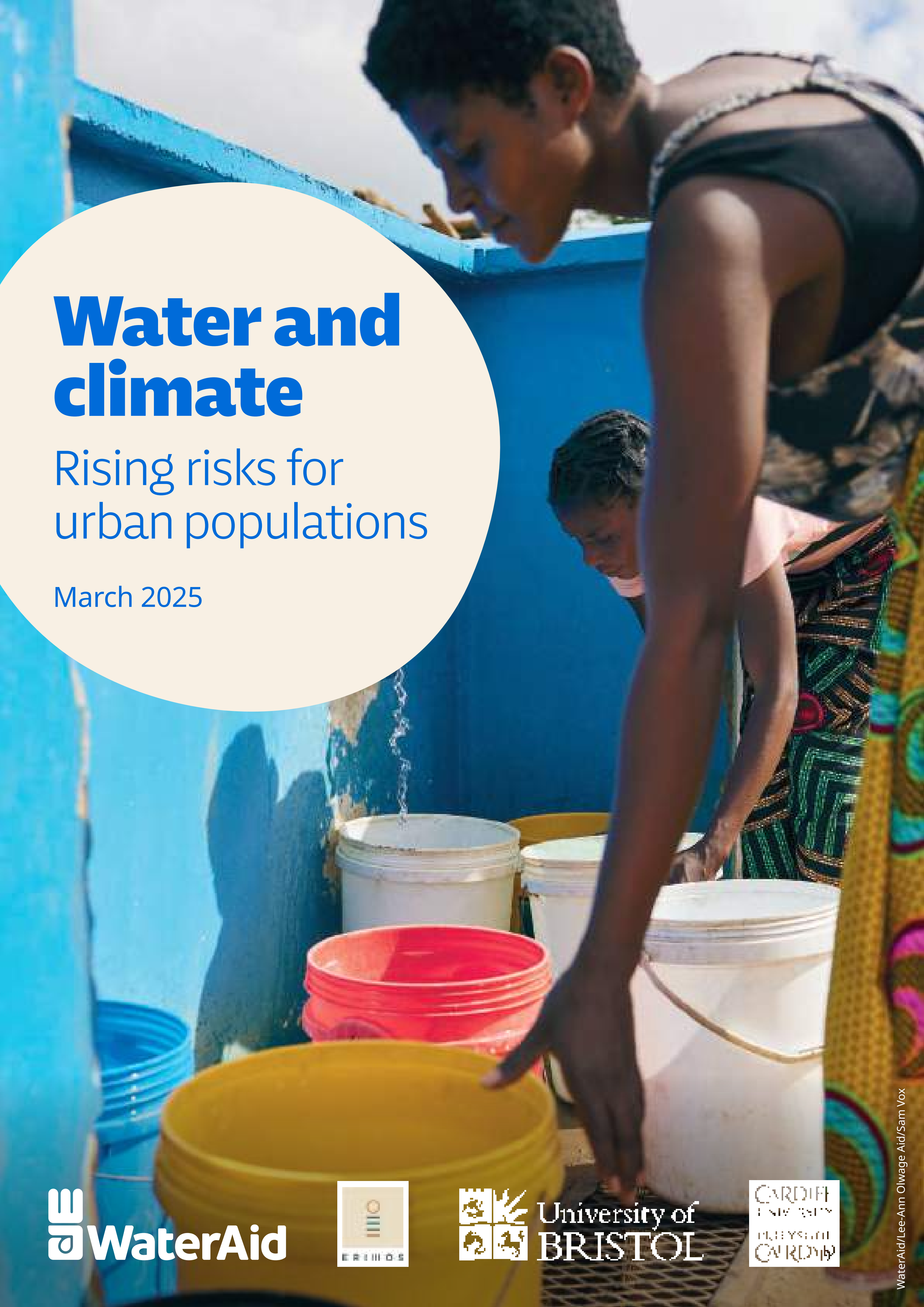


Water and climate

Rising risks for urban populations

March 2025

WaterAid

ERIMOS

University of BRISTOL

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

WaterAid/Lee-Ann Olwage Aid/Sam Vox

Contents

Front cover: Elizabeth Lupugwe (front) and Violet Muswela (back) collect water from a water kiosk in Sylvia Masebo Community. Water is pumped using solar power and the kiosk is open for water collection from 6-10 AM. Lusaka, Zambia. February 2025.

Foreword

Growing up in the city of Buenos Aires, with the Río de la Plata as its backdrop, I've always understood how deeply cities – and their fast-growing populations – depend on water.

More than half of the world's population – around 4.4 billion people – live in towns and cities, and this is projected to increase to more than two thirds by 2050.

Water is vital to a city's growth and stability and is the backbone to healthy societies, yet the threat of too much or too little water puts everything at risk. Today, that balance is more fragile than ever. The term "Day Zero" was coined in Cape Town, South Africa, during a severe drought in 2018, marking the moment when the city's municipal water supply would run dangerously low. It wasn't just a crisis for Cape Town – it was a warning for cities worldwide.

What happens when the 4 billion people already facing water scarcity reach "Day Zero"? How will it affect food, health, energy, ecosystems, and national economies and security?

Water emergencies are becoming more frequent and severe, with climate change making them worse. Right now, 90% of natural disasters are water-related, and cities – especially in low-income countries – are on the frontlines.

This report highlights how the cities facing the worst climate impacts are often those with the highest social vulnerability. Many communities 'whiplash' between droughts that dry up water sources followed closely by floods that overwhelm infrastructure, destroying toilets and sanitation systems and contaminating drinking water, with huge impacts on people's health. Other cities are experiencing dramatic climate reversals – places used to heavy rainfall now face drought, while historically arid regions now grapple with unexpected floods.

The consequences ripple across generations, particularly for women and girls, who are forced to walk for hours to collect water instead of going to school or to work.

Without urgent action, these crises will worsen, and the threat of a global "Day Zero" will loom closer.

But we can change this trajectory.

While we cannot prevent all climate hazards, we can mitigate their impact. With a reliable supply of climate-resilient clean water, communities can more easily recover from disasters, stay healthy, generate income and be ready for whatever the future holds. Ensuring reliable access to clean water is essential for economic growth, political stability, and global security.

Aid remains crucial. The communities WaterAid works with – those on the frontlines of the climate crisis – need urgent investment in water, sanitation, and hygiene. But we can't do it alone. And aid is not enough. Global leaders, multilateral banks, and the private sector must step up and work together to unlock investment and action. Without water, cities cannot function. But with climate-resilient water systems, we can help cities not just survive but thrive in a changing world.

Adapting to climate change starts with water, and we can help people prepare – right now and for future generations – by ensuring every city has the clean, reliable water it needs to withstand the challenges ahead.

Sol Oyuela
Executive Director,
Global Policy
and Campaigns,
WaterAid UK

Executive summary

Water is vital to a city's growth and stability and to the people that live there. It is the backbone to a healthy society, yet too much or too little water can put everything at risk. Right now, 90% of natural disasters are water-related, and cities – especially in low-income countries – are on the frontlines. Understanding the challenge and who is most at risk is critical.

This report highlights how the cities facing the worst climate impacts are often those with the highest social vulnerability. Many communities 'whiplash' between droughts that dry up water sources followed close by floods that overwhelm infrastructure, destroying toilets and sanitation systems, contaminating drinking water. Other cities are experiencing dramatic climate reversals – places accustomed to heavy rainfall now face drought, while historically arid regions now grapple with unexpected floods.

In this research we analyse climate hazard trends and vulnerabilities in the world's top 100 most-populated cities, plus 12 cities where WaterAid works. We examine wetting and drying trends over the past 42 years, often experienced through floods and droughts, and how these changes intersect with social and infrastructural vulnerabilities to threaten people's access to safe and sustainable water, sanitation and hygiene services. Our findings highlight the variability of climate change impacts across the globe and emphasise the heightened risks in highly populated cities with existing vulnerabilities. We then identify some actions needed to address the challenge facing cities and communities around the world experiencing the impact of the climate whiplash.

As the climate crisis throws the water cycle out of balance, it is impacting many of the world's largest cities in ways that are hard to anticipate and plan for. The frequency, magnitude, and impact of events such as floods and droughts are evolving due to climatic trends in wetting or drying and/or intensification of both extremes. When **water, sanitation and hygiene (WASH)** services and systems cannot cope with intensifying and unpredictable climatic extremes, it is often the most vulnerable and marginalised people who suffer the worst impacts on their health, education and livelihoods, pushing them further into poverty.

More than half of the world's population – around 4.4 billion people – live in towns and cities, and the share is projected to increase to more than two thirds by 2050. That figure rises to around 75% of the global population when we consider peri-urban settlements. As the number of people living in cities grows and climate hazards become more intense and erratic, there is an urgent need for decision makers to understand the threats to infrastructure and society, and to do much more to achieve and maintain universal and equitable access to water, sanitation and hygiene in cities.

The loss or disruption of services for water, sanitation and hygiene can be devastating for people, especially the poorest. For example, increasing the spread of diseases, demanding more time to collect water or find somewhere to go to the toilet, especially for girls and women, and hindering people's ability to gain an education or earn a living. On the other hand, ensuring safe and sustainable access to water means families and individuals can be healthier and engage more with opportunities to earn an income and participate in education, all of which strengthen their resilience to climate change. When climate hazards and other crises hit, access to the basic human right of clean water and sanitation is fundamental to allowing people to respond quickly and effectively.

Everyone, everywhere deserves access to safe and sustainable water, sanitation and hygiene. And it is crucial that these services are climate resilient. This means they can withstand extreme weather events such as floods and droughts, backed by systems that can cope, adapt, transform and recover in the face of extreme weather events. **Without climate-resilient WASH services for every person in every city, billions of people face increasing risks, such as of dirty water and unsafe or non-existent toilets, which can have devastating consequences.**

As the global water cycle becomes more unpredictable and extreme, climate-resilient water, sanitation and hygiene services and systems will be essential to the social wellbeing, development and stability of cities, empowering people to cope, adapt, transform and recover in the face of climate hazards.

Solar powered water tanks provide clean drinking water to the Sylvia Masebo Community, Lusaka, Zambia. February 2025.

Key findings

- **15% of the cities examined in this report show an intensification trend**, which we have termed **'climate whiplash',** where both extreme dry and wet episodes are substantially increasing. These whiplashing extremes in quick succession can be particularly hard for communities to prepare for and recover from. These cities are found across the world, from Asia to the Middle East and Africa and the USA.
- **South and Southeast Asia** is a regional hotspot with a strong wetting trend. This region is experiencing an increase in wet and extreme wet climate, which increases the likelihood of extreme flooding. Many of the world's largest cities are located in this area.
- **Europe, the Middle East, and North Africa** are experiencing a drying trend and are likely to face more frequent and long-lasting droughts.
- **Over 20% of the cities are experiencing a reversal in their climate extremes.** Approximately 13% are flipping toward a more extreme wet climate, while about 7% are flipping toward a more extreme dry climate.
- **The convergence of underlying social and infrastructure vulnerabilities** with these climatic patterns results in hotspots of risk in two key regions:
  - **South and Southeast Asia**, which is experiencing increases in wet extremes.
  - **North and East Africa**, which is experiencing increases in both wet and dry extremes.

WaterAid calls for...

Greater investment to tackle the water crisis

Development partners, multilateral banks and the private sector should work together to unlock investment in climate-resilient water, sanitation and hygiene systems that benefits the most vulnerable.

Global leadership to accelerate action on water

Governments and development partners must work through the existing multilateral platforms to deliver ambitious action on climate and water, including through the UNFCCC, the G7 Water Coalition and the G20 Call to Action on Strengthening Drinking-water, Sanitation, and Hygiene Services.

National government leadership to urgently deliver water plans

Governments in affected countries to mainstream and implement water, sanitation and hygiene measures into their national and city-level climate adaptation plans with a focus on vulnerable groups, especially women and girls.

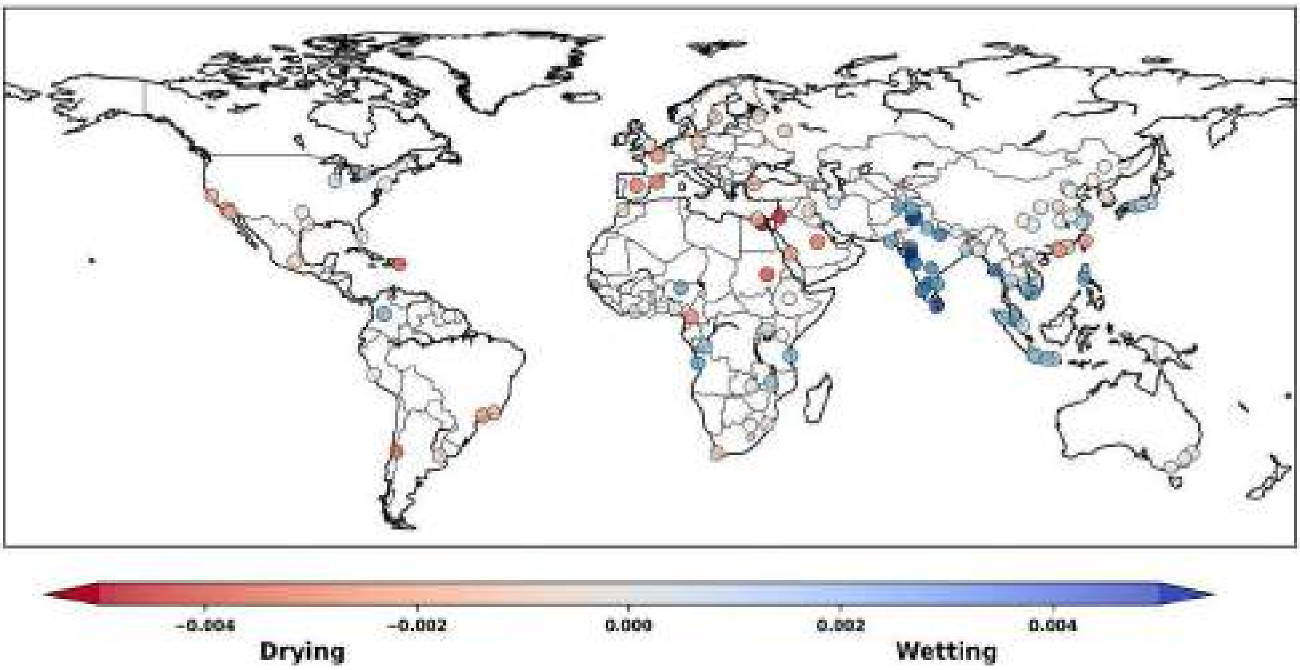
Prioritise the most vulnerable communities

All decision-makers to recognise overlapping vulnerabilities and prioritise the leadership and needs of women, girls and marginalised groups in climate-resilient water, sanitation, and hygiene plans.

