CLIMATE EXTREMES & CHANGES IN HUMAN SETTLEMENT PATTERNS - A FOCUS ON DROUGHTS IN AFRICA

AU UN IST Photo / Tobin Jones. Original public domain image from Flickr

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Prof. Serena Ceola – serena.ceola@unibo.it
Department of Civil, Chemical, Environmental and Materials Engineering
Alma Mater Studiorum Università di Bologna - Italy

Mechanisms and Pathways for Modeling the Impacts of Catastrophic Events on Human Migration

Why DROUGHTS?

- One of the most devastating hydrologic extremes
- Climate change is contributing to increased likelihood and severity of drought impacts worldwide

Aghakouchack et al., SCIENCE, 2014
IPCC, 2022, AR6, Chapter 4: Water

During 1970-2019

TYPE OF EVENT
7% droughts

FATALITIES
34% droughts

WMO, 2021

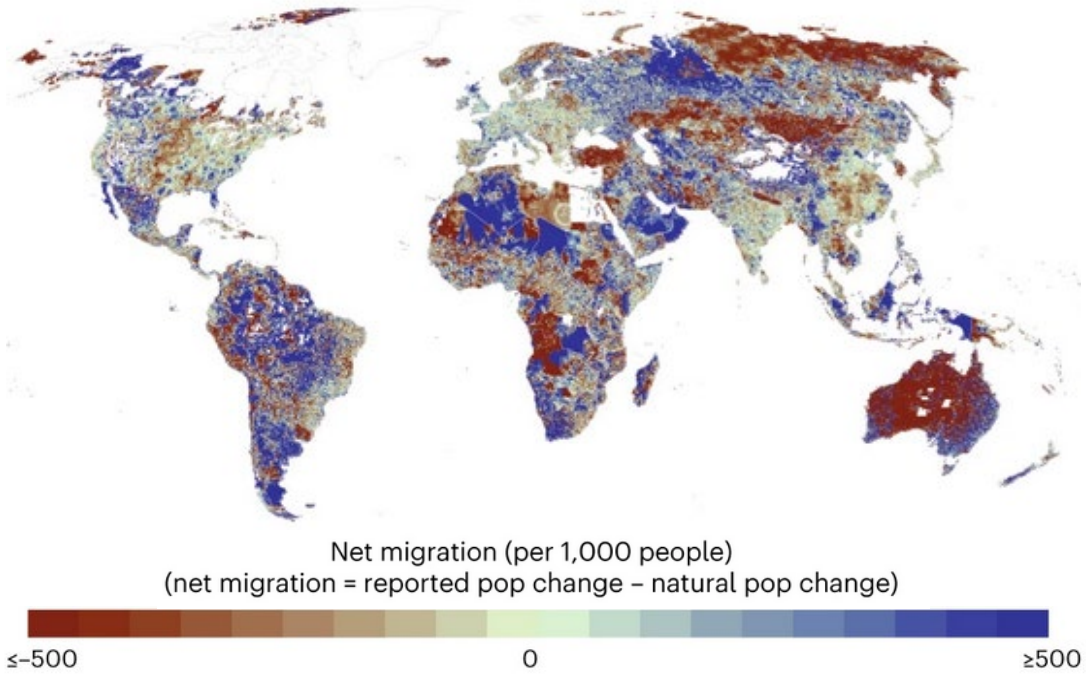
- Droughts in Africa have become more intense, frequent and widespread over the past 50 years

Masih et al., HESS, 2014
IPCC, 2022, AR6, Chapter 9: Africa

Drought | Credit: Jose Antonio Alba | Water Alternatives Photos | Flickr

Mechanisms and Pathways for Modeling the Impacts of Catastrophic Events on Human Migration

