 (79)	0.013
Infrastructure damage	157 (54)	42 (46)	19 (36)	15 (31)	310 (68)	**< 0.001***	233 (48)	310 (68)	**< 0.001***
Disease outbreaks	213 (74)	57 (63)	27 (51)	28 (58)	322 (71)	**0.003***	325 (68)	322 (71)	0.313

5. Discussions

This study finds that although GKMA and Kasese municipality face multiple climate stressors such as floods, storms, heatwaves, dry spells and drought with flooding being the primary hazard experienced and exacerbated by inadequate drainage and environmental degradation. Further, while urban populations interpret flooding through varying sources and characteristics, both regions face complex flooding dynamics, with GKMA predominantly grappling with flash and pluvial floods, yet Kasese experiences severe fluvial floods. Flooding being the primary hazard amidst various climate stressors aligns with broader trends observed in SSA and rapidly urbanizing regions. For example, evidence from East Africa and Madagascar shows that urbanization, land-use change, wetland degradation and poorly designed or undersized drainage systems are central drivers of growing urban flood risk, often overweighing purely climatic factors, and leading to recurrent pluvial and flash flooding in low-lying densely settled areas [22], [89], [90]. Similar to the GKMA case, a systematic review for Greater Kumasi(Ghana) finds that floods are overwhelmingly human-induced, driven by rapid, poorly regulated expansion into wetlands and waterways, compounded by deficient drainage and waste management [15]. Studies in cities like Shanghai and New Cairo further emphasizes the interplay between intense rainfall and local drainage capacities, causing serious pluvial floods [89], [91], [92], and yet in Ougadougou, the co-existence of floods with other climate extremes creates a complex risk landscape under climate change (Kalantari et al., 2018; Miller et al., 2022). Although, the distinction between pluvial and fluvial flooding, as seen in GKMA and Kasese, points to different drivers and management challenges [88], [93], [94], emerging research on compound flooding suggests growing interactions between flood types, despite the limitedness in quantitative understanding [93], [95]. Flooding is contextually recognized as a key hazard in urbanizing Africa, but balancing climate-driven rainfall changes versus land-use factors varies by city, indicating the importance of tailored approaches to drainage and environmental management [15], [22]. In general, inadequate drainage and environmental degradation critically heighten urban flood risks, hence stressing the necessity to address pluvial, flash and fluvial floods as interconnected yet locally specific facets of a broader multi-hazard climate risk landscape.

Results across GKMA and Kasese municipality indicate significant disparities in flood characteristics reported, with the later experiencing frequent and longer-lasting events, compared to the former which faces more frequent and severe flooding characterised by rapid onset. These findings broadly align with wider evidence on how urbanization and flood type shape flood characteristics, and strongly supports the observed contrast between GKMA and Kasese, while indicating that such distinctions may blur under compound or evolving hazard conditions driven by both changes in climate and land use. The results also collectively validate dual-typology framing of flood risk in Uganda's urban councils as reflected in disaster profiles and climate vulnerability and risk assessments. Urbanization and increasing impervious surface area are consistently linked to higher runoff, shorter response times and increased flash or pluvial flood peaks, producing frequent, short-duration events in cities similar to GKMA [96], [97], [98], [99]. Likewise, experimental and modelling studies of pluvial urban flooding studies show that intense rainfall over dense built-up areas with constrained drainage leads to fast-rising, short-lived inundation, especially on road networks and small urban catchments [92], [100], [101], [102]. In contrast, fluvial floods in larger or more rural catchments tend to be governed by basin-scale hydrology, producing less frequent but sometimes prolonged riverine flooding, consistent with the Kasese pattern [103], [104]. Yet, comparative works on flash, pluvial and fluvial floods confirms that flash and urban pluvial floods generally have the most rapid onset and shortest duration, while fluvial floods often evolve more slowly and can persist longer over wider areas [105], [106], [107]. Similarly, the literature stresses that urban flood responses are highly heterogeneous, with mixed mechanisms even within a single metropolitan region; though some urban catchment show only moderate or mixed trends in fluvial flood frequency, suggesting that climate drivers and local management can partly counteract or complicate the literal relationship/rhetoric that more urbanization equates more frequent floods [99], [104], [108]. Moreover, interactions between flash/urban pluvial flooding and upstream fluvial processes are increasingly recognized with some mountainous or coastal cities experiencing compound events where rapid flash floods and more sustained river or coastal flooding overlap [109], [110].

