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Refugee settlements are highly exposed to extreme weather conditions

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Involuntary displacement from conflict and other causes leads to clustering of refugees and internally displaced people, often in long-term settlements. Within refugee-hosting countries, refugee settlements are frequently located in isolated and remote areas, characterized by poor-quality land and harsh climatic conditions. Yet, the exposure of refugee settlements to climatic events is underresearched. In this article, we study the exposure of the 20 largest refugee settlements worldwide to extreme variations in climatic conditions. The analysis integrates exposure of camp locations compared to the national trends for both slow- and rapid-onset events and includes descriptive statistics, signal-to-noise analyses, and trend analyses. Our findings show that most refugee settlements included face relatively high exposure to slow-onset events, including high temperatures (for settlements in Kenya, Ethiopia, Rwanda, Sudan, and Uganda), low temperatures (in the case of Jordan and Pakistan), and low levels of rainfall (in Ethiopia, Rwanda, Kenya, and Uganda) compared to national averages. Our findings for rapid-onset events—heatwaves, coldwaves, and extreme rainfall—are less conclusive compared to country trends, although we find relatively high exposure to extreme rainfall in Cox's Bazar, Bangladesh. Our analyses confirm that refugee populations are exposed to extreme weather conditions postdisplacement, which, in combination with their sociopolitical exclusion, poses a threat to well-being and increased marginalization. Our findings call for an inclusive and integrated approach, including refugees and their host communities, in designing climate adaptation and sustainable development policies, in order to promote equitable sustainable development pathways in refugee-hosting countries.

refugee settlements | extreme weather conditions | exposure | signal-to-noise analysis

Significance

Refugee settlements are often located in countries most vulnerable to climate variability. This article provides a systematic analysis examining the exposure to slow- and rapid-onset events of the 20 largest refugee settlements worldwide. We find that refugee populations in the settlements are highly exposed to extreme weather conditions, particularly low rainfall, high temperatures, and extreme rainfall (in the case of Bangladesh). This high level of exposure, in combination with often-limited abilities to cope and adapt, enhances the vulnerability of already-marginalized populations and their host communities, and reduces their ability to create sustainable livelihoods. Climate adaptation and sustainable development policies should therefore strive for the inclusion of displaced populations, in order to create equitable sustainable development pathways in refugee-hosting countries.

Forced displacement, the involuntary relocation of individuals abroad or within their own countries, is increasing worldwide. Approximately 90 million individuals, including refugees, internally displaced persons (IDPs), and asylum seekers, were forcibly displaced at the end of 2021 (1), compared to 79.5 million in 2019 (2). The vast majority of refugees remain near to their countries of origin, which tend to be countries with low- to medium-income levels (3). Refugee-hosting countries are also among the countries most vulnerable to climate variability. The recent Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment highlights that areas of constrained human development are particularly vulnerable to—inter alia—climate variability. The report names East Arica and South Asia as "global hot spots of high human vulnerability", areas that presently host among the largest refugee settlements (4).

There are increasing indications that refugee populations are vulnerable to extreme weather. Displaced populations often reside in local "climate hot spots," with limited abilities to cope and adapt.* Results of a survey conducted by the United Nations High Commissioner for Refugees (UNHCR) showed that 6% of camp-based refugees had been affected by natural disasters in 2014 (5). Recent reports detail how, in the first half of 2021 alone, six refugees were reported dead in flooding in Cox's Bazaar refugee camp in Bangladesh†, while in late 2021, Alganaa refugee camp in South Sudan was destroyed by flooding, rendering 35,000 refugees dislocated‡. In Lebanon, winter storms with exceptionally low temperatures, torrential rains, heavy snowfall, and high winds exacerbated the precarious living conditions of Syrian refugees in 2019§ and 2020. The precarity of refugee camp environments in Europe was exposed by the fire that destroyed the Moria camp on Lesbos in 2020 (6).

Designed as temporary solutions, camps are often located at the margins both politically and geographically, on low-value land unsuitable for large-scale self-reliance activities (7),

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*UNHCR. Climate change and disaster displacement. Available at: https://www.unhcr.org/climate-change-and-disasters.html

†The Guardian 2021. At least six Rohingya refugees killed as flood hit camps in Bangladesh. Available at: https://www.theguardian.com/global-development/2021/jul/29/at-least-six-rohingya-refugees-killed-as-floods-hit-camps-in-bangladesh.

‡UNHCR 2021. Refugees count their losses as flood destroy camp in Sudan. Available at: https://www.unhcr.org/news/stories/2021/11/619c9aea4/refugees-count-losses-floods-destroy-camp-sudan.html.

§Aljazeera 2019. Syrian refugees at risk as extreme weather hits Lebanon. Available at: https://www.aljazeera.com/news/2019/1/10/syrian-refugees-at-risk-as-extreme-weather-hits-lebanon.

isolated from urban areas and the locus of a country's economy (8). For example, several of the largest displacement camps in the world are located in East Africa's unforgiving arid landscapes (9). In Kenya, the two principal refugee camps are located in areas of untypically low population density, in arid and semi-arid areas; in Sudan, refugee camps were located away from key resources (10). Recent work in Turkey has concluded that refugee camps were suboptimally located in terms of geographical, risk, infrastructure, and social criteria (Cetinkaya et al., 2016). The determination of camp location is intertwined with a broader set of political decisions, which often leads to environmental vulnerability and geographic isolation. Despite the proliferation of refugee camps in Africa in the quarter of a century between 1962 and 1987, for example, no environmental impact study was conducted prior to their construction (11).

