Anthropogenic droughts are expected to exacerbate water inequalities in postcolonial cities

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Analysis

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Title page

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Abstract

There are growing concerns about the impacts of climate change on equitable urban development. As cities are becoming increasingly exposed to anthropogenic droughts, stakes are particularly high in contexts of severe vulnerability. Yet, the impacts of future urban droughts and the societal responses they will elicit remain poorly understood. Here we develop social-environmental scenarios of anthropogenic drought-related impacts in postcolonial cities, characterized by highly uneven development and differentiated levels of vulnerability. We show how unprecedented droughts are expected to polarize existing inequalities in water access and well-being across genders, race and socio-economic groups. Specifically, unprecedented droughts will likely exacerbate spatial inequalities, generate localized public health crises, and regress development progress in water access. These results suggest that effective climate policies must address water insecurity and other pre-existing inequalities, and develop equitable water conservation measures to ensure effective adaptation to future unprecedented extreme droughts.

Main text

Anthropogenic climate change, urbanization, deforestation, and/or large water infrastructure have intensified the severity of recent droughts in several regions, including Brazil[1], California[2,3] China [4,5], Spain[6], and Southern Africa[7]. These regions are therefore at risk of experiencing future droughts that are unprecedented in the historical record. At the same time, the rapid urban growth of the past two decades, much of which has occurred and continues to occur in the Global South, is placing cities under significant risk of water stress[8]. Human water consumption has exceeded renewable freshwater resources in many parts of the world[9,10] Consequently, drought events often lead to severe socio-economic losses and water shortages[11,12]. Today, urban droughts pose a key challenge to the achievement of the United Nations' Sustainable Development Goals[13] and, as stated in a recent Nature Sustainability editorial[14], "every world city should prepare [to 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 captured public attention worldwide, and Chennai (India), São Paulo (Brazil), and Istanbul and several other cities in Turkey have undergone or are undergoing similar water crises[15–17]. This underscores the urgency of exploring how future, unprecedented drought events may impact urban populations and what societal responses they might elicit. Here, we seek to address this major scientific gap. Our primary focus in this paper is to analyze how post-colonial cities in the Global South are responding and might respond to unprecedented droughts. Urban droughts are particularly concerning in post-colonial cities, where splintered infrastructures are the norm[18]. In stark contrast with the 'modern infrastructural ideal' envisaging universal standardized services and networked infrastructures[19], since colonial times cities in the global South are characterized by stark inequalities in water and sanitation (in)security across urban spaces[18,20,21]. According to a recent World Bank report, water utilities in sub-Saharan Africa only reach, on average, sixty percent of the urban population[22]. Moreover, whilst there is a tendency to consider urban inequalities as a split between connected and unconnected residents, recent research on Global South cities has exposed differentiated levels of water (in)security within centralized water supply networks[23–25]. Crucially, understanding why some urban dwellers are disproportionately more vulnerable to droughts than others is essential to reduce drought risk both today and in the future. Numerous approaches and frameworks have been recently developed in the attempt to further theorization and predictions of drought events and other extremes[26–31]. These approaches, however, largely overlook the role of power and politics, the heterogeneity of society, and variability in the exercise of agency of different social groups and individuals. This prevents a comprehensive understanding of the complex feedback between society and droughts generating extreme events and the uneven distribution of negative impacts[32,33]. Here, we implement a framework termed Social-Environmental Extremes Scenario Approach (SEEA, see Figure 1)[33].

This approach expands the reductionist hydroclimatic conceptualization of water scarcity by integrating analyses of how power, differentiated agency, economic development and policy visions shape drought phenomena, risk accumulation, and differentiated vulnerability and recovery trajectories. We specifically develop a combined qualitative and quantitative assessment to build a scenario of human responses to unprecedented droughts in Maputo, Mozambique. Fast growing cities in low-income African countries with high levels of socio-economic inequalities, limited water supply infrastructure and inadequate services, such as Maputo, provide a case-in-point of the threat that urban droughts pose to water security in postcolonial cities. We build our scenario based on four pillars: critical social sciences theories on societal responses to urban droughts (Pillar 1; Figure 2 and Table S1); historical climate data and regional numerical climate projections (Pillar 2); socio-economic responses to past droughts at the location of interest (here the 2015-2017 drought in Maputo, Pillar 3); and a conceptual transfer to future unprecedented droughts at the location of interest from past droughts at other locations (here the 2015-2017 drought in Cape Town, which was of greater magnitude than any drought in Maputo in recent history, Pillar 4). The aim of this framework is not to make a deterministic forecast, but rather to build a story-line highlighting criticalities from a sustainability and social justice perspective.

Maputo is likely to face unprecedented droughts

For Pillar 2, we note that Mozambique ranks amongst the world's most vulnerable countries to climate change[34] and has experienced repeated severe droughts in recent decades[35], which have been especially frequent in the central and southern parts of the country[36]. These extreme events have occurred on the background of a multi-decadal drying trend (e.g.[37]). Focusing on the Southern part of the country, where Maputo is located, the latest generation of global climate models points to a future aggravation of the regional risk of extreme meteorological and agricultural drought conditions[38]. Regional climate simulations using precipitation and evapotranspiration jointly to diagnose drought, support these conclusions[39]. There are large uncertainties in future climate projections of precipitation, and diagnosing drought often requires considering additional variables – such as evapotranspiration – which bear their own uncertainties. Nonetheless, the ongoing climate trends and numerical projections of future climates all point to the possibility that Southern Mozambique may be affected by a future, unprecedented drought with a higher likelihood than one may expect from a statistical analysis of historical data series. Moreover, Maputo and its surroundings have emerged as a regional drought hotspot over the last several decades (see Methods). Based on the above, we argue for the relevance of an unprecedented drought scenario in Maputo.

Colonial legacy shapes drought vulnerability

The theoretical synthesis (Pillar 1), coupled with empirical work in Maputo (Pillar 3) and Cape Town (Pillar 4), points to levels of chronic water (in)security experienced before the unprecedented drought event as the main predictor of vulnerability. Differentiated levels of water (in)security are a legacy of the colonial era[16,40–42], and attempts to revert this legacy have met with limited success[43]. Maputo is an exemplary expression of the nexus between race, class, variegated citizenship, heterogeneous infrastructure and vulnerability conceptualized by critical scholars (Pillar 1). Colonial Maputo was grounded on principles of racial segregation that generated spatial, economic and social inequalities. Due to this heritage, processes of marginalization and dispossession from basic services persist to date. Housing and sanitation policies continue to marginalize lower-income groups, which suffer the most from significant infrastructural deficits and absence of property rights[41,44–47].

Service configurations reflect these uneven developments (Figure 2a). The water utility Águas de Região de Maputo (AdeRM), which relies on surface water from the Umbelúzi river, stored in the Pequenos Libombos dam, has for decades focused on serving higher income residents in the so-called cement city. Whilst water coverage has significantly increased over the past decade[48], reaching approximately 63% of the city[47], quality of the service varies across neighborhoods. Recently developed outer peri-urban areas, inhabited by middle income residents, are primarily supplied by over 800 highly-skilled, small-scale private operators that undertook large investment to develop decentralised networks that increasingly mimic the formal water utility[49,50]. These are regulated by the government, who controls rates of groundwater abstraction, water quality and pricing regimes[51]. In contrast, the poorer urban belt neighborhoods rely on self-supply, household water resales or the formal water utility, which is often unable to deliver the same quality of service offered to neighborhoods in the city center[48].

