UNDERSTANDING FLOOD RISKS IN CHAD

CENTRE FOR DISASTER PROTECTION

CERDI

BRIEF

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ACRONYMS

APSNP	Adaptive and Productive Safety Nets Project
ACAPS	Assessment Capacities Project
ECOSIT	Enquête sur les Conditions de Vie des Ménages et la Pauvreté au Tchad (Household Poverty and Living Standards Survey)
EM-DAT	Emergency Events Database
ENSA	Enquête Nationale sur la Sécurité Alimentaire (National Food Security Survey)
FAO	Food and Agriculture Organization (of the United Nations)
FERDI	Fondation pour les Études et Recherches sur le Développement International
GDP	Gross Domestic Product
INSEED	Institut National de la Statistique, des Études Économiques et Démographiques (National Institute for Statistics, Economic Studies, and Demography)
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
MASAH	Ministère de l'Action Sociale, de la Solidarité Nationale et des Affaires Humanitaires (Chad Ministry of Social Action, National Solidarity and Humanitarian Affairs)
MODIS	Moderate Resolution Imaging Spectroradiometer
ND	N'Djamena (capital of Chad, sometimes abbreviated)
NOAA	National Oceanic and Atmospheric Administration
SASPP	Sahel Adaptive Social Protection Program
SISAAP	Système d'Information sur la Sécurité Alimentaire et d'Alerte Précoce (Food Security and Early Warning Information System)
SSP	Shared Socioeconomic Pathways
UCA	Université Clermont Auvergne
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USD	United States Dollar
VFM	VIIRS Flood Mapping (NOAA/George Mason University)
VIIRS	Visible Infrared Imaging Radiometer Suite
WFP	World Food Programme

1. INTRODUCTION

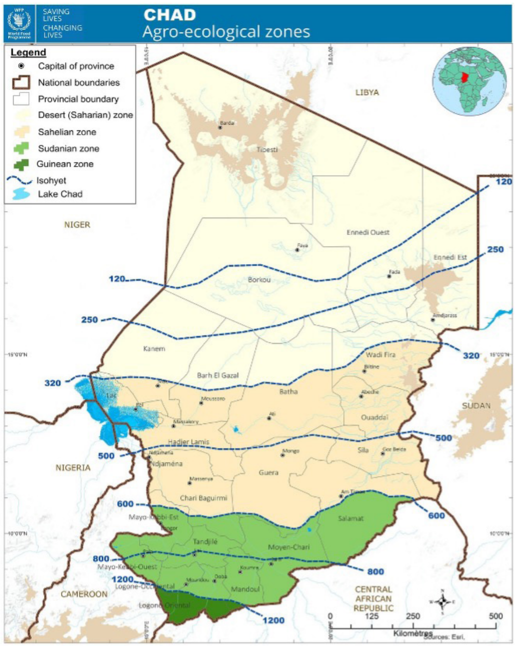
The Republic of Chad is one of the largest countries in Africa, covering nearly 1.3 million square kilometres (km²). Much of the north is in the Sahara Desert while the arid Sahel runs through the centre. Chad's primarily rural population of over 20 million is one of the fastest growing in the world and is concentrated in the more agricultural south of the country. In line with this, the main household activity is subsistence agriculture focused on staples such as millet, sorghum, and maize. Around 40% of the population lives below the poverty line. Chad's government revenues come largely from exploiting its considerable oil reserves, the exports of which account for 40% of gross domestic product (GDP) compared to 30% for agriculture.

Chad is consistently rated among the most vulnerable countries in the world to climate change (Chen et al., 2015; Thow et al., 2023). Increasing temperatures and precipitation are raising the threat of drought, flood, heatwaves and vector- borne diseases. Infrastructure challenges and Chad's young, poor and growing population make it especially vulnerable to these stressors. The threat from floods in particular is becoming increasingly salient in Chad, as major floods have become an almost annual occurrence in the past decade (Table 1). Nearly three-quarters of floods reported in Chad since 1980 have occurred in the last 20 years. The floods in 2022 and 2024 were particularly devastating, directly affecting millions of people and causing displacement, infrastructure damage, destruction of homes and agricultural production, and hundreds of deaths. Economic losses from the 2022 floods are estimated at over USD400 million (World Bank, 2023), and the 2024 floods were even more destructive.

This brief presents the key results and takeaways from an analysis of flood risk and incidence in Chad, with particular attention to population exposure to floods. The primary objective of the brief is to inform planning around the World Bank's Adaptive and Productive Safety Nets Project (APSNP, P502142) in Chad, which was made effective in December 2024 and will be implemented until June 2029. The project aims to support the Government of Chad in establishing a national adaptive safety net, providing cash transfers and accompanying measures to low-income populations, as well as providing emergency cash transfers to shock-affected populations, notably those affected by floods and inflows of refugee populations. The project includes two planned flood response mechanisms. First, for 25,000 beneficiary households, a single emergency cash transfer will be provided in the case of either floods or a major refugee inflow. Second, for another 3,000 beneficiary households a rapid flood response mechanism will be developed and piloted to provide rapid responses (including cash transfers) as soon as possible following the detection of flooding.

