Analysis

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Unprecedented droughts are expected to exacerbate urban inequalities in Southern Africa

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Climate change-related drought risks are intensifying in many urban areas, making stakes particularly high in contexts of severe vulnerability. Yet, how social power, differential agency and economic visions will shape societal responses to droughts remains poorly understood. Here, we build a social-environmental scenario of the possible impacts of an unprecedented drought in Maputo, which epitomizes a Southern African city with highly uneven development and differential vulnerability across urban areas. To build the scenario, we draw on theoretical insights from critical social sciences and take Cape Town (2015–2017) as a case-in-point of a locally unprecedented drought in Southern Africa. We show that future droughts in Southern Africa will probably polarize urban inequalities, generate localized public health crises and regress progress in water access. Climate policies must address these inequalities and develop equitable water distribution and conservation measures to ensure sustainable and inclusive adaptation to future droughts.

Anthropogenic climate change, deforestation, agriculture, urbanization and large water infrastructures have intensified the severity of recent droughts in several regions, including Brazil[1], California[2], China[3,4], Spain[5] and Southern Africa[6]. These regions are at risk of experiencing future droughts that are locally unprecedented in the historical record—droughts more intense than any previously recorded at that given location. This will be uncharted territory from both a hydroclimatic and societal perspective. Concurrently, the rapid urban growth of the past two decades, much of which has occurred in the Global South, is placing cities under substantial risk of water stress[7]. Today, urban droughts pose a key challenge to the achievement of the United Nations' Sustainable Development Goals[8] and, as stated in a recent Nature Sustainability editorial[9], 'every world city should prepare (for droughts) before it's too late'.

Many cities have been close to experiencing or have experienced a countdown to 'Day Zero'—the day in which a city will be unable to supply water to its residents. Cape Town (South Africa) has recently drawn public attention worldwide, and Chennai (India), São Paulo (Brazil), Istanbul and other cities in Turkey have undergone or are undergoing similar crises[10–12]. However, as noted for Cape Town, it is flawed to attribute drought-related crises to climate change only[13]. A rich geographical scholarship has shown that urban water crises and vulnerability to droughts are socially constructed[11,14–17]. This underscores the urgency of exploring where unprecedented droughts may occur, whether and why they may unevenly impact urban populations and how social power, differential agency and developmental-economic visions might influence future water crises and societal responses. Our primary focus is on Southern African cities, where the use of scientific knowledge for decision making in times of crisis is often exogenous and only partly effective[18,19], and water and sanitation infrastructure and services deficits persist since colonial times[20–24]. According to the World Bank, on average only 60% of the urban population in the region

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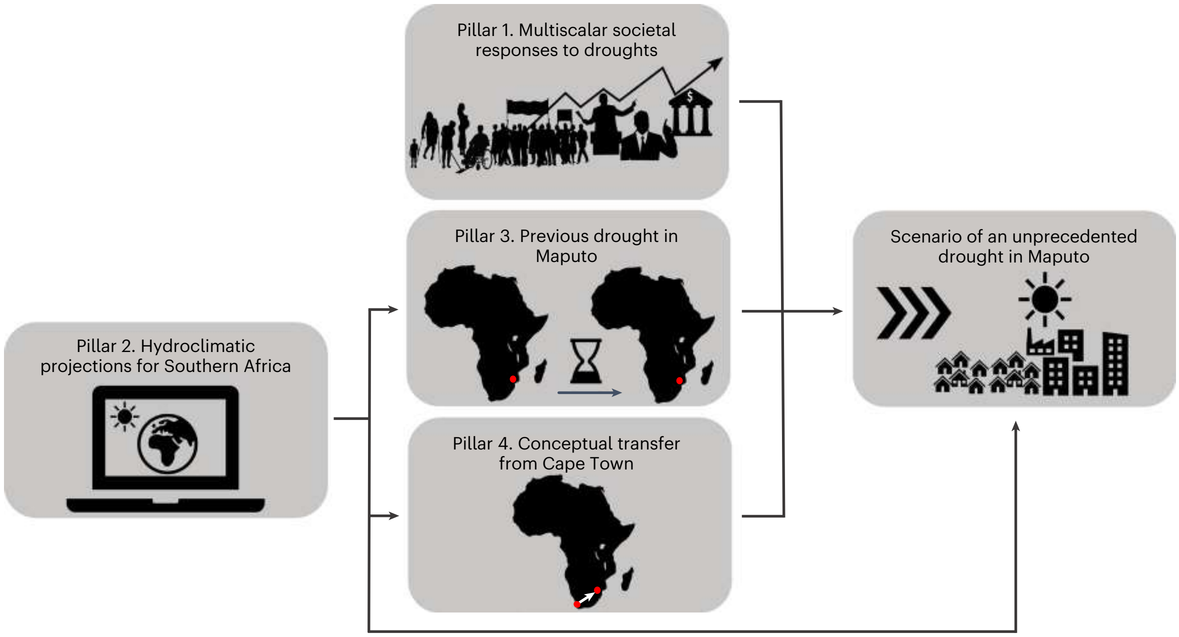

Fig. 1 | Schematic of the SEEA for urban droughts. The approach rests on a synergy of literature-based projections of drought conditions in Southern Africa, critical social science theoretical perspectives on societal responses to drought events and effective use of empirical data from past drought events in Maputo, Mozambique (2016–2018) and Cape Town, South Africa (2015–2017).

is connected to a centralized water supply network[25]. Moreover, recent research has exposed differentiated levels of water (in)security also among residents connected to the centralized network[26–29].

Here we develop a scenario of societal responses to unprecedented droughts in Maputo, Mozambique, as a case-in-point of the threat that urban droughts pose to water security in Southern African cities. Scenario-based analyses of future climates are generally not informed by social sciences[30–33] and tend to perpetuate a reductionist and apolitical conceptualization of societal responses to hydroclimatic extremes. This prevents a comprehensive understanding of the complex historical and socio-political dynamics underpinning drought vulnerability and water crises[34,35]. To address this major scientific gap, we implement the novel social-environmental extremes scenario approach (SEEA)[35], which synergistically combines four research pillars: theoretical insights from critical social sciences (Pillar 1), climate projections (Pillar 2), and empirical analyses of how power, variability in the exercise of agency, and economic and policy visions shape differentiated vulnerability to and recovery from drought events (Pillars 3 and 4; Methods).

In the following sections, we tailor the four SEEA pillars to study drought-related water crises in Maputo (Fig. 1), which epitomizes a Southern African city with highly uneven development and differential vulnerability. Pillar 1 combines a narrative literature review and a meta-synthesis to generate integrated theoretical explanations of multiscalar societal responses to urban droughts. Pillar 2 uses historical hydroclimatic data and regional numerical climate projections to develop a plausible scenario of a future unprecedented drought in Maputo. Pillars 3 and 4 present fine-grained historically contingent empirical analyses of the 2016–2018 drought in Maputo and the 2015–2017 drought in Cape Town. Cape Town was chosen to support the understanding of impacts of an unprecedented drought in Maputo for two reasons. First, analogies may be drawn between the two cities' historical trajectories, urban forms and socioeconomic characteristics, which in turn shape their drought vulnerability profiles (Methods). Second, Cape Town experienced a drought that is larger in magnitude than any experienced in Maputo in recent history (Extended Data Fig. 1). Thus, the analysis from Cape Town is instrumental in enabling us to build our scenario for Maputo, since relying solely on past observations in Maputo is unlikely to capture the implications of a future unprecedented drought there. We then integrate the four pillars into a scenario of unprecedented drought events in Maputo. The aim is not to generate a high-confidence forecast, but rather to identify major criticalities from a sustainability and social justice perspective.