The sanitation landscape is even more unequal. A minority of the population (9 percent) enjoys publicly managed, supply-driven sanitation services; the middle class relies on pour-flush toilets with septic tanks (49 percent), and low-income residents make do with unimproved or improved pit latrines (41 percent) or (approximately 1 percent) practice open defecation[52]. New investments in wastewater infrastructures[53] are targeting rehabilitation and upgrading of the sewerage systems and the treatment facility, thereby reproducing existing infrastructural inequalities and the segregationist logic embedded in the sanitation landscape. Present and future drought vulnerability can only be understood in relation to Maputo's urban form and the variegated water and sanitation (in)security levels it generates.

Polarized urban inequalities and public health crises from anthropogenic droughts

A synergistic application of the SEEA suggests that an unprecedented drought in Maputo could significantly exacerbate existing inequalities. Chronically water insecure households will suffer the most from water shortages, with a cascading effect on other urban inequalities. From Pillar 3 (Precedents in Maputo), we infer that the impact of an unprecedented drought will disproportionately affect residents served by the water utility as compared to areas served by small-scale water providers. Levels of water insecurity are expected to differ across the urban spaces served by the water utility, as water rationing measures are likely to generate longer and more severe water shortages in peripheral neighborhoods at the margins of the water supply network. As noted for other postcolonial cities (Pillar 1, Theoretical Synthesis), the technical specification of the network in Maputo will likely allow higher income neighborhoods located closer to the distribution centers to capture most of the rationed water. Moreover, affluent households are expected to rely on larger storage tanks to buffer rationing measures, whilst mid and lower income residents may only be able to store between 20 and 250 liters per household and day to cope with restrictions (Pillar 3, Precedents in Maputo). We also expect demand management measures to include tariff increments to reduce consumption, as occurred during the unprecedented drought in Cape Town (Pillar 4, Conceptual transfer) and in other locations (Pillar 1, Theoretical synthesis). This measure will probably affect the behavior of residents that already consume a limited amount of water the most, making them severely water-insecure. In contrast, higher income residents that can afford higher rates will likely continue to consume at unsustainable rates, thus remaining more water secure.

Prolonged water shortages are expected to exacerbate other urban inequalities (Figure 3). From Pillar 1 (Theoretical synthesis) and 3 (Precedents in Maputo) we note that women will likely be disproportionately burdened with the task of finding alternative water sources, with consequences on their employment and income, physical and psychological stress associated with both fetching and not being able to fetch water, and increased risks of violence if sourcing water in the dark or from distant locations. An unprecedented drought might exacerbate food-insecurity of lower income households due to both inflated food prices and the impact of water rationing measures on the ability of lower income residents to maintain their vegetable urban gardens. This, in turn, is expected to increase residents – and particularly women's – vulnerability to widely spread diseases such as HIV[54]. Last, prolonged shortages will most likely exacerbate water-related health risks and generate unprecedented public health crises, largely concentrated in low-income neighborhoods. Drawing on Pillar 3 (Precedents in Maputo), we infer that outbreaks of waterborne diseases and malaria cases will be concentrated in areas with the most significant infrastructure deficits. Chronic water shortages might force residents to resort to unimproved sources such as river streams or to cut pipes to access water from the mains, thereby increasing risks of re-contaminated drinking water. Low-lying neighborhoods served by pit latrines will likely be the most at risk. These areas are expected to simultaneously experience prolonged water shortages and more frequent flash floods, because drought events reduce the capacity of soil to absorb water. This will probably increase risks of fecal contamination of drinking water sources and, in turn, waterborne diseases. Moreover, storage practices of low-income dwellers relying on uncovered water facilities located near humans, can increase risks of mosquito breeding and, in turn, of vector-borne diseases like dengue and malaria.

Reversing progress in water access or vicious supply-demand cycle?

Global political economy is expected to significantly shape the Mozambican government's response to the drought, which largely depends on its ability to access global capital. As this outcome is largely unpredictable, we consider a scenario in which the government does not have access to global capital and one of large capital inflows. In the first scenario, the recent corruption and hidden debt scandals[55] will continue to limit the Mozambican government's access to global capital and the government is unlikely to have the resources to develop large-scale infrastructures to increase supply. Based on Pillar 3 (Precedents in Maputo), we predict that the pressure to manage a limited supply for existing customers will constrain the water utility's ability to expand services to unserved urban populations. The city center, inhabited by high income populations, will likely continue to receive water from the water utility, whilst low-income peri-urban areas served by the water utility will suffer from increasing water shortages. As a result, residents will perform different forms of 'going off the grid': a synergistic application of SEEAs Pillars suggests that those with access to land in areas with high water table and financial resources will opt for developing alternative or additional water sources, including boreholes, larger storage tanks and rain-tanks. Those in proximity of areas served by small scale providers that provide more reliable services will add a second connection to augment water availability for the household, whilst others will have to revert to buying water from communal water points or private boreholes or to rely on unimproved water sources. These coping strategies, alongside rapid urbanization, will reverse progress in water access achieved by the service provider over the past decade and increase fragmentation of services in Maputo. For those who can integrate household water sources, this process will ultimately lead to increased resilience, whilst for those who cannot afford access to safe alternative sources, the process of going off the grid will lead to increased vulnerability.

In an alternative scenario, access to global capital will allow the government to implement its 10-years Capital Investment Program aimed at enhancing water security and resilience to climate change by expanding water supplies through the construction of large water infrastructures. Based on Pillars 1 (Theoretical synthesis) and 4 (Conceptual transfer from Cape Town), we suggest that in response to an unprecedented drought, Maputo will enter a vicious cycle of water supply expansion. In the aftermath of a drought event, the water utility and residents will return to 'business as usual' management and consumption practices, characterized by over-allocation to and overconsumption by elites, rather than conservation practices. These practices will be sustained by the increase in water supply, financed through global capital. The government will develop large scale infrastructures that will meet the growing demand and allow to pursue network expansion without addressing inequalities in access and unsustainable consumption patterns. Paradoxically, this increment in water supplies will increase the city's vulnerability to drought events. Development of large water infrastructures will generate a false sense of security, also grounded on the expectation that the city will face droughts of similar intensity to the past, rather than unprecedented in nature. This assumption will lead to increased consumption patterns that in the long term will reproduce water stress conditions and force the government to reactive responses to future drought events.

Intra-urban and inter-national water conflicts

Unprecedented droughts might increase the likelihood of water-related conflicts across intra-urban spaces and water providers, as well as among riparian states. Water shortages will trigger both households and some providers to access new water sources, with risks of overexploitation and increased competition over available water resources. Intra-urban conflicts could be generated by the increased reliance on groundwater resources by the water utility. We note from Pillar 3 (Precedents in Maputo) that the water utility will likely identify groundwater as the short-term and most affordable solution to cope with the effects of a drought event. Increased reliance on groundwater resources is expected to exacerbate saltwater intrusion in coastal areas[56] and, in the longer term, reduce water availability and lower the groundwater table, causing some boreholes to dry up. The reduced quality and quantity of groundwater availability will extend the impact of the water crisis to previously buffered areas, exacerbating the existing tensions among providers relying on this water source. Conflicts with small-scale water providers (SSIPs) are also expected to be exacerbated by the government's plan to expand services to unserved areas, thereby shrinking SSIP market and income.