The results may also be useful for the World Bank's Sahel Adaptive Social Protection Program (SASPP) global team and for other stakeholders working on issues related to flood risk in Chad. These include the Chad Ministry of Social Action, National Solidarity and Humanitarian Affairs (MASAH), Chad Office of National Solidarity, the World Food Programme, and the Red Cross of Chad.

Figure 1: Agroecological zones of Chad



Source: World Food Programme.

Table 1: Summary of reported effects of recent major flood events

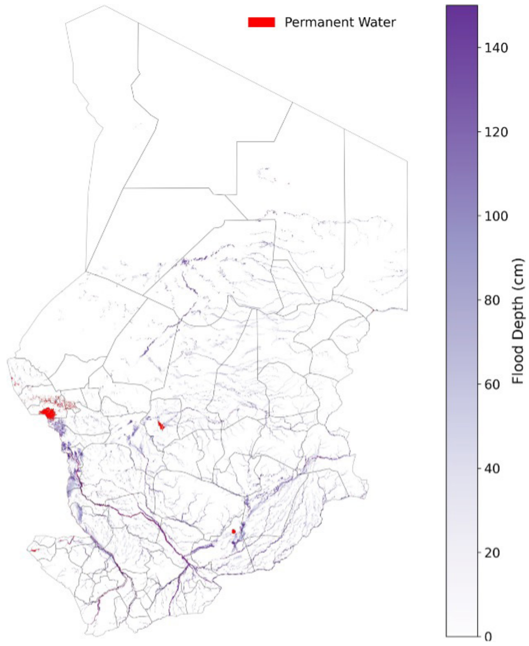
Year	Affected population	Flooded land (ha)	Houses destroyed
2012	466,000[a] - 613,631[e]	255,000[a]	96,000[a]
2014	8,000[a]	-	-
2019	171,000[a]	18,000[a]	2,700[a]
2020	36,934[d] - 388,000[a]	150,000[a]	-
2021	255,000[a] - 269,180[d]	-	-
2022	1,100,229[d] - 1,426,948[b]	465,030[b]	80,000[b]
2023	-	18,130[a]	2,700[a]
2024	1,945,674[d] - 2,000,000[c]	1,862,800[e]	218,000[c]

Source: Author's analysis based on data from [a] UNOCHA=United Nations Office for the Coordination of Humanitarian Affairs, [b] the Government of Chad, [c] ACAPS, [d] the EM-DAT database, and [e] the FAO=UN Food and Agriculture Organization.

2. FLOOD HAZARD AND EXPOSURE IN CHAD

Large parts of Chad face high and increasing risk from floods caused by periods of heavy concentrated rainfall, exacerbated by population growth in flood-prone zones, land degradation and poor drainage and water management infrastructure. The main driver of flood hazards in Chad is fluvial (or riverine) flooding as heavy precipitation flows into river networks and lakes, increasing water levels and inundating nearby areas. Extreme rainfall may also cause pluvial flooding if water cannot be absorbed or drain away towards rivers fast enough, as well as direct damage not associated with inundation. According to data from Fathom, a global leader in flood hazard mapping, just 4% of Chad's land area is estimated to be at risk from fluvial floods compared to 18% for pluvial floods. However, the median inundation depth of a pluvial flood with a 100-year return period is less than 10 cm compared to 45 cm for a fluvial flood. Figure 2 visualises estimated flood depths of 100-year fluvial floods across Chad, showing how hazards are concentrated in the areas near to Chad's rivers, including seasonal wadis.

Figure 2: Inundation depths of 100-year fluvial floods



Source: Author's calculations based on data from Fathom (2022).

Rural communities are vulnerable to flood damage due to their reliance on rain-fed agriculture and often less durable dwelling materials. However, the greatest population exposure to flood risk is in urban areas which tend to be located near lakes and rivers. The higher flooding hazard in these areas is compounded by the spread of informal settlements, especially in the capital N'Djamena, which have often expanded into low-lying, flood-prone zones. Poorly maintained or non-existent drainage systems are often unable to cope with heavy precipitation or higher river flows, leading to chronic flooding, housing destruction and widespread water stagnation. The area around and between the Logone and Chari rivers, in the country's south west, stands out as combining both high flood hazard and high population

DEFINITIONS

Fluvial/riverine flood : Inundation due to overflowing rivers or other water bodies.

Pluvial flood : Inundation due to precipitation **exceeding soil absorption or drainage capacities.**