The perception of refugee settlements as temporary solutions to humanitarian crises also affects infrastructure and design. Refugee settlements are rarely based on sustainability principles that enhance the resilience and adaptive capacity of refugees (12, 13) and often do not contain adequate and protective accommodation (14). This makes camp-based refugees highly susceptible to extreme weather events. Moreover, refugees are frequently deprived from their basic and fundamental human rights, such as the right to work and the right to move (15), which would allow them to cope with, and adapt to, extreme weather. These combinations of various forms of spatial and sociopolitical exclusion make refugees particularly vulnerable to climatic events associated with climate change, which, in turn, reduces their well-being and increases their marginalization in host countries.

The vulnerability of displaced populations is a growing area of attention in the sustainability literature. Recent studies focus on the impacts of extreme weather events, such as flooding and landslides, in Cox's Bazar, Bangladesh (see e.g., refs. 16–20). Another recent publication studies the vulnerability of residents of IDP camps in Myanmar, who were affected by cyclones between 2007 and 2017 (21). Yet there is, to our knowledge, no existing systematic analysis examining the exposure of refugee and IDP settlements to extreme weather conditions within refugee-hosting countries.

To address this gap, this article uses climate and weather data, combined with UNHCR data on the geographic locations of refugee settlements, to study the exposure of the 20 largest refugee camps worldwide to extreme weather conditions between the 1980s and 2020. The 20 largest formal camps that constitute our sample jointly host over 4.5 million of the estimated 6.6 million refugees that reportedly lived in camps in 2021 with a further 2.1 million residing in informal or other camps (22). Informal or non-UNHCR mandate camps were excluded as data are difficult to obtain and self-settled or informal camps may imply a degree of integration and self-reliance not often witnessed in formal encampments. Selecting the 20 largest refugee settlements gives a comprehensive overview of the exposure to climatic events of refugees residing in areas in which adaptation and absorption capacities are limited.

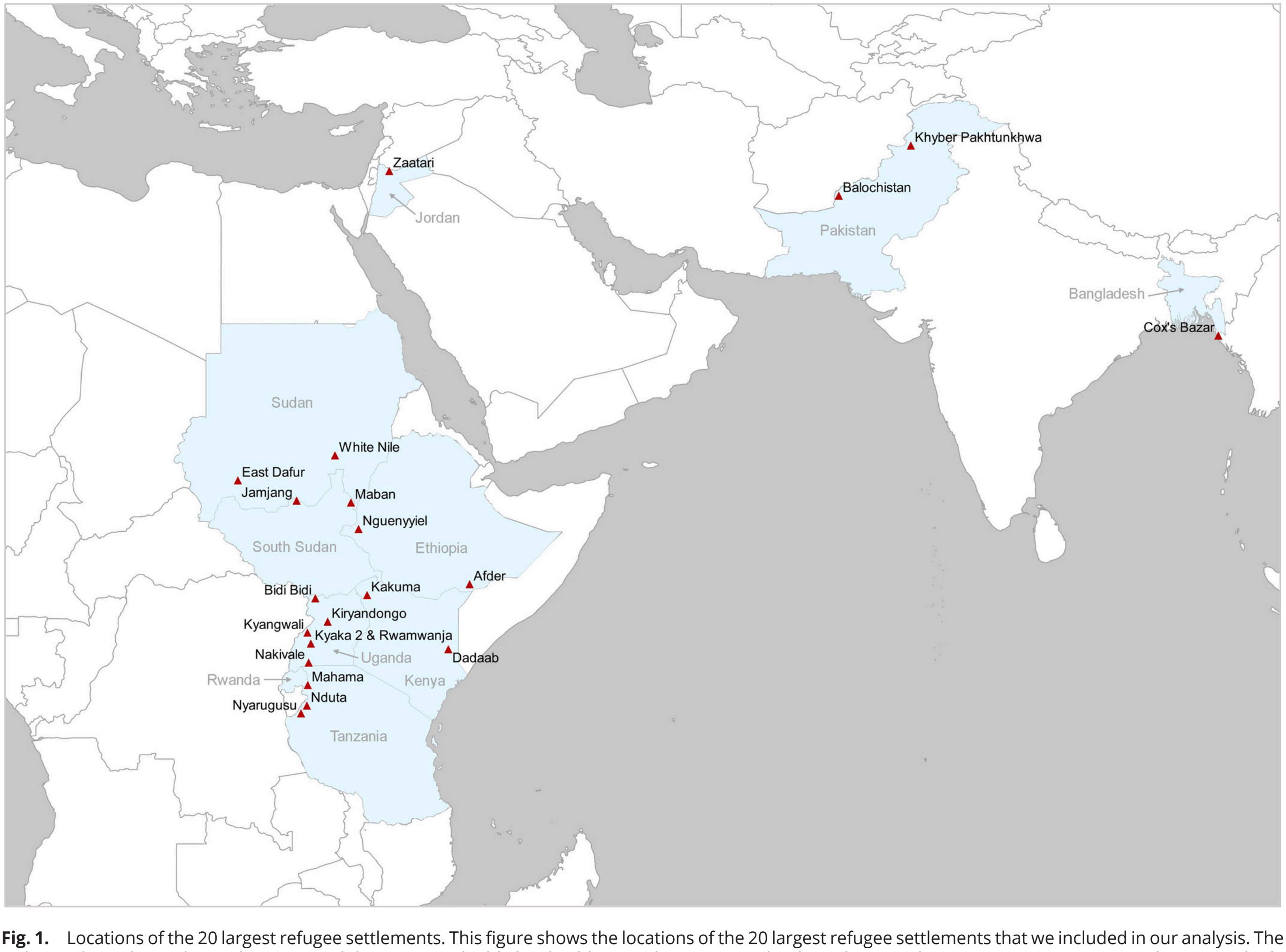

Fig. 1. Locations of the 20 largest refugee settlements. This figure shows the locations of the 20 largest refugee settlements that we included in our analysis. The red triangles indicate the settlements, and the countries highlighted in blue are the countries that host these settlements. Some countries are host to multiple refugee settlements. Information about the locations of the settlements was derived from multiple sources, including UNHCR reports.