In the past, the assumption that in international river basins characterized by growing water uses or stress, cooperation efforts would prevail over conflicts has held true for the Incomati, Umbeluzi and Maputo rivers[57,58]. However, Mozambique's plans of developing large infrastructures on these basins in combination with a future extreme drought might reduce the ability and willingness of riparian South Africa and Swaziland to reach consensus on water allocation and on how to cope with multiple and conflicting demands. As the Maputo river is less developed in terms of dams and water allocation, tensions are more likely to arise on the Umbeluzi and Incomati river. The Umbeluzi river is currently the source of a large irrigation scheme in Swaziland and of several smallholder farmers in Mozambique. The Incomati river is the selected site for one of the largest dam projects of the Mozambican government. An unprecedented drought could lead to tensions over water allocation and priorities among the three countries.

Conclusions

We developed scenarios of urban droughts in post-colonial cities, characterized by highly unequal development, using the city of Maputo, Mozambique, as a case-in-point. We have shown that the impact of present and future droughts can only be understood in relation to the colonial history of these cities. The design of the infrastructure, its purposes, and the heritage of the colonial urban form crucially determine what remaining without water – or Day Zero – means for different citizens. As shown by our scenario, spatial and social inequalities, including access to basic services, well-being, gender and socio-economic status generate differential vulnerability to unprecedented extreme droughts. If future policies neglect the heterogeneity of water insecurity and other pre-existing inequalities, only a small part of the urban population will effectively cope with and adapt to future drought events. High levels of vulnerability to droughts are bound to be continuously reproduced or exacerbated if spatial and socio-economic economic inequalities are not addressed. In parallel with this, all actors need to account for the changing physical-environmental context of urban droughts. The ongoing climate change has the potential to lead to large regional hydroclimatic shifts – in the case of Southern Africa towards more drought – prone conditions[35,37–39]. Our scenario is not a deterministic projection, but rather a storyline (or scenario-based) evaluation seeking to identify aspects that are critical in responding to future drought events. However, it allows to us to conclude that more optimistic scenarios are only possible if multiple dimensions of urban inequalities are addressed before the next Day Zero, whilst also abandoning the assumption that future droughts will be similar in scale to those experienced in the past.

References

1. Loon, A. F. V. *et al.* Drought in the Anthropocene. *Nature Geoscience* **9**, 89–91 (2016).
2. Diffenbaugh, N. S., Swain, D. L. & Touma, D. Anthropogenic warming has increased drought risk in California. *PNAS* **112**, 3931–3936 (2015).
3. AghaKouchak, A., Feldman, D., Hoerling, M., Huxman, T. & Lund, J. Water and climate: Recognize anthropogenic drought. *Nature News* **524**, 409 (2015).
4. Qiu, J. China drought highlights future climate threats. *Nature* **465**, 142–143 (2010).
5. Xu, K. *et al.* Spatio-temporal variation of drought in China during 1961–2012: A climatic perspective. *Journal of Hydrology* **526**, 253–264 (2015).
6. Van Loon, A. F. & Van Lanen, H. a. J. Making the distinction between water scarcity and drought using an observation-modeling framework. *Water Resources Research* **49**, 1483–1502 (2013).
7. Yuan, X., Wang, L. & Wood, E. F. Anthropogenic intensification of southern African flash droughts as exemplified by the 2015/16 season. *Herring, SC, N. Christidis, A. Hoell, JP Kossin, CJ Schreck III & PA Stott, Eds* 586–589 (2018).
8. Ray, B. & Rajib, S. *Urban Drought*. (Springer, 2019).
9. Gleick, P. H. & Palaniappan, M. Peak water limits to freshwater withdrawal and use. *PNAS* **107**, 11155–11162 (2010).
10. Vörösmarty, C. J., Green, P., Salisbury, J. & Lammers, R. B. Global water resources: vulnerability from climate change and population growth. *science* **289**, 284–288 (2000).
11. AghaKouchak, A. *et al.* Anthropogenic Drought: Definition, Challenges, and Opportunities. *Reviews of Geophysics* **59**, e2019RG000683 (2021).
12. Di Baldassarre, G. *et al.* Water shortages worsened by reservoir effects. *Nature Sustainability* **1**, 617–622 (2018).

13. Zhang, X. *et al.* Urban drought challenge to 2030 sustainable development goals. *Science of The Total Environment* **693**, 133536 (2019).
14. Not a drop to spare. *Nat Sustain* **1**, 151–152 (2018).
15. Anandharuban, P. & Elango, L. Spatio-temporal analysis of rainfall, meteorological drought and response from a water supply reservoir in the megacity of Chennai, India. *J Earth Syst Sci* **130**, 17 (2021).
16. Millington, N. Producing water scarcity in São Paulo, Brazil: The 2014-2015 water crisis and the binding politics of infrastructure. *Political Geography* **65**, 26–34 (2018).
17. NASA. Turkey Experiences Intense Drought. https://earthobservatory.nasa.gov/images/147811/turkey-experiences-intense-drought (2021).
18. Ahlers, R., Cleaver, F., Rusca, M. & Schwartz, K. Informal space in the urban waterscape: Disaggregation and co-production of water services. *Water Alternatives* **7**, 1–14 (2014).
19. Graham, S. & Marvin, S. *Splintering urbanism: networked infrastructures, technological mobilities and the urban condition*. (Psychology Press, 2001).
20. Kooy, M. & Bakker, K. Technologies of government: Constituting subjectivities, spaces, and infrastructures in colonial and contemporary Jakarta. *International Journal of Urban and Regional Research* **32**, 375–391 (2008).
21. WHO/UNICEF. *Progress on household drinking water, sanitation and hygiene 2000-2017: Special focus on inequalities*. vol. 1 (United Nations Children's Fund (UNICEF) and World Health Organization, 2019).
22. van den Berg, C. & Danilenko, A. *Performance of Water Utilities in Africa*. (World Bank, Washington, DC, 2017). doi:10.1596/26186.

23. Anand, N. Municipal disconnect: On abject water and its urban infrastructures. *Ethnography* **13**, 487–509 (2012).
24. Björkman, L. *Pipe politics, contested waters*. (Duke University Press, 2015).
25. Rusca, M., Boakye-Ansah, A. S., Loftus, A., Ferrero, G. & Van Der Zaag, P. An interdisciplinary political ecology of drinking water quality. Exploring socio-ecological inequalities in Lilongwe's water supply network. *Geoforum* **84**, 138–146 (2017).
26. Balch, J. K. *et al.* Social-environmental extremes: Rethinking extraordinary events as outcomes of interacting biophysical and social systems. *Earth's Future* **8**, e2019EF001319 (2020).
27. Barnes, M. L. *et al.* Social determinants of adaptive and transformative responses to climate change. *Nature Climate Change* **10**, 823–828 (2020).
28. Moss, R. H. *et al.* The next generation of scenarios for climate change research and assessment. *Nature* **463**, 747–756 (2010).
29. O'Neill, B. C. *et al.* Achievements and needs for the climate change scenario framework. *Nature climate change* 1–11 (2020).
30. Rao, N. D., van Ruijven, B. J., Riahi, K. & Bosetti, V. Improving poverty and inequality modelling in climate research. *Nature Clim Change* **7**, 857–862 (2017).
31. Wilson, R. S., Herziger, A., Hamilton, M. & Brooks, J. S. From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. *Nature Climate Change* **10**, 200–208 (2020).
32. Castree, N. Changing the Anthropo (s) cene: Geographers, global environmental change and the politics of knowledge. *Dialogues in Human Geography* **5**, 301–316 (2015).
33. Rusca, M., Messori, G. & Di Baldassarre, G. Scenarios of human responses to unprecedented social-environmental extreme events. *Earth's Future* **9**, e2020EF001911 (2021).