Pillar 1. Drought vulnerability is socially produced

To understand multiscalar societal responses to drought events in urban areas, we leverage critical social science theories in the fields of political ecology, environmental justice and critical disaster studies, originating from early geographic work on natural hazards and the social construction of risk. By design, here we examine societal responses to droughts in cities in sub-Saharan Africa and beyond, see Methods and Extended Data Figs. 2 and 3[17,36,37]. Altogether, this scholarship explains drought-related vulnerability through: (1) the intersecting dimensions of inequality that shape vulnerability (household responses and intersectionality); (2) the linking of vulnerability to broader patterns of uneven development (production of water scarcity); and (3) the potential for changes in the social contract and in development trajectories, triggered by a drought-related crisis (transformative potential). Table 1 provides a synthetic overview of the theoretical explanations emerging from our synthesis.

Pillar 2. An unprecedented drought in Maputo is plausible

Mozambique has experienced several droughts in recent decades, in the context of repeated drought conditions in Southern Africa[18,38]. This has been especially notable in the central and southern parts of the country[39]. Such drought events have occurred on the background of a multi-decadal trend towards decreased precipitation and enhanced drought conditions[40]. Focusing on the Southern part of Mozambique where Maputo is located, the latest generation of global climate models points to a future aggravation of the regional risk of extreme drought conditions. Under a high emissions scenario, the Maputo region is expected to experience an increased risk of precipitation deficit (meteorological drought) and surface drying (agricultural drought) by the end of the century. Specifically, models point to the end-of-century likelihood of

Table 1 | Summary of findings of the theoretical synthesis

	Theoretical explanations	Authors
Household responses and intersectionality	Vulnerability mediates the impacts of the drought on different social groups and individuals	All
	Vulnerability differs across intra-urban spaces, identities (e.g. gender, race), and income groups	64–68
	Vulnerability is tied to the levels of water (in)security experienced before the event	65,69–71
	Water (in)security is also experienced by residents connected to the centralized water supply network	26,28,67,72–75
	Water restrictions targeting urban vegetable gardens exacerbate food insecurity	76–78
	Water restrictions and increrased food insecurity have a cascading effect on health and safety inequalties	5–17
	Water shortages have a cascading effect on gender inequalities	65–68
	Water rationing and demand management measures exacerbate inequalities in access to water	11,27,70,79,80
	Theoretical explanations	**Authors**
Social production of water scarcity	Droughts are generated by combined physical and human-produced water scarcity	69,81,82
	Uneven, exclusionary development trajectories determine unequal impacts of the drought	71,81–85
	Water infrastructures are key in generating water (in)security and in exacerbating the impacts of extreme events	11,70,73,74,84,86
	Colonial segregation, racial capitalism, patriarchy shape uneven drought impacts	15,87–89
	Water (in)security is generated by investment priorities, housing policies, market-based water pricing regimes	71,84,87,90
	Development-oriented interests, politicians and water providers might profit or politically benefit from droughts	67,70,91,92
	Development lending to finance water infrastructures lead to utility and user indebtedness	93,94
	Market-based reforms have increased vulnerability to droughts	95
	Water (in)security is also generated by overconsumption of water by elite users	69,84,96,97
	Theoretical explanations	**Authors**
Transformative potential	Droughts are framed as a natural and unpredictable, deflecting attention from political responsibility	70,91
	Framing nature as the problem generates consent for unlimited infrastructure development and consumption	86,91,95
	Demand management measures can pave the way to managerial approaches and privatization of water utilities	70,86
	Drought generates new coalitions and trigger multiple moral claims on water beyond its economic value	71,96,98
	Droughts intensify protests against the privatization and bottled water	99
	Powerful and affluent residents often contest and do not comply with water restrictions	86,97,100
	Social pressure is exerted on overconsuming users to reduce their use during droughts	101,102

The table outlines the main theoretical findings on (1) household responses and intersectionality, (2) social production of water scarcity and (3) transformative potential of drought. The geographical focus of the theoretical synthesis is broader in scope than the other pillars. Following recent advances in comparative urbanism, we take a global analytical approach to develop theoretical explanations of societal responses to urban droughts (Methods).

an extreme single-year meteorological or agricultural drought during the wet season in excess of 15% (ref. 41). An even higher likelihood is projected for the wet season[41]. Regional climate simulations using precipitation and evapotranspiration to jointly diagnose drought (standardized precipitation evapotranspiration index (SPEI)) support these conclusions. They specifically point to robust increases in extreme one-year drought frequency in Maputo under moderate-to-high emission scenarios[42]. There are large uncertainties in future hydroclimate projections, and results can depend on the chosen drought definition and climate scenario[43] (Methods). Moreover, climate models do not consider socio-historical, institutional and ecological dimensions which may modulate local drought occurrences. Nonetheless, both past climate trends and numerical projections under moderate-to-high emission scenarios show increased likelihoods of extreme one-year droughts, and thus support the possibility that Southern Mozambique may be affected by a future unprecedented drought. On the basis of the above, we argue for the relevance of an unprecedented drought scenario in Maputo.

Pillar 3. Uneven drought outcomes in Maputo

The recent drought in Maputo (2016–2018) epitomizes the nexus between race, class, gender, variegated citizenship and differential vulnerability (see also Supplementary Information, Extended Case study: Maputo). In conjunction with a prolonged period of low precipitation in the Pequeno Limbobos basin, which feeds the main water reservoir serving Maputo, the water utility introduced rationing measures (2017–2020). This drought period occurred in the context of a multi-decadal decrease in precipitation in the region (Pillar 2). Water shortages were longer and more frequent in low-income neighbourhoods than in the more affluent areas of the city. Moreover, higher-income dwellers could afford storage facilities between 500 and 1,500 litres to cope with the rationing measures, while lower-income residents used 250 litre to 1.5 litre containers. This exacerbated health, wellbeing and gender inequalities across the city. Women in low-income neighbourhoods faced higher physical and psychological stress, increased risks of violence and loss of income due to having to find alternative water sources. Moreover, low-income neighbourhoods suffered from a cholera outbreak, also causing the stigmatization of those affected[44]. Here, water rationing, exposure to flash floods due to the lack of a drainage system, poor sanitation and shallow-laid water pipes, combined with the practice of informally tapping into the network to cope with shortages, exponentially increased risks of water contamination.

These uneven levels of drought vulnerability are socially produced and must be understood in relation to Maputo's form, shaped by colonial segregation, racial capitalism and neoliberal reforms. Since colonial times, investment priorities, planning and housing policies and selective water infrastructure developments have systematically prioritized urban elites, thereby generating a spatially segregated city, stark income inequalities and, in turn, water secure and water-insecure spaces[45–49] (Fig. 2). High levels of non-revenue water (close to 50%) and

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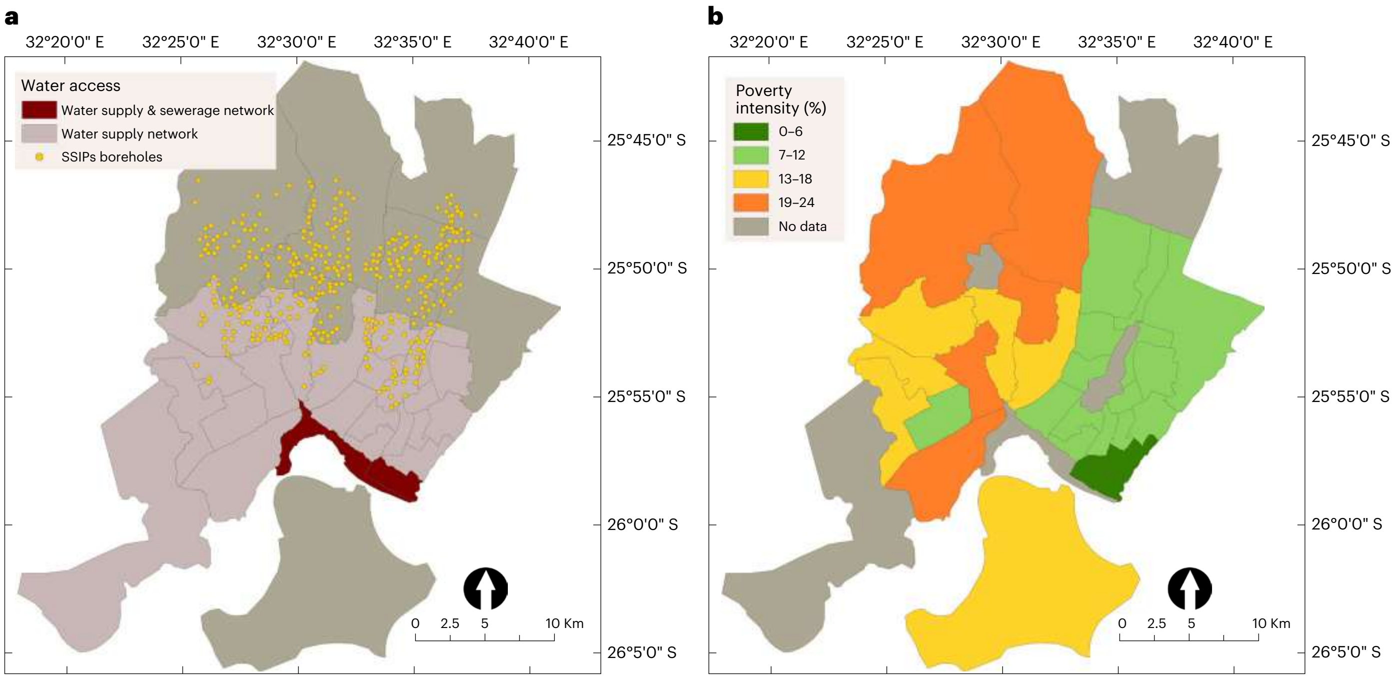