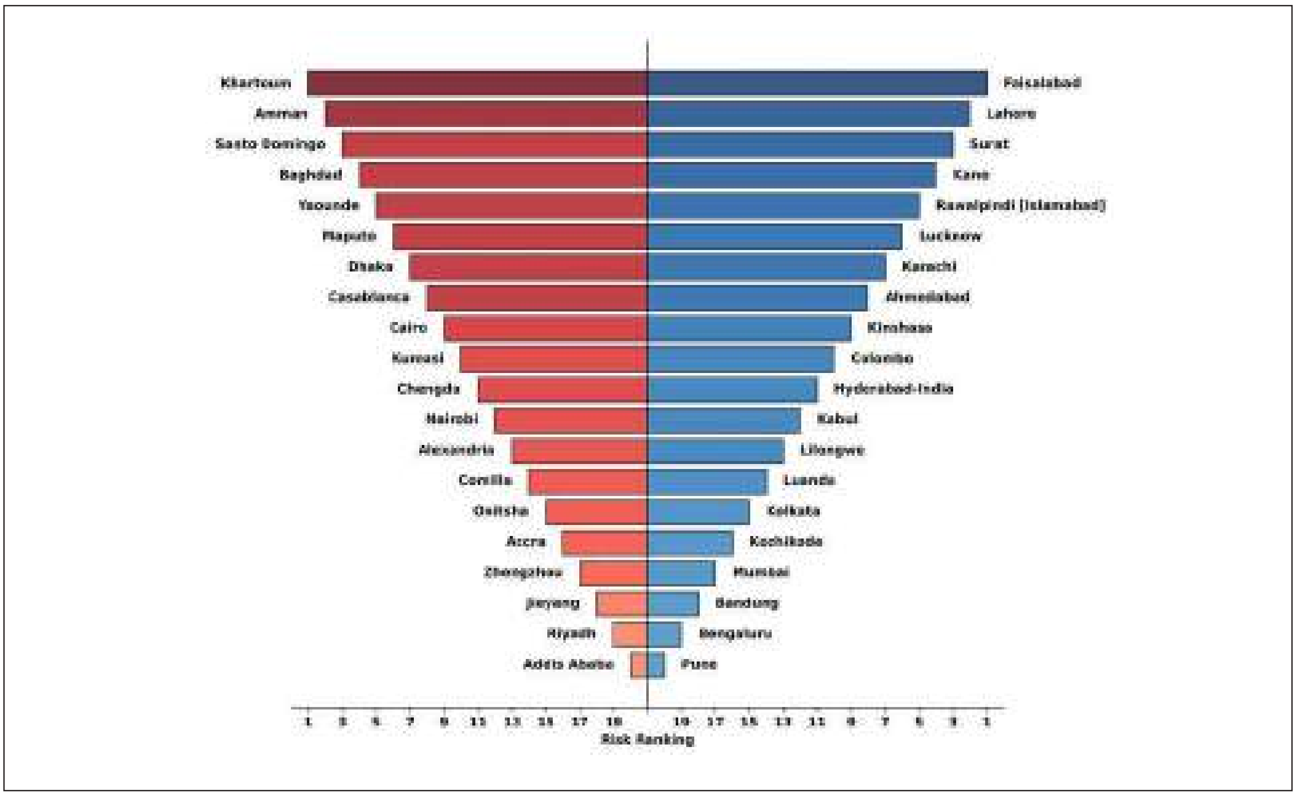
A caretaker waters the crops at Karachi University's agriculture field. Gulshan-e-Iqbal Town, Karachi East, Sindh, Pakistan. January 2025.

WaterAid/Khaula Jamil

Examples of key data visualisation in report:



Example 1. Trends in wetting and drying over the 112 cities. The more intense the colour (blue or red) is, the stronger the trend in either wetting or drying respectively.



Example 2. Critical cities that rank highly both for climate hazard trends and vulnerability (based on the average of social and infrastructural vulnerability scores). The graph presents the top 20 cities with a high-risk ranking (combining vulnerability and climate hazard) for cities experiencing a wetting (blue) and drying (red).

Construction workers working on a new tap stand, funded by WaterAid, where students will be able to drink water. Addis Ababa, Ethiopia. September 2020.

WaterAid/Frehiwot Gebrewold

Background

As the climate crisis throws the water cycle out of balance, it is impacting many of the world's largest cities in ways that are hard to anticipate and plan for. The frequency, magnitude, and impact of events such as floods and droughts are evolving due to climatic trends in wetting or drying and/or intensification of both extremes.

When water, sanitation and hygiene (WASH) services and systems cannot cope with intensifying and unpredictable climatic extremes, it is often the most vulnerable and marginalised people who suffer the worst impacts on their health, education and livelihoods.

More than half of the world's population – around 4.4 billion people – live in towns and cities, and the share is projected to increase to more than two thirds by 2050[1]. That figure rises to around 75% of the global population when we consider peri-urban settlements[2]. In cities across the world, 19% of the global urban population don't have access to safe water and 35% of the global urban population lack a safely managed sanitation service.

Often, cities' water supply, sanitation, and flood management infrastructure, and the systems that support them, were designed and developed when the impacts of climate change were less extreme and populations much smaller. Today, the water sector is under growing pressure from pollution, damage to ecosystems, inadequate management of resources, and increasing demand. Water scarcity, for example during drought, may impede sanitation and wastewater systems and cause drinking water sources to dry up. Flooding may destroy WASH facilities and infrastructure, including contaminating water resources.

Climate change worsens many of these threats and brings additional pressures and unpredictable consequences, which are especially acute within lower- and middle-income countries[3]. In some cases, a mixture of political decisions, underinvestment and socio-historical factors, have created urban concentrations of deprivation where deep and intersecting social and infrastructural vulnerabilities are being exposed and exacerbated by intensifying climate hazards[3].

The loss or disruption of water, sanitation and hygiene services increases the spread of diseases, demands more time to collect water or find somewhere to go to the toilet, especially for girls and women, and hinders people's ability to gain an education or earn a living. Without their human rights to safe water and sanitation, women, children, older people and people with disabilities are the most vulnerable to the resulting diseases and indignities.

Water is the backbone of a healthy society, where communities are equipped to adapt and thrive in a changing climate. Access to safe and sustainable water, sanitation and hygiene supports people to be healthier, have increased income and education, and stronger social connections. All of this supports their ability to anticipate extreme events, adjust in advance of and when crises hit, and advocate for themselves and their communities. As governments and communities globally adjust to a new climate reality, **change starts with water**.

WaterAid/Sam Vox

WaterAid's vision is of a world where everyone, everywhere, has safe and sustainable water, sanitation and hygiene. **In simple terms, this means clean water at home and a decent, private toilet where human waste is disposed of safely.** As the number of people living in cities grows and climate hazards become more intense and erratic, there is an urgent need for those in power to understand the threats to infrastructure and society, and to do much more to achieve and maintain universal and equitable access to WASH in cities. And it is crucial that these WASH services are climate-resilient.

Climate-resilient water, sanitation and hygiene refers to services that can withstand extreme climate hazards such as floods and droughts, backed by systems that can cope, adapt, transform and recover in the face of shifting frequency and severity of these climatic events, all while striving to maintain universal and equitable access to safe and sustainable WASH services.

Effective adaptation interventions must draw from local circumstances, knowledge and insights, and it is vital they are led and 'owned' by communities themselves. A strong water sector and the necessary political, economic and regulatory conditions are essential to create the systems that keep services running. Through wastewater treatment and safe reuse, climate-resilient WASH also has an underestimated potential to contribute to climate mitigation and net zero emissions efforts.

Ensuring climate-resilient water, sanitation and hygiene for every person in every city is an essential part of climate adaptation, protecting public health and ecosystems, and laying the foundation for a safer, fairer and more sustainable future.

Hawa Mohammedi, 32, sitting outside her pit latrine in Magogoni, Kigamboni. Dar Es Salaam, Tanzania. March 2021.

Methodology and scope

In this report, we analyse changes in the climate hazard profile – specifically wetting and drying – in the world's top 100 most-populated cities over recent decades, plus 12 additional cities where WaterAid works. The selected 112 cities are broadly distributed across the globe and span all income categories (Figure 1, Appendix 2). We examine changes in climatic hazards based on the atmospheric water balance summarised by an index of wet and dry months over the last 42 years for each city.

We examine trends of: 1) overall wetting or drying; 2) notable switches in the prevalence of climatic extremes (e.g., wet to dry or dry to wet); and 3) intensification or abatement of the frequency of both wet and dry climatic extremes (increasing or decreasing intensity of both flood and drought periods). We then explore the convergence between the resulting climate hazard profile for each city and its social and infrastructural vulnerability, based on publicly available city-level data. (Figure 2; also see Appendix 1 for the full Methodology).

This report focuses on strong shifts in wetting and drying patterns by analysing the global water cycle, noting changes in rainfall supply and evaporative demand, which heighten climate hazards linked to flooding and drought. **It is important to note that many other climate impacts, such as wildfires and hurricanes, are not examined in this report.**

Based on our analysis, we rank cities in terms of climate hazards and vulnerability and also, on the convergence between hazard and vulnerability. We present this information in the form of maps, time series plots, and ranked lists. We also provide regional 'snapshots' of East Africa, South and Southeast Asia, and Europe.

While there is some existing awareness of the intersectional challenges that link shifting climate hazards to people's exposure and vulnerability, there is a need for more detailed evidence on how and where these trends are interacting. To address this gap, we investigate the trends and geographical patterns of climate change in terms of shifts toward wetter or drier conditions overall, and we explore whether cities are experiencing significant changes in climatic extremes.

These metrics are indicators of how climate hazards such as floods and droughts have been evolving in frequency, magnitude, and impact over the last four-plus decades. We then compare the results of these analyses to several indices of city-level societal and infrastructural vulnerability. This allows us to better understand how changes in climatic hazards may exacerbate inherent vulnerability in cities across the globe, leading to climate adaptation challenges and opportunities. This analysis may support improvements in community-based efforts to adapt to increasing climate hazards, in addition to advancing long-term planning and investment to address potential impacts of unanticipated futures under climate change.

Overall, the analysis presented in this report highlights some of the critical challenges faced by people living in urban areas in terms of wetting and drying trends in the context of existing societal and infrastructural vulnerabilities. This information may be useful to support efforts to plan for the future in terms of community-based adaptation and long-term systems-wide investment from governments to support communities to be more climate-resilient in the world's most populated cities.

Introduction to the analysis

Our analysis highlights the top 20 cities in the dataset experiencing long-term wetting trends (topped by Colombo, Faisalabad and Surat) and drying trends (led by Cairo, Amman and Khartoum). We also spotlight the top cities experiencing dramatic switches (flips) in their climate hazard extremes from wet to dry (led by Cairo, Madrid and Riyadh) and from dry to wet (led by Lucknow, Surat and Kano).

Then we show which cities are experiencing an intensification of both wet and dry extremes, facing what we have termed **'climate whiplash'**, (the list is topped by Hangzhou, Jakarta and Dallas), and those experiencing an abatement of these extremes (led by Nagoya, Yangon and Tokyo).

In terms of vulnerability, we show that social vulnerability is highly correlated with infrastructural vulnerability in our studied cities, and that these metrics are generally consistent with other indices of economic development, highlighting lower- and middle-income countries as those with high vulnerability in both categories.

Our analysis of the convergence of climate hazards and vulnerability highlights at risk cities, with Khartoum, Faisalabad, Amman, Lahore, Surabaya and Baghdad at the top of our rankings.

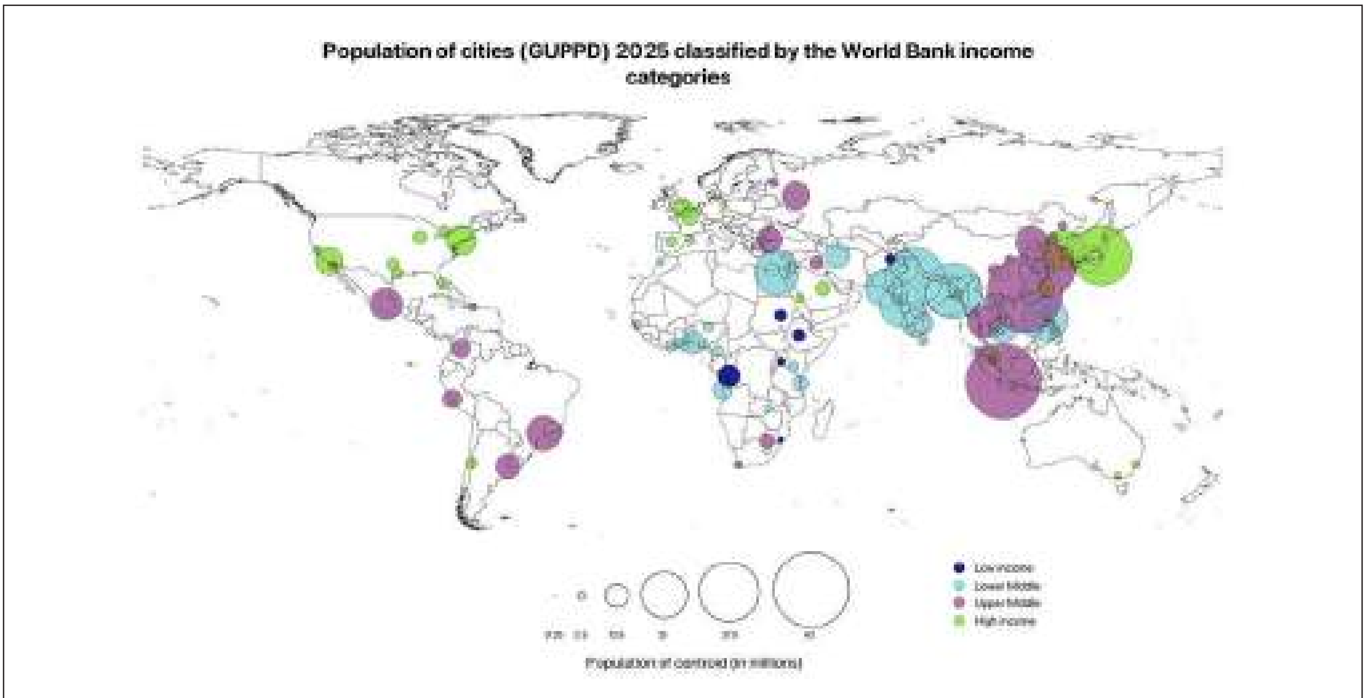


Figure 1. Global distribution of top 100 cities plus the 12 WaterAid cities considered in this report ranked by population and World Bank income classification.