The study reveals that flood severity is primarily driven by flood dynamics rather than basic socio-demographic factors, with instantaneous and rapid-onset floods, as well as prolonged durations, significantly producing more severe impacts. Kira and Kasese municipalities are identified as hotspots for acute flood severity, while higher household incomes tend to correlate with lower severity, hence the need to consider both socio-demographics and flood dynamics in vulnerability assessments. These findings are in line with global evidence that total rainfall, storm speed and event duration are primary controls in fluvial and pluvial food security [111], [112], [113]. Research on tropical cyclones and global flood records similarly show that slow-moving or long-lasting events, and intense short-duration rainfall extremes, noticeably increase flood magnitude and affected areas, reinforcing emphasis on onset speed and duration in this study [111], [112], [113]. For Kira and Kasese being identified severity hotspots is consistent with work showing strong spatial heterogeneity in flood risk, where particular basins or urban districts become focal points of severe flooding due to local hydrology, drainage and land use patterns [24], [113], [114]. The observed negative association between household income and severity also echoes a large body of research in both Global North and South, which links higher income, property values and infrastructure quality with reduced vulnerability, while poorer or lower-value neighborhoods face more damaging outcomes despite similar or even lower hazard levels [114], [115], [116], [117], [118]. Yet, studies that validate social vulnerability indices show that socio-demographic factors can explain as much or more variation in flood deaths and damage as hazard intensity alone, suggesting that, although this study rightly foregrounds flood dynamics as the proximate driver of severity, socio-economic conditions remain critical co-determinants that shape who suffers most within severe events [115], [118], [119], [120]. With these perspectives, the results are broadly in line with existing evidence that robust vulnerability assessment must integrate both the physical dynamics of flooding (onset, duration, depth) and the socio-economic profiles of exposed populations.

Findings show that residential and commercial neighborhoods, infrastructure and public facilities are widely exposed to flooding across GKMA and Kasese, but impacts especially loss of life, injury, displacement, disease outbreaks and infrastructure damage are markedly more sever in Kasese, where floods intensify health risks, disrupt mobility and services and deepen poverty. The results are consistent with existing evidence that urbanization and land-use change have widely increased flood risk in African cities and towns [15], [121], [122], [123], [124]. However, the finding that outcomes are markedly more severe in Kasese, manifesting in higher loss of life, injuries, displacement, infrastructure damage, service disruption and deepening poverty, aligns with research showing that hazard exposure alone does not explain outcomes since local vulnerability, settlement patterns and livelihoods strongly condition flood consequences [24], [123], [124], [125]. Studies in Kasese and neighboring Ugandan towns similarly report recurrent river flooding that devastates homes, roads, bridges, schools, and health centers, disrupts transport and services, and undermines agriculture-based livelihoods, leading to food insecurity and entrenched poverty [2], [24], [123]. Regional and global reviews also confirm that floods in SSA disproportionately trigger disease outbreaks, especially water and vector-borne diseases, and strain health systems [126], [127], [128], reflecting the intensified health risks documented for Kasese. Evidence from other African cities shows that flood-related mobility disruptions and reduced access to jobs and critical services are greatest for poorer [129], [130], [131], more exposed communities, reinforcing the pattern of socially unequal impacts implied by Kasese's experience. Altogether, the findings align with existing work that distinguishes between widespread exposure and highly unequal, place-specific impacts, underscoring the need for vulnerability- and poverty-sensitive flood risk reduction rather than hazard-focused measures alone.