Fig. 2 | Uneven water supply and sewerage networks in Greater Maputo. a, Map displaying areas served by the public and centralized water supply and sewerage network (red), areas served by the public centralized water supply network but without access to the sewerage network (light grey) and areas that are not served by public providers (dark grey). The water supply network covers approximately 64% of the urban population, while the rest is supplied by SSIPs (yellow circles) who developed decentralized, technologically sophisticated small-scale networks drawing on groundwater resources[103]. Only 9% of the residents is connected to the sewerage system, and the rest relies on pour-flush toilets with septic tanks (49%) and unimproved or improved pit latrines[104]. **b**, Map displaying poverty intensity of neighbourhoods in Greater Maputo[105]. Together, the maps show how neighbourhoods with higher poverty intensity suffer greater infrastructure deficits.

recent network expansions have further reduced water availability, and thus continuity in peripheries[50]. Lastly, a unique feature of the city is the presence of over 800 small-scale water providers (SSIPs), primarily catering to middle-class customers and serving approximately 34% of the peri-urban population (Fig. 2). As their networks rely on groundwater, they ensure continuity of supply also during drought. Some capitalize on drought by expanding their market to areas underserved by the water utility. This, however, generated tensions with the water utility over water resources control and increased the vulnerability of the aquifer.

The government's response to the drought perpetuated the notion of unavoidability of water shortages and the idea that the drought affected all residents equally. Rather than enforcing conservation and water (re)distribution measures, the government largely focused on augmenting supplies. This strategy was enabled by discursively framing the drought as natural, and boreholes and large dams as unavoidable solutions. Given the financial requirements tied to this strategy, the government promoted a greater role for the private sector in water service provision[51]. Although the implementation of this strategy was slowed down by the country's hidden debt scandal[52], this approach denotes how droughts are mobilized to promote supply-driven strategies and how they can become a profit-seeking enterprise for development-oriented interests.

Pillar 4. Uneven drought outcomes in Cape Town

The 2015–2017 drought plunged Cape Town into an unprecedented water crisis. The demand management measures adopted by the municipality to stop the countdown to 'Day Zero' mostly affected townships and working-class households (see also Supplementary Information – Extended Case Study: Cape Town). White affluent and middle-income households consuming up to 8,500 litres per inhabitant per day (average values are 250–300 litres per inhabitant per day) had to suspend water-intense activities (car washing, filling swimming pools, watering lawns, bathing). Yet, they could rely on additional water by either stocking hectolitres of bottled water in their homes or developing private water systems, such as rainwater harvesting tanks and boreholes. Thus, much of the reduction of the City's demand from 1,000 to 500 million litres (ML) per day was due to elite consumers going off the grid[53]. Conversely, township and working-class households experienced severe water shortages due to tariff increases, overconsumption fines, the partial withdrawal of the free basic service and metering devices halting water supply at 350 litres per unit per day. These measures further contracted an already limited water availability, especially for high-density households[54,55]. Moreover, the restrictions prevented watering of vegetable gardens, an essential source of livelihood and food security for many indigent families.

These uneven outcomes are tied to the city's exclusionary colonial and apartheid regimes, which determined capital investment priorities in water infrastructures and beyond. Despite post-apartheid attempts to revert racial segregation and stark economic inequalities, policies promoting growth through capital accumulation, reproduced uneven access to resources and services[56–58]. Thus, water inequalities and highly uneven consumption levels across the city persist, reinforced by the commercialization of water services (1997–2001)[29]. In the aftermath of the drought, these inequalities polarized. Low-income households are still enduring a water crisis as some of the restrictions introduced during the drought have been made permanent. In contrast, higher-income residents enhanced their resilience to future droughts by investing in alternative water sources.

Despite recognizing the need to protect the most vulnerable[59], the post-crisis roadmap centred on fast-tracking alternative sources to increase supply by 300 ML per day in 10 years[59,60]. This narrow focus risks perpetuating the vicious cycle of incremental water use by Capetonian elites that increased the city's vulnerability to droughts in the

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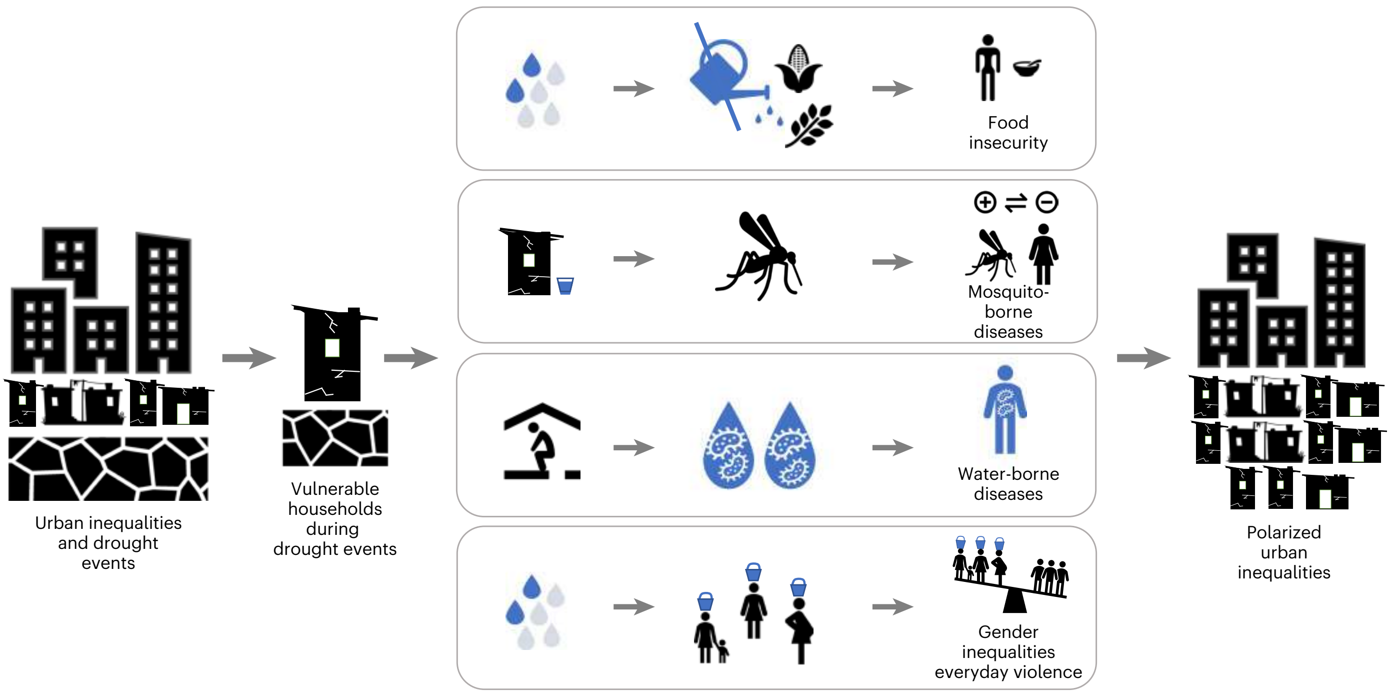