The regional analysis illustrates that several major cities in East Africa are experiencing intensification of climatic extremes, requiring climate adaptation efforts to plan for both extreme wet and extreme dry conditions. Additionally, one East Africa city (Khartoum) is experiencing a flip in its climatic hazard profile from wet to dry and Dar es Salaam is experiencing a wetting trend.

European cities studied here are generally getting drier, albeit with periods of flooding. Some cities are flipping from a predominance of extreme wet to extreme dry periods (Madrid and Barcelona). The region comprising South and Southeast Asia is experiencing the strongest wetting trends across the globe, as well as expressing climate hazard flips from dry to wet for many of these cities, and two flips from extreme wet to extreme dry in Taipei and Hong Kong. Some of these findings may be a consequence of an intensification of the regional monsoon, but they do present an important challenge for the region to adapt to a more extreme environment of flood hazard, particularly for countries with high vulnerability.

WaterAid/Sam Vox

Julius Chisengo, 53, is the Group Operator for the DEWATS, with Ladislaus Stephano, 42, a site worker in Kigamboni, Dar Es Salaam, Tanzania. March 2021.

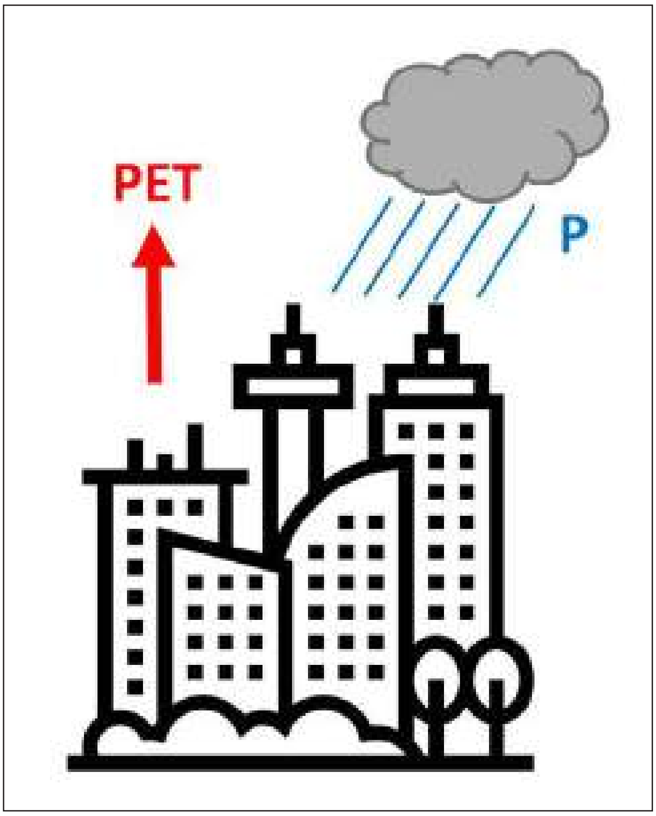


Figure 2: Diagram illustrating the main climate inputs (P = precipitation) and outputs (PET = potential evapotranspiration) of water used to calculate metrics of climate hazard as indicated by changes in the surplus or deficits of water over cities. (City life icons created by Freepik – Flaticon).

Climate hazard changes for cities

1

To provide the context of how climate hazards are evolving for each city, below we summarise key results obtained from analysing the wetting/drying index over time which include long-term (multi-decadal) trends of wetting/drying, climate hazard flips, intensification of climatic extremes, and abatement of climate extremes.

1.1 Wetting/drying trends

Wetting and drying trends over the last 42 years give an indication of whether a city's climate is becoming more flood-prone or drought-prone respectively. Figure 3 illustrates the overall trends in wetting and drying across the 112 cities, with blue indicating wetting and red representing drying. The intensity of each colour of each symbol reflects the strength of the trend. The map reveals notable spatial patterns, including **strong wetting trends in South and Southeast Asia and pronounced drying trends over the Arabian Peninsula, Europe, South America, and the western, southwestern, and southeastern United States**.

African cities, which are distributed across the continent (including North, East, West, and Southern Africa) exhibit a mix of wetting and drying signals, as do cities in China. The global patterns and regional variability in wetting and drying trends highlight that the expression of climate change is complex and affected by more than just increases in global temperature and atmospheric moisture-holding capacity – factors such as moisture availability and prevailing wind directions also play an important role. Table 1 lists the top 20 cities by the strength of their wetting or drying trend.

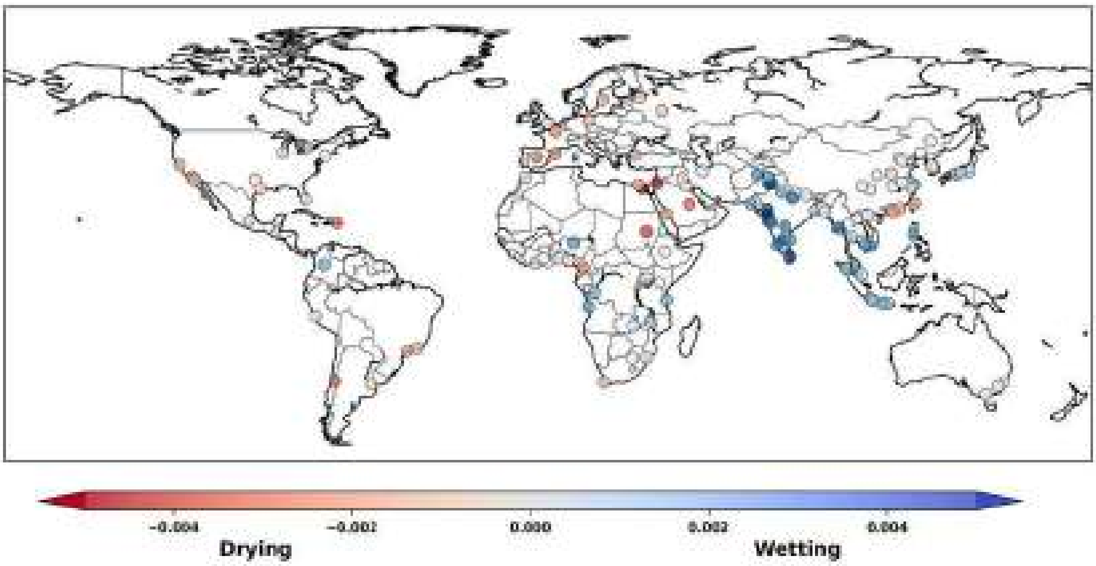


Figure 3. Trends in wetting and drying over the 112 cities. The more intense the colour (blue or red) is, the stronger the trend in either wetting or drying respectively.

Overall trends of wetting or drying do not eliminate the possibility of episodes that deviate from the trend. In other words, regions experiencing a general drying trend may still encounter periods of extreme wet conditions (e.g., Berlin in 2018, Figure 4), while areas with a wetting trend can experience episodes of extreme dryness (e.g., Kozhikode in 2017, Figure 4).

Out of the 112 cities analysed, 58 have a wetting trend and 49 have a drying trend, of varying magnitudes.

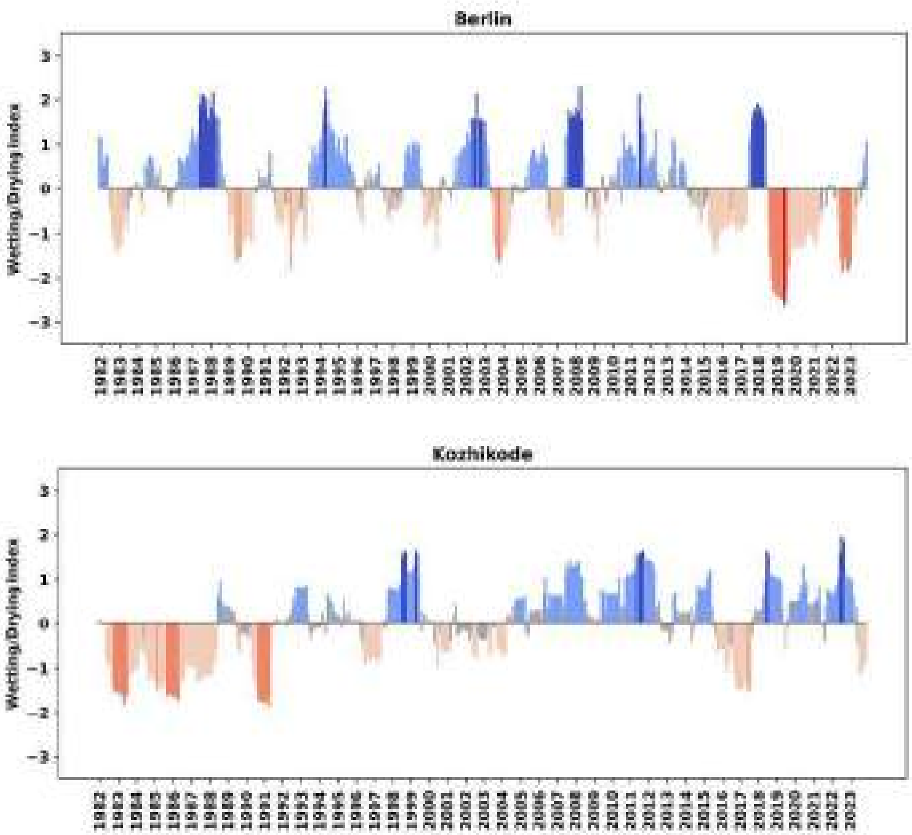


Figure 4. Example of a city with an overall drying trend (Berlin) and a city with an overall wetting trend (Kozhikode) demonstrating that episodes that deviate from the overall trend may still occur.

Rank	Wetting Trend	Drying Trend
1	Colombo	Cairo
2	Faisalabad	Amman
3	Surat	Khartoum
4	Bengaluru	Santiago
5	Mumbai	Riyadh
6	Ahmedabad	Yaoundé
7	Kozhikode	Santo Domingo
8	Lucknow	Madrid
9	Pune	Paris
10	Kuala Lumpur	Barcelona
11	Lahore	Los Angeles
12	Hyderabad – India	Tijuana
13	Kabul	Sao Paolo
14	Yangon	Hong Kong
15	Ho Chi Minh City	Cape Town
16	Luanda	Jeddah
17	Chennai	New Taipei
18	Rawalpindi (Islamabad)	Berlin
19	Kano	Baghdad
20	New Delhi	Rio de Janeiro

Table 1. Top 20 cities experiencing a wetting and drying trend.

1.2 Climate hazard flips in extremes

An important and potentially devastating manifestation of climate change is a reversal in its extremes. If a city is experiencing fewer extreme wet months and more extreme dry months, it represents a shift in its hazard profile from flood-prone to drought-prone, and vice versa. This means that the urban population would be subjected to a new set of challenges to water, sanitation and hygiene services for which they may not be prepared, and the urban policies, systems and infrastructure may not be suitable to handle this new hazard profile.

Climate hazard flips – the switch from predominantly extreme wet to extreme dry, or from predominantly extreme dry to extreme wet climatic conditions – have significant implications for city populations and their ability to adapt to climate change.

Cities long adapted to a wet climate tend to have policies, systems, infrastructure and strategies tailored to managing a surplus of water. A flip to drier conditions poses new challenges to such cities that may lack the water supply and sanitation systems to deal with more frequent droughts and water deficits. The corollary – cities adapted to water scarcity and drought – also face significant adaptation challenges to extreme wet conditions that may result in more frequent flooding, potentially overwhelming water supply and storage, wastewater and drainage systems and exposing vulnerable low-lying settlements to risk of disease outbreaks.

Of the 112 cities analysed, 24 display a climate hazard flip signal, of which 10 show a flip from wet to dry extremes (Figure 5 and Table 2), and 14 show a flip from dry to wet extremes (Figure 5 and Table 3). **This amounts to at least over a quarter of a billion people across the world exposed to a reversing climate hazard profile** (Figure 6) from the top 100 (+12) cities.

The list of climate hazard flip cities facing increasing dry extremes is topped by Cairo, Madrid, Riyadh, Hong Kong and Jeddah, while those facing increasing wet extremes are led by Lucknow, Surat, Kano, Ahmedabad and Bogotá.

Rank	City	Country
1	Cairo	Egypt
2	Madrid	Spain
3	Riyadh	Saudi Arabia
4	Hong Kong	China
5	Jeddah	Saudi Arabia
6	Yaoundé	Cameroon
7	San Jose	USA
8	Khartoum	Sudan
9	New Taipei	Taiwan
10	Barcelona	Spain

Table 2. Ranked cities experiencing a strong flip from wet to dry climatic extremes, based on a predominance of drought months (extreme dry) and a reduction in extreme wet months.

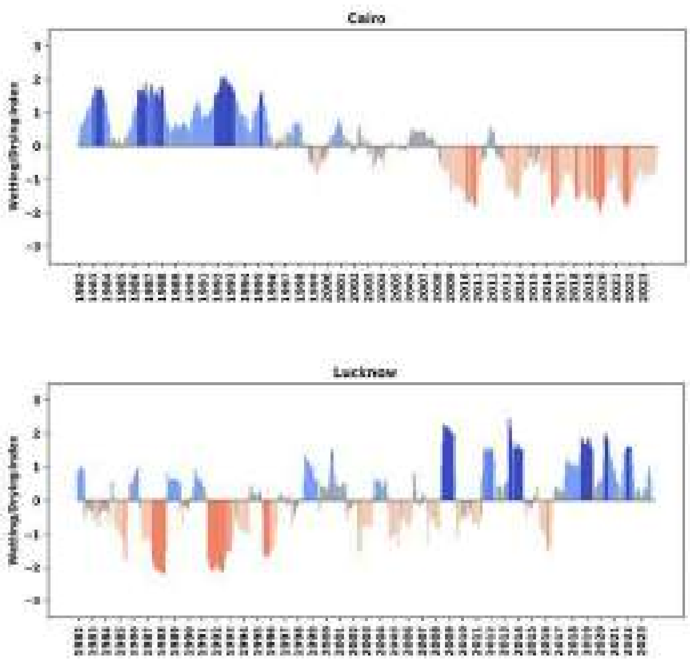


Figure 5. Example of a flip to drier extremes (Cairo) and a flip to wet extremes (Lucknow).