34. Chen, C. *et al.* University of Notre Dame global adaptation index country index technical report. *ND-GAIN: South Bend, IN, USA* (2015).
35. Masih, I., Maskey, S., Mussá, F. E. F. & Trambauer, P. A review of droughts on the African continent: a geospatial and long-term perspective. *Hydrology and Earth System Sciences* **18**, 3635–3649 (2014).
36. Ministry of Foreign Affairs of the Netherlands. *Climate Change Profile: Mozambique*. (2018).
37. Dai, A. & Zhao, T. Uncertainties in historical changes and future projections of drought. Part I: Estimates of historical drought changes. *Climatic Change* **144**, 519–533 (2017).
38. Cook, B. I. *et al.* Twenty-First Century Drought Projections in the CMIP6 Forcing Scenarios. *Earth's Future* **8**, e2019EF001461 (2020).
39. Abiodun, B. J., Makhanya, N., Petja, B., Abatan, A. A. & Oguntunde, P. G. Future projection of droughts over major river basins in Southern Africa at specific global warming levels. *Theor Appl Climatol* **137**, 1785–1799 (2019).
40. Anand, N. PRESSURE: The PoliTechnics of Water Supply in Mumbai. *Cultural Anthropology* **26**, 542–564 (2011).
41. Biza, A., Kooy, M., Manuel, S. & Zwarteveen, M. Sanitary governmentalities: Producing and naturalizing social differentiation in Maputo City, Mozambique (1887–2017). *Environment and Planning E: Nature and Space* 2514848621996583 (2021) doi:10.1177/2514848621996583.
42. Kimari, W. & Ernstson, H. Imperial Remains and Imperial Invitations: Centering Race within the Contemporary Large-Scale Infrastructures of East Africa. *Antipode* **52**, 825–846 (2020).
43. Myers, G. *African cities: alternative visions of urban theory and practice*. (Zed Books Ltd., 2011).

44. Barros, C. P., Chivangue, A. & Samagaio, A. Urban dynamics in Maputo, Mozambique. *Cities* **36**, 74–82 (2014).
45. Jenkins, P. City profile: Maputo. *Cities* **17**, 207–218 (2000).
46. Roque, S., Mucavele, M. & Noronha, N. Subúrbios and Cityness: Exploring Imbrications and Urbanity in Maputo, Mozambique. *Journal of Southern African Studies* **42**, 643–658 (2016).
47. Rusca, M. *et al.* The Urban Metabolism of Waterborne Diseases: Variegated Citizenship, (Waste) Water Flows, and Climatic Variability in Maputo, Mozambique. *Annals of the American Association of Geographers* 1–20 (2021).
48. Zuin, V. & Nicholson, M. The Impact of Pro-Poor Reforms on Consumers and the Water Utility in Maputo, Mozambique. *Water Alternatives* **14**, 158–185 (2021).
49. Alda-Vidal, C., Rusca, M., Zwarteveen, M., Schwartz, K. & Pouw, N. Occupational genders and gendered occupations: the case of water provisioning in Maputo, Mozambique. *Gender, Place & Culture* **24**, 974–990 (2017).
50. Schwartz, K., Tutusaus Luque, M., Rusca, M. & Ahlers, R. (In) formality: the meshwork of water service provisioning. *Wiley Interdisciplinary Reviews: Water* **2**, 31–36 (2015).
51. Ahlers, R., Perez Güida, V., Rusca, M. & Schwartz, K. Unleashing entrepreneurs or controlling unruly providers? The formalisation of small-scale water providers in Greater Maputo, Mozambique. *The Journal of Development Studies* **49**, 470–482 (2013).
52. Hawkins, P. & Muxímpua, O. Developing business models for fecal sludge management in Maputo. *Water and Sanitation Program: Report by International Bank for Reconstruction and Development/The World Bank* (2015).
53. WB. *Internal Development Association Project on Mozambique Urban Sanitation Project (P161777)*. (2019).

54. Austin, K. F., Noble, M. D. & Berndt, V. K. Drying Climates and Gendered Suffering: Links Between Drought, Food Insecurity, and Women's HIV in Less-Developed Countries. *Soc Indic Res* **154**, 313–334 (2021).

55. Cortez, E. *et al. Costs and consequences of the hidden debt scandal of Mozambique*. 142 (2021).

56. Casillas-Trasvina, A., Zhou, Y., Stigter, T. Y., Mussáa, F. E. F. & Juízo, D. Application of numerical models to assess multi-source saltwater intrusion under natural and pumping conditions in the Great Maputo aquifer, Mozambique. *Hydrogeol J* **27**, 2973–2992 (2019).

57. Juízo, D. & Hjorth, P. Application of a district management approach to Southern African river basin systems: the case of the Umbeluzi, Incomati and Maputo river basins. *Water Policy* **11**, 719–730 (2009).

58. van der Zaag, P. & Carmo Vaz, Á. Sharing the Incomati waters: cooperation and competition in the balance. *Water Policy* **5**, 349–368 (2003).

59. World Bank. *Greater Maputo: Urban Poverty and Inclusive Growth. World Bank Report*. https://openknowledge.worldbank.org/handle/10986/29828 (2017).

Figures and tables

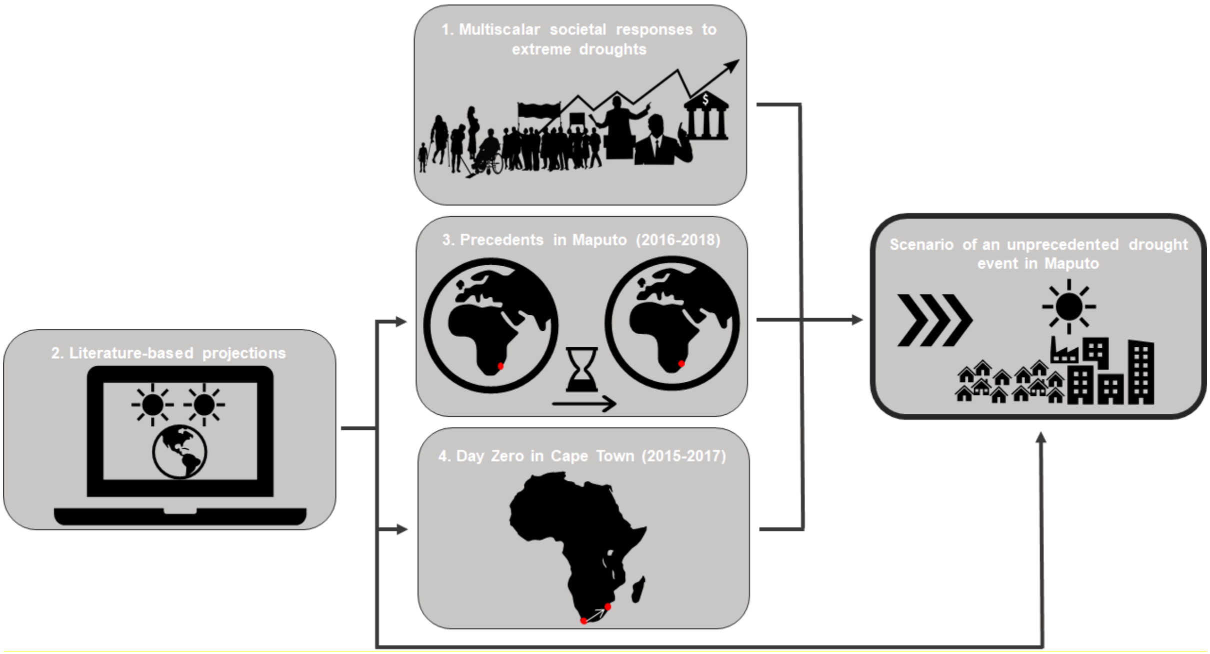

Figure 1 Schematic of the Social-Environmental Extremes Scenarios Approach for urban droughts. The approach rests on a synergy of literature-based projections of drought conditions in Southern Africa, critical social science theoretical perspectives on societal responses to drought events, and effective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