Fig. 3 | Cascading effects of water shortages on other urban inequalities. Acute water shortages, which will mostly affect residents in low-income areas, generate or exacerbate food insecurity, mosquito-borne and waterborne diseases, as well as gender inequalities.

first place[55]. Between September 2018 and March 2020, water demand has increased from about 500 ML to 800 ML, underscoring the risk of a return to pre-drought consumption levels[61]. Concurrently, the drought triggered demands for change from civil society groups invoking more sustainable and equitable water use. Protests against water tariffs increases and restrictions were tied to wider political stands against commodification of water and claims of citizenship[54,62]. Moreover, campaigns reframed around water conservation gained momentum, and succeeded in protecting farming land from rezoning and the Cape Flats Aquifer from being exploited[63], and in reclaiming water springs from South African Breweries[54].

Unprecedented droughts may polarize inequalities in Maputo

An unprecedented drought in Maputo will probably come in the form of reduced precipitation and/or soil moisture (Pillar 2). The rationing measures could significantly polarize inequalities in water access, since chronically water-insecure households will probably be disproportionately affected, with a cascading effect on other urban inequalities (Pillar 3, Fig. 3). Drought management measures could additionally include tariff increments, as occurred in Cape Town and elsewhere (Pillars 1 and 4, Table 1), further limiting access for low-income residents. From Pillars 1 and 3 (Table 1), we note that women will probably be burdened with the task of finding alternative water sources, with multifarious consequences on employment, income, mental wellbeing and physical safety. As a result, practices of informally tapping into the water supply network to access water are likely to proliferate (Pillar 3). This will probably contribute to an increase in waterborne diseases and public health crises, largely concentrated in low-income areas. Moreover, reliance on uncovered water storage facilities located near humans might increase risks of mosquito breeding and vector-borne diseases such as dengue and malaria (Pillar 1). From Pillars 1 and 4, we also infer that an unprecedented drought might exacerbate food insecurity due to both inflated food prices and the impact of water rationing measures on vegetable urban gardens. The latter are an essential livelihood strategy for some lower-income residents and their need for irrigation will also be exacerbated by the dry soils and lack of precipitation (Pillar 2). This is expected to increase residents', particularly women's, vulnerability to widely spread diseases, including human immunodeficiency virus (HIV) (Pillar 1).

An unprecedented drought will probably unleash institutional change and investment opportunities. However, a synergistic application of Pillars 1, 3 and 4 suggest that if systemic inequalities are overlooked, future reforms will increase differential vulnerability and perpetuate unsustainable consumption patterns. In the aftermath of the drought, emergency measures such as tariff increases could be maintained. This will probably strengthen the financial sustainability of water utilities while rendering low-consuming residents chronically water-insecure. Concurrently, the government will probably frame the drought as natural and unpredictable to deflect attention from political responsibilities, and to generate consensus for large-scale infrastructure development that will most probably lead to increased water demand.

The infrastructure development will largely depend on foreign capital inflow to Mozambique. We consider both the possibility that the government is unable to access global capital and the possibility of large capital inflows. In the first case, on the basis of Pillar 3, we predict that pressure to manage a limited supply while increasing coverage will further reduce continuity of supply. Technical specification of the network will continue to allow higher-income neighbourhoods to access most of the water, while the rest will suffer from increasing shortages. Pillars 3 and 4 suggest that this will generate different forms of 'going off the grid'. Those with access to land and financial resources will develop alternative water sources or connect to SSIPs, thereby increasing their resilience to droughts. SSIPs will probably expand coverage and unsustainably increase the use of groundwater, while lower-income residents will revert to communal water points, water resale, private boreholes or unimproved water sources, thereby increasing their vulnerability to droughts. In the case of access to global capital, the government will implement the 10-year Capital Investment Program aimed at enhancing coping capacity by developing large infrastructures. Paradoxically, augmenting water supply could increase Maputo's vulnerability to future droughts if issues of equity, distribution and sustainability continue to be overlooked. Incremental infrastructures might generate a false sense of security and a return to 'business as usual' in water resources management, as seen in Cape Town (Pillar 4). Over-allocation to and overconsumption of water by elites could lead to a vicious cycle of increased water stress and reactive responses by the government. Moreover, Pillar 1 suggests that incremental infrastructure development can exacerbate inequalities in water access. While benefitting for-profit development interests, development lending for capital-intensive water infrastructures will indebt the water utility. Cost recovery mechanisms, often combined with pre-paid metres and service disconnections for non-paying users, will probably be introduced as a mechanism for debt repayment. This, in turn, will have highly uneven impacts on Maputo's urban population, with cascading effects for lower-income residents (Fig. 3).

Sustainable and inclusive adaptation to droughts

In a rapidly changing world, what today are unprecedented urban droughts may become the norm in many cities. We build a scenario that seeks to identify critical aspects of responses to future drought events in Maputo. While some aspects of the scenario are largely specific to Maputo, others are relevant to future droughts in other cities in Southern Africa and beyond. We specifically argue that measures narrowly focused on structural and physical responses address the symptoms of drought outcomes, rather than the underlying causes. Disregarding sustainability issues and differential levels of water insecurity across urban spaces will inevitably lead to increased urban inequalities and vulnerability to future droughts.

As we show with our scenario, the physical dimension of drought alone does not explain the drought's fundamentally uneven outcomes. Recognizing and accounting for the role of social power and variability in the exercise of agency underpinning the production and distribution of drought risk is essential to advance our understanding of future societal responses to unprecedented events. We note four significant contributions of critical social sciences to further understandings of drought outcomes in cities. First, by drawing attention to processes of racial segregation, exclusionary development trajectories, selective investment priorities serving the interests of urban elites and gendered processes of social differentiation, critical social sciences reveal how differential vulnerability to droughts is produced. Second, this scholarship reconceptualizes infrastructure as more than a technological artefact. Infrastructure design and water circulation in the city is shaped by multiscalar power relations which in turn mediate the impacts of extreme events and determine what a drought, or Day Zero, means for different citizens. Third, a focus on uneven levels of water consumption across the city (rather than on averaged city consumption) discloses the disproportionate role of elites in exacerbating the impacts of unprecedented droughts. Lastly, critical social sciences reject interpretations of droughts as natural and unpredictable, and refocus attention on political responsibilities. Only by accounting for these dimensions, as we do here, is it possible to unravel future outcomes of urban droughts and provide actionable insights.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-022-01546-8.

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Methods

This study develops a scenario of unprecedented drought for the city of Maputo. We implement the novel SEEA framework, which bridges natural and critical social sciences to integrate different forms of knowledge into a comprehensive social-environmental scenario[35].

Integrated scenarios crossing natural and social sciences are increasingly invoked in climate and global environmental change research[31,106–108]. However, scenarios continue to be largely based on natural science methods and on a simplified understanding of societal processes[31,107,108]. The challenge of working across different conceptual and methodological approaches all too often constrains collaborative engagements between natural and social scientists[108,109]. This is especially the case for critical social sciences, which are generally at the margins of disciplinary bridging collaborations. Barriers include the perceived methodological and epistemological incompatibility between natural sciences, often grounded in numerical, quantitative approaches, and critical social sciences grounded in qualitative methods. A second major challenge concerns bridging different spatiotemporal scales. Climate projections are routinely based on shared socioeconomic pathways that, being global in nature, cannot account for detailed local to regional socio-political developments. These projections are also not designed to represent specific extreme events. In contrast, critical social sciences largely focus on specific events and work at smaller scales that are relevant from a vulnerability perspective[110]. Capturing contextual socio-political factors underlying the construction of disasters and of differentiated vulnerability requires analyses of nested experiences and responses of households, neighbourhoods, city agencies and national governments over time. Finally, there is an unbridged divide between the critical social sciences which adopt a retrospective approach, and the natural sciences which routinely consider future projections.