Human migration and mobility

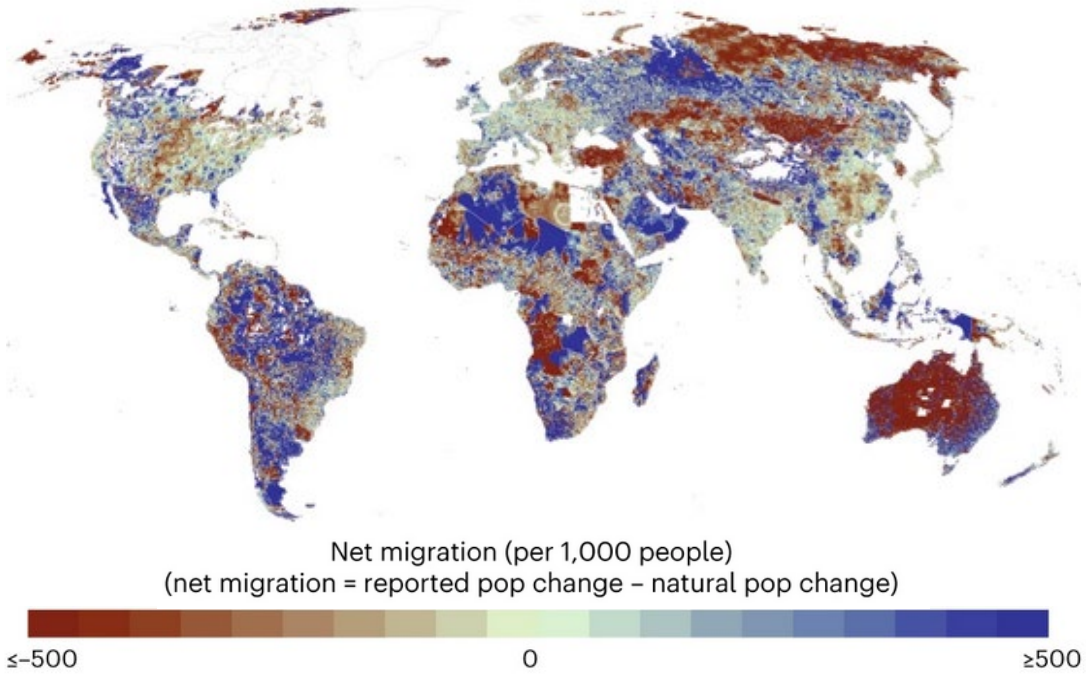


Around 50% of the world's urban population lives in areas where migration accelerated urban population growth

Niva et al., NAT. HUM. BEHAV., 2023

Mechanisms and Pathways for Modeling the Impacts of Catastrophic Events on Human Migration

Human migration and mobility



Around 50% of the world's urban population lives in areas where migration accelerated urban population growth

*Niva et al., **NAT. HUM. BEHAV.**, 2023*

Short distance mobility is the most prevalent form of migration

Human migration, NATURE, 2017
IPCC, 2022
Xu & Famiglietti, WIREs Water, 2023

Climate change & hydrologic extremes are impacting the risk of temporary and permanent migration

IPCC, 2022, AR6, Chapter 4: Water

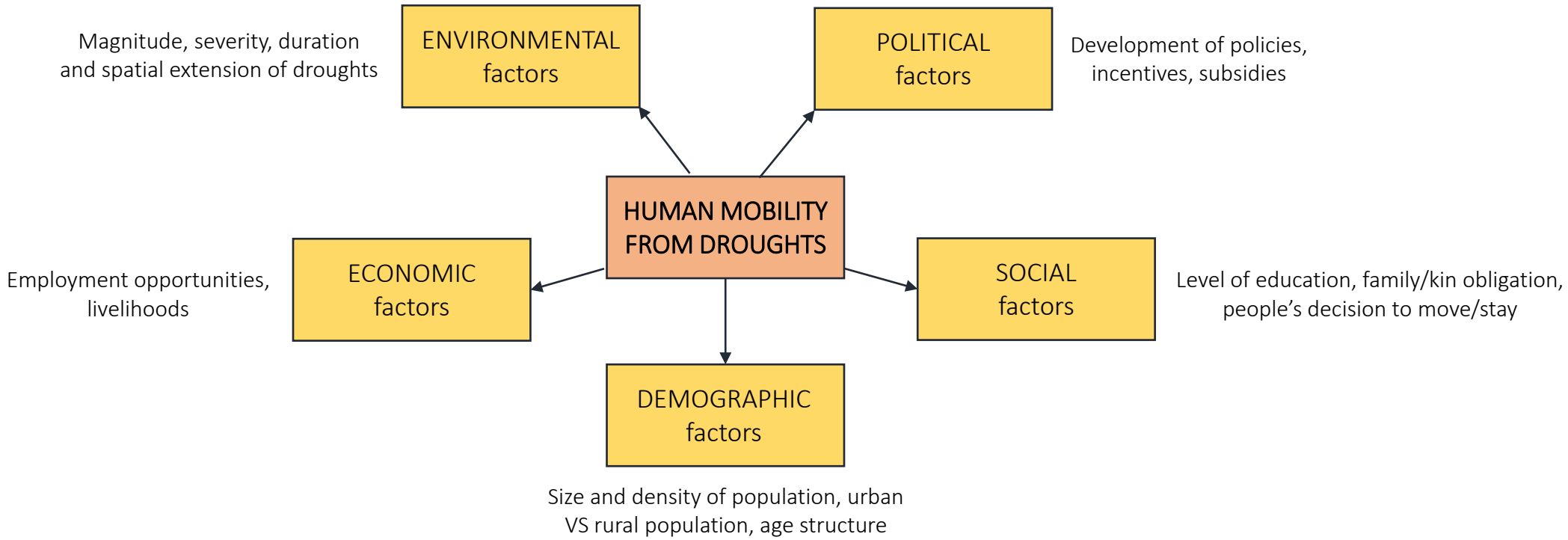
Climate-induced migration more common within national borders

