Flooding in Chad: Analyzing incidence and impacts

Pierre E. Biscaye
Chaire de Professeur Junior
Université Clermont Auvergne, CERDI, CNRS, IRD and FERDI

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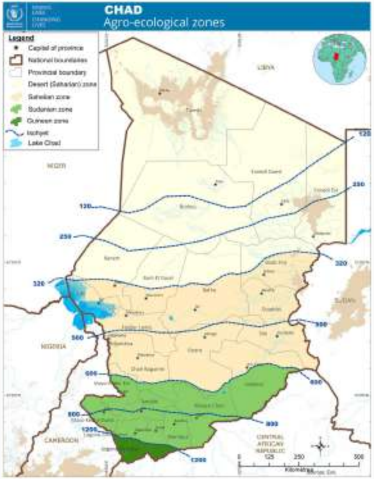
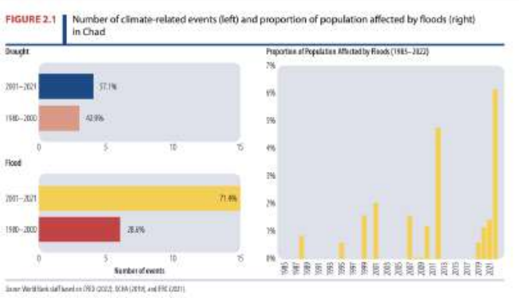
Context: Republic of Chad

- One of the largest countries in Africa, much of it in Sahara Desert and arid Sahel
- Population of 17 million
  - One of fastest growing in the world, expected to at least double by 2050
  - Primarily rural and concentrated in more agricultural south of country, but increasing movement to urban areas
  - Around 40% living below the poverty line
- Highly vulnerable to climate change
  - Threat of droughts, floods, heatwaves, and vector-borne diseases
  - Exposed population and insufficient defensive infrastructure



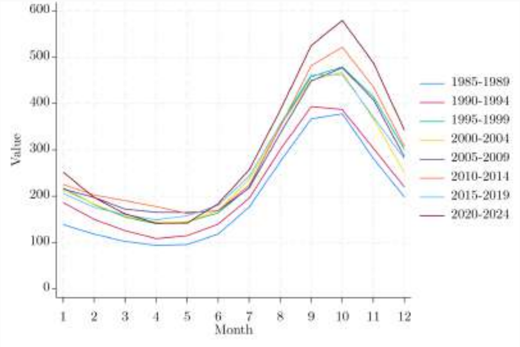
Source: World Food Programme

A) Major flood events over time //



Source: World Bank (2023).

B) Monthly average river station levels



Sources: Authors' analysis based on Chad DRE data.

Objective: Analyze flood risk and incidence in Chad

- Identify areas most exposed to floods
- Inform planning around the World Bank's Adaptive and Productive Safety Nets Project (APSNP) in Chad
  - Emergency cash transfers
  - Rapid flood response mechanism
- Inform flood policy more generally

Project overview: Three main components

1. Flood risk profile
   - Literature review on flood risk in Chad
   - Analysis of flood hazard and population exposure over space
     - Under current conditions and central climate and population change scenarios
2. Historical flood incidence (focus on post-2012)
   - Literature review: country-level flooding in recent decades
   - Mapping flood incidence over time using survey and remote sensing sources
     - Presentation of selected near real-time flood tracking databases
     - Analysis of survey-satellite flood identification alignment
3. Household impacts of flood exposure in 2019-2022
   - Literature review
   - Econometric analysis using ECOSIT survey data

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Drivers of flood risk in Chad

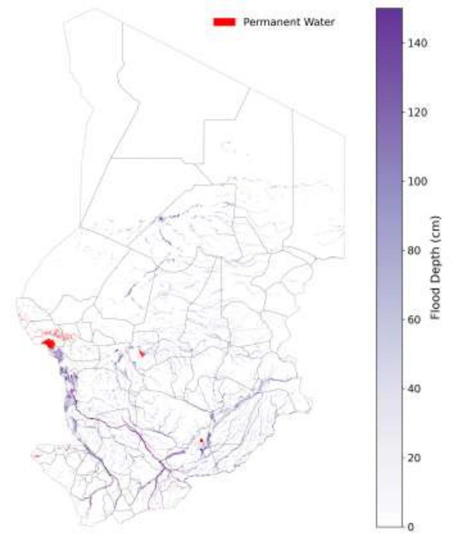
- Primary cause: more frequent episodes of heavy downpours of precipitation
  - Threat largely distributed through river networks (fluvial floods)
  - Local pluvial floods widespread but less severe on average
- Factors contributing to vulnerability
  - Population growth in flood-prone zones, often in informal urban settlements with non-durable housing and limited infrastructure
  - Insufficient or poorly-managed water drainage /management infrastructure
  - Deforestation and land degradation: reduced natural flood protection and soil absorption

Flood risk: key terms

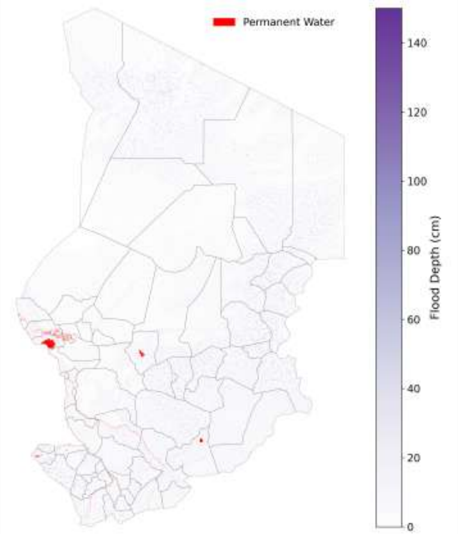
- *Fluvial/riverine flood*: Inundation due to overflowing rivers or other water bodies.
- *Pluvial flood*: Inundation due to precipitation exceeding soil absorption or drainage capacities.
- *Return period*: The number of years within which a flood of a particular depth of inundation would be expected to occur once.
- *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 projecting global changes up to 2100 as defined in the IPCC Sixth Assessment Report.