6. Conclusions

This study demonstrates that climate change is fundamentally reshaping urban risk landscapes in the GKMA and Kasese municipality through a suite of hydro-climatic extremes, with floods emerging as the most persistent and destructive hazards. Nearly all households in the study sites experienced flooding in the past decade, driven by intense rainfall, that is compounded by rapid and largely unplanned urbanization, degradation of wetlands and hillslopes and existence of undersized drainage systems, poorly maintained and frequently clogged by waste and sediment. These conditions produce recurrent pluvial and flash floods in low-lying and hillside settlements of GKMA, and severe flash and riverine floods in Kasese.

The findings underscore that flood characteristics are highly dynamic and place-specific. In GKMA, floods are frequent, short-lived and often abrupt, with rapid onset after intense downpours repeatedly testing community preparedness and recovery capacities. In Kasese, floods are generally frequent but more prolonged and spatially extensive, tied to heavy rainfall, ice melt and landscape degradation in the Rwenzori catchments and expressed primarily as fluvial flooding along major rivers. These contrasting typologies generate differentiated yet equally profound socio-economic and health consequences including

loss of life and injury, recurrent displacement, damage to homes, business and critical infrastructure and enduring disruption of mobility, health care, education and other essential urban services.

Results further show that the severity of flood outcomes is shaped more by hazard dynamics, spatial exposure and local land-use patterns than by basic demographic characteristics alone. Higher income and education levels can moderate perceived severity but pronounced hot hotspots continue to experience acute outcomes. This indicates that socio-economic status, settlement morphology, environmental degradation and governance deficits intersect in complex ways to (re)produce vulnerability. Climate-induced flooding is not creating risks in a vacuum but rather amplifying pre-existing urban challenges linked to unplanned growth, ecosystem loss and fragile infrastructure, leading to locally specific patterns of flood frequency, onset, duration and intensity.

These insights point to the need for intergraded, place-based adaptation that simultaneously addresses climatic, environmental and socio-institutional drivers of risk. Priority actions include; upgrading and maintaining drainage networks, restoring wetlands, hilltops and riparian buffers; enforcing land-use regulations and restricting development in high-risk zones; and strengthening early warning systems and downscaled climate information services that are trusted and usable at community level. Equally, effective adaptation depends on embedding local knowledge, lived experiences and community participation at the center of urban planning, and disaster risk governance. Tailored multi-sectoral strategies that connect neighborhood-level actions with city and catchment scale interventions are essential to safeguard lives, protect livelihoods and steer cities in similar settings towards more just and resilient urban futures under a changing climate.

Declarations

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9. Ethics declarations

9.1 Ethics statement

This study was conducted following the ethical guidelines and regulations of the Makerere University Institutional Review Boards (IRBs) the Uganda National Council of Science and Technology (UNCST) ethical committees. The study protocol was approved by the Makerere University's School of Public Health IRB (Letter No. HS3003ES) and registered and approved by the UNCST (Letter No. HS3003ES), aligned with the regulations for scientific research in Uganda [132], [133] and in accordance with the Declaration of Helsinki and the Council for International Organizations of Medical Sciences (CIOMS) International Ethical Guidelines for Health-related Research Involving Humans, as well as the principles of the Belmont Report. Informed consent was obtained from all participants prior to data collection. To safeguard participants' privacy and confidentiality, all data were anonymized and unique identification numbers were assigned to each participant. No identifying information is reported. This ethical framework ensured that the rights, dignity, and well-being of all individuals involved in the research were respected and protected throughout the study.

9.2 Consent for publication

Informed consent was obtained from all the individual participants for publication.

9.3 Competing interests

The authors declare no competing interests.

9.4 Clinical trial number

Not applicable

9.5 Data availability

The author confirms that all data generated or analysed during this study are included in this published article. Supplementary File I shows the variables and assumed relationship while modelling flooding severity.