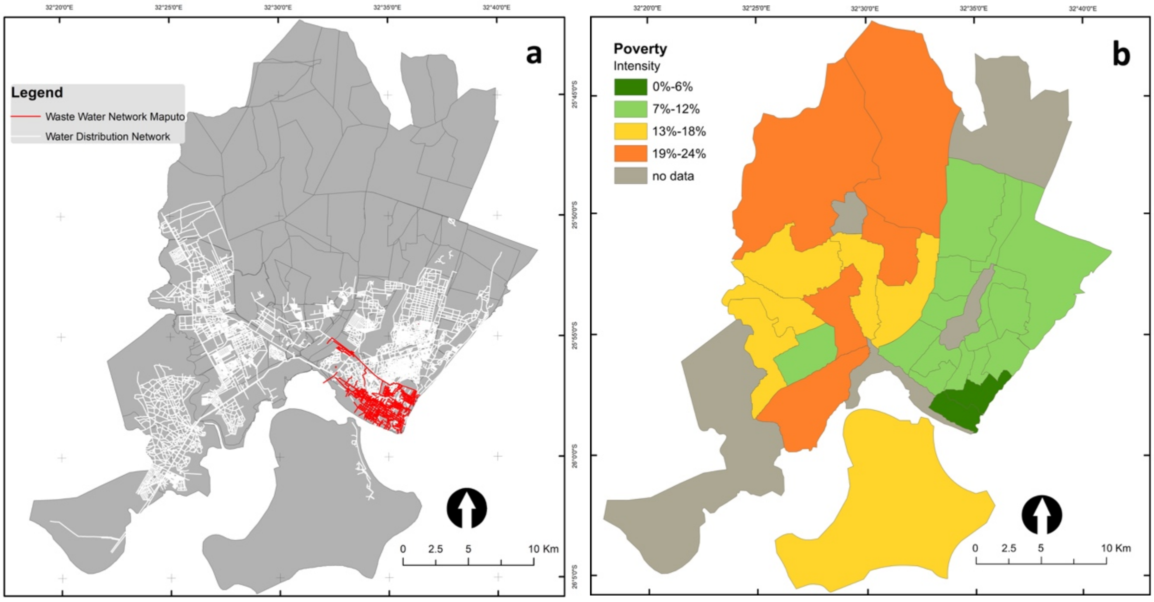

Figure 2a Map displaying water sewerage (red) and public water supply network (white) in Greater Maputo. Figure 2b Map displaying poverty intensity of neighborhood in Greater Maputo (Source: World Bank[59]).

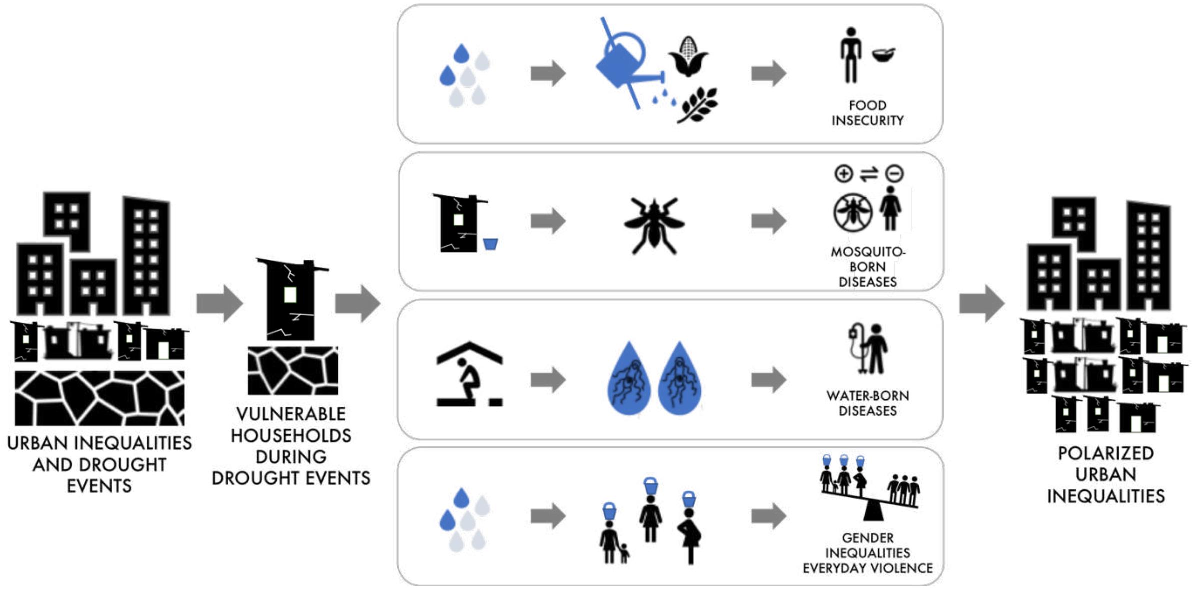

Figure 3 Cascading effect of water shortages on other urban inequalities. Acute water shortages, which will mostly affect residents in low-income areas, generate or exacerbate food insecurity, mosquito-borne and water-borne diseases, as well as gendered inequalities.

Methods

The Social-Environmental Extremes Scenario Approach is grounded on: a synergy of critical social science theoretical perspectives on multiscalar societal responses to extreme events (Pillar 1); literature-based climate projections identifying plausible areas at risk of unprecedented extreme occurrences (Pillar 2); empirical research on past social-environmental extremes in the location of interest (Pillar 3) and in other locations to examine events of greater magnitude than those observed at the location of interest (Pillar 4) (see Figure S1)[1]. In this study, we focus on droughts as extreme event of interest. Maputo (i.e. the location of interest – Pillar 3) and Cape Town (i.e. conceptual transfer – Pillar 4) were chosen as instrumental case studies because both cities were recently affected by a drought, share several historical legacy and social characteristics and Maputo is likely to experience unprecedented drought events in the future (Pillar 2). Empirical analyses of past events in Maputo and Cape Town were conducted through mixed method approaches (see Pillar 3 and Pillar 4). Below, we provide a detailed outline of Pillars 1–4, from which we develop the Social-Environmental Extremes Scenario of unprecedented drought in Maputo, Mozambique.

Pillar 1 – Societal responses to drought events: a theoretical synthesis

For this study, the theoretical synthesis has examined three interrelated multiscalar components of societal responses to urban droughts: household responses and intersectional dimensions of inequality; the power relations generating drought-induced urban water shortages and the uneven distribution of costs and benefits thereof (i.e. production of water scarcity); and state-civil society relations during and in the aftermath of a severe urban drought (i.e. transformative potential). Figure S2 maps the case studies examined in the theoretical synthesis and Table S1 provides a summary of the phenomena, locations and authors of the research. Last, Table S2 provides a synthetic overview of the main findings of the review.