Current fluvial and pluvial flood hazard (Fathom)

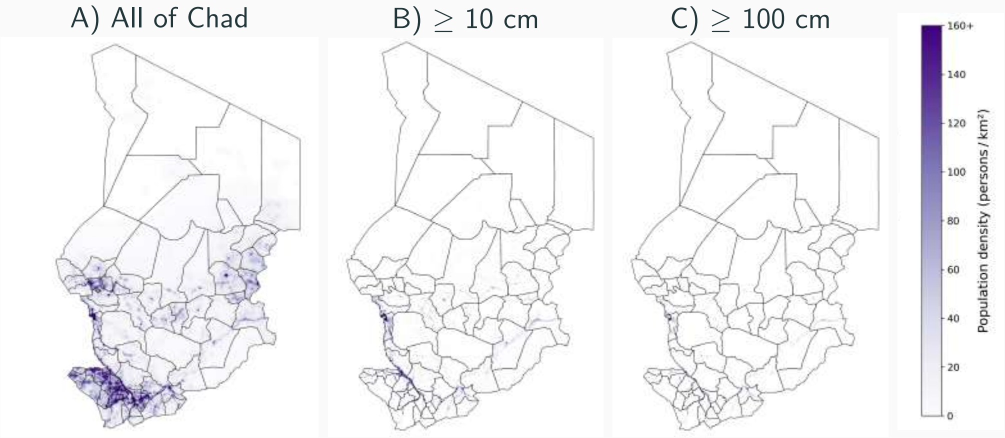
A) Fluvial floods



B) Pluvial floods

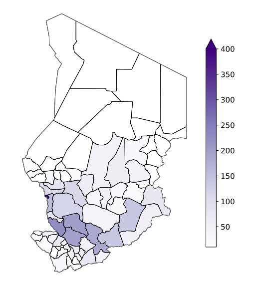


Population flood exposure: pop. density by 100-yr flood hazard level (Fathom)

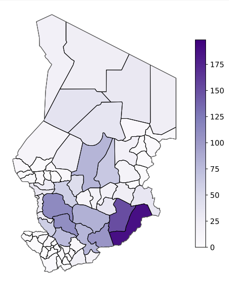


Departement-level land and population exposure to ≥10 cm 100-year flood depths (Rogers et al 2025)

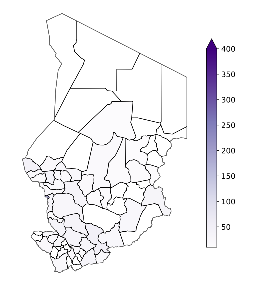
A) Fluvial floods
Population (1000s)



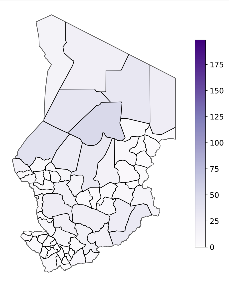
B) Fluvial floods
Land (100s km^2)



C) Pluvial floods
Population (1000s)



D) Pluvial floods
Land (100s km^2)

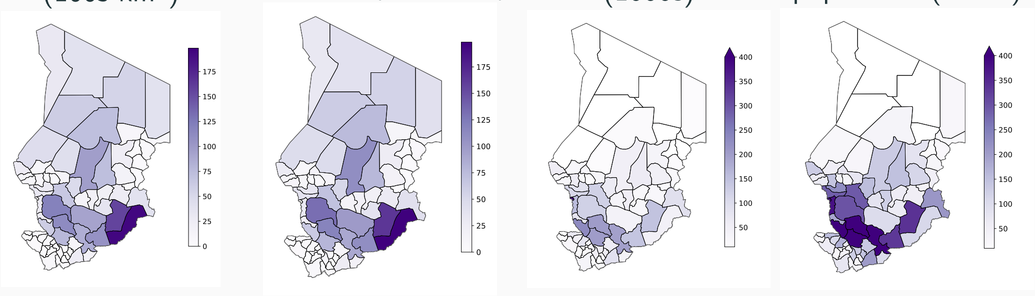


Projected changes in flood risk

- Several key factors: climate, population, infrastructure, defense
  - Changes in infrastructure and defense difficult to model
- IPCC Sixth Assessment Report on climate change in 2021
  - Multiple possible scenarios for climate and population change
  - SSP2-4.5: middle of the read/business as usual
- Fathom projects (small) increases in flood hazard Figures
- Rogers et al. (2025): climate v. population change in global flood exposure
  - Result: 21% of population flood exposure increase by 2100 attributed to climate, 77% to population change, 2% to combination $\Rightarrow$ similar in Chad
  - Projection: 225k$\Rightarrow$238k km^2 and 4.2$\Rightarrow$9.9M people exposed Top departements

Projected 100-year flood exposure: 2020 v. 2050 conditions (Rogers et al)

A) 2020, land area (100s km^2) | B) 2050 SSP2-4.5, land area (100s km^2) | C) 2020, population (1000s) | D) 2050 SSP2-4.5, population (1000s)



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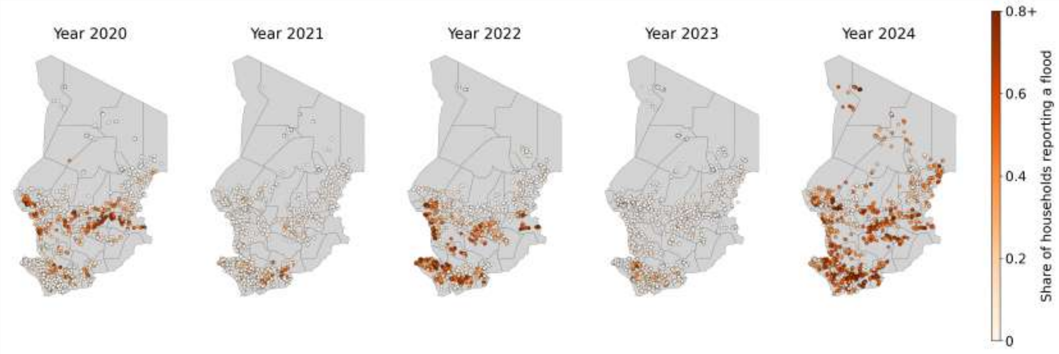
Sources of flood incidence information