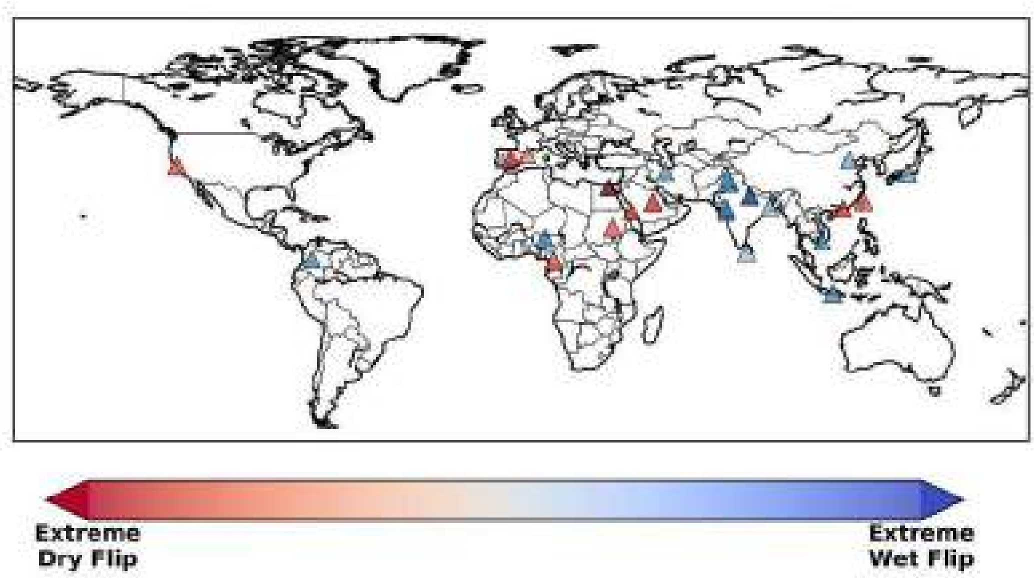


Figure 6. Map of all cities displaying a flip in climatic extremes – blue indicates a flip to wetter extremes and red indicates a flip to drier extremes.

Rank	City	Country
1	Lucknow	India
2	Surat	India
3	Kano	Nigeria
4	Ahmedabad	India
5	Bogotá	Colombia
6	Lahore	Pakistan
7	Faisalabad	Pakistan
8	Rawalpindi	Pakistan
9	Jakarta	Indonesia
10	Tehran	Iran
11	Ho Chi Minh City	Vietnam
12	Beijing	China
13	Kolkata	India
14	Colombo	Sri Lanka

Table 3. Ranked cities experiencing a strong flip from dry to wet climatic extremes, based on a predominance of flood-prone months (extreme wet) and a reduction in extreme dry months.

1.3. Climate Hazard Intensification

An important manifestation of climate change is the shifting magnitude of both types of climate hazard events (droughts and floods). If both these events become more intense, it could overwhelm existing capacity in global cities to adapt to climate change, especially in cases where both wet and dry periods both become more intense (wetter and drier than they were in previous decades).

As the atmosphere becomes warmer, it can hold more moisture[4]. This phenomenon has two distinct potential consequences.

First, a warmer atmosphere will tend to draw more moisture upward from land areas through evapotranspiration that may not be replaced by incoming precipitation. As a result, the land will become drier allowing anomalously warm and dry periods to become more intense, potentially leading to deeper droughts.

Second, a warmer atmosphere will tend to hold more moisture so that when precipitation does occur over a city, it may arrive in larger amounts for the same storm duration, potentially leading to increased flooding.

We addressed climate hazard intensification (increase in both wet and dry extremes in the period 2003-2023 compared to 1982-2002) and identified 17 (of the 112) global cities that experienced climate hazard intensification (both wet and dry) over the last two decades (Table 4).

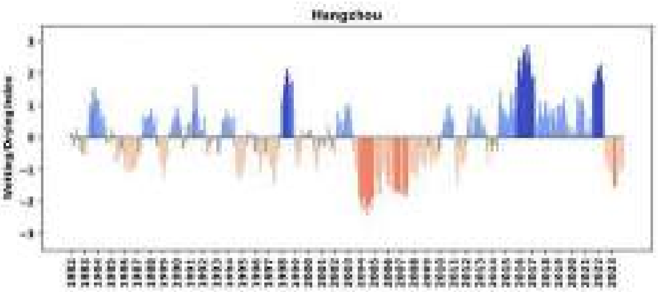
This intensification of both extreme floods and droughts, known as 'climate whiplash', can be particularly difficult for communities to prepare for and adapt to, creating challenges in planning for long-term climate resilience, particularly in low-income countries.

Asian cities are disproportionately represented in the list of cities experiencing intensification (9 out of the 17), with Hangzhou and Jakarta (Figure 7) topping this list, but intensification appears be occurring over much of the globe, affecting cities in North America, Africa and Australia. In East African cities, including Nairobi, Addis Ababa and Kampala, 'climate whiplash' or intensification has resulted in communities experiencing both severe droughts and floods back-to-back creating major water management challenges, from water shortages to contamination and disease spread.

Notably, there are no European or South American cities experiencing climate hazard intensification, even though some may be experiencing intensification of wet periods or dry periods but not both (see Section 2.2).

Intensification rank	City	Country
1 (highest)	Hangzhou	China
2	Jakarta	Indonesia
3	Dallas	USA
4	Shanghai	China
5	Baghdad	Iraq
6	Hefei	China
7	Canberra	Australia
8	Surabaya	Indonesia
9	Bangkok	Thailand
10	Addis Ababa	Ethiopia
11	Chicago	USA
12	Suzhou	China
13	Nairobi	Kenya
14	Cape Town	South Africa
15	Melbourne	Australia
16	Zhengzhou	China
17	Kampala	Uganda

Table 4. Ranked cities experiencing an intensifying climate (an increase in both wet and dry extremes).



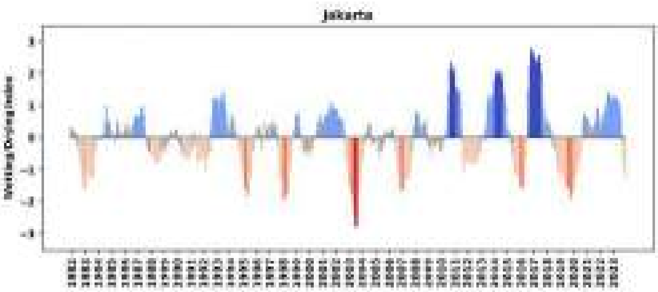


Figure 7. Example of cities experiencing climate hazard intensification (increase in both extreme dry and wet months).

1.4 Climate Hazard Abatement

It is perhaps counterintuitive that some cities in the world may experience a decreasing severity of climatic hazards. This may happen when the climatic patterns in a particular region change because of shifts in the prevailing winds, high/low pressure cells, and/or storm tracks. In general, if wetting and drying severity decrease through time, it represents a lessening of the potential risk that climate hazards will cause damage or impact to society.

We addressed climate hazard abatement (decrease in both wet and dry extremes in the period 2003-2023 compared to 1982-2002) and found 11 cities (Table 5) in 5 continents ranging from massive population centres (Guangzhou, Tokyo, Dhaka) to smaller urban centres (Onitsha, Kathmandu, Lusaka). Asian cities top the list (e.g., Nagoya and Yangon, Figure 8) of climate hazard abatement, and comprise more than half.

The preponderance of Asian cities on both the hazard intensification (Table 4) and hazard abatement (Table 5) lists suggests that the size and geographical variability on the Asian continent leads to a wide range of climatic conditions that may impact the frequency and magnitude of extreme events.

Abatement rank	City	Country
1 (highest)	Nagoya	Japan
2	Yangon	Myanmar
3	Tokyo	Japan
4	Lusaka	Zambia
5	Guangzhou	China
6	Kathmandu	Nepal
7	Onitsha	Nigeria
8	Dhaka	Bangladesh
9	Lima	Peru
10	London	United Kingdom
11	Miami	USA

Table 5. Ranked cities experiencing an abating climate.

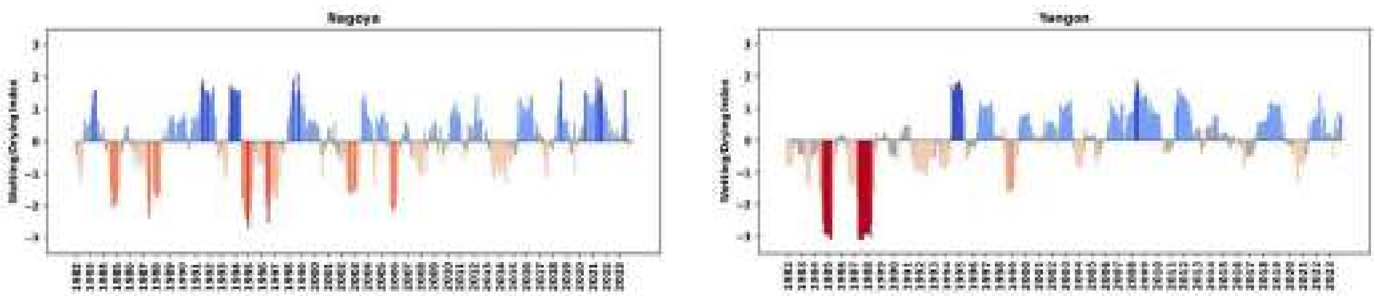


Figure 8. Example of cities experiencing climate hazard abatement.

Vulnerability of urban populations to climate hazards

2

2.1 Assessing social vulnerability with the Human Development Index

Social vulnerability is broadly defined as socially determined susceptibility to harm from shocks or hazards. While social vulnerability can be highly context-specific and linked to local social, political or cultural factors (e.g. discrimination), relative poverty is closely associated with relative vulnerability everywhere[5,6]. To assess relative poverty, we use the Human Development Index (HDI). This is a well-established measure that provides a holistic assessment of human development that goes beyond standard economic measures[7]. HDI combines average measures of three fundamental aspects essential for human well-being: health, education and standard of living. Health is measured through life expectancy at birth, reflecting access to healthcare, nutrition, and general well-being.

Education is assessed by measures of mean years of schooling for adults and expected years of schooling for children, highlighting the importance of education in empowering individuals. Standard of living is measured through Gross National Income (GNI) per capita, which serves as an indicator of economic resources available to individuals to meet their basic needs and enjoy a decent quality of life. Together, these dimensions provide a multidimensional view of human development, going beyond economic metrics like Gross Domestic Product (GDP) to capture the broader aspects of well-being and societal advancement. **And recent evidence shows that HDI is closely correlated with resilience to natural hazards (including climate hazards such as droughts and floods)**[8,9,10].

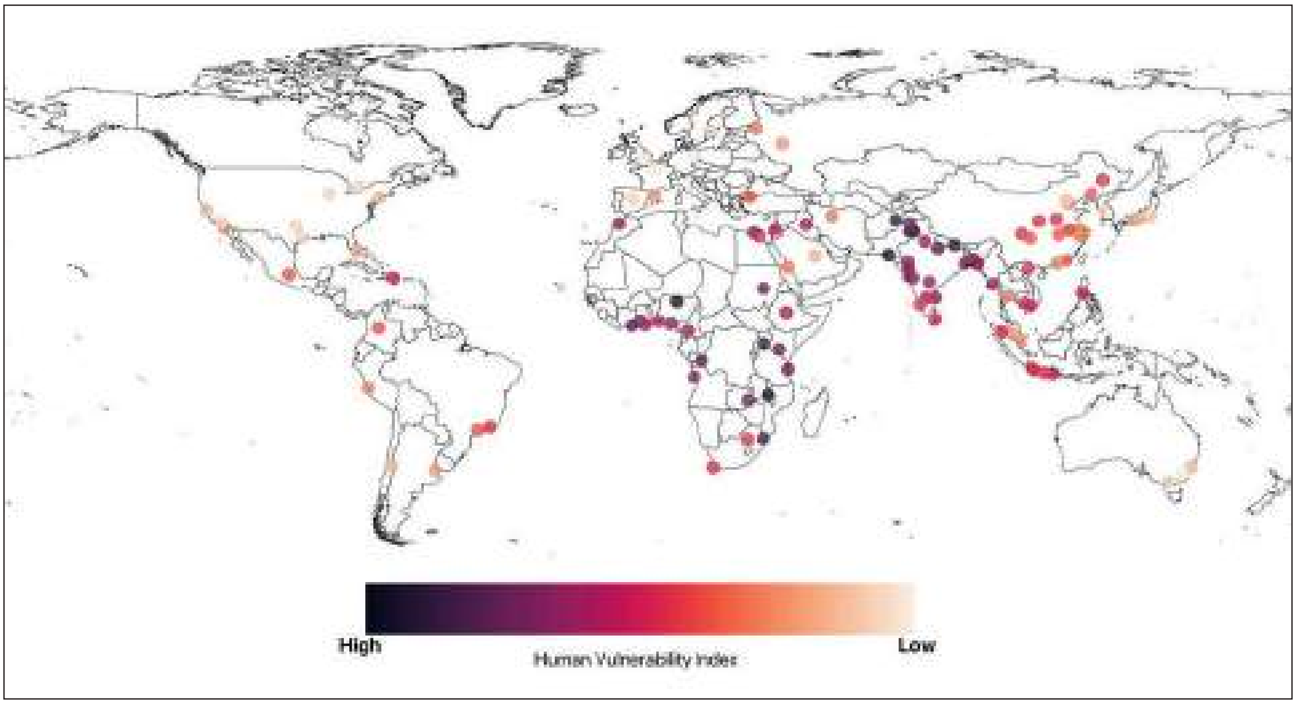


Figure 9. Map of the Human Vulnerability Index (HVI) for the 112 cities.

By inverting the values of the initial HDI, we obtained a 'Human Vulnerability Index' (HVI) (Appendix 1.3). We mapped the HVI of the top 100 (+12) global cities (Figure 9), where we see the highest levels of social vulnerability in south Asia and sub-Saharan Africa, followed by lower HVI scores in East Asia, Southeast Asia, the Middle East and parts of Central and South America. There is comparatively low HVI in the cites of the USA, Europe, Australia and Japan.

In cities with high HVI, there will be significant numbers of people living in poverty with limited access to healthcare and education who already lack basic WASH services. Such communities often only have access to 'limited' WASH services, rely on surface water sources and/or practise open defecation. Furthermore, limited opportunities for diversified and sustainable livelihoods undermine communities' abilities to invest in and prepare for climate shocks. Similarly, limited awareness of climate risks and response options can hinder a community's engagement, advocacy and planning in relation to adaptation efforts.

2.2 Infrastructural vulnerability

Urban infrastructure also plays a crucial role in determining the harm and damaged caused by climate hazards[11-13] and is closely linked to human development. Strong WASH infrastructure is an essential part of climate adaptation and has an underestimated potential to contribute to climate mitigation and net zero emissions efforts, primarily through improved wastewater treatment and safe reuse.

The map of combined water and waste infrastructural vulnerability (Figure 10) is generally very similar to the HVI map (Figure 9), indicating the strong link between general societal development and infrastructural development (e.g., high infrastructural vulnerability in Sub-Saharan Africa and South Asia). However, there are notable differences. For example, water and waste infrastructural vulnerability is generally low across both North and South America, and Europe. Additionally, East Asia contains many cities with high water/waste infrastructural vulnerability.