To compare the camps with the national situation, we provide descriptive statistics, the trend, and the signal-to-noise ratio (SNR) as compared to country performance. The trend and the average are based on population-weighted means, to represent the climate in the regions where most people live, thereby discounting for often less populated areas with extreme climate such as deserts. This allows us to study whether refugee settlements are placed in high-exposure areas within their respective host countries. The SNR of a difference between the country-wide and the settlement's indicators can help to understand the nature of the deviations: whether they are random "noise-like" or strong and significant. Our analysis integrates exposure of camp locations to both slow-onset and rapid-onset events to take into account both systemic stress and extreme weather events. The results highlight that several refugee settlements are based in areas with relatively high exposure to particularly slow-onset events (temperature and rainfall). Our findings support the development of inclusive climate change adaption and sustainable development policies that include refugee populations, their vulnerable localities, and host communities.

Results

Settlement Locations. We focus our analysis on the 20 largest refugee settlements worldwide (see methodology for the selection of refugee settlements), of which the majority is located in Africa; three are in Asia and one is in the Middle East (Fig. 1 and Table 1). Based on the Köppen–Geiger climate classification (23), most East African camps are in the tropical savanna zone, while Cox's Bazar (Bangladesh, Asia) is situated in the tropical monsoon zone. Many camps in the Horn of Africa are located in arid desert (hot), while the settlements in Pakistan are in arid steppe (hot) and Zaatari in Jordan is located in arid steppe (cold).

Descriptive Statistics. Initial insight into the exposure of refugee settlements to extreme weather events relative to the average conditions in their host country is given in Table 2. In terms of slow-onset events, refugee camps are located in areas with high temperatures relative to the means of their host countries. Refugee settlements in Kenya and Ethiopia are in arid desert and tropical savanna climate zones, with average temperatures in the camp areas on average 7.65 and 8.75 °C higher than population-weighted national averages, respectively. In Dadaab (Kenya), for example, daytime temperatures routinely soar to approximately 40°. In combination with low average levels of rainfall, settlement locations in Kenya experience heat, routine droughts, and low water supply (24, 25). In Balochistan province, Pakistan, settlement locations have relatively low average annual temperatures compared to national averages (4.12 °C lower). Afghan residents in Malgagai camp, for example, are located in mountainous areas, with

Table 1. Refugee settlement characteristics

Settlement	Administrative unit (level 2) included	Country	World region	Estimated population (2020/2021) [3]	Estimated period of establishment[4]	Climatic zone[5]
Cox's Bazar	Cox's Bazar	Bangladesh	Asia	913,000	2017 (informally since 1991)	Tropical monsoon
Bidi Bidi	Ajumani, Yumbe, Moyo, Madi Okollo, Arua	Uganda	Africa	780,923	2016	Tropical savanna
Khyber Pakhtunkhwa[2]	Peshawar	Pakistan	Asia	384,850	1980s	Arid steppe hot
Balochistan[2]	Killa Abdullah	Pakistan	Asia	279,072	c. 2001	Arid steppe hot
White Nile[2]	Kosti, Ad Diwaim, Al Gitaina, Aj Jabalain	Sudan	Africa	273,601	2013	Arid desert hot
Dadaab	Lagdera, Fafi	Kenya	Africa	225,675	1991	Arid desert hot
Kakuma	Turkana West	Kenya	Africa	210,384	Early 1990s	Arid desert hot
Kyaka 2 & Rwamwanja	Kyegegwa, Kamwenge	Uganda	Africa	201,471	2005	Tropical savanna
Afdera[1]	Afder	Ethiopia	Africa	168,679	-	Arid desert hot
Maban[1]	Maban	South Sudan	Africa	165,215	2011	Tropical savanna
Nakivale	Isingiro	Uganda	Africa	139,343	1960	Tropical savanna
Nyarugusu	Kigoma	Tanzania	Africa	132,221	1996	Tropical savanna
Kyangwali	Kikuube	Uganda	Africa	127,291	1960s	Tropical savanna
Jamjang	Pariang	South Sudan	Africa	122,628	2011	Arid steppe hot
Nguenyyiel	Agnewak	Ethiopia	Africa	82,654	2016	Tropical savanna
Zaatari	Mafraq	Jordan	Asia	77,497	2012	Arid steppe cold
Kiryandongo	Kiryandongo	Uganda	Africa	71,865	2008 (managed by UNHCR)	Tropical savanna
Nduta	Kibondo	Tanzania	Africa	63,240	2015 (reopened)	Tropical savanna
East Dafur[2]	Ad Du'ayn, Abu Jabrah, Abu Karinka, Adila, Assalaya, Bahr Al Arab, Al Firdous, Yassin	Sudan	Africa	52,367	2013	Arid steppe hot
Mahama	Kirehe	Rwanda	Africa	45,703	2015	Tropical savanna

Notes: [1]Name of administrative unit (level 2). [2]Name of region (admin level 1). [3,4]Estimates based on different sources, including UNHCR documents. [5]Based on the Koppen climate classification (Beck et al. 2018).