- Media, administrative and NGO/IGO reports examples: ground truth but subject to bias and error, aggregated Table EM-DAT
- Survey reports: ground truth but subject to measurement issues, available only at selected points in space/time
- Meteorological data: driver of flood incidence, proxy for flooding but concerns about validity
- River flow data: ground truth driver of flood hazard, but available at very few points in space
- Remote sensing data: detection of surface water from space
  - Available at high resolution and high frequency
  - Constraints: flash floods, detection in urban, forested, and arid/bare earth areas
  - Need to define what constitutes a ‘flood’

Surveys: Local ground truth on flood incidence More ENSA RIMA/ECOSIT



Note: Authors' calculations based on data from the ENSA surveys.

Widespread survey-reported floods even in years of no major flood events

Survey	Round (period)	Total respondents	Count reporting any flood	% Survey communities w/ any flood reported	Time period covered	Geographic identifier	Coverage
RIMA	Oct 2014	8516	–	3.57	Apr – Oct 2014	ADM2	Rural
ENSA	Oct 2016	9544	209	8.85	May – Oct 2016	ADM3	Rural
	Oct 2017	9165	413	15.80	May – Oct 2017	ADM3	Rural
	Oct 2018	8924	181	10.23	May – Oct 2018	ADM3	Rural
	Oct–Nov 2019	6920	542	25.41	May – Nov 2019	ADM3	Rural
	Oct–Nov 2020	13208	2627	45.20	May – Nov 2020	Community	Rural
	Oct–Nov 2021	14761	893	25.39	May – Nov 2021	Community	Rural
	Oct–Nov 2022	13691	4291	60.52	May – Nov 2022	Community	Rural
	Oct–Nov 2023	14776	803	21.92	May – Nov 2023	Community	Rural
	Oct–Nov 2024	19672	9151	85.94	May – Nov 2024	Community	Rural
ECOSIT 4	Jun–Sept 2018 (R1)	3744	387	51.25	Jun 2015 – Sep 2018	Community	National
	Jan–Apr 2019 (R2)	3756	368	48.74	Jan 2016 – Apr 2019	Community	National
ECOSIT 5	Jan-Apr 2022 (R1)	3809	438	52.20	Jan 2019 – Apr 2022	Community	National
	Sep-Dec 2022 (R2)	3723	284	42.12	Sep 2019 – Dec 2022	Community	National
DIEM	Nov–Dec 2021(R2)	1692	173	4.49	Aug – Dec 2021	ADM2	Limited
	Aug–Sep 2022 (R3)	3704	194	5.04	May – Sept 2022	ADM2	Limited
	Dec 2022–Jan 2023 (R4)	5310	1425	37.05	Sept 2022– Jan 2023	ADM2	Limited
	Aug–Oct 2023 (R5)	5821	122	3.17	May – Oct 2023	ADM2	Limited
	Dec 2023–Jan 2024 (R6)	5683	409	10.63	Sept 2023– Jan 2024	ADM2	Limited
	Aug–Sep 2024 (R7)	4853	825	21.45	May – Sept 2024	ADM2	Limited
	Jan–Feb 2025 (R8)	5624	698	18.14	Oct 2024 – Feb 2025	ADM2	Limited

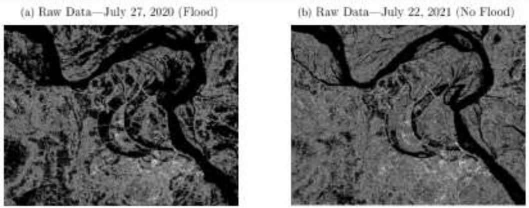
Within-community variation in exposure driven by direct vulnerability

	(1)	(2)	(3)
Rural location	-0.017***		
	(0.006)		
Any HH crop or livestock activity	0.012	0.032***	0.071***
	(0.009)	(0.011)	(0.023)
Household size	0.003**	0.002*	0.005*
	(0.001)	(0.001)	(0.002)
Roof is cement or metal	-0.006	-0.024**	-0.054**
	(0.009)	(0.011)	(0.023)
Floor is tile or cement	-0.045***	-0.055***	-0.089***
	(0.011)	(0.013)	(0.022)
Household has toilet or latrine	-0.004	-0.020	-0.036
	(0.010)	(0.013)	(0.024)
Count of other HHs in comm. reporting flood	0.064***		
	(0.003)		
Observations	7493	7493	3718
Mean, HH reported flood	0.101	0.101	0.203
Community FE	No	Yes	Yes
Wave FE	Yes	Yes	Yes
Sample	All	All	Any comm. flood rept.