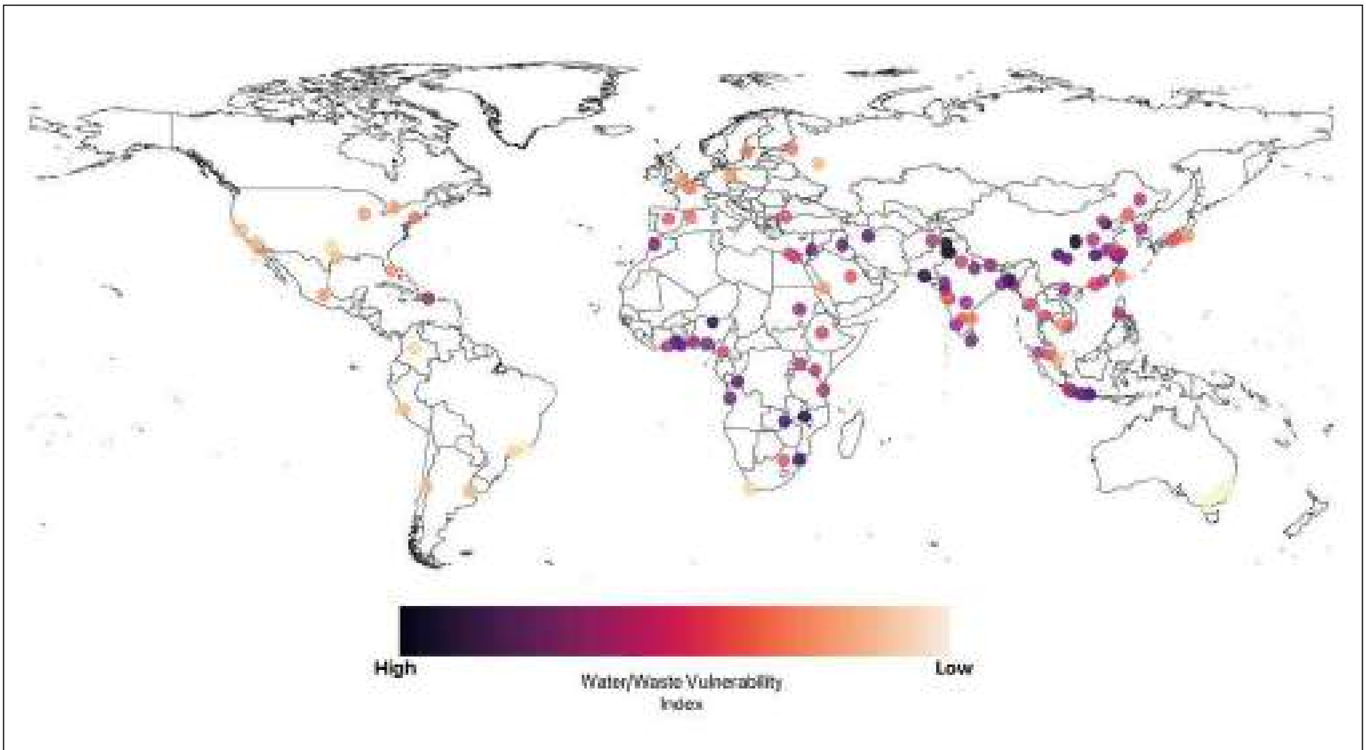


Figure 10. Map of infrastructural vulnerability (combining water and waste infrastructure) for the 112 cities.

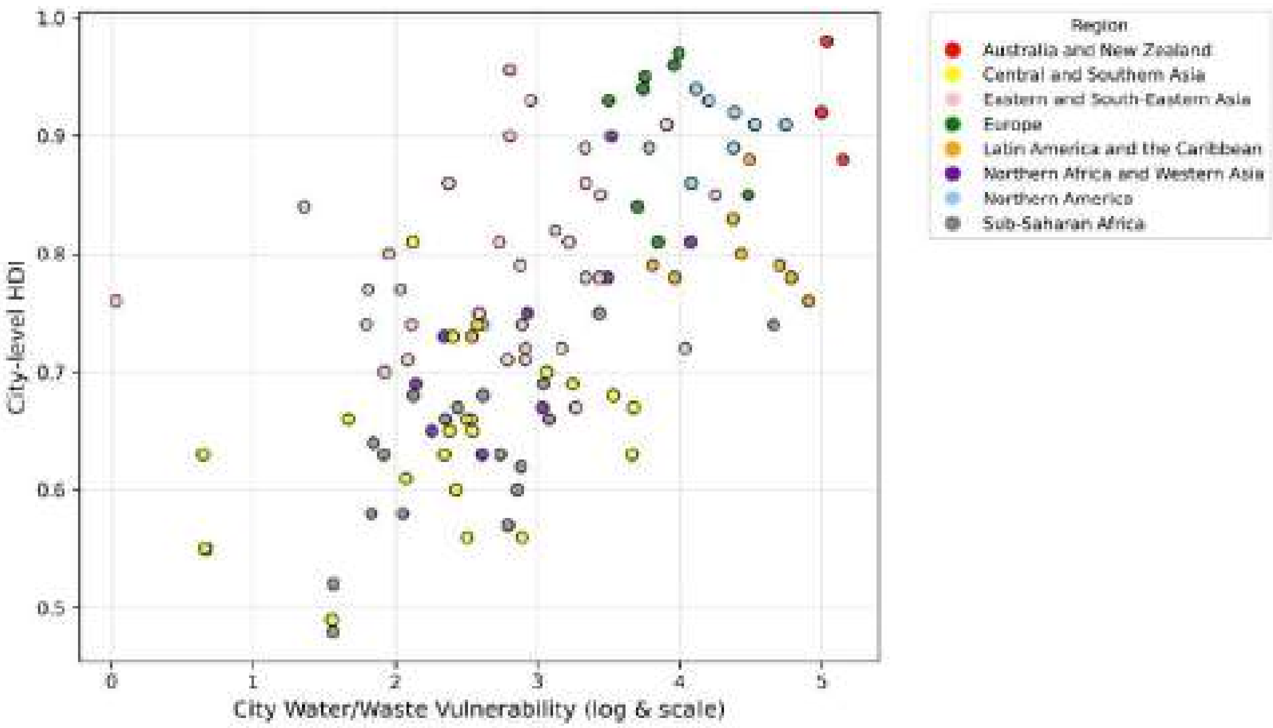


Figure 11. Infrastructural vulnerability is correlated with HDI at the city level (note that the two datasets are independent and unrelated).

City infrastructure, including water and waste infrastructure, plays a vital role in building resilience and adapting to the challenges of floods and droughts caused by climate change. Effective drainage systems and flood barriers can reduce the impact of heavy rainfall and protect urban areas from flooding. Green infrastructure, such as permeable surfaces, urban wetlands, and green roofs, help absorb excess water during floods while also conserving water during dry periods. Reliable water storage and distribution systems, along with contextually-appropriate approaches such as rainwater harvesting and wastewater recycling, are essential for mitigating the effects of prolonged droughts. Sanitation facilities and services that can withstand flooding and prevent spilling of human waste, and can operate during times of drought, are critical for public health.

Cities with poor infrastructure are highly vulnerable to the impacts of floods and droughts. Inadequate drainage systems and lack of flood defences can lead to severe urban flooding, damaging homes, disrupting transportation, and endangering lives. Similarly, poorly maintained or insufficient water storage and distribution systems exacerbate the effects of droughts, causing water shortages, reduced access to clean drinking water, and economic losses. Sanitation that stops working during drought, or gets damaged during flooding and contaminates the environment with human waste, can spread diseases such as cholera and typhoid, placing extra burden on healthcare services and reducing economic productivity. Poor infrastructure also limits a city's ability to recover from these events, leaving communities more exposed to future climate risks.

At the household level, urban infrastructure has a direct bearing on human development and resilience. Easy access to safe drinking water and effective waste and sanitation systems reduces disease risk and strengthens education and economic outcomes. As Figure 11 shows, there is a close correlation between the city-level Human Development Index and the infrastructure quality index.

Convergence between climate hazards and urban vulnerability

3

Some of the biggest challenges in climate change adaptation will be faced by cities that are experiencing dramatic changes in their climate and are most susceptible to the negative impacts of these changes due to high vulnerability. We compared the top 20 cities that were highest on both climate hazard and vulnerability lists to assess the relative convergence of hazards and its potential impact on urban population centres. This information is shown in two ways below.

Figure 12 shows these cities ranked by their individual rankings on both hazard trends and the average of social and infrastructural vulnerability. It can be seen that Khartoum, Amman and Santo Domingo, followed by Baghdad and Yaoundé, top the list of cities experiencing a drying trend. On the other side, Faisalabad, Lahore, and Surat, followed by Kano and Rawalpindi (Islamabad), sit at the top of the list for those experiencing wetting trends.

Separately, we also plot the rankings of cities experiencing climate hazard intensification (increase in both wet and dry extremes) as a convergence with their combined social and infrastructural vulnerability scores. Figure 13 shows that Surubaya, Baghdad, Nairobi and Kampala top this list of cities showing a convergence in intensification of extremes and vulnerability. It is interesting to note that Baghdad appears near the top of both of these lists, suggesting its precarious status in terms of vulnerability and also that, despite a drying trend, the Iraqi city is also experiencing an intensification of both drought and flood conditions.


WaterAid/Sam Vox

Juma Ngombo, 54, is a Gulper Operator for the Newanga Usafishaji Mazingira Group (NUMAGRO). Temeke, Dar Es Salaam, Tanzania. March 2021.

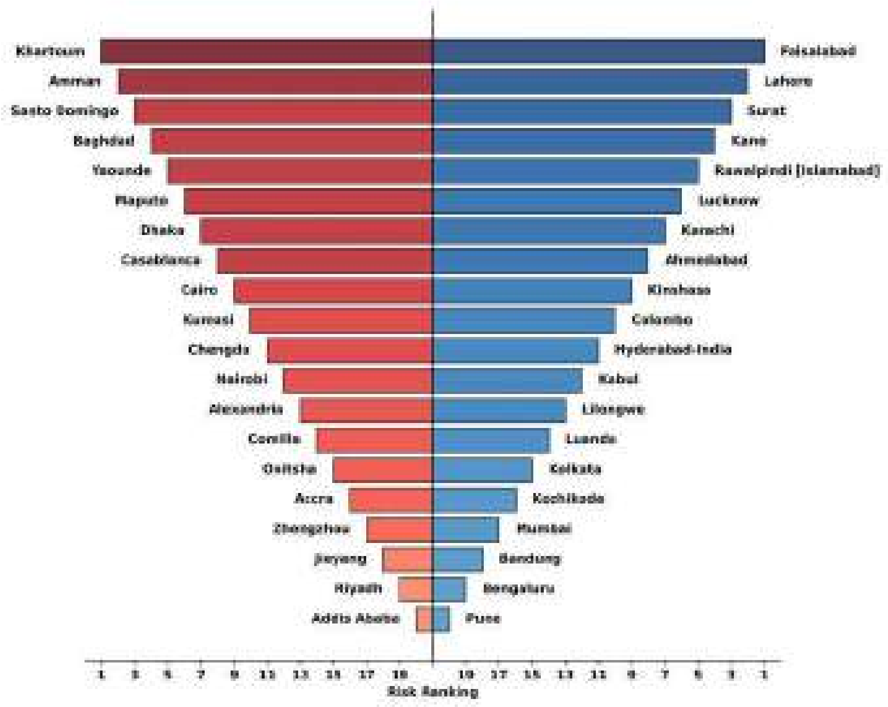


Figure 12. Critical cities that rank highly both for climate hazard trends and vulnerability (based on the average of social and infrastructural vulnerability scores). The graph presents the top 20 cities with a high-risk ranking (combining vulnerability and climate hazard) for cities experiencing a wetting (blue) and drying (red).

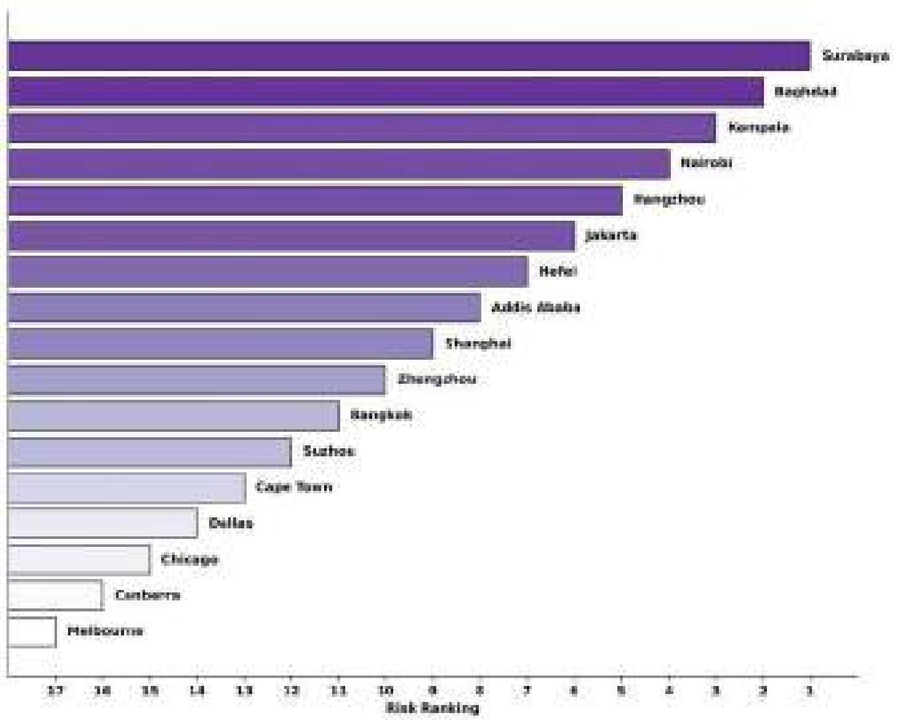


Figure 13. Critical cities that rank highly both for climate intensification and vulnerability (based on the average of social and infrastructural vulnerability scores). The graph presents the top 20 cities with a high-risk ranking (combining vulnerability and climate hazard) for cities experiencing intensification.

Regional snapshots

4

4.1 East Africa

Several countries in East Africa are extremely vulnerable to climate change impacts due to the dependence of lives and livelihoods on small-scale agriculture in rural areas, and high levels of social and infrastructural vulnerability, particularly in urban areas, which hinder people's ability to adapt and cope with climatic shocks[15]. East Africa is known for its devastating droughts over the last few decades[16]. However, extreme floods are getting more frequent and extreme. Figures 15 and 16 show that three major cities in East Africa – Nairobi, Addis Ababa and Kampala – are experiencing an intensification of both extreme droughts and floods, while Khartoum is experiencing a climate hazard flip from wet to dry extremes.