Table 2. Descriptive statistics slow onset events

Country	Settlement	Temperature[1]			Rainfall[1]		
		National average	Settlement	Difference	National average	Settlement	Difference
Bangladesh	Cox's Bazar	24.02	25.01	0.99	5.89	6.77	0.88
Jordan	Zaatari	17.43	17.03	-0.41	0.54	0.37	-0.17
Rwanda	Mahama	18.29	21.01	2.73	4.05	3.26	-0.79
Ethiopia	Nguenyyiel	18.55	27.11	8.56	4.41	3.05	-1.36
	Dolo Ado	18.55	27.52	8.97	4.41	1.02	-3.39
Kenya	Dadaab	20.19	27.73	7.54	3.56	0.97	-2.58
	Kakuma	20.19	27.95	7.77	3.56	1.42	-2.14
Pakistan	Khyber Pakhtunkhwa	22.72	21.11	-1.61	1.58	2.31	0.73
	Balochistan	22.72	16.08	-6.64	1.58	0.79	-0.79
South Sudan	Maban	26.76	28.35	1.59	3.11	2.44	-0.67
	Jamjang	26.76	28.43	1.67	3.11	2.49	-0.62
Sudan	White Nile	27.97	29.30	1.33	0.81	0.68	-0.13
	East Dafur	27.97	28.00	0.03	0.81	1.31	0.50
Tanzania	Nyarugusu	21.59	23.55	1.96	3.11	6.68	3.57
	Nduta	21.59	22.41	0.82	3.11	3.08	-0.03
0Uganda	Bidi Bidi	21.49	25.00	3.51	5.02	3.37	-1.64
	Kyaka 2 & Rwamwanja	21.49	21.26	-0.23	5.02	2.87	-2.14
	Nakivale	21.49	20.69	-0.80	5.02	2.53	-2.48
	Kiryandongo	21.49	23.40	1.91	5.02	4.11	-0.91
	Kyangwali	21.49	23.56	2.07	5.02	4.55	-0.47

Notes: [1]Mean annual score from 1981-2020.

hot, dry summers and cold winters with extreme rainfall and snow (26). Most of the settlements in our analyses experienced relatively high levels of rainfall compared to national averages. This is particularly the case in Bangladesh (mean difference of 6.71 mm/day as compared to population-weighted average), Tanzania, and Uganda.

In terms of rapid-onset events, we find that 15 of the 20 settlements score relatively high on the Warm Spell Duration Index (WSDI), i.e., number of consecutive days per season with extremely high temperatures, with high scores and an increasing trend in Kenya (Kakuma), South Sudan (Jamjang), and Bangladesh (Cox Bazar), while we do not find similar deviations for the Cold Spell Duration Index (CSDI), which measures the number of consecutive days with extremely low temperatures. Finally, several settlement locations had extreme rainfall patterns, which were higher than the population-weighted national average, with particularly high scores in Bangladesh. Other studies have shown that floods resulting from extreme rainfall have implications for waterborne diseases as well as provision of aid services in Bangladesh (27). Sanitation facilities and water provision infrastructure are often severely damaged by flooding during the monsoon season, contributing to health risks (28).

Signal-to-Noise Analyses. Fig. 2 presents a set of descriptive statistics (mean deviation from country average; SD) and SNRs for the slow-onset events included in our analyses: temperature and precipitation. Each subplot in a figure has two elements: 1) we visualize the difference between the countries' and settlements' averages with a line plot, and 2) we plot a linear regression model of the deviation from country average over time, signified by the black line. We calculated the SNRs in the settlement locations—aggregated by country to facilitate interpretation—relative to the country-level values to explore whether the refugee settlements are indeed located in climate "hot spots" within countries. Because of the relatively short time period, we calculated a single SNR per country over all available years.

Large SNRs are observed for the mean monthly temperature. Because the values provided are relatively smooth, with a low SD (<0.2), the resulting signal is very clear. In total, 9 out of the 10 SNRs for mean monthly temperature have high values, meaning that the "signal," the difference in mean temperature between the settlements and the national average, is strong, and that random temperature, the "noise," fluctuations are low. The highest SNRs are observed for refugee settlements in Kenya and Rwanda (SNR = 3.55), followed by Ethiopia (SNR = 3.54) and Uganda (SNR = 3.5). Refugee settlements in Pakistan and Jordan have negative but significant SNRs (SNR = −3.36 and SNR = −2.33, respectively), which means that the mean temperatures in the refugee settlements are lower than the population-weighted national averages (deviation of −4.12 °C for Pakistan and −0.47 °C for Jordan). As described before, the Pakistan refugee settlements included in our analyses are in mountainous areas, with extreme temperatures in both summer and winter. Zaatari refugee camp in Northern Jordan, located close to the border with Syria, is in a cold arid steppe zone, with dry hot summers and harsh winter conditions.

SNRs for the monthly average precipitation show a more mixed picture. Again, because the variable presents an average, SDs are low. However, this is in many cases compensated by a very low deviation from national average. Some of the countries that have high SNRs for temperature also display high (negative) SNRs for precipitation. Precipitation is particularly low in Kenya (SNR = −3.16), Uganda (SNR = −3.32), Ethiopia (SNR = −3.11), Rwanda (SNR = −2.7), and to a lesser extent in South Sudan (SNR = −2.35). Confirming