Note: Authors' calculations based on data from the ECOSIT 4 surveys

Remotely-sensed flooding: identifying floods from space

1. Use characteristics of satellite data (imagery or radar) to identify surface water at a given point in time (e.g., NDWI)
2. Compare to presence of surface water at another point in time
3. Mask out problematic pixels (e.g., steep slopes, cloud cover, shadow) and (sometimes) known permanent (or seasonal) surface water pixels
4. Classify unexpected surface water as likely flooding



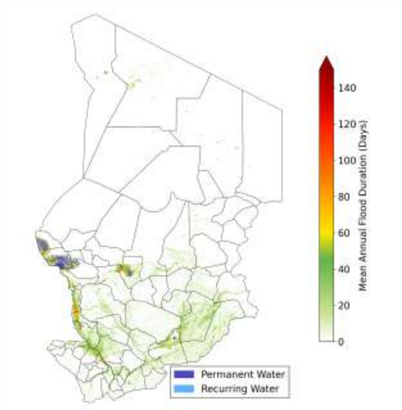
Source: Patel (2024), from Sentinel-1 SAR

Near real-time remote flood mapping NASA MODIS GFM

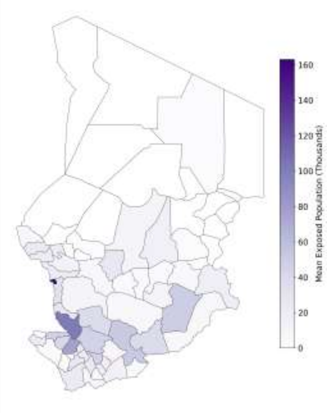
Database	Data	Years of coverage	Spatial resolution	Temporal resolution	Accessibility
VIIRS Flood Mapping (VFM)	VIIRS imagery	2012-present	375 m	1/5 day composites	Publicly available archive
GloFAS Global Flood Monitoring (GFM)	Sentinel-1 SAR	2021-present	20 m	6-12 days	Web portal/API with download restrictions
Global Flood Monitoring System (GFMS)	TRMM/ GPM precipitation	2013-present	12 km	Daily	Publicly available archive
Near Real-Time (NRT) Global Flood Product	MODIS imagery	2011-2022 (legacy); 2021-present (current)	250 m	1/2/3 day composites	Web portal for last 8 days
African Flood and Drought Monitor	Precipitation gauges + satellite-derived precipitation	2008-present	5 km	Daily	Web portal viewing but not downloading
Automated Disaster Analysis and Mapping (ADAM) Floods	VIIRS, MODIS, and Sentinel-1 satellites, Floodscan	post 2018-present	At least 375 m	Unclear	Web portal viewing but not downloading
FloodScan	Satellite microwaves and imagery	1998-present	90 m	Daily	Web portal viewing but not downloading

Mean exposure to NOAA/GMU VFM-detected floods, 2012-2024

A) Annual days of detected flooding



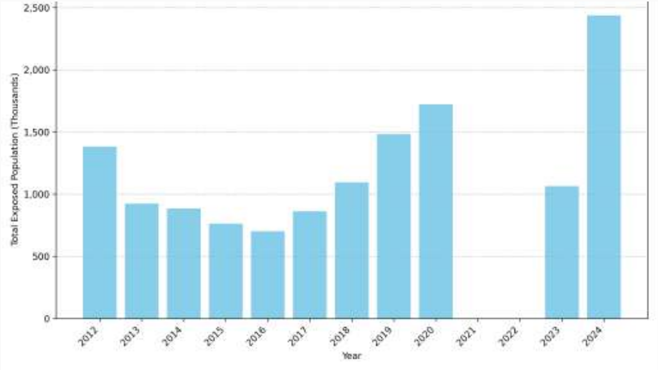
B) Annual population exposure by departement



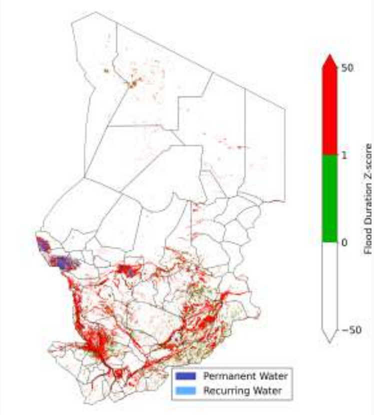
Source: Authors' calculations based on data from the VFM archive (2025) and WorldPop (2025).

Annual exposure to VFM-detected floods

A) Population exposure



B) 2024 land exposure



Source: Authors' calculations based on data from the VFM archive (2025) and WorldPop (2025).

Comparing survey and satellite flood identification

- Both flood measures concentrated relatively more in areas with higher flood hazard and in years of major flooding disasters
- Strong correlation between local VFM flood detection and probability of an ENSA or ECOSIT survey food report
- Limited alignment of community flood exposure classifications ECOSIT
- Limitations of remotely-sensed measures: challenges in capturing pluvial, short duration, and urban floods in particular
  - Could potentially be addressed with more sophisticated remotely-sensed flood detection techniques
- Erroneous survey reports: measurement error, or heavy precipitation shocks that do not result in inundation
  - Will always create some survey-satellite disagreement

Using satellite detection to target flood response

- Local VFM flood detection is strongly correlated with survey food reports
  - Of communities with at least 10% of pixels detected as flooded within 1 km, 86% had at least one survey flood report in the ENSA surveys, compared to 64% in ECOSIT 4
  - Accuracy could potentially be improved by analyzing choice of threshold and bandwidth
    - For example, 89% accuracy for 20% threshold within 5 km for ENSA surveys
  - Shows promise for use of satellites to target flood reponses
- Downside: basis risk $\Rightarrow$ floods experienced but not detected or below threshold
  - 45% of ENSA communities and 17% of ECOSIT 4 communities with a HH flood report do not have any flooded pixels detected even within 5 km
    - Compare to 72% and 42% with a 1 km radius
  - Basis risk may be lower if consider larger geographic areas, but at cost of lower accuracy of flood detection
  - Some of the basis risk may represent non-flood shocks

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Estimated aggregate impacts of major floods since 2012 Back

Year	Affected population	Flooded land (ha)	Houses destroyed
2012	466,000[a] - 613,631[f]	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]

[a] OCHA 2012. [b] OCHA 2014. [c] OCHA 2020. [d] Government of Chad 2023. [e] ACAPS 2024. [f] EM-DAT 2025. [g] FAO 2024