Intensification is particularly problematic as it 'whiplashes' cities between both hydroclimatic extremes (droughts and floods). Prolonged droughts lead to water shortages, food insecurity, and electricity disruptions due to reliance on hydropower. Following intense rain periods, urban drainage systems struggle to cope, resulting in flash floods that displace communities, damage roads, and spread waterborne diseases.

In cities experiencing severe droughts and floods back-to-back, people with only limited water, sanitation and hygiene services face significant challenges in accessing the services they need to stay healthy and productive. The rapid shift between these extremes makes it difficult for people to prepare and recover, damaging economies and endangering lives. Ineffective decision-making and weak systems related to WASH increase these cities' exposure to climatic risks and place already-vulnerable populations in an even more dangerous situation. For example, a prolonged drought may dry up a family's water source, meaning they have to spend extra hours travelling to collect water, have less time to spend on earning income and become less healthy due to reduced water available for drinking and hygiene. When a flood suddenly hits, the parched ground cannot absorb the excess water, leading to drains and sanitation systems overflowing and polluting the remaining water sources. Whilst there is now lots of water around, it is not safe to drink, and the family is even more exposed to disease.

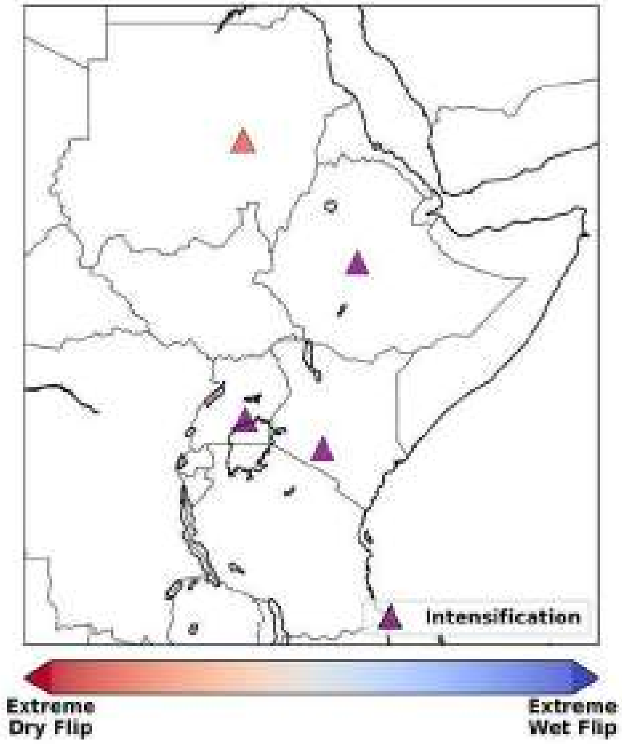
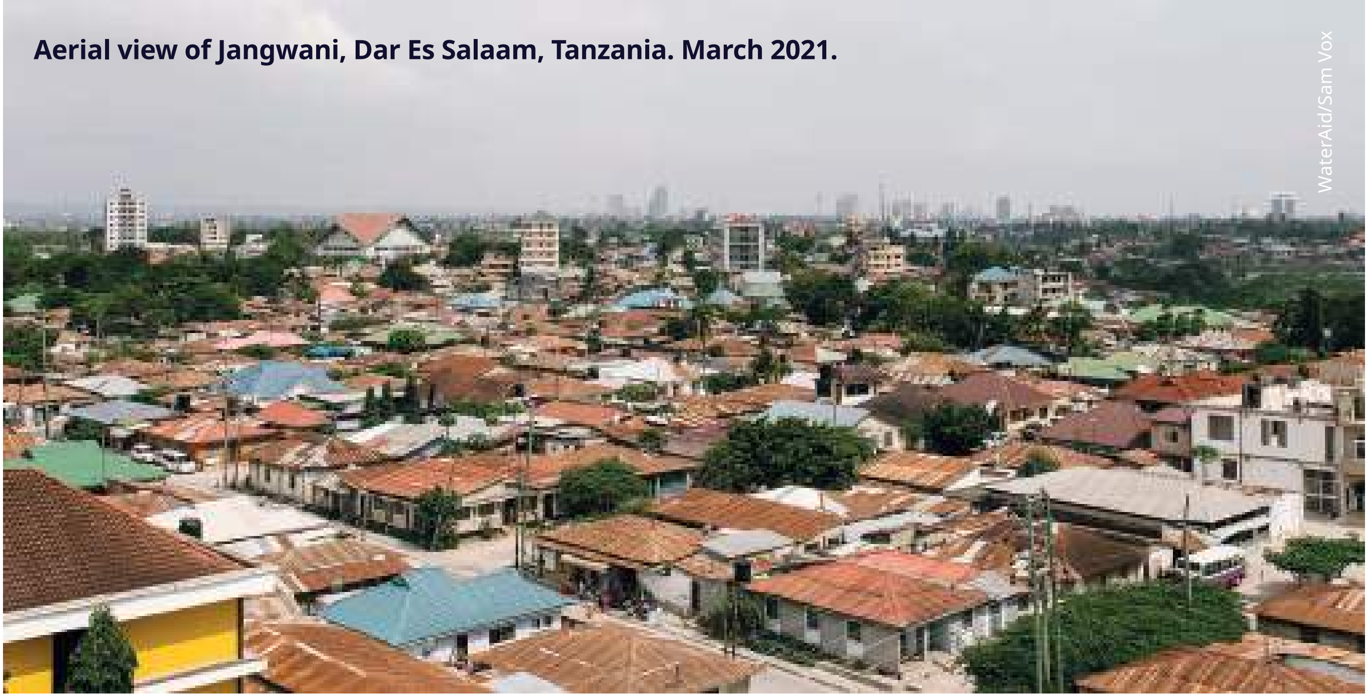


Figure 14. Cities in East Africa experiencing intensification (increase in both wet and dry extremes) and a flip to extreme dry conditions.

Aerial view of Jangwani, Dar Es Salaam, Tanzania. March 2021.



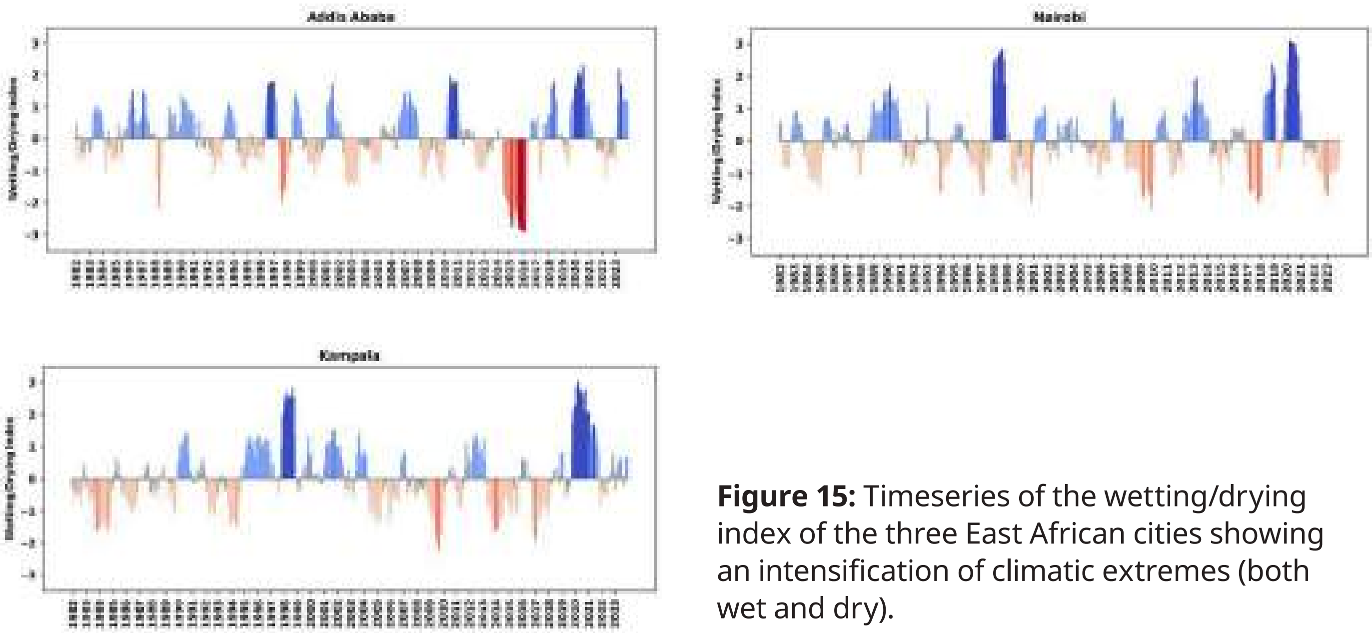


Figure 15: Timeseries of the wetting/drying index of the three East African cities showing an intensification of climatic extremes (both wet and dry).

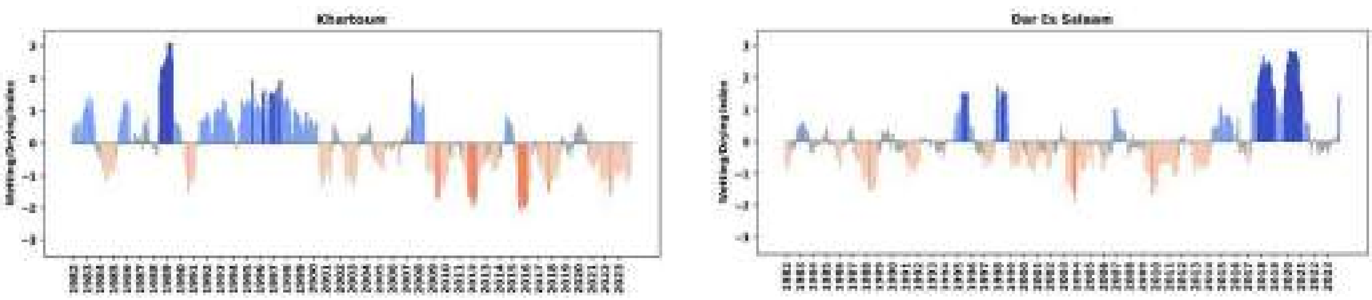


Figure 16: Timeseries of the wetting/drying index Khartoum (Sudan) showing an increase in drier climatic extremes and Dar Es Salaam (Tanzania) which is showing a wetting trend.

4.2 Europe

All European cities we analysed exhibit drying trends, despite wide variations in their geographical positions in the continent. The strongest drying trends are in the Iberian Peninsula and Paris, while cities further north and east have more muted drying trends (Figure 17). The only European cities in our analysis showing climate hazard flips are Madrid and Barcelona, both of which are seeing a flip to dry climatic extremes superimposed on their overall drying trends (Figure 18). It is notable that all the European cities studied here are drying overall, in spite of many studies and news articles indicating that Europe is getting wetter[17-19], our results suggest the opposite. Namely, we see that the last two decades have been drier overall for all European cities studied, often with deeper and more prolonged dry periods (Figure 18). However, it is important to remember that drying trends (or even climate hazard flips to dry) do not preclude the possibility of extreme flood-prone periods, which have occurred in the recent past, for example in Stockholm, Berlin, and London.

Given the overall higher level of economic development in Europe, it is an open question how these drying trends (and climate hazard flips for the Spanish cities) will affect water supply and water and sanitation infrastructure. Our analysis of urban vulnerability for European cities showed that these cities generally have lower social vulnerability scores (Figure 9).

Interestingly, European cities' infrastructural vulnerability scores are relatively high compared to other high income regions such as Australia and the USA (Figure 10), despite generally low social vulnerability. Many of these urban centres are relatively long-established and therefore may have ageing water supply and sanitation infrastructure. A drying climate, punctuated by both drought and flood extremes, may present significant and extremely costly challenges for these cities in terms of adapting their water, sanitation and hygiene services for a new climatic reality. It is also crucial to consider that the measurements of vulnerability within this report considers vulnerability at a city-level. We do not provide insight into specific subcommunities or groups within that city. Despite lower social vulnerability scores overall, there may well still be people with significantly higher levels of vulnerability living within these cities. As climatic hazards become more difficult to predict and mitigate, existing inequalities such as those linked to poverty, age, health, and ability to evacuate or relocate are exacerbated. These inequalities often intersect and deepen one another, meaning that climate inequality and individual vulnerability can be significant even in cities with high HDI.

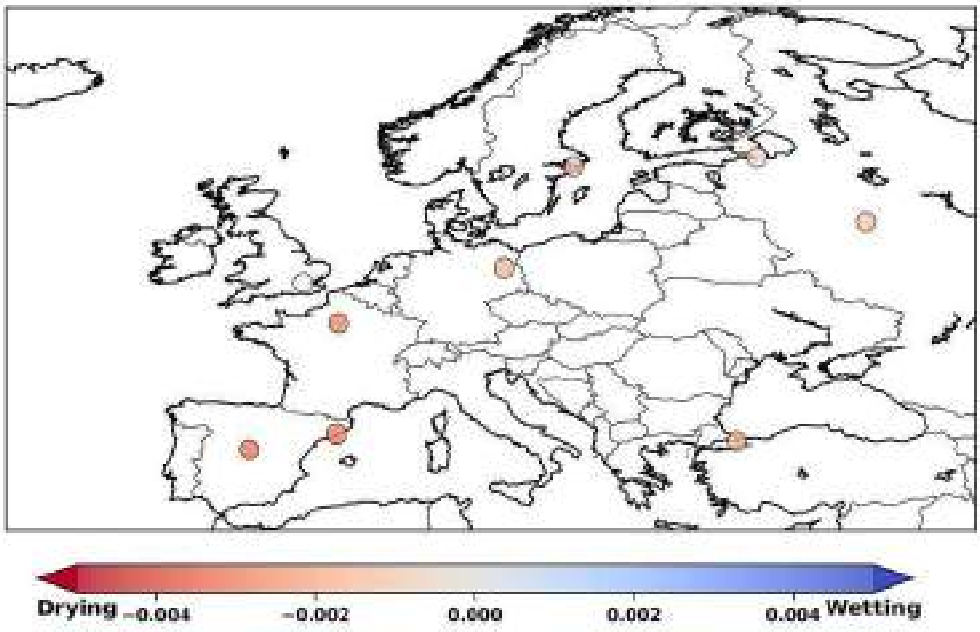


Figure 17. Trends in wetting and drying over cities located in Europe. The more intense the colour (blue or red) is, the stronger the trend in either wetting or drying respectively.