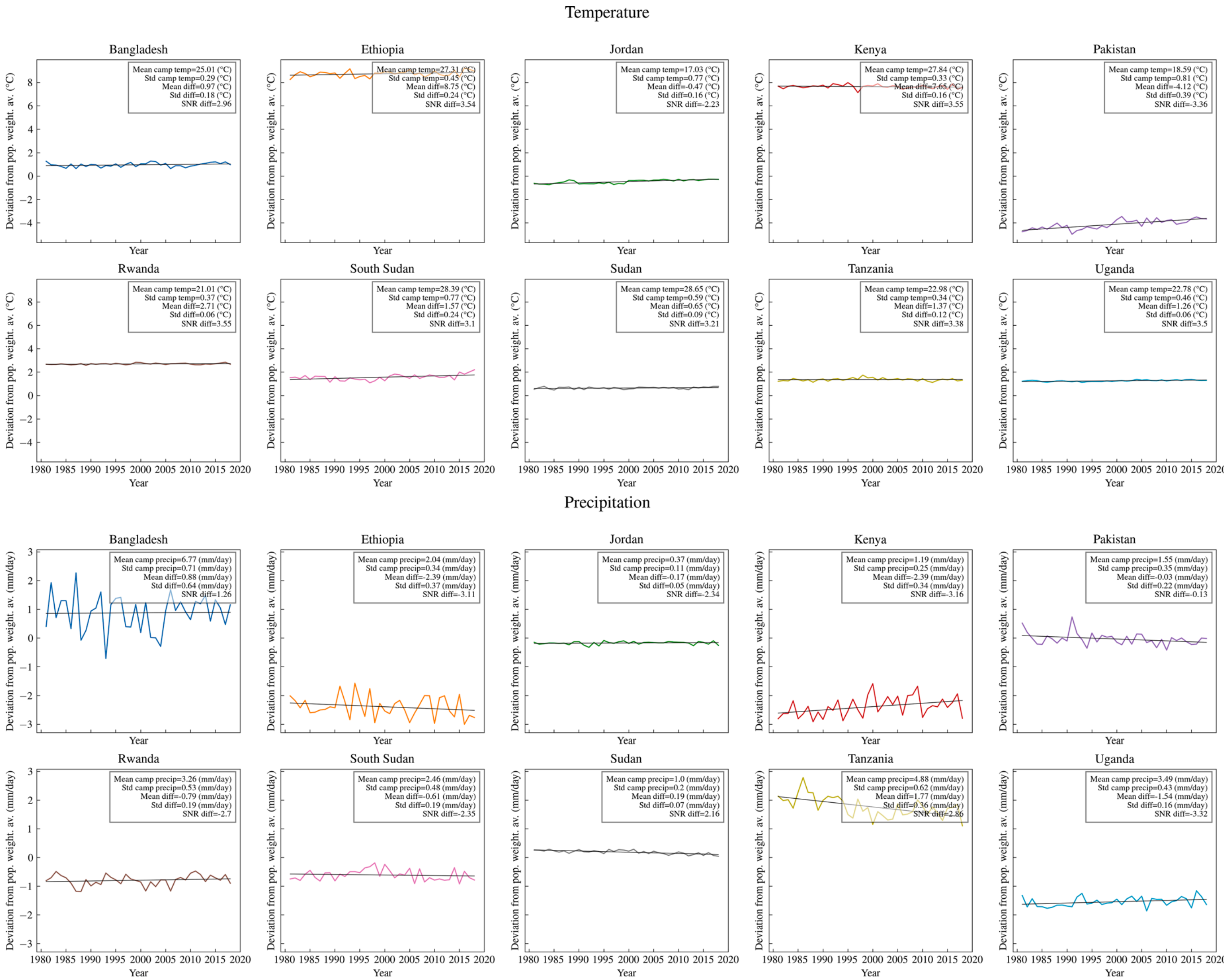

Fig. 2. Signal-to-noise analyses for slow-onset events. This figure shows the results of our analysis for the slow-onset events included in our analyses: temperature and precipitation. The figures include descriptive statistics (mean deviation from population-weighted country average; SD) and SNRs. The SNRs in the settlement locations are aggregated by country to facilitate interpretation and calculated relative to population-weighted country-level values. Each subplot visualizes 1) the difference between the countries' (population weighted) and settlements' averages with a line plot, and 2) a linear regression model of the deviation from the population-weighted country average over time, signified by the black line.

the descriptive statistics in Table 2, Nyarugusu refugee camp in North-Western Tanzania experiences relatively more rain, on average, than the country as a whole (mean difference 1.77 mm/day, SNR = 2.86). However, we observe a decreasing trend (compared to country average), indicating that the excess amount of rain is declining over time. Despite a relatively high SD, also Bangladesh shows an SNR of 1.26, indicating higher levels of precipitation. Pakistan and South Sudan are less conclusive, with mean differences of less than 0.25 mm/day.

For the rapid-onset events included in our analyses (Fig. 3), the SNRs are overall low, driven by the high variability of all indicators. Further, we also observe a relatively high in-country variability during some cold or heat spells, as indicated by the widening corridors of the 25th and 27th percentiles, especially around the peaks.

The SNRs for our heatwave indicator, the WSDI, are all between −0.16 and 0.35. The trend lines in our figures do show some interesting patterns, as the length of extremely high temperature periods at the refugee settlement areas in Kenya, Ethiopia, Bangladesh, Rwanda, Sudan, South Sudan, and Uganda increases over time relative to the population-weighted national average. Given the short data frame, it is not possible to determine whether this represents a long-term trend or short-term cycle.

For the coldwave indicator, the SNRs range between −0.3 and 0.3 as well, which means we cannot separate the "noise" from the "signal." The length of extremely cold periods does seem to increase slightly in particular Pakistan, Jordan, and Ethiopia, in comparison to population-weighted national figures. In the presence of adequate shelter and protection, cold weather can present as much of a health hazard as extreme heat. However, these figures should be interpreted with caution as the overall high temperatures in South Sudan mean that lower temperatures may not in absolute terms represent a risk to health and livelihoods.