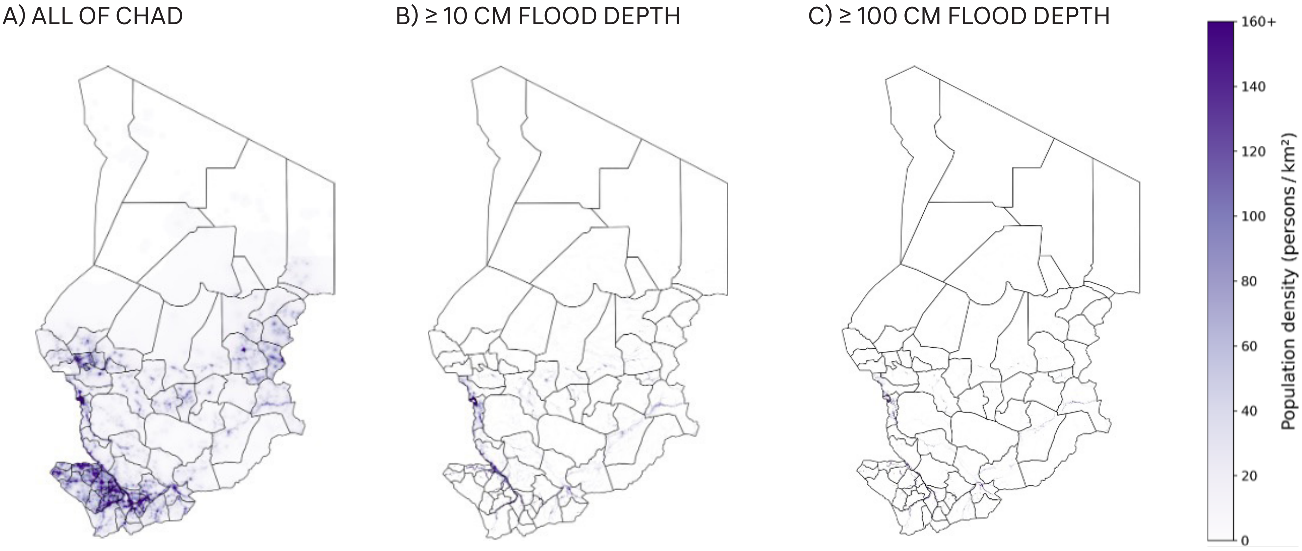
Return period: The number of years within which a flood of a particular depth of inundation would be expected to occur once. For example, inundation depths for floods with a 100-year return period have a 1% chance of occurring in a given year. This means they are expected to occur once in 100 years.

Flood hazard : Estimated inundation depths of floods with a given return period.

Flood exposure: Land area, population or economic activity at risk from a given level of flooding hazard.

SSP climate scenarios: Shared Socioeconomic Pathways (SSPs) projecting global changes up to 2100 as defined in the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report in 2021. SSP1-2.6 represents an optimistic 'sustainable development' scenario, and SSP2-4.5 a 'middle of the road/business as usual' scenario.

Figure 3: Population density exposed to different 100-year flooding hazards



Source: Author's calculations based on data from Fathom (2022) and WorldPop (2025). Flood hazard is based on the estimated depth of 100-year fluvial floods under current conditions.

exposure. Figure 3 illustrates this by mapping population densities in areas with a particular level of flood hazard. The maps show clearly that although flood hazard is widespread in Chad, population exposure is concentrated primarily in particular *départements*, the second administrative level in Chad, below provinces.

Climate change is projected to increase flood hazard, making floods of a given severity or inundation depth more common across much of the country. However, the estimated average increases in 100-year flood depths are not large. According to Fathom's projections for conditions in 2050 under the SSP1-2.6 climate change scenario, the share of land area exposed to fluvial floods will increase from 4.1% to 4.4%. The median depth of 100-year floods will increase from slightly under to slightly over 45 cm. Results are similar under the less optimistic SSP2-4.5 scenario. Increasing fluvial flood hazard in recent decades is reflected in data from the Chad Office of Water Resources on river flows through hydrological stations. Average river levels have been increasing over time and particularly in the flooding season from July through November, despite flat or slightly decreasing trends in total precipitation since the 1950s.

Despite limited increases in flood hazard, flood exposure in Chad will rise because its population is expected to at least double between 2017 and 2050 (UNDESA, 2017). Rogers et al. (2025) analyse the relative contribution of changes in flood hazard and population to determine future flood exposure. They find that 77% of predicted changes in exposure by 2100 globally are due to population growth, compared to 21% due to climate change (and 2% due to a combination of the two). Their analysis combines pluvial and fluvial flooding and finds that most of the increased exposure in Chad will occur in the same départements with the highest current levels of population exposure, as population is projected to grow most in already densely populated areas.

Table 2 summarises information from this analysis on the 10 départements in Chad with the greatest population exposure to combined flood risk, which aligns well with the maps in Figure 3. Although the area exposed to 100-year floods of at least 10 cm only increases from 17.9% to 18.9% of Chad's land area by 2050 under the SSP2-4.5 scenario, the population exposed to such a flood risk is projected to increase from 4.2 to 9.9 million people. The fraction of the population exposed in each département is also only predicted to increase slightly, indicating that the predictions are based on similar rates of population growth inside and outside of high flood hazard areas. These results indicate that flood protection interventions targeting areas with the highest current levels of flood exposure will also be useful in protecting against projected increases in flood risk over time.

Table 2: Départements with greatest exposure to ≥10 cm 100-year floods

	2020 conditions				2050 SSP2-4.5 conditions			
Department	**Pop.**	**Pop. (%)**	**Area (km²)**	**Area (%)**	**Pop.**	**Pop. (%)**	**Area (km²)**	**Area (%)**
Baguirmi	123,720	43,85	11,980	44,26	299,930	48,24	13,180	48,70
Bahr-Azoum	145,930	58,34	15,620	58,64	338,660	61,45	16,450	61,76
Bahr-Kôh	195,880	48,82	8,490	49,45	453,930	51,35	8,930	52,01
Chari	156,540	57,28	2,770	63,86	380,700	63,22	3,040	70,24
Dababa	122,830	39,70	6,480	40,11	293,060	42,99	7,020	43,44
Lac Iro	143,950	59,91	10,570	60,43	330,110	62,36	11,000	62,90
Loug-Chari	202,360	72,81	11,210	73,74	469,470	76,67	11,810	77,69
Mayo-Boneye	231,110	71,02	6,090	72,04	527,200	73,53	6,300	74,59
N'Djamena	538,090	38,41	0,170	42,26	1,412,120	45,75	0,210	50,95
Tandjilé Est	202,500	61,50	7,770	62,57	456,780	62,97	7,960	64,07
Total	**4,176,850**	**25,50**	**225,930**	**17,95**	**9,852,030**	**27,30**	**238,240**	**18,93**