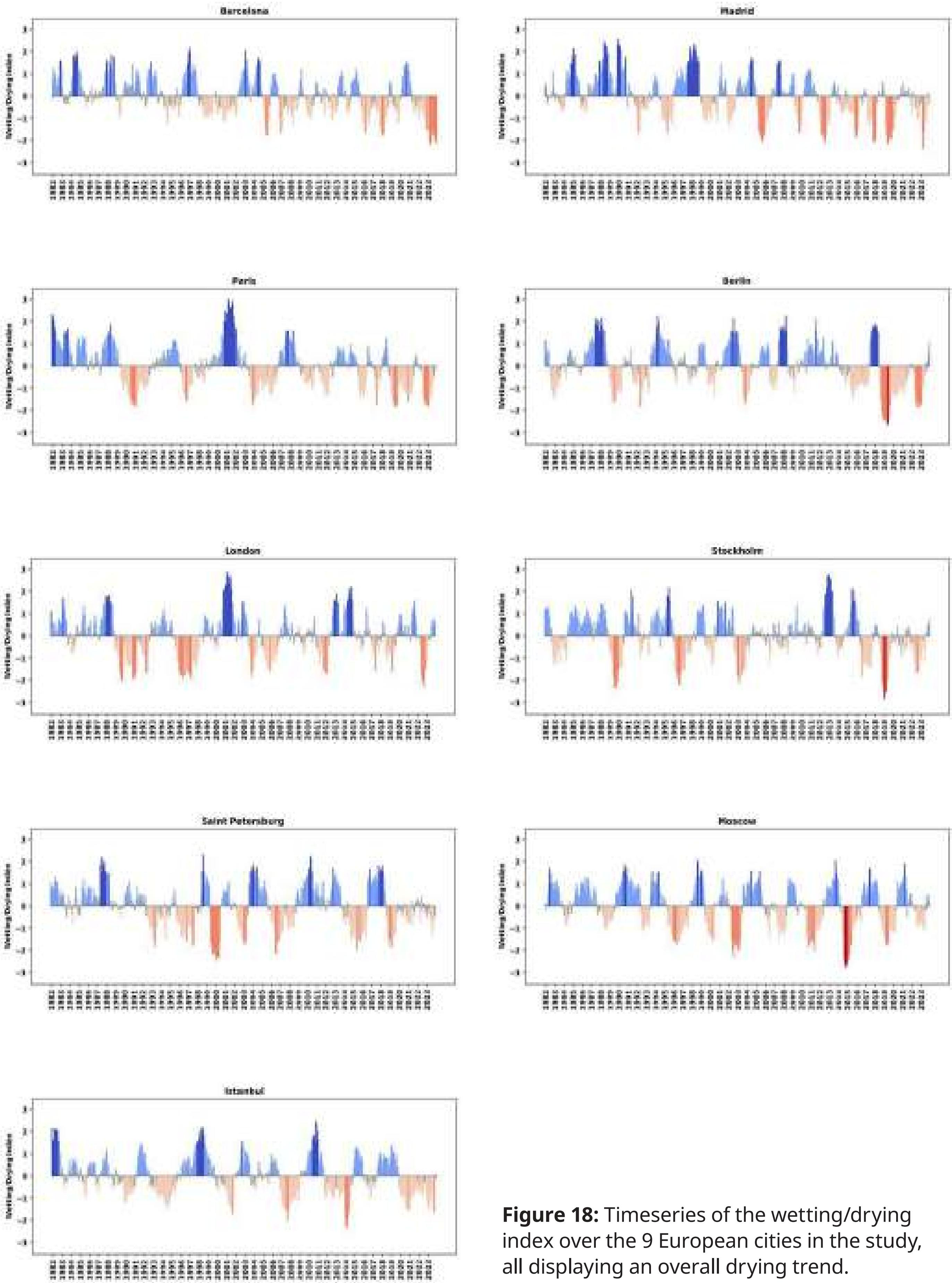


Figure 18: Timeseries of the wetting/drying index over the 9 European cities in the study, all displaying an overall drying trend.

4.3 South and Southeast Asia

Cities in South and Southeast Asia are some of the most populous in the world – and make up a large percentage of the 100 cities in this analysis. The major cities in South Asia, Southeast Asia and East Asia are dominated by wetting trends across much of the region. However, the strength of this wetting trend is highest in the southern and western parts of this Asian region and tends to be weaker in the eastern and northern cities.

The strongest wetting trends (Figure 19) occur in Colombo (Sri Lanka), Faisalabad (Pakistan) and Surat (India). 90% of the top 20 cities exhibiting wetting trends, and 75% of all (59) wetting cities in the analysis, are in South Asia and Southeast Asia. Additionally, 80% of cities displaying a flip to wetter extremes and 50% of intensifying (both wet and dry extremes) cities are in South and Southeast Asia (Figure 20). Around 20% of cities display a flip to more extreme dry months.

Interestingly, several eastern coastal and interior cities of China are experiencing drying trends, suggesting that they are affected by completely different climatic conditions to South and Southeast Asia, which is dominated by an intensifying monsoon. Hong Kong in particular is not only drying but also experiencing a flip in climate hazards to more extreme dry conditions.

An intensifying Asian monsoon with wetter conditions will significantly impact WASH services in major Asian cities. Heavy rainfall and flooding can overwhelm drainage and damage sanitation infrastructure, leading to water contamination and increased risks of deadly waterborne diseases like cholera and dysentery. Poorly managed floodwaters can mix with raw sewage, exposing communities – especially those in informal settlements with only access to limited WASH services – to severe health hazards. Without effective decision-making and robust systems needed to quickly restore WASH services, people may have no choice but to use unsafe water and use inadequate toilets or practise open defecation, compounding the negative health impacts of a flood impact.

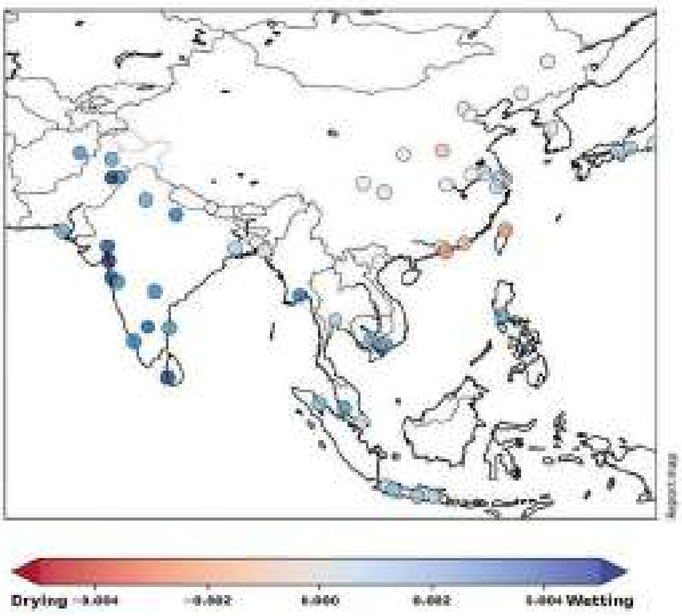


Figure 19. Trends in wetting and drying over top 100 cities located in South and Southeast Asia. The more intense the colour (blue or red) is, the stronger the trend in either wetting or drying respectively.

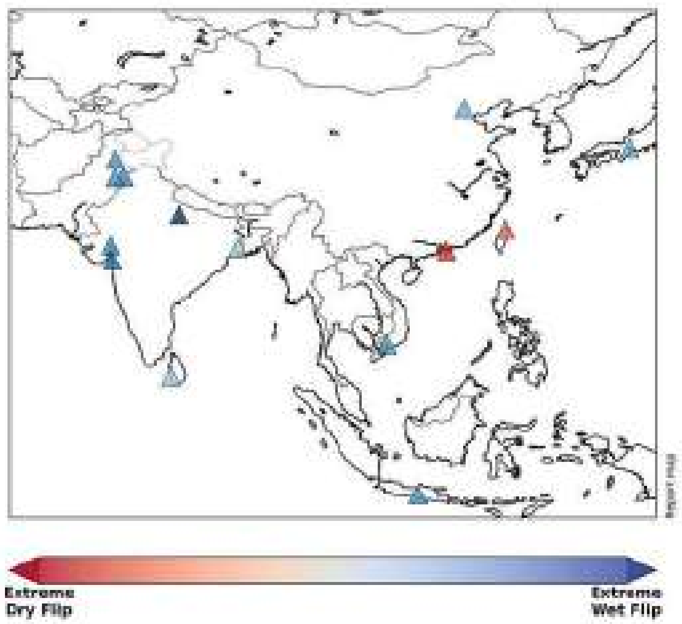


Figure 20. Cities within South and Southeast Asia displaying a significant climate hazard flip.

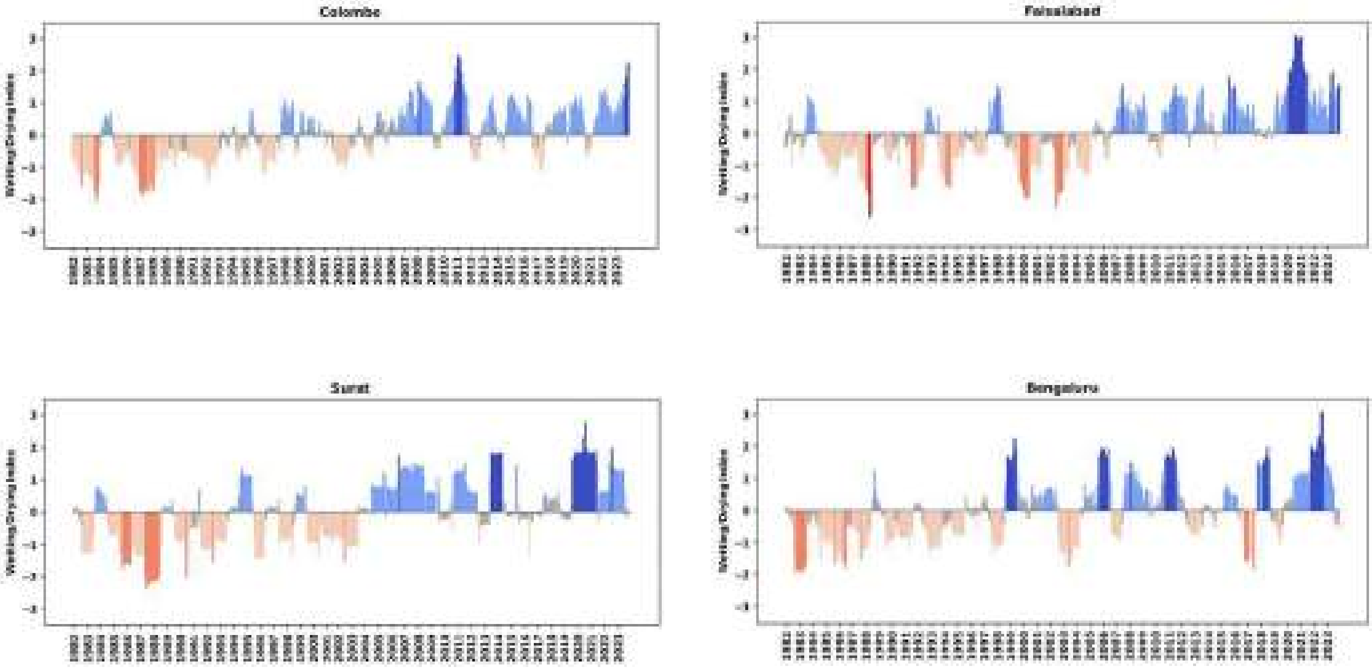


Figure 21. The top 4 cities within South and Southeast Asia showing a wetting trend.

Jannatul and other Community children are very pleased to get safe drinking water from the community water point. This water source came through direct pipeline from Saidabad Water Treatment Plant. Jatrabari, Dhaka. September 2022.

WaterAid/Habibul Haque

Key findings

5

In this report we analysed changes in the expression of climate over the last 42 years in the world's top 100 cities for population and we investigated potential hotspots of heightened risk due to the overlap between climate hazard and urban vulnerability.

Our analysis identifies several key, findings:

1. **15% of the cities analysed display an intensification trend** whereby both extreme dry and wet episodes are increasing substantially. We find these cities across the world from Asia to the Middle East and Africa and the USA.

2. South and Southeast Asia is a regional hotspot with a strong wetting trend. Home to many of the world's largest cities, this region has been **facing an increase in wet and extreme wet climate** which presents an increase in the likelihood of extreme flooding.

3. Europe, the Middle East and North Africa represent regions seeing a drying trend and **will likely face more frequent and long-lasting droughts**.

4. **Over 20% of the cities analysed are experiencing a reversal in their extremes** – ~13% of which are flipping towards more extreme wet climate and ~7% are flipping towards more extreme dry climate.

5. The convergence between underlying social and infrastructure vulnerabilities and these **climatic patterns produces hotspots of heightened risk** in two key regions: south and southeast Asia and north and east Africa, which are exhibiting increases in wet extremes and in both wet and dry extremes respectively. The report highlights the variability in the expression of climate change across the globe and the heightened risks in highly populated cities with existing underlying vulnerabilities.

As the global water cycle changes throughout the world, often becoming less predictable and more extreme, climate-resilient water, sanitation and hygiene services and systems will be essential to the health and social stability of cities. They are crucial in empowering people to cope, adapt, transform and recover in the face of increasing climate hazards.

Women line up to collect water from a water kiosk in Sylvia Masebo Community. Water is pumped using solar power and the kiosk is open for water collection from 6-10 AM. Lusaka, Zambia. February 2025.

WaterAid/Lee-Ann Olwage

Appendix 1 methodology

We used de facto city boundaries defined by population size and density, rather than administrative units. This new approach, made available by advances in geospatial population data, solves a well-known problem with traditional population statistics: every country in the world has a different way of defining urban and rural areas[2,5,14].

As a result, estimates of urban populations as defined by national statistical agencies are not strictly comparable across countries. The new geo-spatial approach used in this report, which was endorsed by the United Nations in 2020, solves this problem by applying a consistent urban definition to gridded population data.

It also resolves another issue: the administrative boundaries of many cities do not match the footprint of the actual urban area. For example, the city of San Francisco in California has a population less than 1 million, but the contiguous built-up area of the wider Bay Area (e.g. including San Jose, Palo Alto, Fremont, Oakland, etc) is home to more than 5 million people.

This geo-spatial methodology, which is blind to formal administrative boundaries, yields a different list of the top 100 than traditional UN statistics, city boundary and population data for 2025 were derived from the Global Urban Polygons and Points Dataset, Version 1 (GUPPD) available here: www.earthdata.nasa.gov/data/catalog/sedac-ciesin-sedac-uspat-guppd-v1-1.00. Appendix 2 lists all 112 cities in decreasing order of their population.

A1.1 Climate data and analysis

To investigate frequency, magnitude, and trends in wetting and drying, we calculated a metric called SPEI (Standardised Precipitation-Evapotranspiration Index[15] at 0.1° resolution (~10 km at the equator) over each of the cities. SPEI accounts for both changes in rainfall supply (i.e., precipitation, P) and evaporative demand (i.e., potential evapotranspiration, PET), which are the key atmospheric components of the water balance.