Extreme rainfall, which can be used as a proxy for flooding, is most present in Bangladesh, even though we record an SNR of only 0.33. The area in which Cox's Bazar is located is in the tropical monsoon climate zone and extreme rainfall is common there, yet seems to also be indicative for the major population centers of the country. Without adequate access to water management infrastructure, rainfall and associated flooding can present a risk to the

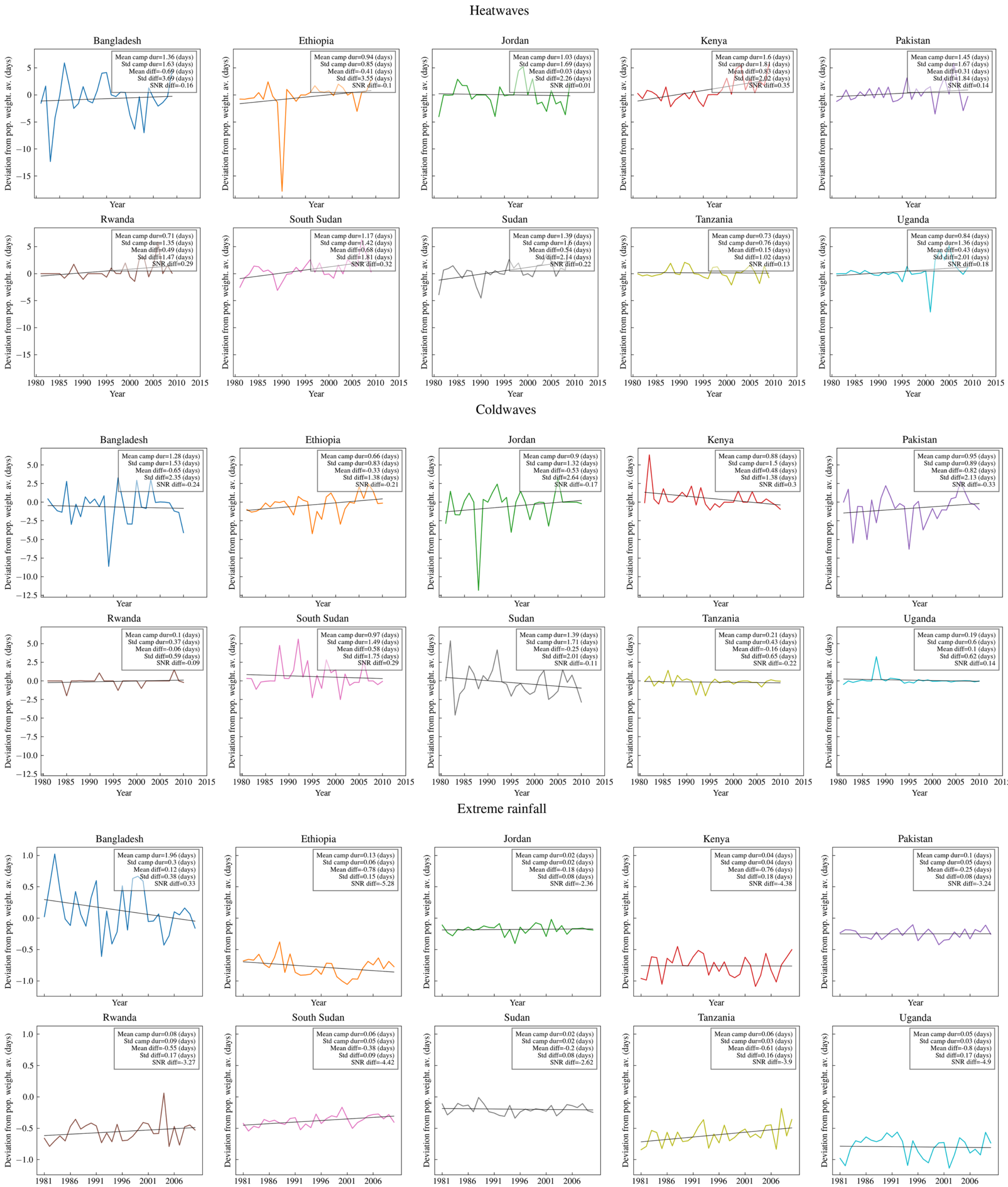

Fig. 3. Signal-to-noise analyses for rapid-onset events. This figure depicts our findings for the rapid-onset events included in our analyses: heatwaves, coldwaves, and extreme rainfall, which we use as an indicator for flooding. As shown in Fig. 2, the figures include descriptive statistics (mean deviation from population-weighted country average; SD) and SNRs. The SNRs in the settlement locations are aggregated by country to facilitate interpretation and calculated relative to population-weighted country-level values. Each subplot visualizes 1) the difference between the countries' (population weighted) and settlements' averages with a line plot, and 2) a linear regression model of the deviation from the population-weighted country average over time, signified by the black line.

integrity of temporary shelters, while stagnant water as a result of rainfall presents a health risk (29, 30). For the other locations, we observe negative SNRs between −2.36 (Jordan) and −5.28 (Ethiopia), indicating that these settlements are in relatively dry, albeit hot regions as compared to the population-weighted national average.