Hoffman et al., NAT. CLIM. CHANGE, 2020

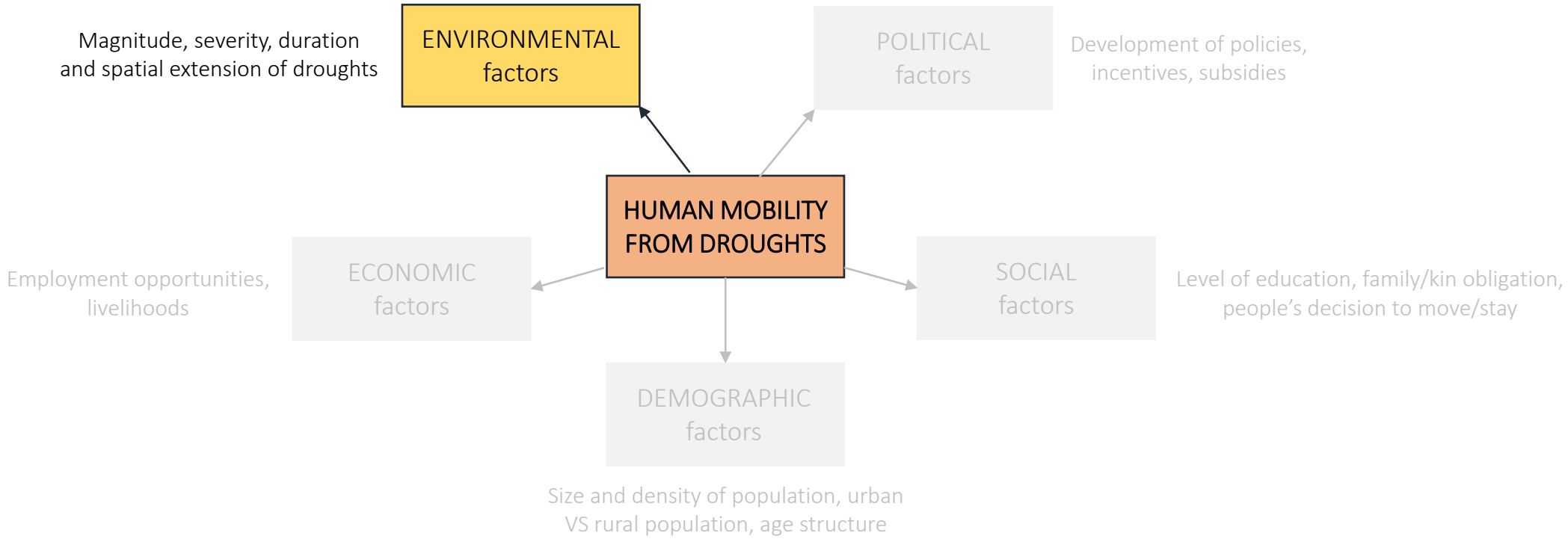
Disaster displacements are 3 x conflict & violence displacements

IDMC, 2020

Droughts & Human Mobility



Droughts & Human Mobility



RESEARCH QUESTION

Are drought occurrences, other things being equal, associated with human mobility toward rivers or cities?