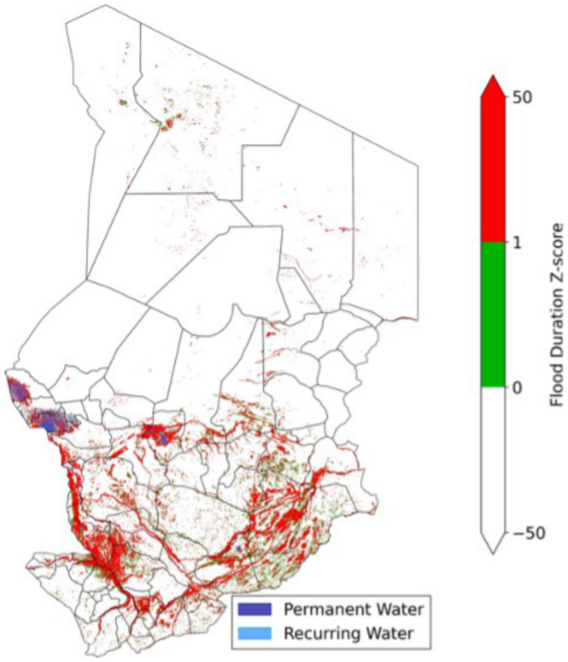
Source: Author's calculations based on data from Rogers et al. (2025). Flood exposure is based on 100-year floods with at least 10 cm of inundation depth.

3. INCIDENCE OF FLOODING SINCE 2012

Historically, major flood disasters in Chad were infrequent, but now they occur in most years. An analysis of survey and satellite data shows that the share of areas with flooding reports and detection is much greater in years of major disasters. It also provides greater insight into the specific areas affected than media or government reports which often aggregate information to the province or country level, or focus on a subset of specific locations. For example, 47% of households covering 86% of rural communities in the 2024 Enquête Nationale sur la Sécurité Alimentaire (ENSA, National Food Security Survey) reported experiencing a flood shock over the previous six months, compared to just 5% of households in the previous year.

The National Oceanic and Atmospheric Administration (NOAA)/George Mason University VIIRS Flood Mapping (VFM) archive uses Visible Infrared Imaging Radiometer Suite (VIIRS) daily satellite imagery at the level of 375 m pixels to identify changes in the presence of surface water and detect remotely-sensed flooding. The VFM archive shows that flooding was detected in 6.3% of Chad's land area in 2024, by far the most since the start of the archive in 2012. To illustrate this, Figure 4 shows deviations in flood detection in 2024 relative to 2012-2023. The mean count of days with flooding detected for flooded pixels in 2024 was 33 days, compared to less than 20 days in

Figure 4: Deviations in days of detected flooding in 2024 relative to 2012-2023 mean



Source: Author's calculations based on data from the VFM archive (2025). The figure shows Z-scores for the difference in pixel-level flooding days detected in 2024 compared to the 2012-2023 mean, normalised by the standard deviation in flooding days from 2012-2023. Larger Z-scores indicate significantly more flooding days in 2024 relative to previous years.

KEY FLOOD INCIDENCE DATA SOURCES

Enquête Nationale sur la Sécurité Alimentaire (ENSA, National Food Security Survey): Represents rural communities nationwide, conducted annually. Data from 2016-2024 obtained from Chad's SISAAP (Food Security and Early Warning Information System).

Enquête sur les Conditions de Vie des Ménages et la Pauvreté au Tchad (ECOSIT, Household Poverty and Living Standards Survey): Nationally-representative using data from 2018-19 and 2022, obtained from Chad's INSEED (National Institute for Statistics, Economic Studies, and Demography).

VFM Archive: Global database of daily flood detection at a 375-metre resolution based on an algorithm using VIIRS satellite imagery to identify changes in the presence of surface water. Provided by the National Oceanic and Atmospheric Administration (NOAA)/ George Mason University.

most years. The 75th percentile was 43 days compared to less than 30 in all other years. Overlaying WorldPop population data on VFM flood detection suggests that over 2.4 million households were exposed to flooding in 2024, consistent with official reports of the affected population.

Both data sources also show that flooding is quite common even outside years of major floods that have been the subject of major media attention. The VFM archive shows that at least 2% of land pixels have some flooding detected in every year, although some portion of this may represent seasonal water fluctuations not fully captured in the VFM algorithm. At least 600,000 people are identified as exposed to VFM-detected floods in each year, indicating regular exposure for many populations even if this does not always lead to adverse impacts. Three percent of households in the ENSA surveys from 2016-2018 reported experiencing a flood shock each year on average. Ten percent of households in the 2018-19 Enquête sur les Conditions de Vie des Ménages et la Pauvreté au Tchad (ECOSIT, Household Poverty and Living Standards Survey) reported at least one flood shock from 2015-2018, although no major flood events occurred in this period. These events are generally concentrated in areas with a high flooding hazard, implying a potential need for more flood monitoring in these areas to respond to more isolated flood shocks.