Table 3. Descriptive statistics rapid onset events

Country	Settlement	Heatwaves[1] National average	Heatwaves[1] Settlement	Heatwaves[1] Difference	Coldwaves[1] National average	Coldwaves[1] Settlement	Coldwaves[1] Difference	Extreme rainfall[2] National average	Extreme rainfall[2] Settlement	Extreme rainfall[2] Difference
Bangladesh	Cox's Bazar	1.56	1.36	-0.20	1.62	1.29	-0.33	1.62	1.29	-0.33
Jordan	Zaatari	0.86	1.03	0.18	1.12	0.91	-0.21	1.12	0.91	-0.21
Rwanda	Mahama	0.20	0.71	0.50	0.14	0.10	-0.04	0.14	0.10	-0.04
Ethiopia	Nguenyyiel	1.29	0.65	-0.63	0.80	0.24	-0.56	0.80	0.24	-0.56
	Dolo Ado	1.29	1.23	-0.06	0.80	1.10	0.30	0.80	1.10	0.30
Kenya	Dadaab	1.20	0.81	-0.39	0.31	1.16	0.85	0.31	1.16	0.85
	Kakuma	1.20	2.39	1.19	0.31	0.61	0.30	0.31	0.61	0.30
Pakistan	Khyber Pakhtunkhwa	1.17	1.32	0.14	1.83	0.81	-1.02	1.83	0.81	-1.02
	Balochistan	1.17	1.57	0.40	1.83	1.09	-0.74	1.83	1.09	-0.74
South Sudan	Maban	0.45	1.04	0.59	0.31	0.86	0.55	0.31	0.86	0.55
	Jamjang	0.45	1.30	0.86	0.31	1.09	0.78	0.31	1.09	0.78
Sudan	White Nile	0.86	1.58	0.71	1.38	1.43	0.04	1.38	1.43	0.04
	East Dafur	0.86	1.20	0.34	1.38	1.38	-0.01	1.38	1.38	-0.01
Tanzania	Nyarugusu	1.49	0.58	-0.91	0.30	0.17	-0.13	0.30	0.17	-0.13
	Nduta	1.49	0.88	-0.61	0.30	0.25	-0.05	0.30	0.25	-0.05
Uganda	Bidi Bidi	0.85	1.03	0.19	0.08	0.32	0.24	0.08	0.32	0.24
	Kyaka 2 & Rwamwanja	0.85	0.74	-0.10	0.08	0.12	0.04	0.08	0.12	0.04
	Nakivale	0.85	0.63	-0.22	0.08	0.04	-0.05	0.08	0.04	-0.05
	Kiryandongo	0.85	0.86	0.02	0.08	0.27	0.19	0.08	0.27	0.19
	Kyangwali	0.85	0.94	0.09	0.08	0.20	0.12	0.08	0.20	0.12

Notes: [1]Mean annual max seasonal WSDI or CSDI from 1981-2010. [2] Mean annual number of days with extreme rainfall from 1981-2018.

Discussion

Recent IPCC findings indicate that refugee-hosting regions are among the most vulnerable to climate variability in the world and are likely to experience more incidences of extreme weather as a result of climate change (31). In this paper, we explored whether within refugee-hosting countries, refugee settlements are in areas with high exposure to climatic events. Our analyses of the 20 largest refugee settlements worldwide illustrates how many refugee settlements are located in suboptimal locations, particularly in terms of temperature and precipitation. Covering more than 70% of the global camp-based refugee populations, we find that the areas of refugee settlements in Kenya, Ethiopia, Sudan, Uganda, and Rwanda show higher exposure to high temperatures compared to other areas in host countries, while rainfall is less than average in these settlement areas (except for in Sudan). Conversely, refugees in Jordan and Pakistan are exposed to relatively extreme low temperatures, which is likely a result of harsh winter conditions in the settlement areas there.

Table 4. Indicators for slow and rapid onset climatic events

Category	Variable	Explanation	Data source	Time scale
Population	Population data	Number of people living in an area.	Worldpop (https://www.worldpop.org/)	2020
Slow onset	Mean temperature	Monthly mean temperature [°C], 2m above the surface	Hersbach et al. (2019)	Monthly, 1981–2020
	Mean precipitation	Monthly mean of total rainfall per day [mm/day]	Hersbach et al. (2019)	Monthly, 1981–2020
Rapid onset	Warm spell duration index (WSDI)	Number of days per season with at least 6 consecutive days when TX > TX90th, where TX is the daily maximum temperature and TX90th is the calendar day 90th percentile.	Nobakht et al. (2019)	Seasonal, 1981–2009
	Cold spell duration index (CSDI)	Number of days per season with at least 6 consecutive days when TN < TN10th' where TN is the daily minimum temperature and TN10th is the calendar day 10th percentile.	Nobakht et al. (2019)	Seasonal, 1981–2010
	Extreme rainfall	Number of days per 10 days when RR > 20mm, where RR is the daily precipitation sum.	Nobakht et al. (2019)	Every 10 days, 1981-2010

For most of the settlements that formed part of this review, we did not detect higher than country-average exposure to rapid-onset variables. This is most likely due to the nature of the events, which are relatively localized and lead to an increase in within-country variability. Yet, this does not imply that the camps are not exposed to extreme events. Especially for heat- and coldwaves, all settlements (and countries) are regularly exposed to extreme conditions. For extreme rainfall, which with poor water management infrastructure may result in flooding, we identified a significant and notable problem for refugees in Cox's Bazaar, Bangladesh. This settlement also experienced higher monthly average precipitation levels than the country as a whole. This high level of exposure impacts the habitability of the settlements, undermines agriculture-based livelihood programs, and can disrupt fragile aid supply systems in aid-dependent scenarios. Although we are not able to draw conclusions on weather and implications on the viability and sustainability of (agriculture based) livelihoods, changes to both the average and variability in a region's climate have been associated with an increase in the frequency of extreme climate events (32).