Household-level impacts of floods in the literature

- Decreased food security (Amolegbe et al. 2023; Devereux 2007; Reed et al. 2022)
- Adverse health effects (Djoumessi Tiague 2022; Escobar Carias et al 2022; Sajid & Bevis 2021)
- Increased poverty, decreased well-being (Baez et al. 2020; Freudenrich & Kebede 2022; Stein & Weisser 2022)
- Reduced crop production (Banerjee 2020; Bangalore & McDermott 2024; Djoumessi Tiague 2023)
- Short-term increases in out-migration, diversification of labor supply (Akter 2021; Chen et al. 2017; Gray & Mueller 2012; Maystadt et al. 2016; Mueller & Quisumbing 2011; Vitellozzi & Giannelli 2023)
- Most studies focus on short-term, with recent exceptions (Biscaye 2024; Patel 2024; Sajid 2023)
- Fewer studies in African countries; none in Chad

Empirical strategy: Impacts on ECOSIT sample households

- 3 waves constituting unbalanced panel: 6,223 HHs observed at least twice
  - 2018-19, 2020-2021 (phone surveys with subsample), 2022 (partial panel)
- 'Treatment': community-level flood exposure between rounds ('intent to treat')
  - Satellite: any flooding detected within 1 km of community centroid in 2019 or 2020
  - Survey: any household report of flood shock from 2019-2022 (recall)
  - 235/616 communities not flooded, 146 flooded by both measures, 147 survey only and 88 satellite only Map
- Empirical approach: difference-in-differences
  - Deal with non-random risk of exposure by recentering shock measure around estimated probability of exposure (Borusyak & Hull 2023)
  - Identify impacts by comparing changes over time within HH in comms. exposed to floods against those in non-exposed comms. in the same province and with the same probability of exposure
  - Household characteristics at baseline are well-balanced
- Outcomes: measures of household well-being and livelihoods

Average impacts of community-flood exposure

	(1) Any flooded pixel (SE)	(2) Any flood report (SE)
Respondent did any work in last 7 days	-0.05	-0.01
	(0.03)	(0.03)
Any HH non-farm enterprise	0.07*	0.04
	(0.04)	(0.03)
Any HH crop or livestock activity	-0.00	0.04***
	(0.02)	(0.01)
HH believes is is worse off than neighbors	-0.03	-0.03
	(0.03)	(0.02)
HH believes it is poor or very poor	0.02	0.01
	(0.02)	(0.02)
Normalized HH food insecurity index	0.09	0.03
	(0.07)	(0.05)
Household reported a non-flood shock	-0.06	0.10***
	(0.04)	(0.03)

Impacts of community flood exposure over time (satellite measure)

	(1) Respondent working	(2) Any non-farm enterprise	(3) Any HH agriculture	(4) Well-being worse than neighbors	(5) Considers HH poor	(6) Food insecurity index
t-1	-0.07	0.06	-0.02	0.03	0.01	0.08
	(0.07)	(0.08)	(0.03)	(0.08)	(0.04)	(0.21)
Treatment period	0.04	0.11**	0.00	-0.07*	0.04	0.08
	(0.04)	(0.05)	(0.02)	(0.04)	(0.03)	(0.10)
t+1	0.02	0.11**	0.00	-0.03	-0.01	0.02
	(0.04)	(0.05)	(0.03)	(0.04)	(0.03)	(0.11)
t+2	0.02	0.08	0.00	-0.04	0.00	-0.02
	(0.04)	(0.05)	(0.03)	(0.04)	(0.04)	(0.11)
t+3	-0.04	0.08	0.01	-0.07**	0.02	0.02
	(0.04)	(0.05)	(0.02)	(0.04)	(0.03)	(0.08)
t+4	-0.04	0.06	0.00	-0.03	0.03	0.06
	(0.05)	(0.06)	(0.03)	(0.04)	(0.03)	(0.09)
Observations	14267	14267	14267	13478	14171	14267
Average effect	-0.01	0.08	0.00	-0.05	0.02	0.03
(Standard error)	0.03	0.04	0.02	0.03	0.02	0.07

Discussion

- Increased non-farm enterprise engagement, particularly in urban areas soon after exposure $\Rightarrow$ potential efforts at livelihood diversification
- No average effects among the sample households of flood exposure on measures of household well-being such as food insecurity or perceived well-being
- Intent to treat effects likely mask important heterogeneity; only ~20% of HH in exposed communities report being directly affected by a flood shock
  - Positive and large coefficient for the effect on food insecurity index may be driven by directly affected households
  - Could use community exposure to instrument for HH exposure, but requires strong assumptions
- Future work: additional outcomes using ECOSIT 4 & 5 only; stacked cross-sectional event study using ENSA, HH-level treatment

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Conclusions: Flood risk

- Both flood hazard and population exposure concentrated along bodies of water
  - Pluvial flooding also important but affects smaller share of population
- Areas combining highest mean days of annual satellite flooding detected together with higher population densities and higher flood hazard are largely all concentrated in the areas around the Logone River
  - Given limited resources, investments in flood mitigation and response may therefore be most impactful in these areas
- Flood exposure projected to $\Uparrow$ in coming decades, primarily driven by pop. growth
  - Could be mitigated by investment in communication, flood defenses, water/drainage infrastrucutre, durable housing, relocation from high-hazard zones, esp. near rivers
- Particular support needed for more vulnerable households: engaged in agriculture and with non-durable housing

Conclusion: Flood monitoring

- Many floods may occur in remote areas and go unreported by media or government sources
  - Hundreds of thousands of people 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
  - $\Rightarrow$ Need for additional monitoring resources in remote but high-risk areas with vulnerable populations
- Challenges in using remote sensing alone to identify flood incidence
  - Need for multiple sources and ML models trained on ground truth to reduce false negatives
  - Need to tune algorithms to local conditions to reduce false positives
- Some promise for using satellites to detect flooded communities $\Rightarrow$ useful for flood response
  - Quite accurate predictions, but misses some communities with flood reports

Thank you!