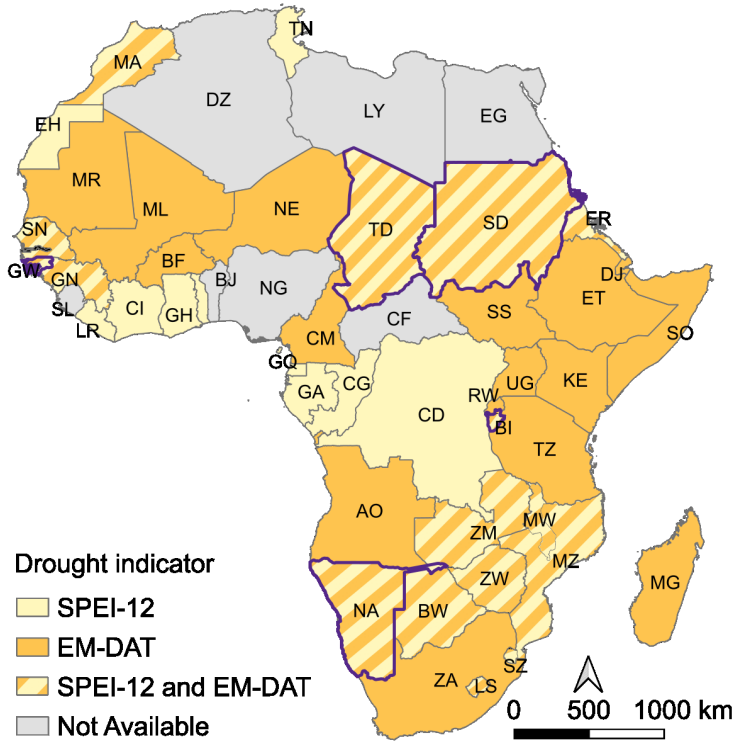
Ceola et al., EARTH'S FUTURE, 2023

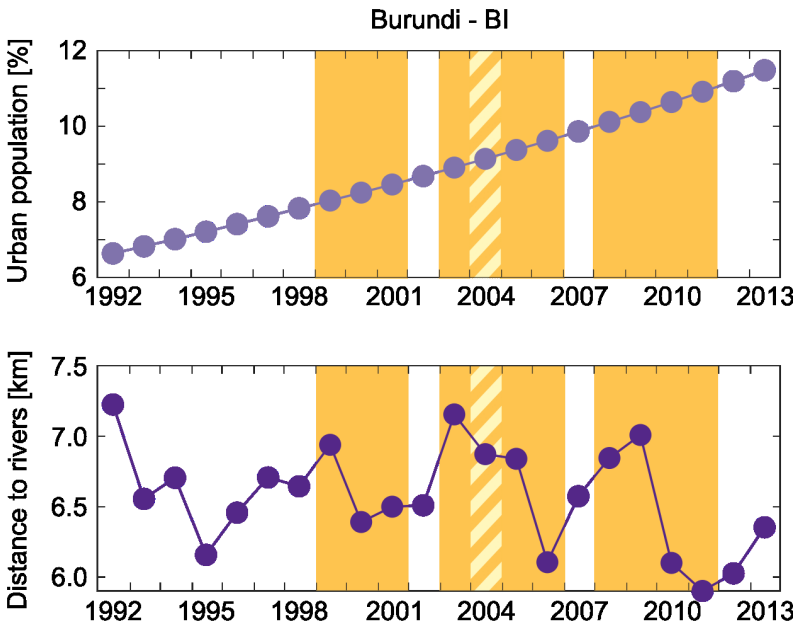
Droughts influence patterns of human settlements in Africa

Past work was unable to identify the interplay between drought occurrence and changes in human settlements in Africa because of limited data.

Here we explore this relationship across **50 countries from 1992 to 2013** and extract:

- **annual drought occurrences** from two indicators (EM-DAT and SPEI-12)
- **human settlement patterns** (from urban population data and human distance to rivers)





Ceola et al., EARTH'S FUTURE, 2023

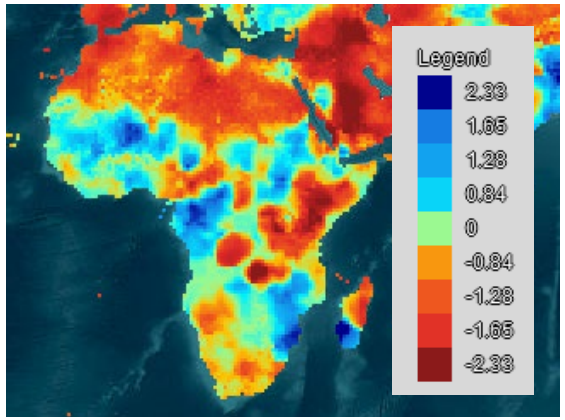
Droughts influence patterns of human settlements in Africa

IDENTIFICATION OF DROUGHT OCCURRENCE

For each country c, a generic year y is classified as **drought year** y_D if:

- **SPEI-12**: yearly country-based average values ≤ -1

Begueria et al., INT. J. CLIMATOL., 2014



https://spei.csic.es/spei_database_2_9/

- **EM-DAT**: available data on people affected

https://www.emdat.be

	year	…	1994	1995	1996	1997	…
COUNTRY *c*	SPEI-12	…	NOT-DROUGHT	DROUGHT	NOT-DROUGHT	DROUGHT	…
	EM-DAT	…	DROUGHT	NOT-DROUGHT	NOT-DROUGHT	DROUGHT	…

Ceola et al., EARTH'S FUTURE, 2023

Droughts influence patterns of human settlements in Africa

CHANGES IN HUMAN SETTLEMENT PATTERNS

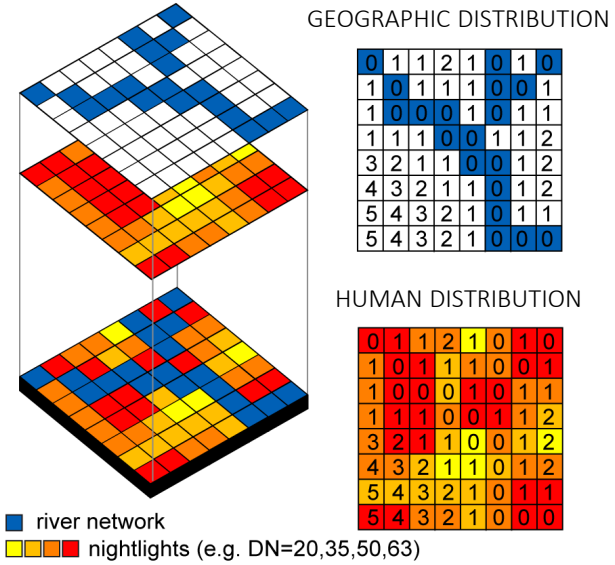
- **Human distance to rivers**, $h(c,y) = rd(c,y)$: estimated, for each country c and each year y, by coupling NOAA's nighttime lights and HydroSHEDS river network data