There is substantial variation in flood exposure across households within communities. The majority of households in communities with at least one household flood report in a given period indicate that they did not experience any flood shock. Households engaged in agricultural production or liv- ing in dwellings made of less durable materials are more likely to report a flood shock, highlighting how differences in vulnerability can determine who is affected by flooding as opposed to simply exposed.

Household surveys are useful for understanding who is be- ing affected by floods, but they are limited in their spatial and temporal coverage and may also conflate inundation shocks with shocks related to

Table 3: Summary of survey flood reports, 2016-2024

Time period	Percentage of respondents	Percentage of communities	Survey
May-Oct 2016	2.19	8.85	ENSA
May-Oct 2017	4.51	15.80	ENSA
May-Oct 2018	2.03	10.23	ENSA
May-Nov 2019	7.83	25.41	ENSA
May-Nov 2020	19.89	45.20	ENSA
May-Nov 2021	6.05	25.39	ENSA
May-Nov 2022	31.34	60.52	ENSA
May-Nov 2023	5.43	21.92	ENSA
May-Nov 2024	46.52	85.94	ENSA
Jun 2015-Sept 2018	10.33	51.25	ECOSIT
Jan 2016–Apr 2019	9.80	48.74	ECOSIT
Jan 2019-Apr 2022	11.50	52.20	ECOSIT
Sep 2019-Dec 2022	7.63	42.12	ECOSIT

Source: Author’s analysis based on data from the ENSA and ECOSIT surveys. Community-level results are based on the presence of any household flood report within the community.

heavy precipitation that does not lead to inundation. For the same reason, deviations in local precipitation from historical averages can only roughly proxy for flood incidence. River flow data serves as a validated indicator of fluvial flood hazard but cannot measure inundation outside of the river and is only available at a small number of locations. Remote sensing and particularly satellite imagery, radar and microwave data now enable flood detection at a granular temporal and spatial level. Satellite-based measures remain constrained by measurement issues (cloud cover for imagery, long revisit periods for radar, challenges with water detected in urban, forest and arid areas) and are subject to flood detection algorithm decisions, such as how to account for seasonal water fluctuations. For these reasons, satellite-based sources should not be considered as definitive measures of flood incidence, particularly at very specific points in time and space. At more aggregate scales, however, they are very useful in identifying and monitoring areas where floods are likely to have occurred.

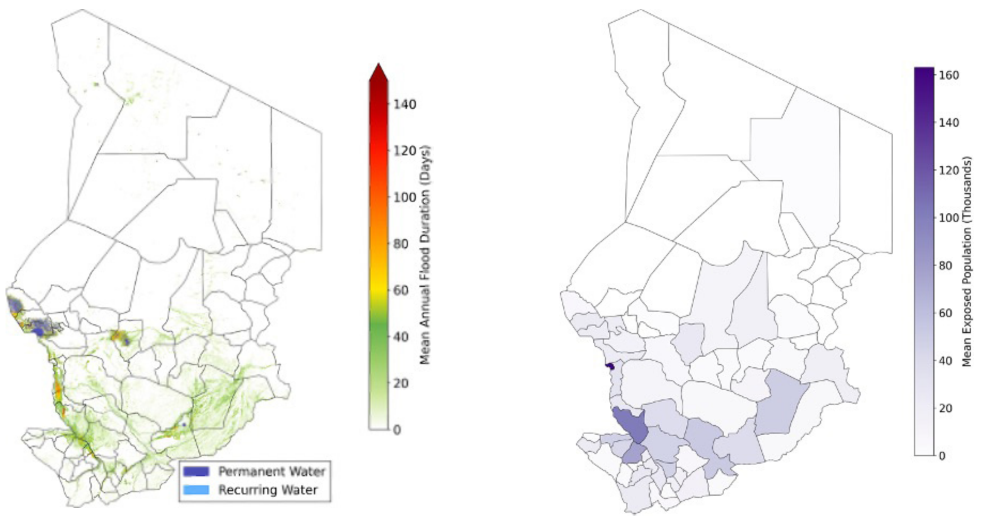
Several publicly available databases monitor near-real time flooding worldwide using different data inputs and algorithms. The results from these databases could be combined for real-time monitoring of flooding in Chad to inform disaster response. For example, the World Food Programme in Chad has used data from the Automated Disaster Analysis and Mapping (ADAM) floods database, which uses an algorithm combining satellite imagery from VIIRS and Moderate Resolution Imaging Spectroradiometer (MODIS), satellite synthetic aperture radar from Sentinel-1, and FloodScan data to map out flooding incidence during the major floods in 2022 and 2024. For tracking historical incidence, the VFM archive provides the best combination of years of coverage, spatial resolution, temporal resolution and accessibility among publicly available databases.