Feedback welcome

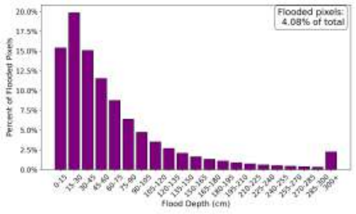
pierre.biscaye@uca.fr

Roadmap

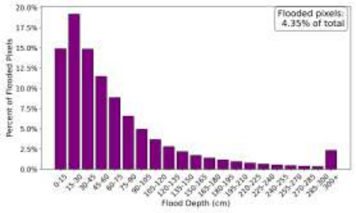
Appendix

Projected changes in 100-year flood hazard (Chad) Back

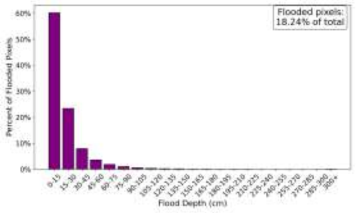
A) Fluvial floods (defended), 2020



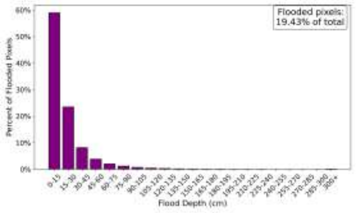
B) Fluvial floods (defended), 2050
SSP1-2.6



C) Pluvial floods (defended), 2020



D) Pluvial floods (defended), 2050
SSP1-2.6



100-year flood most-affected departments (by pop.) Back

	2020 conditions				2050 SSP2-4.5 conditions			
Departement	Pop. (1000s)	Pop. (%)	Area (1000s km^2)	Area (%)	Pop. (1000s)	Pop. (%)	Area (1000s km^2)	Area (%)
Baguirmi	123.72	43.85	11.98	44.26	299.93	48.24	13.18	48.70
Bahr-Azoum	145.93	58.34	15.62	58.64	338.66	61.45	16.45	61.76
Bahr-Köh	195.88	48.82	8.49	49.45	453.93	51.35	8.93	52.01
Chari	156.54	57.28	2.77	63.86	380.70	63.22	3.04	70.24
Dababa	122.83	39.70	6.48	40.11	293.06	42.99	7.02	43.44
Lac Iro	143.95	59.91	10.57	60.43	330.11	62.36	11.00	62.90
Loug-Chari	202.36	72.81	11.21	73.74	469.47	76.67	11.81	77.69
Mayo-Boneye	231.11	71.02	6.09	72.04	527.20	73.53	6.30	74.59
N'Djaména	538.09	38.41	0.17	42.26	1412.12	45.75	0.21	50.95
Tandjilé Est	202.50	61.50	7.77	62.57	456.78	62.97	7.96	64.07
Total	**4176.85**	**25.50**	**225.93**	**17.95**	**9852.03**	**27.30**	**238.24**	**18.93**

Source: Authors, based on data from Rogers et al. (2025)

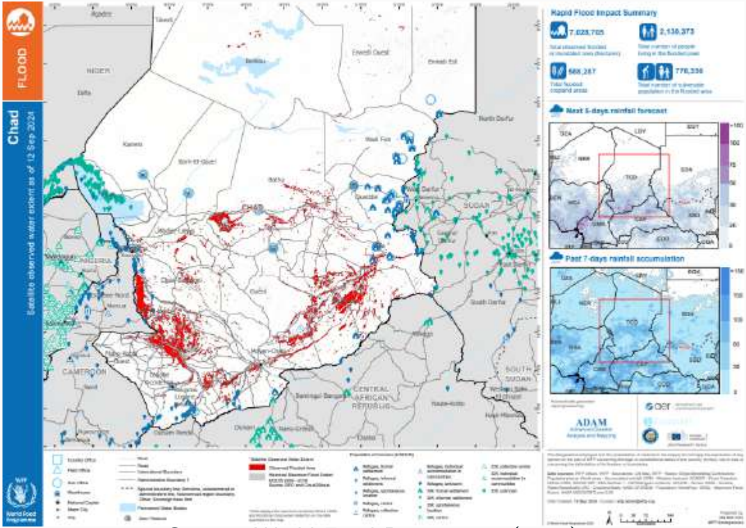
Administrative/NGO reporting not systematic Back

But more sources tracking incidence of recent major flood events

- WFP ADAM (Advanced Disaster Analysis & Mapping) Example: Sept. 2024
  - Based on near real-time paid Floodscan remotely-sensed incidence data
  - Overlay with spatial population and land cover data $\Rightarrow$ estimated exposure/impacts
- FAO DIEM (Data in Emergencies Monitoring) Example: Jul. 2024
  - Based on ADAM, combine with other data sources
- OCHA (UN Office for the Coordination of Humanitarian Affairs) Example: Jul.-Aug. 2024
  - Based on administrative reports and local NGOs
- Government agencies: Ministère de l'Administration du Territoire et de la Décentralisation, Comité Stratégique de Gestion et de Prévention des Inondations, etc.
- Other agencies: IFRC, Chadian Red Cross, etc.