https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html
https://www.hydrosheds.org/products/hydrorivers#downloads

https://worldview.earthdata.nasa.gov/

$$rd(c,y) = \frac{\sum_{j=1}^{10} j \cdot SOL_j(c,y)}{\sum_{j=1}^{10} SOL_j(c,y)}$$

where $SOL_j(c,y)$ is the sum of lights for distance class j, country c and year y



Ceola et al., 2015, WRR

- **Urban population**, $h(c,y) = urb(c,y)$: relative urban population data (i.e., % of total population)

https://data.worldbank.org

Ceola et al., EARTH'S FUTURE, 2023

Droughts influence patterns of human settlements in Africa

METHODS

For all countries *c:*

$$\Delta h(c,y) = h(c,y) - h(c,y-1)$$

Compute human displacements for every year y as the difference in human distribution $h(c,y)$ between 2 adjacent years (both antecedent and subsequent)

Is the year y a drought year (y_D)?

YES → $\Delta h(c,y_D) \rightarrow \Delta h_{50,D}(c)$

NO → $\Delta h(c,y_{ND}) \rightarrow \Delta h_{50,ND}(c)$

Median values during drought VS non-drought years

Ceola et al., EARTH'S FUTURE, 2023

Droughts influence patterns of human settlements in Africa

METHODS

For all countries *c:*

$$\Delta h(c,y) = h(c,y) - h(c,y-1)$$

Compute human displacements for every year y as the difference in human distribution $h(c,y)$ between 2 adjacent years (both antecedent and subsequent)

Is the year y a drought year (y_D)?

YES → $\Delta h(c,y_D) \rightarrow \Delta h_{50,D}(c)$

NO → $\Delta h(c,y_{ND}) \rightarrow \Delta h_{50,ND}(c)$

Median values during drought VS non-drought years

Research hypotheses

1) reduced human distance to rivers during droughts: $\Delta rd_{50,D}(c) < \Delta rd_{50,ND}(c)$

2) increased urban population during droughts: $\Delta urb_{50,D}(c) > \Delta urb_{50,ND}(c)$

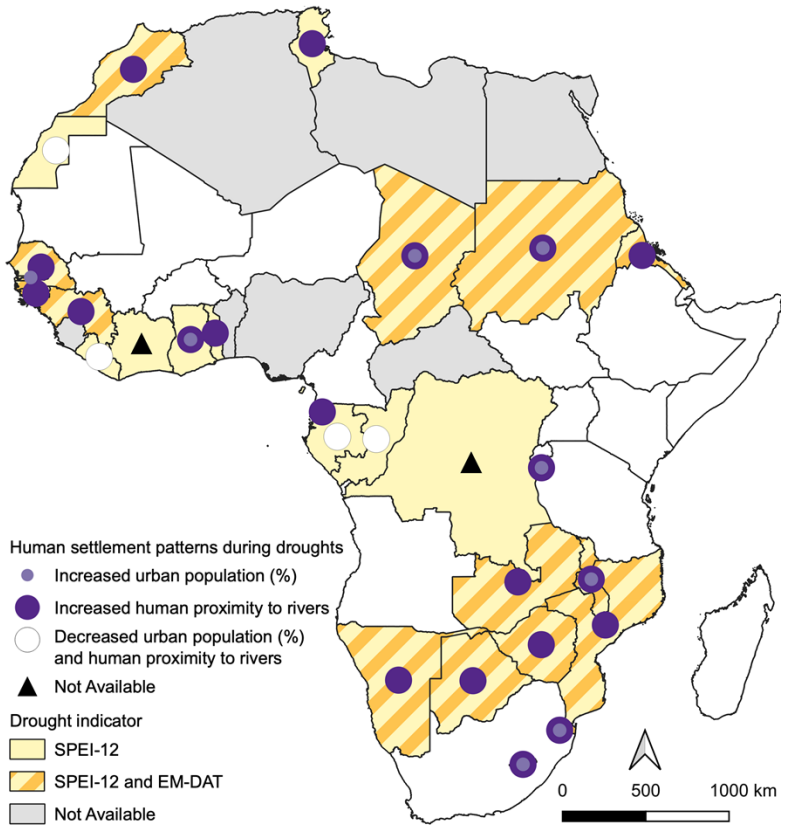
Human patterns during droughts are compared also against patterns from the whole study period