The SEEA is designed to leverage the insights provided by both the natural and critical social sciences while accounting for methodological and epistemological differences[35]. It combines analyses of past societal responses to climatic events with future climate projections to provide an impact-focused understanding of specific events and geographical areas. The approach builds on four Pillars, which we discuss in detail below.

Pillar 1. Theoretical synthesis: multiscalar societal responses to urban droughts

The theoretical synthesis reviews existing literature on multiscalar societal responses to urban droughts and water (in)security to apprehend plausible societal responses to future unprecedented events. It combines a narrative literature review and a meta-synthesis[111,112]. The narrative analysis brings together insights from political ecology, environmental justice and critical disaster studies. These critical lines draw on a rich geographical tradition in natural hazards and originated with the seminal contribution of Gilbert White and colleagues in the 1940s[36,37]. This work, which conceptualized hazards as generated by natural and social processes, has been brought forward by critical geographers focusing on the political economy of vulnerability. In the 1980s, the path-breaking work of Hewitt[17] unravelled the socioeconomic conditions that made some people more vulnerable than others. More recently, this line of inquiry has coalesced in work in political ecology, environmental justice and critical disaster studies on droughts and other hazards. Concurrently, White and colleagues[113] have advanced understandings of the ambiguous role of technology in exacerbating/mitigating the impacts of natural hazards. While their work focused on floodplains, the notion that infrastructures could paradoxically increase risks of natural hazards has also become prominent in drought-related research (Table 1).

The meta-analysis identified key themes and theoretical similarities, which were systematically developed into new, integrated theoretical explanations (Table 1). To reflect the multiscalar nature of our scenario, the narrative literature review and the meta-synthesis focused on three interrelated scales: (1) household responses to examine how intersecting dimensions of inequality shape variability in the exercise of agency and, thus, vulnerability to droughts[114–116]; (2) uneven urban development to explore the relation between wider development processes and the production of differentiated vulnerability to droughts[17,117,118]; (3) state-society relations to gain insights on the potential of a disaster to generate 'deliberate transformations' of the social contract, including changes in governments' roles and responsibilities as the nature of risk and vulnerability evolves[119–121].

By design, the geographical focus of the theoretical synthesis is broader in scope than the other Pillars. Attending to calls of urban scholars for a more cosmopolitan approach to comparative urbanism[122,123], in this study we examine societal responses to droughts in cities in sub-Saharan Africa and beyond (Extended Data Figs. 2 and 3). We conceptualize all cities as ordinary[123] and place them 'on a level analytical plain'[124] to develop a set of global theoretical explanations[124] that identify comparable processes, common grounds and the diversity of all cities. As urban scholarship has shown, African cities share several similarities along historical trajectories, urban form, as well as the nature, scale and distribution of hydroclimatic risk and vulnerability[124–129]. It is also widely recognized that the political economy of colonialism, grounded on the attempt to entirely re-structure and transform social, political and economic relations, played a crucial role in shaping contemporary African cities[22,129,130]. Concurrently, urban scholars increasingly argue that the legacy of dividing and understanding cities as North/South or developed/developing has prevented comparative possibilities beyond these constructed divides[22,123,131].

We thus move away from comparative analyses exclusively grounded on particularities of African urbanism[122–124,132] and examine a multitude of urban experiences to capture both the distinctiveness of African cities and patterns that are common across different geographical contexts. To illustrate, we found that vulnerabilities generated by heterogenous water infrastructure are significantly more common in cities in sub-Saharan Africa and in the global South more broadly. In contrast, the relation between demand management measures and consumption patterns across socioeconomic groups stands across different geographical contexts: tariff increases and water rationing measures have shown to modify the consumption patterns of lower-income residents the most, with severe consequences on water security. Lastly, the framing of drought as natural and unpredictable to deflect attention from political responsibilities is common across cases, while social protests and activism in the aftermath of a drought have proven more frequent in global North cases.

Pillar 2. Literature-based hydroclimatic projections

In Pillar 2, we review the literature on hydroclimatic projections to identify regions that may plausibly experience a future drought, which is locally unprecedented in magnitude. This review needs to give appropriate weight to the robustness of the projections and to the presence or absence of multiple lines of evidence—for example, both numerical climate projections and detectable trends in drought occurrence in recent decades. There are some general challenges not specific to droughts. For example, all climate projections are based on one or more scenarios of future socioeconomic development and/or greenhouse gas emissions, and different scenarios may lead to very different changes in the frequency and magnitude of a given class of events. However, droughts also bring challenges of their own. Crucially, there is no single definition of drought from a physical-environmental perspective. The sources used in our analysis adopt different definitions, generally including some measure of precipitation deficit and optionally additional factors such as estimates of soil moisture deficit or evapotranspiration. Moreover, hydroclimate is a realm where the agreement across different models is comparatively weak at regional scales, especially when it comes to extreme events[133].

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We argue that Southern Africa, and Maputo specifically, is at risk of a future unprecedented drought, relying on both ongoing drying trends[40] and a combination of global and regional projections[41,42]. We nonetheless note that the available evidence only supports the plausibility of a future unprecedented drought striking Maputo under moderate-to-high emission scenarios. We underscore that Pillar 2 neither seeks to make deterministic or probabilistic predictions, nor does it assign weights or probabilities to the different climate models or scenarios. Rather, the pillar develops a qualitative evaluation without any associated probability (see Main text).

Pillars 3 and 4. Empirical analyses of precedent drought events in urban context

Pillars 3 and 4 consist of fine-grained, historically contingent empirical analyses of how power, variability in the exercise of agency, economic and policy visions shape differentiated vulnerability to and recovery from past drought events for the city on which the scenario is developed (Maputo, Pillar 3), and for a location affected by a drought that is larger in magnitude than any drought experienced at the location of interest in recent history (Cape Town, Pillar 4).

Selection of the case studies. Maputo and Cape Town were chosen as instrumental case studies because both cities were recently affected by a drought and provide a case-in-point of the threat that urban droughts pose to water security in cities in sub-Saharan Africa. For evaluating the 2016–18 drought in Maputo and the 2015–17 drought in Cape Town, we have combined data on the filling levels of the water reservoirs of the two cities with SPEI data from SPEIbase[134]. This analysis and the associated visualization were implemented in MatLab R2018b. The SPEI is a drought index that considers a climatic water balance including the effects of temperature and evapotranspiration at multiple temporal scales. This index was specifically designed to explore the impacts of global warming on drought. We used the SPEI gridpoint closest to the cities of Maputo and Cape Town. The most recent drought episode in Maputo peaked in 2016–2017 (thin red line in Extended Data Fig. 1). Cape Town has recently experienced a drought of greater magnitude than any drought in Maputo in recent history, which peaked in 2018 (thin blue line in Extended Data Fig. 1). This matches the period when the water reservoirs were at their lowest (thick blue line), and when the most severe water restrictions were implemented (January to October 2018). Our approach has a major caveat in that remote precipitation may affect the water resources of the two cities through rivers feeding into reservoirs, and water consumption patterns may also play a large role in reservoir levels. For example, a short recovery of the SPEI value in Maputo to wet conditions during 2017 was not followed by a corresponding increase in reservoir levels, plausibly because adjacent regions to the south and west of Maputo continued to have negative SPEI values (not shown). Nonetheless, we note that the drought periods evidenced by the SPEI index broadly reflect the periods of reported water shortage in the two cities.