Overall, our findings highlight that refugee populations and host populations face relatively high exposure to extreme weather events. In combination with the structural spatial, sociopolitical, and sociocultural vulnerabilities that displaced populations often face (33), exposure to extreme weather may have severe impacts on well-being and livelihoods. In contexts of fragile infrastructure, dependence on aid, limited livelihood opportunities, unsustainable housing, and in a context of carceral humanitarianism (34), high exposure to extreme weather not only presents an important obstacle for refugees in their trajectories toward self-reliance and resilience, but may also lead to further marginalization and increased vulnerability. Extreme weather may also put additional strain on host communities that are already living in precarious conditions. As research continues to focus on the vulnerabilities of displaced populations, future studies should explore the interactions between exposure to extreme weather and sociopolitical vulnerabilities. Better understanding these interactions, as well as the impacts that climate events have on displaced populations, will lay a foundation for targeted, evidence-based policies and programs that enhance adaptation and reduce risk in displacement contexts.

Increasing vulnerability of displaced populations and their marginal communities, also challenges the condition of equity for sustainable development pathways. As Clark and Harley (35) argue, a "society cannot achieve the goals of sustainable development that it has repeatedly endorsed without creating more just distributions of well-being both within and between generations." To avoid exclusion and to create equity, more attention should be paid to environmental risks in location selection and camp/settlement design. Moreover, national climate adaptation and sustainable development policies should include displaced populations and host communities and tailor-made programs should be designed that reduce their vulnerabilities. A comprehensive and integrated—including displaced populations and host communities—policy agenda is needed that not only reduces risks and exposure to shocks, but one that also mitigates the impacts of shocks if they occur. This policy change requires a transition to long-term planning with an emphasis on sustainable livelihoods from the outset of the displacement pathway.

Materials and Methods

Settlement Selection. In our selection strategy for the refugee settlements in our analysis, several camps were considered as one settlement in the following cases: 1) they had an official settlement name (e.g., Kakuma), 2) UNHCR population data were only available at the regional level and disaggregation at the camp level was not possible, and 3) the camps were in close geographic proximity to each other, since this study compares exposure based on geographic locations. Where possible, the names of individual camps that were included in each settlement are indicated. The climate data frame, which underpins analysis presented in this paper, predates the establishment of the camps that constitute the analytic sample, with the exception of cases in Uganda, where camps were established in the 1960s. Using data from the 1980s establishes a baseline trend in the event that the establishment of the camp had a bearing on climate outcomes in the camp area.

Climate, Weather, and Population Data. We draw on several climate, weather, and population data sources (Table 4). Our two indicators for slow-onset events (temperature and rainfall) are based on the European Centre for Medium Range Weather Forecasts (ECMWF) fifth generation of Re-Analysis (ERA5) data. Three indicators for rapid-onset events (heatwaves, coldwaves, and extreme rainfall) are based on ERA-interim Re-Analysis data from the ECMWF. All data sources provide gridded data, consistent across space and time, by combining information from weather stations, satellites, and climate models. This minimizes biases due to lack of coverage from weather stations, which is especially relevant in remote areas.

To match the data with refugee settlement locations, the gridded climate data were matched to the administrative zones in the refugee-hosting countries, by calculating zonal means. The zones are at administrative level two, i.e., districts or subcounties (see Table 1 for the zones of the refugee settlements). The shapefiles with the administrative zones for each country are retrieved from the Humanitarian Data Exchange. Where settlements span several zones, the average of the zones was taken.

To determine deviations from the national average for each indicator and each settlement, the population-weighted national averages were obtained for each host country and compared to the respective score at the settlement's zone. To this end, we used data from Worldpop in a 1 km × 1 km resolution and followed the same procedure of matching grid cells to the climate grid described above. We use data for 2020 as the baseline to factor in the most recent migration movements. Then, we corrected the climate variables per region by a population-weight factor, whereby a grid cell receives the weight that represents the share of the national population living in that area. For the initial climate analysis in Table 2, the data were then aggregated to population-weighted yearly averages (temperature and precipitation), yearly population-weighted maxima (WSDI and CSDI), and yearly population-weighted sums (extreme rainfall, months with Standardized Precipitation Evapotranspiration Index (SPEI) < -1.5).

Analyses. We report a set of descriptive statistics: the mean and the SD of an indicator (e.g., temperature) at the settlement location, the mean and the SD of the difference between the national average and settlement's values, and the SNR of this difference. In the case of the first two sets, we calculate the mean and the SD over all available years (e.g., from 1980 to 2010). We aggregate monthly or quarterly data by year, which can potentially "smooth" extreme weather events and, therefore, the difference between the national and settlement's values. We calculate the SNR, a single numeric value, as a ratio between the mean and the SD of the difference: $SNR = \mu/\sigma$. The SNR can be positive, negative, or equal to zero. A negative SNR means that the national average of a specific indicator is higher than that of the settlement ones. A positive SNR implies the opposite. If the SNR is equal to zero or relatively low (e.g., from −5 to 5), the noise in the original data is "overweight" the signal. A high SNR means the opposite: the difference has a strong "signal" and is substantial. Note that there is no common standard for considering an SNR low or high in the case of any system of interest. These thresholds are domain specific and require an interpretation.

Data, Materials, and Software Availability. All data used in this study are compiled as indicated in Table 4. The full data set providing raw and processed data is available via 4TU. Research Data (https://figshare.com/s/86e5a5d5c4bd206a25c7). The *Methods* section details how we analyzed the data. The code that we used to access, analyze, and visualize the data is available on GitHub (https://github.com/mikhailsirenko/exposure-refugee-camps). All study data are included in the main text.

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