Ceola et al., EARTH'S FUTURE, 2023

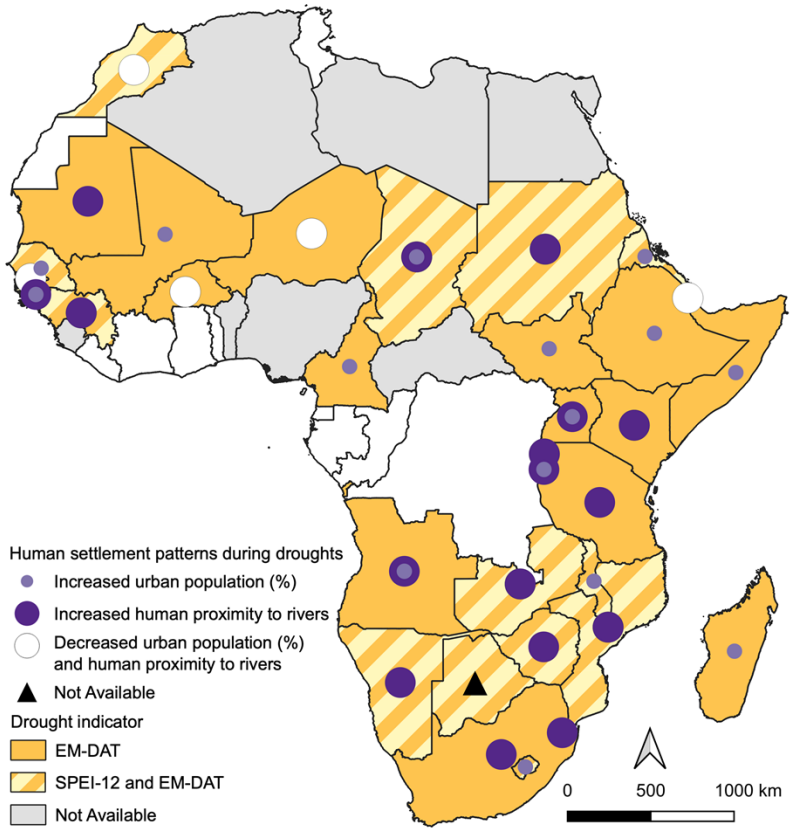
Droughts influence patterns of human settlements in Africa

Country-based patterns of **increased human displacement towards** rivers and urban centers between adjacent years (*drought year and antecedent year*), derived by comparing median values during **drought and non-drought** years