ADAM: 2024 flood incidence map

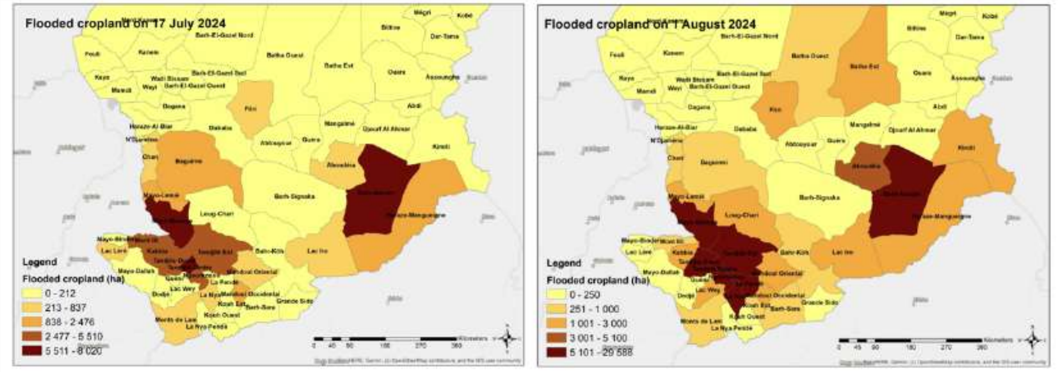
Reports Remote sensing 2024 T&M



Source: World Food Programme (2024)

DIEM: July 2024 flooded cropland (ha) by department

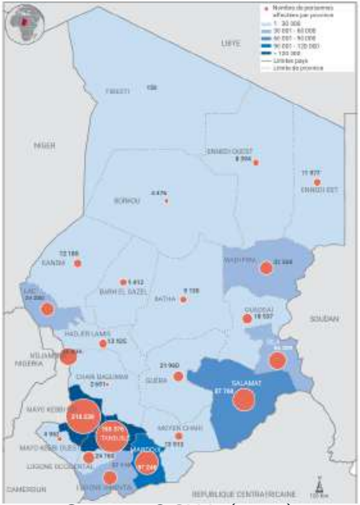
Back



Source: FAO (2024)

OCHA: July-Aug 2024 estimated number of people affected

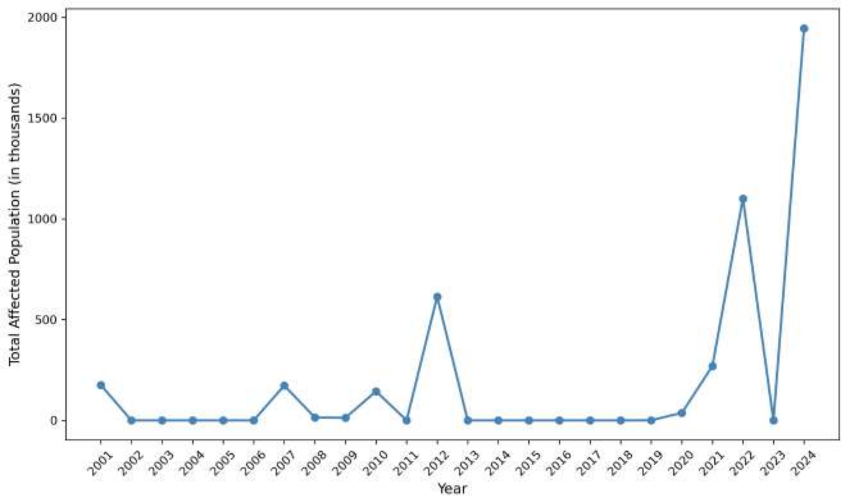
Back



Source: OCHA (2024)

Reported population exposed to major floods since 2000 (EM-DAT)

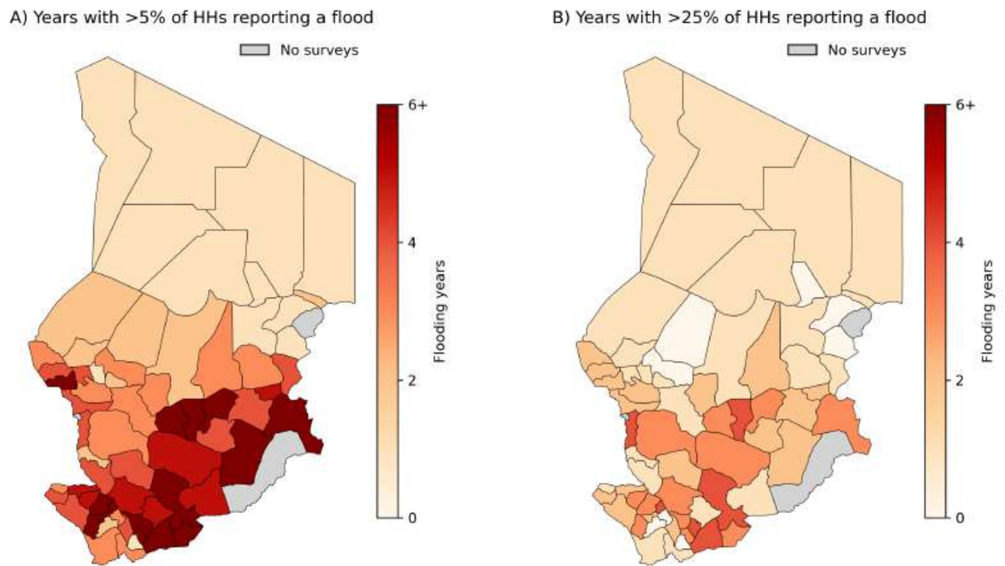
Back



Source: Authors, based on data from EM-DAT

ENSA survey flood exposure over time, 2016-2024

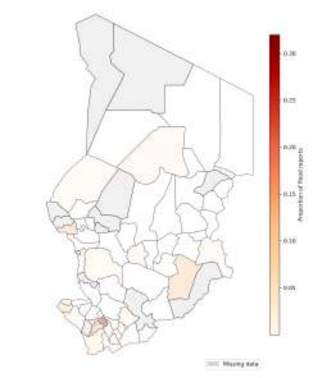
Back



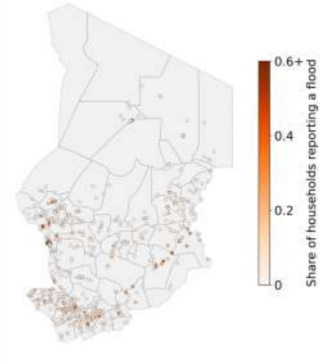
RIMA and ECOSIT flood reports

Back

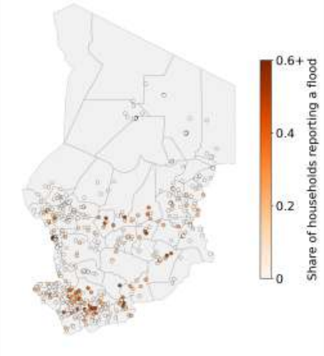
A) 2014 (RIMA)