Pillar 2: Climatic Projection – Southern Africa, Maputo

There are a number of regions which have historically been drought-prone and that are projected to become "drought hotspots" under future climates[56]. In the context of our impacts-based focus on urban droughts, an additional relevant criterion was to identify large urban areas vulnerable to water scarcity, and affected by unequal access to water. Southern Africa represents a "perfect storm" coincidence between these different aspects, being a region currently subject to droughts, projected to experience more severe droughts in the future (see "Maputo is likely to face unprecedented droughts") and having rapidly growing urban agglomerates characterised by large socio-economic inequalities. Cape Town is a natural choice for Pillar 4, having been widely reported as the first major city to be near the "day zero" no-water scenario[57]. Maputo, on the other hand, has experienced severe droughts in the recent past, but in comparison has received scant attention by the media and scientific community. However, it shares Cape Town's vulnerability to water scarcity, large inequalities, a segregated urban form, and additionally has unevenly developed water supply infrastructure[43,58,59]. As such, it is a highly relevant case study on which to build a socio-environmental scenario of future, unprecedented drought.

There is no single definition of drought from a physical-environmental perspective. The sources used in our analysis (see "Maputo is likely to face unprecedented droughts") adopt different definitions, generally including some measure of precipitation deficit and optionally additional factors such as estimates of evapotranspiration. For Fig. S3, we have opted to use the Standardized Precipitation Evapotranspiration Index (SPEI), from the SPEIbase dataset, which 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[60,61]. The figure illustrates the severity of the recent drought in Cape Town (thin blue curve), which peaked between 2015 and 2017, and the less hydroclimatically severe but nonetheless impacting drought in Maputo (thin red curve), peaking in 2016-2017. While remote precipitation may affect the water resources of these cities through rivers feeding into reservoirs, and consumption patterns can also play a large role, we note that the drought periods evidenced by the SPEI index mostly reflect the periods of reported water shortage. For example, in Cape Town the highest level of restrictions was in place between January and October 2018, with the former date closely following both the minimum SPEI value and the minimum reservoir water levels (thick blue curve). In Maputo, water restrictions were put in place in early 2017. A short recovery of the SPEI value to wet conditions during 2017 was not followed by a corresponding increase in reservoir levels (thick red curve), plausibly because adjacent regions to the South and West of Maputo continued to have negative SPEI values. A regional analysis of the SPEI data further shows that Maputo and the surrounding regions have been a regional epicentre for drought episodes over the last 5 decades, typically showing SPEI values in line with or lower than other locations within a roughly 1000 km radius during drought periods (not shown).

Pillar 3: Societal responses to the 2016-2018 drought in Maputo

In Maputo, qualitative data were collected through 65 semi-structured interviews undertaken between November 2013 and February 2014, November and December 2016, and August and November 2017 and a videography project undertaken in August 2017. Follow up interviews were conducted in May-June 2021. Interviews were held with national and local public health and water sector organization, municipal authorities, consultants, water providers (AdeM and Small-Scale Independent Providers) and the national water regulator, as well as with residents in low-income areas and local 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 neighborhoods and risks of waterborne diseases. This data was triangulated with a documentary analysis of drinking water and sanitation policies.

Household responses and intersectionality

The impacts of the drought in Maputo were spatially variegated. First, the households served by the public water utility (approximately 64% of the urban population), were significantly more affected than those served by small-scale water providers (approximately 33-34 % of the urban population). The water utility AdeRM relies on surface water from the Umbeluzi river, which is stored in the Pequenos Libombos dam and supplies 98% of the Maputo's residents connected to the centralized network. Small-scale providers (SSIPs), on the other hand, abstract (sometimes treat) and distribute groundwater through decentralized networks. In January 2017, the water reserves of the Pequenos Libombos dam, reached an alarming 16%[64]. In contrast, in areas served by SSIPs, groundwater worked as a buffer, but increased abstraction rates have exacerbated salt water intrusion in coastal areas[65]. This raised questions on the long-term sustainability of this service modality.

Second, the restrictions introduced by the water utility Águas da Região de Maputo (AdeM) in response to the water shortage affected lower income residents significantly more than affluent ones (see also Pillar 1 and 4). Neighborhoods at the margins of the water supply network experienced much longer and intense shortages than those centrally located. Some only received water twice a week, others experienced water shortages for over three weeks, and some only had water at night. Despite this, residents continued to be billed and charged for regular water consumption, and threatened disconnection in case of non-payment. The drought is exemplary of the uneven impact of reduced water availability across intra-urban spaces. With increased water shortages, storage facilities became the most essential coping strategy. Whilst higher income residents could rely on a higher storage capacity (500 to 1500 L) to cope with water rationing measures, mid and low-income neighborhoods had to make due with 200-250 L to 1.5 L containers. Additionally, affluent households that were already less affected by water rationing measures were able to integrate their supply with private wells, boreholes and bottled water.

Third, water shortages in low income areas generated or exacerbated existing gendered and well-being inequalities. Women in charge of water-intense domestic chores (cleaning, cooking, doing laundry) had to fetch water from boreholes or better served neighborhoods. As a result, they often missed work or had to wake up at night to do laundry and store some water for the day. These coping practices increase women's water labour and stress, as well as everyday risks of violence for women having to collect water at night[66]. Last, the drought also had several negative health implications, especially for low-income dwellers. There is a strong correlation between urban poverty and the use of on-site sanitation. In areas characterized by significant sanitation infrastructure and services deficits, especially those that are flood prone, water stress coalesced with poor sanitation and urban flash floods producing high risk of fecal contamination of water and, in turn, diarrheal diseases[43]. This resulted in a cholera outbreak, concentrated in poorly served neighborhoods. Moreover, uncovered containers located in proximity to humans, frequently found in lower income households, formed suitable habitats for *Aedes aegypti* vectors of chikungunya, dengue, and zika diseases[67].

Producing water scarcity

Differentiated levels of water shortages are generated by the uneven development trajectory of Maputo. Maputo's trajectory was and continues to be shaped by ideas of differentiated citizenship across identities and socio-economic groups, and is reflected in heterogeneous infrastructure and services developments[43]. The colonial state, grounded on principles of racial superiority, developed a segregationist spatial order in which colonial elites and the assimilated population accessed advanced centralized water and sanitation services, whilst natives were excluded [58,59,68]. Following independence, the Mozambican state embraced principles of inclusive development, but largely reproduced existing inequalities. Limited investment in network expansion and the civil war (1977-1992) constrained progress on water and sanitation. The past decade, was marked by a significant increase in water coverage. Reduced connection fees and installment payments for water meters attracted lower income residents, leading to the doubling water connections between 2009 and 2017[69].

Today, approximately 64% of the population is connected to the centralized water supply network. The drought, however, has shown that coverage does not always entail access: increased coverage resulted in reduced availability as the Corumana Dam project to increase supply was not completed before the drought. Moreover, water shortages exacerbated inequalities embedded in the technical characteristics of the network and in the spatial distribution of reservoirs. As noted for other postcolonial cities (Pillar 1), the network in Maputo prioritizes the city center by design. The distribution centers are concentrated in the proximity of the city center and, in times of water rationing, water distributed from the center to the periphery, was mostly consumed by higher income neighborhoods, who also relied on larger storage facilities [43].