SPEI-12 drought records



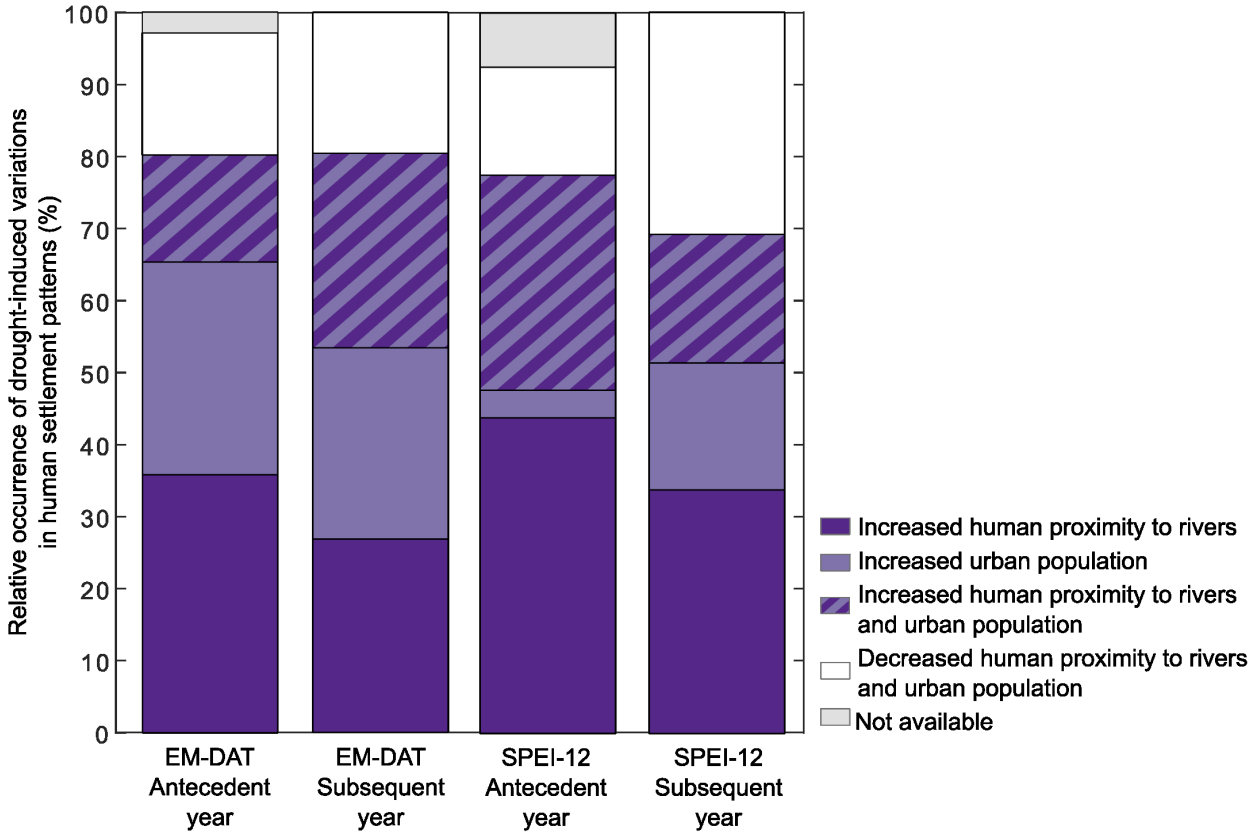
EM-DAT drought records



Ceola et al., EARTH'S FUTURE, 2023

Droughts influence patterns of human settlements in Africa

Relative occurrence (%) of **drought-induced variations in human settlement patterns across Africa**. Statistics are derived by comparing drought and non-drought years and are grouped according to the availability of drought records (EM-DAT and SPEI-12 records), whether the antecedent or subsequent year is considered.



Ceola et al., EARTH'S FUTURE, 2023

What about future climate-human dynamics?

3- to 20-fold increase in droughts for most of Africa

IPCC, 2022

300% - 700% urban extent in drylands by 2030

2x population in drylands by 2050

Güneralp et al., 2015
Mirzabaev et al., 2019

Rapidly growing cities in Africa will be risk hotspots for climate change and climate-induced human displacements

What about future climate-human dynamics?

+3°C → 3- to 20-fold increase in droughts for most of Africa

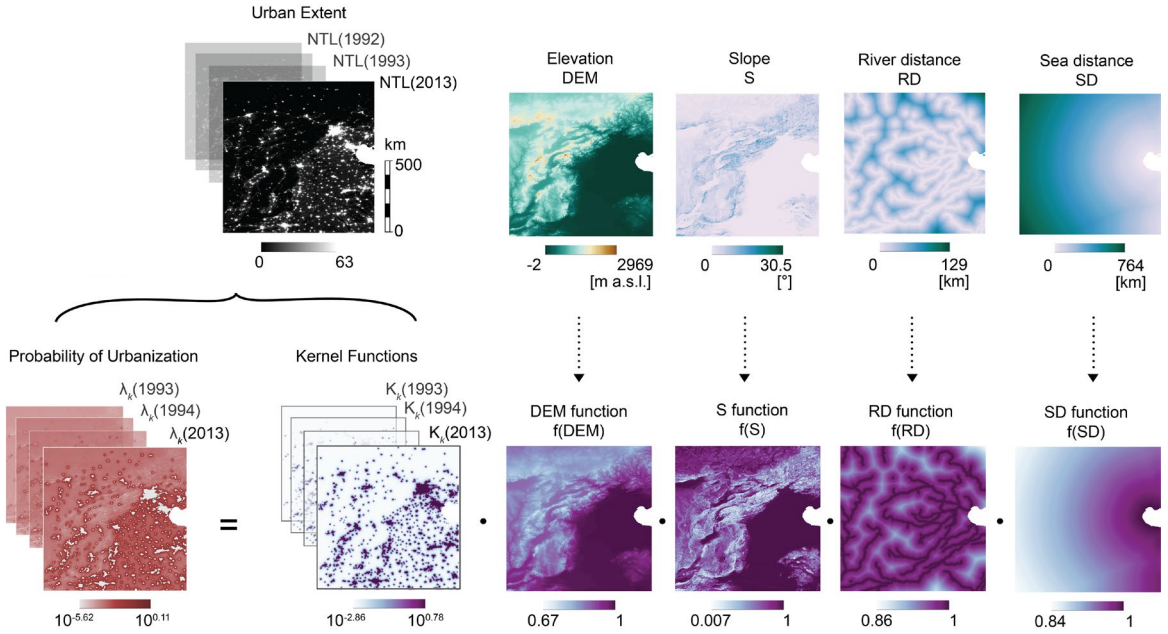
IPCC, 2022

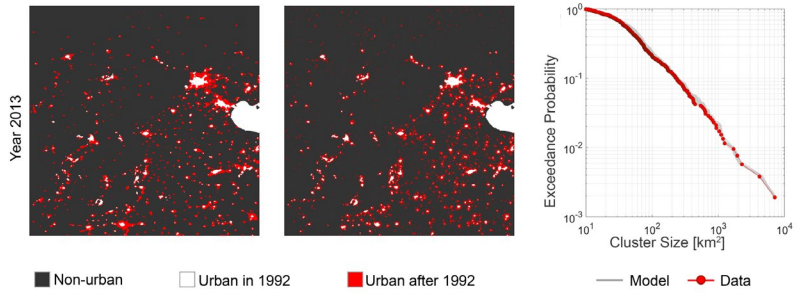
→ 300% - 700% urban extent in drylands by 2030