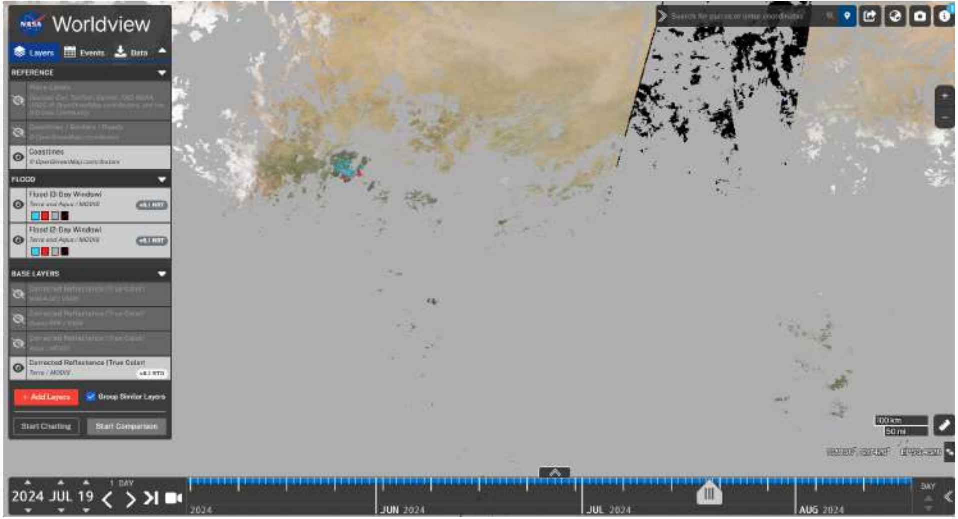
B) 2015-2018 (ECOSIT 4)



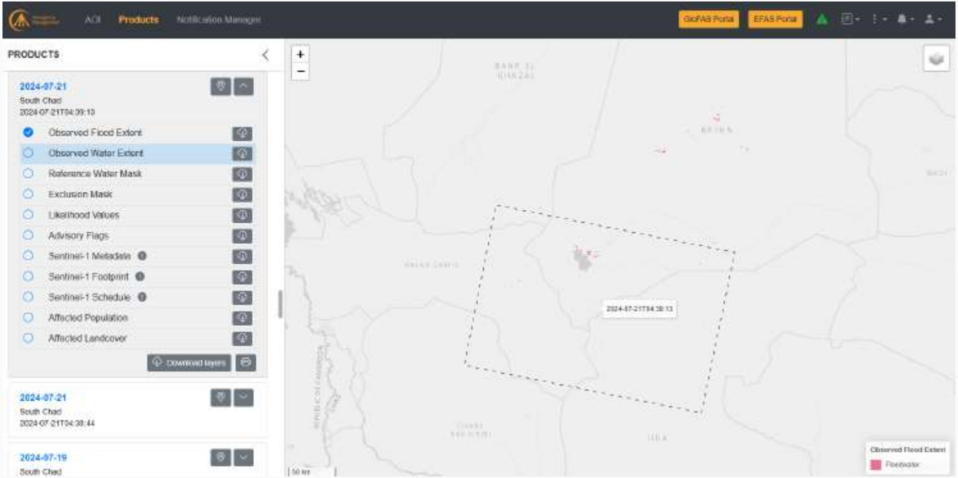
C) 2019-2022 (ECOSIT 5)



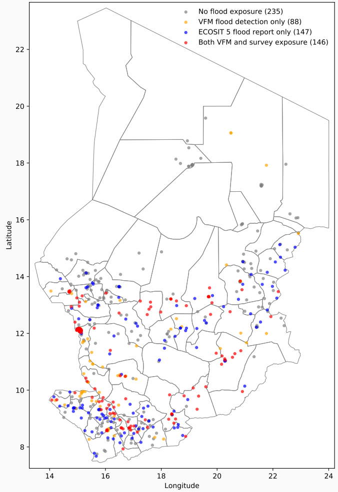
NASA NRT Global Flood Product: July 19, 2024 Back



GloFAS Global Flood Monitor: July 21, 2024 Back



Survey-reported vs satellite-detected flooding, ECOSIT 4 Comparing Analysis



Note: Authors' calculations based on data from ECOSIT 4 and 5 and the VFM archive.

ACAPS (2024). **Impact of Floods in Chad – Briefing Note, 31 October 2024.** Humanitarian Briefing Note.

FAO (Oct. 2024). **West and Central Africa – Floods: Urgent call for assistance, October 2024–May 2025.** Rome: FAO. Some rights reserved. CC BY-NC-SA 3.0 IGO. URL: https://data-in-emergencies.fao.org/pages/diem_eve.

Government of Chad (Mar. 2023). **Summary of Flood Prevention and Management Efforts in 2022.** Report of the Strategic Committee for Flood Prevention and Management.

NOAA and George Mason University (2025). **NOAA/GFM VIIRS Flood Mapping Archive.** URL: https://noaa-jpss.s3.amazonaws.com/index.html#JPSS_Blended_Products/VFM_5day_GLB/ (visited on 04/22/2025).

OCHA (Sept. 2012). **CHAD: Humanitarian Snapshot (as of 24 September 2012).** Accessed: 2025-04-15. URL: https://reliefweb.int/report/chad/chad-humanitarian-snapshot-24-september-2012-enfr.

— (Sept. 2014). **Tchad: Bulletin Humanitaire N°05 — août-septembre 2014.**