Transformative potential

As suggested in Pillar 1 and 4, the drought turned into a market opportunity for existing and emerging profit-oriented providers. SSIPs were able to increase their market share, with many households connected to the water utility and located in proximity to private systems, opted for a second connection to augment supply. Other profit-oriented initiatives included water resale from boreholes or better served in-house connection, and water tankers. Moreover, in 2021 the Ministry of Infrastructures announced an effort to create the conditions for greater private sector participation in water service provision in Greater Maputo[70]. This initiative is linked to the overall strategy of the government in response to the drought, which is largely prioritized incrementing supplies over water conservation.

Water conservation measures were limited to public campaigns on how to save water (e.g. avoid using drinking water to clean, water lawns and washing cars, using buckets rather than showers) rather than sanctioned restrictions. In contrast, incrementing water supplies was and remains the main short- and long-term strategy. This strategy was promoted by discursively framing the drought as natural and water shortages as a problem to be addressed by incrementing supplies. In line with this narrative, the emergency strategy focused on developing groundwater resources and reactivating existing boreholes, whilst the mid and long-term approach focused on large dams, including a number of current (Corumana, Moamba) and new (Tembe, Tre Fronteiras, Movene) dam development projects, treatment facilities (Sabié), groundwater exploitation, and desalination. Although the hidden debt crisis slowed down the implementation of these plans, in 2021 the Sabié treatment facility and new distribution centers funded by the World Bank have been completed. The subsequent network expansion has generated significant tensions and conflicts with SSIPs that are losing market shares and their capital investment[70].

Last, during the emergency households facing extensive water shortages focused on everyday practices to access water rather than on collective action for just transformations. In some neighborhoods, however, residents have mobilized to collectively divert water from the main pipes supplying better served neighborhoods to theirs. Similar practices were performed individually by households in other neighborhoods. Whilst the water utility interpreted this as acts of vandalism that severely affect the network, residents claimed this is their only way to access water.

Pillar 4: Societal responses to the 2015-2017 drought in Cape Town

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 organisations. The interview investigated Capetonians' intersectional dimensions of vulnerability and their heterogeneous responses to the drought. Data were triangulated with media outlets and reports. Quantitative data including time series of rainfall, reservoir storage, human population, and daily water consumption, have been retrieved from the City of Cape Town Data portal. Information on the physical characteristics of past and future droughts was retrieved from the recent academic literature and from the SPEIbase drought dataset[60,61].

Household responses and intersectionality

In response to a severe meteorological drought which lasted from 2015 until 2017, the Water System of Cape Town's metropolitan area dried up almost completely. Shortly after, the City plunged into an unprecedented water crisis widely known as Day Zero. On the 18th of January 2018, the Municipality of Cape Town introduced severe water restrictions and demand management measures to avoid Day Zero, the moment in which the City would run out of water. In line with findings from Pillar 1, these measures -encompassing water rationing of 50 liters/person/day for a maximum of 350 liters/unit/day, increased tariffs, overconsumption fines and installation of metering devices to enforce compliance- affected lower-income and minority groups the most.

Affluent households that were used to consuming up to 8560 liters per day, had to significantly reduce their consumption and give up irrigating lawns, washing cars and filling their swimming pools, Yet, they did not suffer from shortages. These households were largely unaffected by the tariff increases and fines, and were able to access or quickly resort to alternative water sources, such as bottled water, rainwater and groundwater, and substantially increase their water availability. Conversely, the same restrictions are described as “a shock” by townships residents and working-class households who could not afford the increases in tariff, the fines nor the costs of accessing or developing alternative water sources. Moreover, in low-income areas it is common for more than one household to share one housing unit. These housing units, therefore, had to share the allocated 350 liters among up to 15 people. Last, low-income we most of the metering devices that halted the consumption of water at 350 liters/unit/day, were installed in lower-income households[8,71,72]. Many women living in these areas faced a considerable amount of stress every time the metering device interrupted the water provision in the middle of the day. Without relying on any alternative, these women had to give up on washing their clothes, cleaning the house or cooking the family meal[8].

Uneven water insecurity levels across intra-urban spaces and socio-technical measures enforced by the municipality generated different recovery trajectories across the city. In low-income neighborhoods, many households continue to struggle in the aftermath of the drought, due to the increased water tariffs and the rationing imposed through water metering devices. Conversely, higher income residents enhanced their resilience to future droughts by investing in alternative water sources. In fact, the reduction of the City’s water demand from 1000 to 500 Million Liters per/day is attributable to larger consumers going off the grid rather than to actual reductions in consumption[73].

Producing water scarcity

The uneven experience of the drought reflects unequal water (in)securities engendered by colonial legacies, racialized segregation and neoliberal reforms which over time have produced spaces of inequalities and unsustainable water consumption[8,71,72]. The water supply expansion strategy pursued by the Apartheid and post-apartheid government set in motion a vicious cycle of incremental water use by Capetonian elites and incremental infrastructural development, which overlooked environmental and social sustainability concerns, exacerbating the city's vulnerability to water shortages and droughts[8].

Transformative potential

The water crisis generated both possibilities for progressive transformations and new forms of water commodification[72]. The fact that measures such as increased water tariffs are still in place is proof of such commodification. In addition, the City withdrew the universal provision of the first 6 kiloliters of free basic water by making it conditional to the registration of residents as indigents. Moreover, low income residents continue to experience water rationing as a result of the metering devices that limit supply to 350 liters per day. At the same time, the crisis has reinvigorated the City's propension to supply expansion, now directed to desalination and groundwater exploitation.

At the same time, the government's response to the crisis ignited a strong opposition from those most affected by the drought and the subsequent measures. The struggle for water became enmeshed with broader struggles and claims of citizenship[71,74], led by well-established grassroots organizations, such as Environmental Monitoring Group (EMG), and emerging initiatives such as the Water Crisis Coalition (WCC). Trade unions, and activists coalesced to protest water tariffs and restrictions whilst advancing a wider political stand against water privatization and neoliberal policies[74]. Moreover, campaigns that were (re)reframed around water conservation gained momentum, and succeeded in protecting farming land (and Cape Flats Aquifer) from rezoning[75] and in reclaiming water springs from South African Breweries[71].

Author contributions

M.R. and G.M. conceived the study. The writing of the manuscript was led by M.R. with substantive input from G.M. and E.S. Fieldwork in Maputo and data analysis was conducted by M.R. with substantial contribution by A.B., whilst field work in and data analysis of Cape town was undertaken by E. S. Tables and graphs have been developed by G.M., E.S., M.R and G.D.B. and final editing has been done by all authors.

Competing interests

The authors declare no competing interests.

Additional information

No additional information.