Maputo and Cape Town are also comparable in size, complexity, historical legacy, social characteristics and urban form. The population of Greater Maputo has reached almost 2 million[135] and that of Cape Town metropolitan area totals approximately 4.4 million[136]. Both cities were established during colonial times. Today, the urban fabric of Maputo and Cape Town is still marked by stark socioeconomic inequalities and segregated spatial orders, inherited from colonial and postcolonial regimes and more recent neoliberal reforms in the water sector and beyond[47,137,138] (see Supplementary Information, Extended case study: Maputo and Extended case study: Cape Town). In both cities, a large fraction of the population lives below the poverty line, although the relative prevalence of poverty in Cape Town is noticeably higher than in Maputo. According to the World Bank[139], 12% of the population in Maputo lives below the poverty line (US$1.9 per person per day), and spatial patterns reveal higher levels of poverty and infrastructure deficits in peripheral areas further away from the city centre[105]. In these areas, a large majority of the settlements is informal or unplanned[140]. In Cape Town, about 45% of the population is considered to be below the poverty line and 21% of the population lives in shacks or informal settlements[136]. Cape Town is also characterized by a markedly segregated geography, with world class services and privileged areas in the western edge of the city and substandard services, unsafe and decaying spaces on the eastern edge[58]. In both cities, the juxtaposition of informal settlements, townships and sheltered gated communities reflects historical legacies and current developments[57,138]. This is also visible in differential levels of water (in)security across urban spaces. Maputo has an unevenly developed water supply system[44,46,47]. Access to water in Cape Town is also marked by extremely unequal levels of water access and patterns of consumption[55,141].

Data collection methods. Data collection to support the conclusions drawn in Pillars 3 and 4 was undertaken through several qualitative and quantitative methods. In Maputo, qualitative data were collected through archival research on colonial Maputo at the Sociedade de Geografia de Lisboa, Arquivo Histórico Ultramarino and Arquivo Histórico de Moçambique; 65 semi-structured interviews undertaken between November 2013 and February 2014, November and December 2016, and August and November 2017; a videography project undertaken in July–August 2017; and follow up interviews in May–August 2021. Interviews were held with national and local public health and water sector organizations, municipal authorities, consultants, water providers (AdeM and SSIPs) and the national water regulator (Conselho de Regulação do Abastecimento de Água - CRA), as well as with residents in high- and low-income areas, and municipal and district authorities. A drinking water quality sampling campaign was carried out between December 2016 and September 2017 to examine water quality across high- and low-income neighbourhoods and related risks of waterborne diseases. These data were triangulated with a documentary analysis of drinking water and sanitation policies. In Cape Town, qualitative data were collected between May 2019 and March 2020 through 65 semi-structured interviews and 5 focus group discussions with households, and governmental and non-governmental water sector organizations. Data were triangulated with media outlets and reports. Interviews were combined with data collected through a documentary analysis and a literature review. Quantitative data including time series of rainfall, reservoir storage, population and daily water consumption were retrieved from the City of Cape Town Data portal.

The interviews with water sector and public health organizations, local and regional authorities, consultants and non-governmental organizations focused on the water supply systems in Maputo and Cape Town, including (1) the technical specifications, operation and management of the water infrastructure; (2) governance of water service delivery; (3) the governments' short- and long-term responses to the drought; and (4) their perceptions of water (in)security across urban spaces before and after the drought. In Cape Town, the focus group discussions aimed at capturing the shared experiences of residents of different neighbourhoods during and in the aftermath of the drought. To this end, female and male participants were selected and grouped on the basis of their socioeconomic characteristics and the location of their household (informal areas, townships and higher-income areas). In Maputo, the videography project investigated everyday experiences of water (in)security and coping strategies at the margins of the water supply network, and the role of urban development and water infrastructures in generating uneven outcomes of the water crisis. Therefore, videography involved both residents at the margins of the network and water sector organizations in Maputo. Lastly, semi-structured interviews with residents in Maputo and Cape Town largely focused on their experience of the drought, including changes in everyday water practices and coping strategies. Interview participants were selected across diverse socioeconomic groups and neighbourhoods to capture different experiences of the drought across urban spaces.

Integrating the four pillars

The knowledge developed in the four pillars above is synergistically combined into a scenario of unprecedented drought for the city of Maputo (Fig. 1). The scenario is grounded on the integration of spatiotemporal scales of future projections (Pillar 2) with theoretical explanations (Pillar 1) and localized empirical analyses (Pillars 3 and 4) on societal responses to past climate extremes. Climatic projections (Pillar 2) provide the hydroclimatic framework which foregrounds societal responses to a future unprecedented drought. The theoretical synthesis (Pillar 1) serves to identify common patterns of societal responses to droughts across different geographical contexts that might not have emerged yet in the case study areas. We draw on this Pillar to expand the analyses of plausible future responses elicited in Maputo to include systemic patterns and dynamics that emerged elsewhere. Pillar 3 serves to capture context-specific factors, as well as systemic and emerging patterns in Maputo that are likely to play a role in future drought events in the city. The rationale of Pillar 4 is to leverage past observations to infer socio-environmental dynamics under future unprecedented extremes. As a result, Pillar 4 plays out as a conceptual transfer whereby past events in Cape Town may predict future dynamics triggered by an unprecedented drought in Maputo. This is needed as a scenario solely relying on past observations in Maputo is unlikely to capture the implications of a future unprecedented drought there. The plausibility of such an event to occur in Maputo rests on the review conducted in Pillar 2. For the specific case of drought, we also indicated the probable type of drought that would occur (agricultural, hydrological or meteorological). Hydroclimatic projection then co-determines whether and how Pillars 1, 3 and 4 are mobilized and connected. The scenario then generates new knowledge about societal responses to future unprecedented droughts in Maputo beyond what the single Pillars could achieve.

Ethics statement

The research protocol for this study was approved by the Research Ethics Committee of King's College London (LRMR-16/17–2263), the Municipality of Maputo (371–DAS) and Cape Town (PSRR-0259), the Italian Research Ethics and Bioethics Committee (protocol 0043071/2019) and the Swedish Ethical Review Authority (Dnr 2019–03242). All members of the research team followed the guidelines and the protocols set by the European Union under Horizon 2020 (FAIR Data Management and EU General Data Protection Regulation). We obtained informed consent from all participants after duly notifying interviewees about the context and purpose of the interview, expected duration of their participation, funders and lead researchers of the project, data protection/confidentiality/privacy and duration of storage of personal data. Participants were also informed that they were under no obligation to answer any question and that they could withdraw from the interview at any time.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The qualitative data supporting the findings of this Analysis are available within the Analysis and its Supplementary Information (Extended case study: Maputo and Extended case study: Cape Town). Some qualitative data are not publicly available due to ethical restrictions (that is, they contain information that could compromise the anonymity of research participants). These data are available from the corresponding author (maria.rusca@manchester.ac.uk) on reasonable request. Anonymized data will be made available within a month from the request. Data on the filling levels of the water reservoirs of the two cities are available at the City of Cape Town Data portal (https://cip.csag.uct.ac.za/monitoring/bigsix.html), the Direcção Nacional de Gestão de Recursos Hídricos (National Directorate of Water Resources, Mozambique, https://www.dngrh.gov.mz/index.php/publicacoes/boletins-de-bacias-hidrograficas) and the Biblioteca Digital de Teses e Dissertações (Digital Dissertation Repositiry, https://repositorio.bc.ufg.br/tede/handle/tede/10365). The Standardized Precipitation Evapotranspiration Index (SPEI) data can be retrieved from SPEIbase (https://spei.csic.es/).

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Author contributions

M.R. and G.M. conceived and designed the study. M.R., E.S. and A.B. undertook fieldwork in Maputo and Cape Town; M.R., E.S. and G.M. wrote the paper; all authors analysed and interpreted data and G.M., E.S. and M.R. developed the figures. All authors contributed to the revision.

Competing interests

The authors declare no competing interests.