P is the key input of water to land from the atmosphere and PET is the key measure of water loss back to the atmosphere. The difference between them (P-PET) quantifies the moisture surplus/deficit. This difference metric is aggregated (summed) over the previous 12 months, but it is computed for every month of every year in the time series. For example, SPEI for October 2024 is computed by summing the P-PET values for each month over the period November 2023 to October 2024.

If these surpluses and deficits are large enough, they can be interpreted as the conditions that generate floods (surplus) and droughts (deficits). Thus, we refer to SPEI in this study as a wet/dry index. SPEI is scaled using a log-logistic distribution to obtain values anywhere on a scale from -3 to 3, where values larger than ±0.5 indicate significantly wet or dry periods and values larger than ±1.5 indicate extremely wet or dry periods (Figure 2).

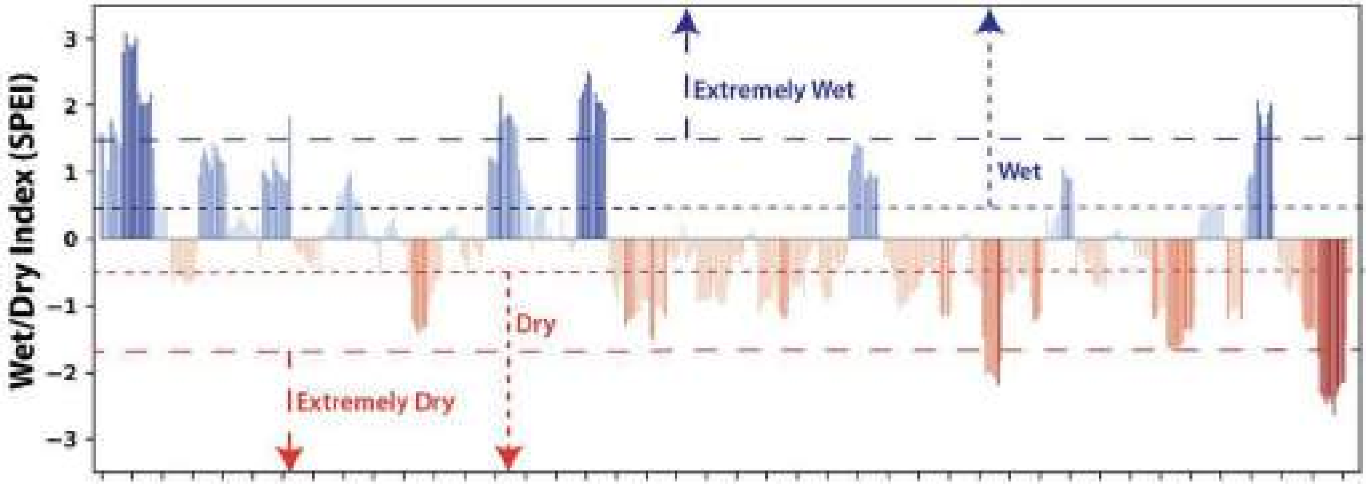


Figure A1. Explanation of our classification for Wet/Dry, Extremely Wet/Dry months based on SPEI.

To calculate SPEI at high spatial resolution, based on the original method (https://journals.ametsoc.org/view/journals/hydr/11/4/2010jhm1224_1.xml), we use monthly total rainfall estimates from:

i. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), a gridded rainfall dataset[16] and

ii. Hourly Potential Evapotranspiration (hPET), produced by our team and published in *Scientific Data,* an hourly global gridded potential evapotranspiration (PET) dataset based on the FAO-56 Penman-Monteith method[17]

The data period used for this analysis is 1982 – 2023 (42 years).

i. Monthly precipitation (P) data from CHIRPS[16] was downloaded from (https://data.chc.ucsb.edu/products/CHIRPS-2.0/africa_monthly/tifs/) processed to 0.1° spatial resolution.

ii. For cities located above 60°N we used EOBS[18] downloaded from (https://www.ecad.eu/download/ensembles/download.php) processed to 0.1° spatial resolution.

Monthly potential evapotranspiration (PET) data was processed by aggregating values from the hPET[17] data repository (https://data.bris.ac.uk/data/dataset/qb8ujazzda0s2aykkv0oq0ctp).

A1.2 Metrics of climate hazard change

Once we generated the monthly SPEI time series for each city over the 42-year period of study, we analysed the data in several ways. First, we calculated long-term trends in monthly SPEI over the entire 42-year period using the Theil-Sen slope estimator, a non-parametric method for robustly fitting a line to sample points by choosing the median of the slopes of all lines through pairs of points[19]. Slopes generated from this method may be positive (wetting) or negative (drying).

Second, we split the entire time series into two halves: 1982-2002 and 2003-2023. For each half of this time series, we computed several metrics:

i. Number of significantly wet/dry months

ii. Number of extremely wet/dry months

These metrics enabled us to assess whether the climate for each city over the last 42 years is switching from wet to dry or dry to wet (climate hazard flips) and whether climatic extremes are becoming more frequent (climate hazard intensification) or less frequent (climate hazard abatement).

Climate Hazard Flips (Extremes)

To determine whether a city is experiencing a climate hazard flip in its extremes between the first half and second half of the 42-year time series, we set a threshold that the city's SPEI series must have lost at least 12 extreme months (~5%) and gained at least 12 months (~5%) of the opposite climatic extreme between the first half (1982-2002) and second half (2003-2023) of the time series. For example, a city would be classified as having a climate hazard flip from wet to dry if the last 21 years had 14 fewer extreme wet months and 20 more extreme dry months than the first 21 years. If a city displayed a 9-month reduction in extreme dry months and 15-month increase in wet months, then it would fall below the threshold and would not be classified as exhibiting a climate hazard flip. However, it may still display a wetting trend overall.

Climate Hazard Intensification

A distinct analysis from the climate hazard flip is an investigation of the increase in both wet and dry climatic extremes. We define intensification as an increase in **both** extreme dry and extreme wet months in the period 2003-2023 compared to 1982-2002. We apply a minimum threshold of 5 months' increase in each of the extremes.

Climate Hazard Abatement

The opposite of climate hazard intensification is climate hazard abatement. We define abatement (reduction) as a decrease in **both** extreme dry and extreme wet months in the period 2003-2023 compared to 1982-2002. We apply a minimum threshold of 5 months' decrease in each of the extremes.

A1.3 Indicators of city vulnerability

Human Development Index as a proxy for social vulnerability

Climate hazards have differential impacts on individuals, households and communities depending on their degree of social vulnerability, defined as susceptibility to harm from a hazard event due to social factors (e.g. poverty or social status). The determinants of social variability can vary substantially according to social, political and cultural context. However, relative poverty is a universal determinant of relative vulnerability[6].

While the HDI has been used for over three decades to assess levels of development across the world, it has traditionally been reported only at national or sectoral (rural/urban) scales. Here, we use a novel geospatial dataset that allows use to measure HDI at the city scale. We use city-level Human Development Index (HDI) estimates from the GHSL Urban Centres Database 2025[20] as a proxy for relative vulnerability. These were computed from the Subnational Human Development Database[7]. The HDI is a multidimensional indicator incorporating data on individual income, education and life expectancy, which collectively determine human well-being and capacities. We inverted the values of the initial HDI to obtain a Human Vulnerability Index (HVI). Therefore, high-scoring HDI countries have a low HVI score and vice versa.

Infrastructural vulnerability

The impacts of natural hazards are also shaped by infrastructure quality in cities, particularly water, sanitation and waste systems. We used water and waste infrastructure data from a global dataset published in a leading journal. This dataset compiles geospatial information on critical infrastructure (CI) systems into a unified database and introduces the Critical Infrastructure Spatial Index (CISI) to measure CI intensity. The CISI aggregates high-resolution OpenStreetMap data for 39 CI types across seven systems, standardised into raster formats with resolutions of 0.1°. From this, we used the "Water CI" and "Waste CI" data and combined them into an infrastructure score as the sum of these two variables.

More details can be found on the dataset dashboard: https://cisi-index.appspot.com/, and in the methodology paper[21]. This is a new and novel methodology relying on volunteered geographic information. It has the benefit of offering global, high-resolution coverage, but will have some errors for individual cities due to the underlying data source. Nevertheless, it offers credible inter-city comparisons of relative infrastructure quality. Water system estimates were missing for 8 cities in our dataset (Kabul, Harbin, Hong Kong, Alexandria, Surat, Baghdad, Onitsha, Faisalabad) so estimates were derived from other similar cities.

Appendix 2

List of cities analysed ranked by population. This list includes the top 100 cities globally by population and an additional 12 cities provided by WaterAid (the bottom 12 depicted in red).

Country	City	Region
China	Guangzhou	Eastern and South-Eastern Asia
Indonesia	Jakarta	Eastern and South-Eastern Asia
Japan	Tokyo	Eastern and South-Eastern Asia
India	Delhi [New Delhi]	Central and Southern Asia
Bangladesh	Dhaka	Central and Southern Asia
China	Shanghai	Eastern and South-Eastern Asia
Egypt	Cairo	Northern Africa and Western Asia
Philippines	Quezon City [Manila]	Eastern and South-Eastern Asia
India	Mumbai	Central and Southern Asia
India	Kolkata	Central and Southern Asia
South Korea	Seoul	Eastern and South-Eastern Asia
Pakistan	Karachi	Central and Southern Asia
Brazil	São Paulo	Latin America and the Caribbean
Thailand	Bangkok	Eastern and South-Eastern Asia
China	Beijing	Eastern and South-Eastern Asia
Mexico	Mexico City	Latin America and the Caribbean
United States	New York	Northern America
Russia	Moscow	Europe
United States	Los Angeles	Northern America
Japan	Osaka [Kyoto]	Eastern and South-Eastern Asia
Vietnam	Ho Chi Minh City	Eastern and South-Eastern Asia
Pakistan	Lahore	Central and Southern Asia

India	Bengaluru	Central and Southern Asia
Turkey	Istanbul	Northern Africa and Western Asia
Argentina	Buenos Aires	Latin America and the Caribbean
Iran	Tehran	Central and Southern Asia
Nigeria	Lagos	Sub-Saharan Africa
Democratic Republic of the Congo	Kinshasa	Sub-Saharan Africa
China	Jieyang	Eastern and South-Eastern Asia
China	Suzhou	Eastern and South-Eastern Asia
India	Chennai	Central and Southern Asia
United Kingdom	London	Europe
Angola	Luanda	Sub-Saharan Africa
Colombia	Bogota	Latin America and the Caribbean
Brazil	Rio De Janeiro	Latin America and the Caribbean
Peru	Lima	Latin America and the Caribbean
France	Paris	Europe
Taiwan	New Taipei [Taipei]	Eastern and South-Eastern Asia
India	Hyderabad	Central and Southern Asia
Indonesia	Bandung	Eastern and South-Eastern Asia
Indonesia	Surabaya	Eastern and South-Eastern Asia
Malaysia	Kuala Lumpur	Eastern and South-Eastern Asia
Tanzania	Dar Es Salaam	Sub-Saharan Africa
South Africa	Johannesburg	Sub-Saharan Africa
China	Wuhan	Eastern and South-Eastern Asia
China	Chongqing	Eastern and South-Eastern Asia
Japan	Nagoya	Eastern and South-Eastern Asia
India	Ahmedabad	Central and Southern Asia
Saudi Arabia	Riyadh	Northern Africa and Western Asia
Singapore	Singapore	Eastern and South-Eastern Asia
Egypt	Alexandria	Northern Africa and Western Asia
China	Tianjin	Eastern and South-Eastern Asia

United States	Chicago	Northern America
Iraq	Baghdad	Northern Africa and Western Asia
Ethiopia	Addis Ababa	Sub-Saharan Africa
India	Surat	Central and Southern Asia
China	Chengdu	Eastern and South-Eastern Asia
India	Pune	Central and Southern Asia
China	Nanjing	Eastern and South-Eastern Asia
China	Hangzhou	Eastern and South-Eastern Asia
Jordan	Amman	Northern Africa and Western Asia
Canada	Toronto	Northern America
Chile	Santiago	Latin America and the Caribbean
Sudan	Khartoum	Northern Africa and Western Asia
Côte d'Ivoire	Abidjan	Sub-Saharan Africa
Myanmar	Yangon	Eastern and South-Eastern Asia
Bangladesh	Comilla	Central and Southern Asia
United States	Houston	Northern America
United States	Dallas	Northern America
Kenya	Nairobi	Sub-Saharan Africa
China	Shenyang	Eastern and South-Eastern Asia
Afghanistan	Kabul	Central and Southern Asia
United States	Miami	Northern America
Spain	Madrid	Europe
China	Hong Kong	Eastern and South-Eastern Asia
Pakistan	Faisalabad	Central and Southern Asia
Bangladesh	Chattogram	Central and Southern Asia
China	Hefei	Eastern and South-Eastern Asia
Ghana	Accra	Sub-Saharan Africa
Cameroon	Yaoundé	Sub-Saharan Africa
Vietnam	Hanoi	Eastern and South-Eastern Asia
China	Xi'An	Eastern and South-Eastern Asia

Nigeria	Kano	Sub-Saharan Africa
Indonesia	Yogyakarta	Eastern and South-Eastern Asia
China	Zhengzhou	Eastern and South-Eastern Asia
Ghana	Kumasi	Sub-Saharan Africa
India	Lucknow	Central and Southern Asia
Nigeria	Onitsha	Sub-Saharan Africa
Russia	Saint Petersburg	Europe
United States	San Jose	Northern America
India	Kozhikode	Central and Southern Asia
Mexico	Tijuana	Latin America and the Caribbean
Sri Lanka	Colombo	Central and Southern Asia
Spain	Barcelona	Europe
Dominican Republic	Santo Domingo	Latin America and the Caribbean
China	Harbin	Eastern and South-Eastern Asia
Morocco	Casablanca	Northern Africa and Western Asia
Saudi Arabia	Jeddah	Northern Africa and Western Asia
Indonesia	Medan	Eastern and South-Eastern Asia
Pakistan	Rawalpindi [Islamabad]	Central and Southern Asia
South Africa	Cape Town	Sub-Saharan Africa
Uganda	Kampala	Sub-Saharan Africa
Australia	Sydney	Australia and New Zealand
Australia	Melbourne	Australia and New Zealand
Nepal	Kathmandu	Central and Southern Asia
Germany	Berlin	Europe
Zambia	Lusaka	Sub-Saharan Africa
Mozambique	Maputo	Sub-Saharan Africa
Cambodia	Phnom Penh	Eastern and South-Eastern Asia
Sweden	Stockholm	Europe
Malawi	Lilongwe	Sub-Saharan Africa
Australia	Canberra	Australia and New Zealand

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