Flooding is detected in the VFM archive in at least one year from 2012-2024 for 10% of all land pixels in Chad (Figure 5, panel A). The highest levels of mean annual flood exposure – measured as the number of days flooding is detected in each pixel – are in the areas identified in the Fathom data as having greater fluvial flood hazard. Around Lakes Chad, Fitri, and Iro, between the Chari and Logone rivers near northern Cameroon, and further south along the Logone river, many pixels experience an average of over 100 days of detected floods annually from 2012-2024. Outside of these areas it is rare for the mean annual days of detected flooding to exceed 40. This is consistent with a greater threat from fluvial floods but could also reflect the fact that VIIRS satellite imagery cannot see through clouds and is therefore

Figure 5: Mean exposure to VFM-detected floods, 2012-2024

A) ANNUAL DAYS OF DETECTED FLOODING

B) ANNUAL POPULATION EXPOSURE BY DÉPARTEMENT



Source: Author's calculations based on data from the VFM archive (2025) and WorldPop (2025). Exposure is defined as any detected flooding in a pixel. Both panels show means over the 2012-2024 period.

constrained in detecting pluvial floods, although it does detect floods in the northern half of Chad that may reflect pluvial floods. The Sentinel-1 satellite captures synthetic aperture radar data which can see through clouds but visits each point on earth much less frequently than the VIIRS satellite and so will miss many short duration floods.

Combining the mean days of flooding data from the VFM archive with data on population density from WorldPop shows the populated areas with the highest recurring flood incidence (Figure 5, panel B). This map closely mirrors the map of population density exposed to 100-year flood depths of at least 10 cm according to Fathom (Figure 2). The spatial concentration of average annual population exposure to VFM-detected floods also aligns well with patterns in estimated flood exposure from Fathom. In particular, the highest levels of population exposure to detected flooding in Chad are primarily concentrated in N'Djamena and the area around the Logone River, although many other populated areas also have high recurring flood incidences.

An important question is how well the remotely-sensed flood detection reflects flooding experiences on the ground. At the community level, there is a strong relationship between the amount of flooding detected in pixels around a community's location in the VFM archive data and the probability that any survey household in the community reports a flood shock in the same time period in both the ECOSIT and ENSA surveys. The ECOSIT surveys show evidence of recency bias in household survey recall, with more recent detected floods more predictive of flood reports over the three-year recall periods. In the ENSA surveys, recency bias is less of a concern because of the six-month recall period, but flood reports are indeed predicted by flooding detected in the same period and not prior years. The association between detected flooding and the probability of any flood report is similar when considering both a 1 and 5 km radius.

Both survey flood reports and satellite-based flood detection using the VFM archive are concentrated relatively more in areas with higher flood hazard and in years of major flooding disasters. There is also a strong statistical correlation between the two measures at the community level. However, there are also differences in the classifications of community flood exposure according to the two measures. In both the ECOSIT and ENSA surveys, many communities with a large share of pixels flooded within 1 km do not have any household flood reports, while many communities with a household flood report do not have any flooded pixels detected even within 5 km. These differences can be attributed to both limitations of remotely-sensed measures – challenges in capturing pluvial, short duration and urban floods in particular – and heavy precipitation shocks that do not result in inundation but cause damages reported in surveys as floods due to a lack of more specific shock categories. Part of the former challenge could potentially be addressed with more sophisticated remotely-sensed flood detection techniques, but the latter challenge suggests there will always be disagreement between survey and satellite flood measures.

Despite these differences, the results suggest that satellite-based flood detection can identify a subset of flooded communities with quite high accuracy. Indeed, 84% of ENSA communities and 64% of ECOSIT communities with at least 10% of pixels within 1 km detected as flooded have at least one survey flood report. The accuracy reaches 89% in the ENSA data when using a 20% threshold for flooded pixels and a 5 km radius around the community. Further analysis could seek to identify a threshold and distance to maximise predictive accuracy.

Cases where the VFM data does not identify flooding in communities where flood shocks are reported are an important challenge from the perspective of identifying a trigger for flood responses, suggesting potentially high levels of basis risk. As the accuracy of flood detection in predicting flood reports is not lower when considering a 5 km radius as opposed to a 1 km radius around a community, larger radiuses may be preferred for determining flood response to help reduce the risk of not identifying some flooded communities. Indeed, the share of ENSA communities with flood reports but no detected flooding, fall from 72% when using a 1 km radius to 45% with a 5 km radius. The corresponding numbers for ECOSIT 4 communities are 42% and 17%. *Sous-préfecture-* or *département*-level flood detection may also be useful as a first pass for identifying areas where communities are at greater risk of flood exposure.

4. HOUSEHOLD-LEVEL IMPACTS OF FLOOD EXPOSURE IN 2019-2022

Flood exposure causes direct damage to agriculture, property, health and life, but also has broader indirect effects on sanitation, disease, land degradation, and infrastructure damage. Many economic studies show the adverse impacts of flood exposure on different household outcomes. They demonstrate how it affects food security, health, agricultural production, poverty and well-being, alongside increases in displacement and temporary migration. Much of this literature has focused on floods in Asian countries and there have been no studies of the impacts of floods in Chad.

At an aggregate level, floods in 2019-2021 were reported to have affected over 500,000 people while the major flood disaster in 2022 affected 1-1.5 million. Panel data from the ECOSIT survey rounds in 2018-2019, 2020-2021 and 2022 allows an analysis of household-level impacts of flooding in Chad. This can be achieved by comparing changes in outcomes over time for households in communities exposed to flooding against households in non-exposed communities in the same provinces with the same estimated probability of exposure.