Additional information

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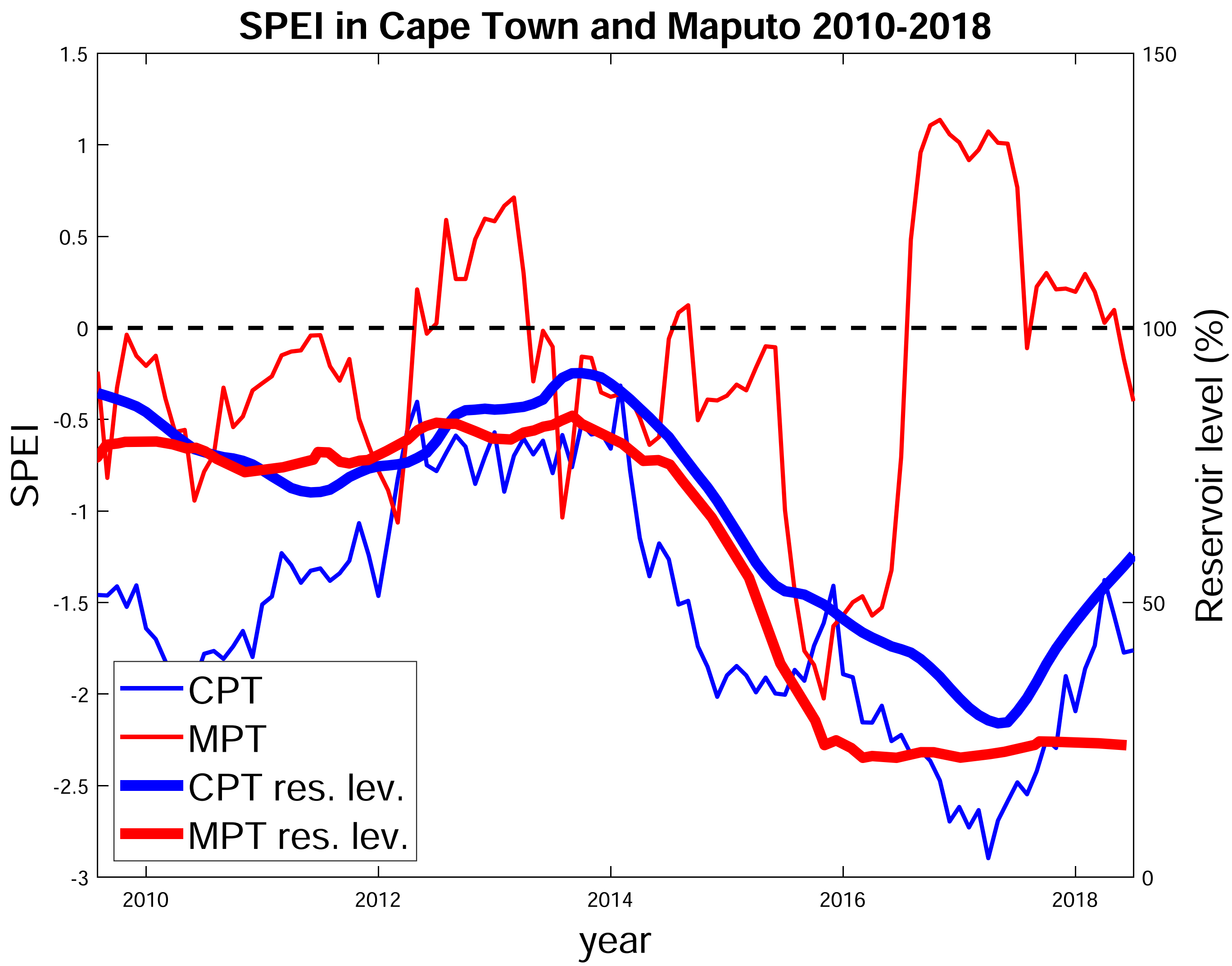

Extended Data Fig. 1 | Twelve-month SPEI index for the cities of Cape Town (blue line) and Maputo (red line). The thick lines show the 13-month running mean of filling levels (%) of the reservoirs supplying Cape Town[61] and Maputo[142]. The labels on the x-axis indicate the center point of each year.

Household Responses and Intersectionality

Phenomena	Locations	Year	Typology	Refs.
Uneven experiences of water (in)security across intra-urban within the centralized water supply network	Bulawayo, Zimbabwe	1982-1992	Drought	78
	Cochabamba, Bolivia	NA	Chronic	68
	Gaborone, Botswana	2015	Drought	143
	Athens, Greece	1989-1993	Drought	70,86
	Barcelona, Spain	1950s and 2007-2008	Drought	144
	Cape Town, South Africa	2015-2017	Drought	54,55,145
	Greater Melbourne, Australia; Greater Perth, Australia	1998-late 2000s	Drought	80
	Greater Maputo, Mozambique	2016-2018	Drought	35
	Delhi, India	NA	Chronic	67
	Northern Brazil - urban areas	2011-2017	Drought	92
	Lilongwe, Malawi	NA	Chronic	72,84
	Dar Es Salaam	NA	Chronic	28
	Mumbai, India	2009	Chronic	89
Hygiene norm violations and stigmatized social identities tied to water (in)security and disease/contagion	Guatemala; Fiji; New Zealand; and United States	NA	Chronic	146
	Lilongwe, Malawi	NA	Chronic	72
Intersectional dimensions of differential water insecurity	Lilongwe, Malawi	NA	Chronic	72
	Cape Town, South Africa Accra, Ghana Cape Town, South Africa	NA	Chronic	65
	Gaborone, Botswana	2015	Drought	143
Water insecurity and food insecurity	Accra, Ghana; Kisumu, Kenya; Lilongwe, Malawi; Lagos, Nigeria; Kampala, Uganda; Cartagena, Colombia; Beirut, Lebanon; Morogoro, Tanzania; Katmandu, Nepal; Ceará, Brazil; Mérida, Mexico; Acatenango, Guatemala; Honda, Colombia; Torreón, Mexico; Pune, India; Rajasthan, India;	NA	Chronic	147
	Gaborone, Botswana	2015	Drought	143
	iLembe, South Africa	2015-2016	Drought	76
	Bulawayo, Zimbabwe	1982-1992	Drought	78

Producing Scarcity

Phenomena	Locations	Year	Typology	Refs.
Production of water insecurity across intra-urban spaces and within the water supply network: uneven quantities, qualities, pricing regimes, and conditions of access	Lilongwe, Malawi	NA	Chronic	27,84
	Sicily, Italy	2002	Drought	85
	Guayaquil, Ecuador	NA	Chronic	15
	Mexico City, Mexico	NA	Chronic	87
	São Paulo, Brazil	2014-2015	Drought	18,71
	Mumbai, India	2009	Chronic	73,89
Capitalizing on drought events	Northern Brazil - urban areas	2011-2017	Drought	92
	Athens, Greece	1989-1993	Drought	70,86,148
	Kutch District, India	Frequent droughts	Drought	149,150
	Medellin, Colombia	NA	Chronic	94
	Santa Barbara, California	1985-1991	Drought	91
Private institutions and the production of droughts	Yorkshire, England	1995	Drought	95

Transformative potential

Phenomena	Locations	Year	Typology	Refs.
Framing droughts as natural and unpredictable	Athens, Greece	1989-1993	Drought	70,86
	Santa Barbara, California	1985-1991	Drought	91
Conservative practices and trajectories	Tampa, Florida	2004-2008	Drought	97
	Santa Barbara, California	1985-1991	Drought	91
	Yorkshire, England	1995	Drought	95
	Barcelona, Spain	1950s and 2007-2008	Drought	144
	Ontario, Canada	2007 and contd.	Drought	99
	Austin, Texas	2008-2015	Drought	100
	São Paulo, Brazil	2014-2015	Drought	11,71
Social pressure on overconsuming users and transformative trajectroies	Ontario, Canada	2007 and contd.	Drought	99
	California, USA	2014-2015	Drought	101,102

Extended Data Fig. 2 | Summary of the phenomena, locations and authors of the case studies mapped in Extended Data Fig. 3. See refs. 143–150.