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Figures

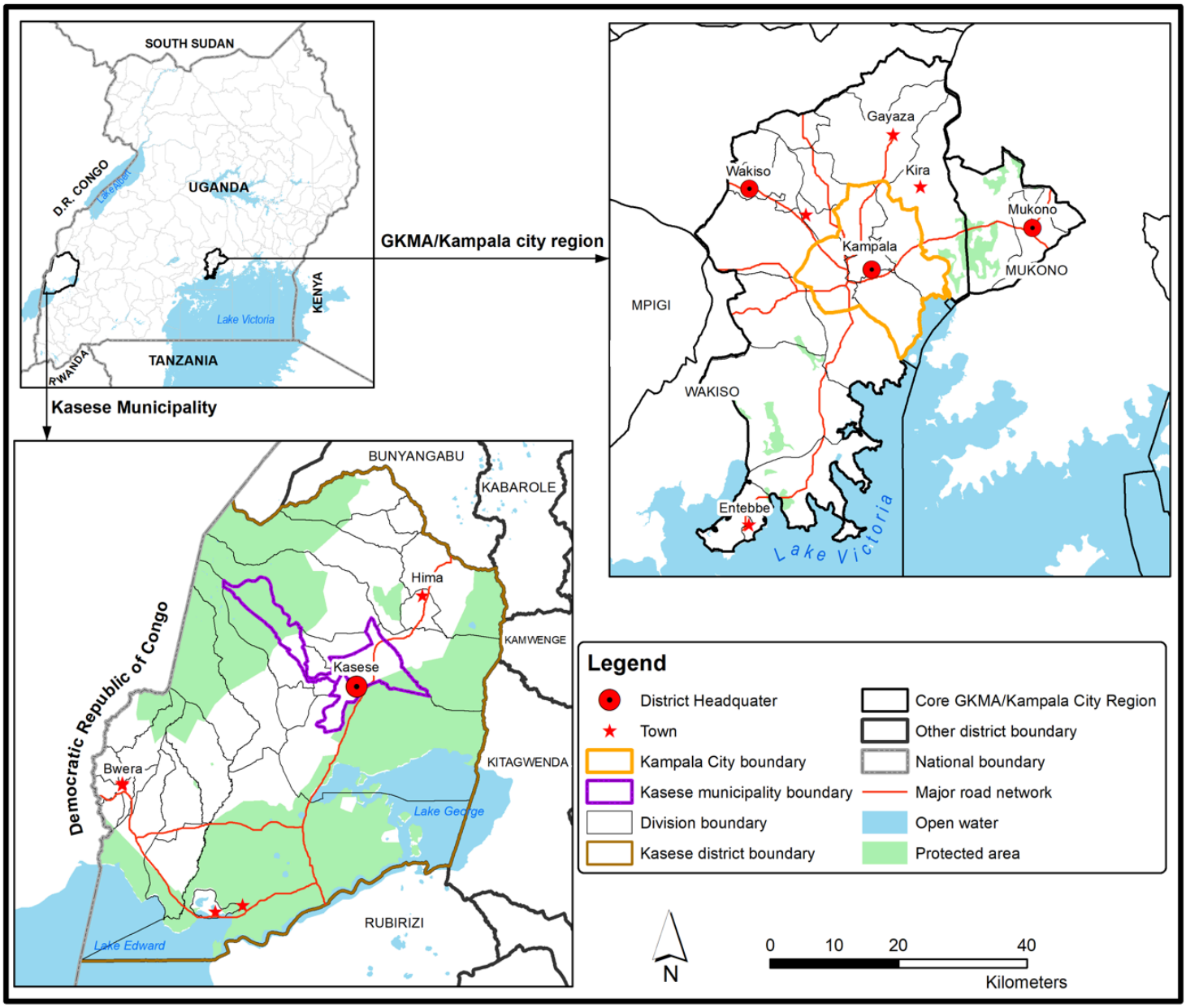


Figure 1

Kampala city region (GKMA) and Kasese Municipality

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- AppendixI.docx