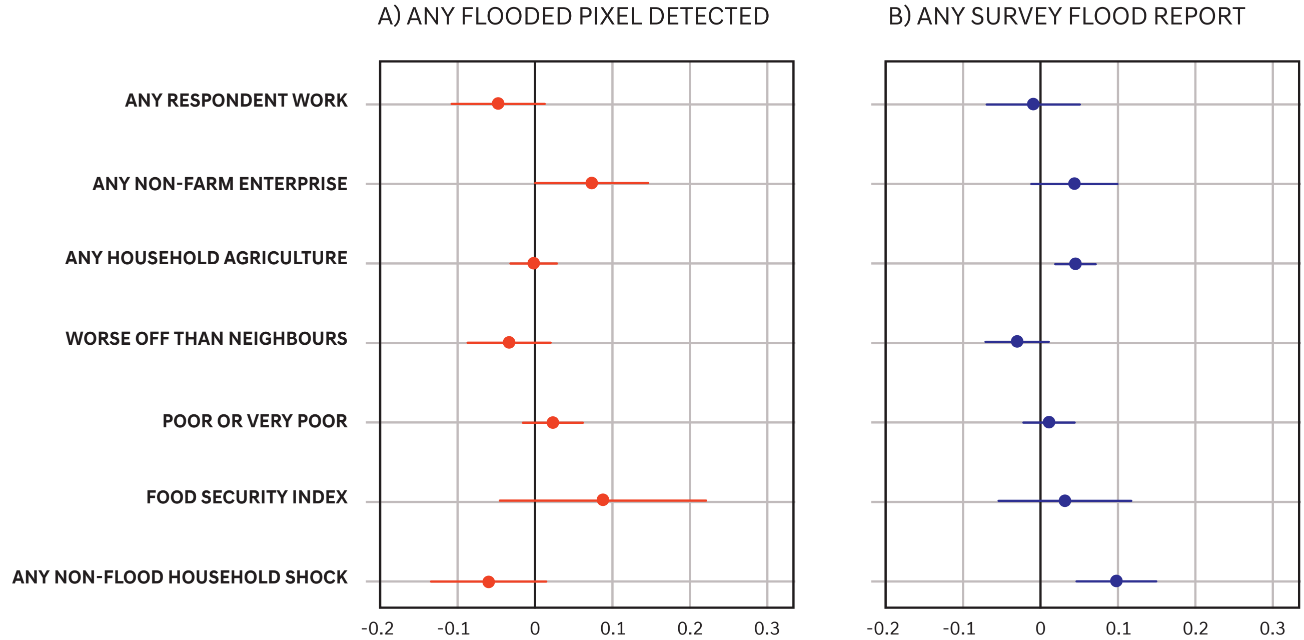
Community-level flood exposure is defined in two ways to account for differences in where surveys and satellites identify flooding. First, community coordinates are matched to observations of flooding incidence in the surrounding area between 2019 and 2020 (between the baseline and subsequent rounds) using data from the VFM archive. Communities with any flooded pixel detected within 1 km of the community centroid in 2019 or 2020 are defined as exposed to remotely-sensed flooding. Second, household reports of flood shocks in the 2022 survey round are used to determine community exposure over the 2019-2022 period. Communities with any household flood report are defined as exposed to survey-reported flooding. While part of flood exposure is random due to variation in precipitation over time and space, another part is determined by geographic characteristics affecting flood risk. The non-random component of flood exposure is captured by estimating the probability of experiencing flooding during these time periods as a function of location characteristics and prior flooding history. Households in exposed and non-exposed communities are well-balanced in terms of baseline characteristics after controlling for this probability, suggesting later differences can be attributed to the impact of flooding.

Exposure to pixels detected as flooded in the VFM data increases the probability that house- holds engage in non-farm enterprise activities in subsequent periods, particularly in urban areas and in the periods immediately following the flood exposure. Being in a community where at least one household reported a flood shock increases engagement in agricultural production in the follow- ing periods, particularly for households with female heads and those engaged in non-farm enterprise at baseline. Effects on participation in non-farm enterprise are positive but not statistically significant at conventional levels. These effects may represent household efforts to diversify their livelihood strategies following a shock to their main source of income, consistent with results from many other studies of weather shocks in low-income contexts.

There are no average effects among the sample households of flood exposure on measures of household well-being such as food insecurity or perceived absolute or relative well-being, although survey-based flood exposure increases the likelihood that households report exposure to other kinds of shock (Figure 6). The average intent to treat effects based on community-level flood exposure likely mask important heterogeneity across households by household-level exposure. This is because only around 20% of households in exposed communities typically report being directly affected by a flood shock themselves. The low levels of direct exposure in most communities may drive estimated impacts of flooding toward zero if other households in the community do not face adverse indirect effects. Though not statistically significant, the positive and large coefficient for the effect of flood exposure on an index of household food insecurity may suggest that directly affected households are persistently more food insecure, but not sufficiently to overcome null effects on other community households.

Further research using the same data and identification strategy could explore this by community flood exposure to instrument for households reporting a flood shock. This approach would identify local average effects of direct flood exposure under the assumption that community-level exposure only affects households through the probability that a household experiences direct flood-related damages. Estimated effects under this strategy would likely be larger than those reported here. Data from the ENSA surveys could also be particularly valuable for testing effects on food insecurity, though the identification strategy would be different because the ENSA data is not a panel. One approach would be to conduct a stacked cross-sectional event study relying on different timing of when communities surveyed in each round of the ENSA are first exposed to satellite-detected flooding.