2x population in drylands by 2050

Güneralp et al., 2015
Mirzabaev et al., 2019

Rapidly growing cities in Africa will be risk hotspots for climate change and climate-induced human displacements





Spatially explicit modeling framework describing changes in human settlement patterns, employed for e.g. human adaptation strategies to worsening climatic and socioeconomic living conditions.

Ceola et al., under review

Take-home messages

- Multi-dataset and satellite-based analysis explores the interplay between changes in **human settlement patterns** and **drought** occurrence across Africa from 1992 to 2013
- Despite changes in human mobility patterns are controlled by multiple factors and depend on the local context, **macro-trends** at the continental scale reveal **drought-induced incentives to move towards rivers and urban centers**
- Larger human displacements toward rivers and urban areas during droughts for **70%–81% of African countries**, other things being equal
- Increased floodplain population associated to drought occurrences can increase losses and fatalities if flood events occur shortly afterwards

Acknowledgments

Giuliano Di Baldassarre, Johanna Mård
-- Uppsala University

Enrico Bertuzzo, Giulia Grandi
-- Cà Foscari University of Venice




Bibliography

Aghakouchak, A., Feldman, D., Stewardson, M. J., Saphores, J.-D., Grant, S., & Sanders, B. (2014). Australia's drought: Lessons for California. Science, 343(6178), 1430–1431. https://doi.org/10.1126/science.343.6178.1430

Beguería, S., Vicente-Serrano, S. M., Reig, F., & Latorre, B. (2014). Standardized precipitation evapotranspiration index (SPEI) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. International Journal of Climatology, 34(10), 3001–3023. https://doi.org/10.1002/joc.3887

Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press.

Ceola, S., Grandi, G., & Bertuzzo, E., Geomorphology and hydroclimate control regional urban expansion (*under review*)

Ceola, S., Laio, F., & Montanari, A. (2015). Human-impacted waters: New perspectives from global high-resolution monitoring. Water Resources Research, 51(9), 7064–7079. https://doi.org/10.1002/2015WR017482

Ceola, S., Mård, J., & Di Baldassarre, G. (2023). Drought and human mobility in Africa. Earth's Future, 11, e2023EF003510. https://doi.org/10.1029/2023EF003510

Güneralp, B., Güneralp, I., & Liu, Y. (2015). Changing global patterns of urban exposure to flood and drought hazards. Global Environmental Change, 31, 217–225. https://doi.org/10.1016/j.gloenvcha.2015.01.002

Hoffmann, R., Dimitrova, A., Muttarak, R., Crespo Cuaresma, J., & Peisker, J. (2020). A meta-analysis of country-level studies on environmental change and migration. Nature Climate Change, 10, 904–912. https://doi.org/10.1038/s41558-020-0898-6

Human migration. Nature 543, 21 (2017)

IDMC. (2020). Global report on internal displacement. Internal Displacement Monitoring Centre. Retrieved from https://www.internal-displacement.org/global-report/grid2020/

Masih, I., Maskey, S., Mussá, F. E. F., and Trambauer, P.: A review of droughts on the African continent: a geospatial and long-term perspective, Hydrol. Earth Syst. Sci., 18, 3635–3649, https://doi.org/10.5194/hess-18-3635-2014, 2014

Mirzabaev, A., Wu, J., Evans, J., García-Oliva, F., Hussein, I. A. G., Iqbal, M. H., et al. (2019). Desertification. In P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, et al. (Eds.), Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge University Press

Niva, V., Horton, A., Virkki, V. et al. World's human migration patterns in 2000–2019 unveiled by high-resolution data. Nat Hum Behav 7, 2023–2037 (2023). https://doi.org/10.1038/s41562-023-01689-4

Xu, L., & Famiglietti, J. S. (2023). Global patterns of water-driven human migration. WIREs Water, 10(4), e1647. https://doi.org/10.1002/wat2.1647

WMO, 2021: Atlas of mortality and economic losses from weather, climate and water extremes (1970–2019), https://library.wmo.int/doc_num.php?explnum_id=10989

CLIMATE EXTREMES & CHANGES IN HUMAN SETTLEMENT PATTERNS - A FOCUS ON DROUGHTS IN AFRICA

AU UN IST Photo / Tobin Jones. Original public domain image from Flickr

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Prof. Serena Ceola – serena.ceola@unibo.it
Department of Civil, Chemical, Environmental and Materials Engineering
Alma Mater Studiorum Università di Bologna - Italy