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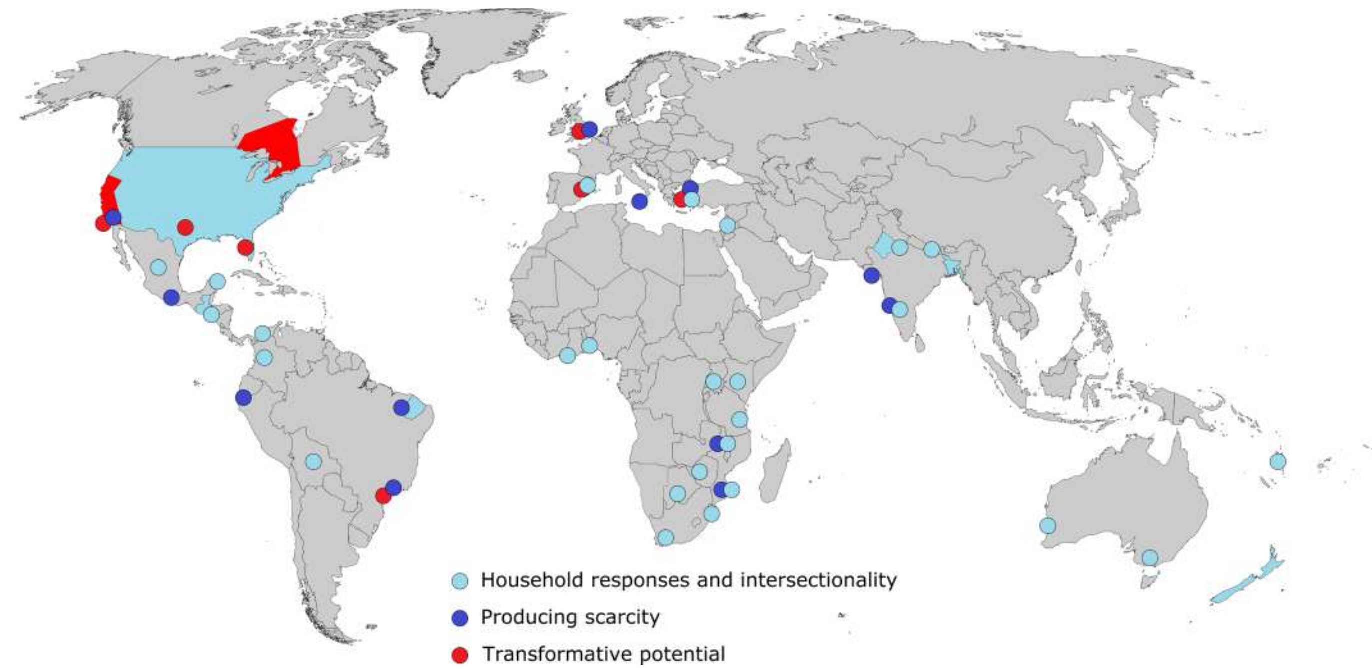

Extended Data Fig. 3 | Locations of the case studies examined for the Theoretical Synthesis (Pillar 1).

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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	The code to compute the SPEI index is publicly available at https://spei.csic.es/database.html (doi: 10.5281/zenodo.834462). This analysis and the associated visualization were implemented in MatLab R2018b.
Data analysis	MatLab code was used for visualisation purposes and to compute spatial and temporal means of the SPEI and reservoir level data.

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The authors confirm that the qualitative data supporting the findings of this Analysis are available within the article and its Supplementary Information (Extended case study: Maputo and Extended case study: Cape Town). Some qualitative data are not publicly available due to ethical restrictions (i.e. they contain information that could compromise the anonymity of research participants). These data are available from the corresponding author (maria.rusca@manchester.ac.uk) on reasonable request. Anonymised data will be made available within a month from the request. Data on the filling levels of the water reservoirs of the two cities are available at the City of Cape Town Data portal (https://cip.csag.uct.ac.za/monitoring/bigsix.html), the Direcção Nacional de Gestão de Recursos Hídricos (National Directorate of Water Resources, Mozambique, https://www.dngrh.gov.mz/index.php/publicacoes/boletins-de-bacias-hidrograficas) and the Biblioteca Digital de Teses e Dissertações (Digital Dissertation Repositiry, https://repositorio.bc.ufg.br/tede/handle/tede/10365). The Standardized Precipitation Evapotranspiration Index (SPEI) data can be retrieved from SPEIbase (https://spei.csic.es/)"

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Behavioural & social sciences study design

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Study description

The project adopted a mixed (qualitative and quantitative data) and archival research methods. The mix of qualitative and quantitative research methods, included semi-structured interviews, unstructured interviews, observations, focus groups discussions and questionnaires. Different data analysis techniques were used (discourse analysis, life histories, summative analysis, historical and comparative analysis).

Research sample

Surveys and semi-structured interviews are established methods in the social sciences. Social behaviors, cultural believes, institutional changes, and perceptions of different stakeholders are investigated by a manifold of disciplines through these methods as they have the potential to provide in-depth and context specific analyses of processes (Denzin & Lincoln, 2000, Strauss, 1987). Given the focus of the study – multiscalar societal responses to drought event – the research sample included households (male and female household members) in different neighborhoods, government and municipal officials, national and local public health and water sector organizations, consultants and other stakeholders involved in managing the drought. No minors were be invited to participate in this project. The sample is qualitative and not statistically relevant.

Sampling strategy

Snowball sampling was used to ensure that no relevant stakeholder was omitted. We undertook a significant number of interviews both in Cape Town (sixty-five) and in Maputo (sixty-five), including key public and private stakeholders in the water and health sector, consultants and non-governmental organization, allowing for a robust understanding of the societal responses to the drought events in the two cities. Saturation was achieved by including the complete range of stakeholders that were involved in managing the drought event. Households were selected using convenience sampling with the criterion of at least two blocks distance between each household and based on location (e.g. a neighborhood that were particularly affected by the drought). Where needed, permission from any relevant authority was asked (e.g. chiefs, local municipal authorities) to ensure they are duly informed. Household responses across intra-urban spaces revealed a number of consistent patterns, associated with income, coping strategies, technical specification of the network. We thus became confident that this category was saturated.

Data collection

Data from surveys was collected on paper based questionnaires undertaken by trained field assistants. Face-to-face interviews were undertaken by the researchers and trained field assistants. Responses of interviewees were jotted during the interviews and integrated after the interviews. As part of the informed consent procedure, the researchers asked permission for audio recording the interview, which was granted in the large majority of the interviews. Interviewees were informed that such practice would not affect the confidentiality and anonymity (if requested), and that data collected both through audio recordings and through text would be safely stored in virtual storage facilities provided by the university.

Timing

In Cape Town, qualitative data were collected between May 2019 and March 2020. In Maputo, qualitative data were collected between November 2013 and February 2014, November-December 2016, and August-November 2017. Follow-up interviews were undertaken in 2021.

Data exclusions

No data were excluded.

Non-participation

No participant declined to participate.

Randomization

Participants were not allocated into experimental groups.

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☐	☒	Human research participants
☒	☐	Clinical data
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Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics

The research samples included stakeholders in the water and health sector, including government officials, water utility managers, small-scale water providers, consultants, charities and NGOs, as well as adult urban dwellers (men and women) residing in different nieghbouhoods of the cities examined for this study.

Recruitment

Households were selected using convenience sampling with the criterion of at least two blocks distance between each household and based on location (e.g. a neighborhood that were particularly affected by the drought). Stakeholders in the water and health sector, including government officials, water utility managers, small-scale water providers, consultants, charities and NGOs were selected based on the role they played in managing the drought events in the selected cities.

Ethics oversight

The research protocol for this study was approved by the Research Ethics Committee of King's College London (LRMR-16/172263), and by the Municipality of Maputo (371–DAS) and Cape Town (PSRR-0259). All members of the research team followed the guidelines provided by the Italian Research Ethics and Bioethics Committee (protocol 0043071/2019) and the Swedish Ethical Review Authority (Dnr 2019-03242), and the protocols set by the ethical standards set by the European Union under Horizon 2020 (FAIR Data Management and EU General Data Protection Regulation). We have obtained informed consent from all participants after duly notifying interviewees about the context and purpose of the interview, expected duration of their participation, funders and lead researchers of the project, data protection/confidentiality/privacy, and duration of storage of personal data. Participants were also informed that they were under no obligation to answer any question and that they could withdrew from the interview at any time.

Note that full information on the approval of the study protocol must also be provided in the manuscript.