Figure 6: Average impacts of recent flood exposure on ECOSIT household outcomes



Source: Author's calculations based on data from the ECOSIT surveys and VFM archive. The figure shows the results of separate regressions of the effect of having been exposed to flooding on a particular variable. Respondent work is defined over the last seven days and can include any household farm or non-farm work as well as wage employment or unpaid labour, but not domestic work. Participation in crop or livestock activity is defined over the past agricultural season. Participation in non-farm enterprise is defined based on any active enterprises at the time of the survey. The food insecurity index is constructed as the sum of eight normalised variables capturing different aspects of self-reported food insecurity. Household well-being is based on the respondent's own perceptions. Non-flood shocks are based on household reports.

5. CONCLUSION

The results of this report may be useful for policymakers and stakeholders working on climate change resilience, disaster response and social protection in Chad. Understanding the geographic distribution of flood risk and occurrences may help to target resources and efforts to support adaptation and resilience to increasing flood risk. Both flood hazard and population exposure are concentrated primarily along bodies of water in Chad. Pluvial flooding also poses an important risk, but it is more challenging to measure and monitor than fluvial floods and affects a smaller share of Chad's population. The areas combining the highest mean days of annual flooding detected in the VFM archive, together with higher population densities, are largely all concentrated in the areas around the Logone River. These are also the areas with the highest levels of flood hazard according to Fathom. Given limited resources, investments in flood mitigation and response may therefore be most impactful in these areas.

Results emphasising the recent and projected increases in flood exposure in Chad may motivate greater attention and investment in these areas. Flood hazard is projected to increase in the coming decades with some areas becoming newly exposed to flood risk and others experiencing floods of greater severity. However, population growth is the main driver of projected increases in population flood exposure. These projected increases could potentially be reduced somewhat if efforts are made to prevent or mitigate flood exposure. Improved flood risk communications, investment in flood defences, water management infrastructure, more durable housing and support for relocation or protection of informal settlements in areas with high flood hazard could reduce vulnerability to flooding even as flood hazards and the exposed population increase. Such policies would be most important in fast-growing parts of urban areas in proximity to rivers. Although this analysis finds limited household-level effects of recent community flood exposure using the ECOSIT surveys, the millions of displaced persons, hundreds of deaths, and hundreds of thousands of homes destroyed and hectares of cropland flooded in recent years suggest large potential economic and human benefits of flood protection policies.

This study also demonstrates that many floods may occur in remote areas and go unreported by media or government sources. Hundreds of thousands live in areas with floods detected by satellite each year and a low but non-trivial share of households report experiencing flood shocks outside the years of major flood events in Chad. These populations are primarily concentrated in areas with high flood hazard, suggesting a need for additional monitoring resources in remote but high-risk areas with vulnerable populations. Vulnerability also varies within communities, suggesting a need for targeted allocation of resources. The probability that a household reports a flood shock is correlated with factors that make direct flood damage more likely, such as engagement in agriculture and use of less durable dwelling materials. Adding flood vulnerability considerations to measures of exposure may help make investments more efficient and effective.

Finally, differences in community flood detection using satellite and survey data highlight chal- lenges in using remote sensing alone to identify flood incidence. Flood detection in the area around a community can identify areas where household flood shocks are very likely, but will also identify areas where households are not affected and can miss many communities reporting flood shocks. This makes rapidly responding to flood events challenging and may result in an inefficient allocation of resources. Flood detection algorithms can mistakenly identify 'floods' in communities with no flood report, but may also correctly identify flooding that does not harm households if the flooding is anticipated or not severe or if households are otherwise protected. More specific measures of deviation in the presence of surface water relative to the same place at the same time of year can reduce potential false positives for flood detection.

This study shows that communities with flooding detected in close proximity are very likely to have households reporting flood shocks. Additional work could consider whether particular thresholds for levels of detected flooding, as well as particular distances around communities, lead to more accurate identification of communities with reported floods. A machine learning approach could consider this prediction problem systematically and allow for different thresholds and distances based on community characteristics such as rural location, distance from a river, and so on.

Failing to detect flooding in communities where households report flood shocks may be more concerning, as this would imply that these areas are less likely to receive relief. This situation also creates greater basis risk from the perspective of a threshold-based flood response policy using remotely-detected flooding. This study finds that the share of communities with a flood report, but no detected flooding in proximity, falls as the area around a community in which flood detection is considered increases. Further work could analyse how basis risk changes with the scale of the geography considered. The trade-off of increasing the geographic scale of flood detection is that the share of communities identified as potentially exposed with actual flood reports will fall.

Constraints in what types of flood events different satellite data can capture mean that some flooding will always be missed, though this can potentially be reduced by combining results from multiple satellites and algorithms. A machine learning model using multiple flood detection inputs and trained on 'ground truth' data (likely survey reports) may be most effective in improving the accuracy of flood detection. Another consideration is that inundation is not the only way that households can be harmed by heavy precipitation, which can cause direct damage on its own. Such shocks require their own set of interventions.

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Cover Photo: Volunteers inspect a dyke during flooding in N'Djamena, Chad (Joris Bolomey / Getty Images)