References

1. Rusca, M., Messori, G. & Di Baldassarre, G. Scenarios of human responses to unprecedented social-environmental extreme events. *Earths Future* **9**, e2020EF001911 (2021).
2. Musemwa, M. Coping with water scarcity: The social and environmental impact of the1982-1992 droughts on Makokoba Township, Bulawayo, Zimbabwe. in *African Cities* 157–185 (Brill, 2009).
3. Kaika, M. Constructing scarcity and sensationalising water politics: 170 days that shook Athens. *Antipode* **35**, 919–954 (2003).
4. Satur, P. & Lindsay, J. Social inequality and water use in Australian cities: the social gradient in domestic water use. *Local Environ.* **25**, 351–364 (2020).
5. March, H. & Sauri, D. When sustainable may not mean just: a critical interpretation of urban water consumption decline in Barcelona. *Local Environ.* **22**, 523–535 (2017).
6. Rusca, M., Alda-Vidal, C., Hordijk, M. & Kral, N. Bathing without water, and other stories of everyday hygiene practices and risk perception in urban low-income areas: The case of Lilongwe, Malawi. *Environ. Urban.* **29**, 533–550 (2017).
7. Rusca, M., Boakye-Ansah, A. S., Loftus, A., Ferrero, G. & Van Der Zaag, P. An interdisciplinary political ecology of drinking water quality. Exploring socio-ecological inequalities in Lilongwe's water supply network. *Geoforum* **84**, 138–146 (2017).
8. Savelli, E., Rusca, M., Cloke, H. & Di Baldassarre, G. Don't blame the rain: Social power and the 2015-2017 drought in Cape Town. *J. Hydrol.* 125953 (2021) doi:10.1016/j.jhydrol.2020.125953.
9. Truelove, Y. (Re-) Conceptualizing water inequality in Delhi, India through a feminist political ecology framework. *Geoforum* **42**, 143–152 (2011).

10. Anand, N. *Hydraulic City : Water and the Infrastructures of Citizenship in Mumbai*. (Duke University Press, 2017).
11. Brewis, A. *et al.* Community hygiene norm violators are consistently stigmatized: Evidence from four global sites and implications for sanitation interventions. *Soc. Sci. Med.* **220**, 12–21 (2019).
12. Sultana, F. Gendered Waters, Poisoned Wells: Political Ecology of the Arsenic Crisis in Bangladesh. *Fluid Bonds Views Gend. Water* (2006).
13. Sultana, F. Fluid lives: subjectivities, gender and water in rural Bangladesh. *Gend. Place Cult.* **16**, 427–444 (2009).
14. Harris, L., Kleiber, D., Goldin, J., Darkwah, A. & Morinville, C. Intersections of gender and water: comparative approaches to everyday gendered negotiations of water access in underserved areas of Accra, Ghana and Cape Town, South Africa. *J. Gend. Stud.* **26**, 561–582 (2017).
15. Wutich, A. Intrahousehold disparities in women and men's experiences of water insecurity and emotional distress in urban Bolivia. *Med. Anthropol. Q.* **23**, 436–454 (2009).
16. Brewis, A., Workman, C., Wutich, A., Jepson, W. & Young, S. Household water insecurity is strongly associated with food insecurity: Evidence from 27 sites in low- and middle-income countries. *Am. J. Hum. Biol.* **32**, e23309 (2020).
17. Young, S. L. *et al.* The Household Water InSecurity Experiences (HWISE) Scale: development and validation of a household water insecurity measure for low-income and middle-income countries. *BMJ Glob. Health* **4**, e001750 (2019).
18. Drysdale, R. E., Bob, U. & Moshabela, M. Socio-economic Determinants of Increasing Household Food Insecurity during and after a Drought in the District of iLembe, South Africa. *Ecol. Food Nutr.* **60**, 25–43 (2021).

19. Swyngedouw, E. Power, nature, and the city. The conquest of water and the political ecology of urbanization in Guayaquil, Ecuador: 1880–1990. *Environ. Plan. A* **29**, 311–332 (1997).

20. Giglioli, I. & Swyngedouw, E. Let's drink to the great thirst! Water and the politics of fractured techno-natures in Sicily. *Int. J. Urban Reg. Res.* **32**, 392–414 (2008).

21. Tiwale, S., Rusca, M. & Zwarteveen, M. The power of pipes: Mapping urban water inequities through the material properties of networked water infrastructures-The case of Lilongwe, Malawi. *Water Altern.* **11**, 314–335 (2018).

22. Björkman, L. *Pipe politics, contested waters*. (Duke University Press, 2015).

23. Millington, N. Producing water scarcity in São Paulo, Brazil: The 2014-2015 water crisis and the binding politics of infrastructure. *Polit. Geogr.* **65**, 26–34 (2018).

24. Schwartz, K., Tutusaus Luque, M., Rusca, M. & Ahlers, R. (In) formality: the meshwork of water service provisioning. *Wiley Interdiscip. Rev. Water* **2**, 31–36 (2015).

25. Ahlers, R., Perez Güida, V., Rusca, M. & Schwartz, K. Unleashing entrepreneurs or controlling unruly providers? The formalisation of small-scale water providers in Greater Maputo, Mozambique. *J. Dev. Stud.* **49**, 470–482 (2013).

26. Pihljak, L. H., Rusca, M., Alda-Vidal, C. & Schwartz, K. Everyday practices in the production of uneven water pricing regimes in Lilongwe, Malawi. *Environ. Plan. C Polit. Space* 2399654419856021 (2019) doi:10.1177/2399654419856021.

27. Vitz, M. *A City on a Lake*. (Duke University Press, 2018).

28. Kallis, G. & Coccossis, H. Managing water for Athens: from the hydraulic to the rational growth paradigm. *Eur. Plan. Stud.* **11**, 245–261 (2003).

29. Nevarez, L. Just Wait Until There's a Drought: Mediating Environmental Crises for Urban Growth. *Antipode* **28**, 246–272 (1996).

30. Tomaz, P., Jepson, W. & Santos, J. de O. Urban Household Water Insecurity from the Margins: Perspectives from Northeast Brazil. *Prof. Geogr.* **72**, 481–498 (2020).

31. Bakker, K. J. Privatizing water, producing scarcity: The Yorkshire drought of 1995. *Econ. Geogr.* **76**, 4–27 (2000).

32. Ozan, L. A. & Alsharif, K. A. The effectiveness of water irrigation policies for residential turfgrass. *Land Use Policy* **31**, 378–384 (2013).

33. Saurií, D. Lights and Shadows of Urban Water Demand Management: The Case of the Metropolitan Region of Barcelona. *Eur. Plan. Stud.* **11**, 229–243 (2003).

34. Albiac, J., Hanemann, M., Calatrava, J., Uche, J. & Tapia, J. The rise and fall of the Ebro water transfer. *Nat. Resour. J.* 727–757 (2006).

35. Jaffee, D. & Case, R. A. Draining us dry: Scarcity discourses in contention over bottled water extraction. *Local Environ.* **23**, 485–501 (2018).

36. Cohen, D. A. The rationed city: The politics of water, housing, and land use in drought-parched São Paulo. *Public Cult.* **28**, 261–289 (2016).

37. Breyer, B., Zipper, S. C. & Qiu, J. Sociohydrological Impacts of Water Conservation Under Anthropogenic Drought in Austin, TX (USA). *Water Resour. Res.* **54**, 3062–3080 (2018).

38. Hackman, R. California drought shaming takes on a class-conscious edge. *the Guardian* (2015).

39. Milbrandt, T. Caught on camera, posted online: mediated moralities, visual politics and the case of urban 'drought-shaming'. *Vis. Stud.* **32**, 3–23 (2017).

40. Grasham, C. F., Korzenevica, M. & Charles, K. J. On considering climate resilience in urban water security: A review of the vulnerability of the urban poor in sub-Saharan Africa. *Wiley Interdiscip. Rev. Water* **6**, e1344 (2019).

41. Wutich, A. & Ragsdale, K. Water insecurity and emotional distress: coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement. *Soc. Sci. Med. 1982* **67**, 2116–2125 (2008).
42. Mehta, L. Whose scarcity? Whose property? The case of water in western India. *Land Use Policy* **24**, 654–663 (2007).
43. Rusca, M. *et al.* The Urban Metabolism of Waterborne Diseases: Variegated Citizenship, (Waste) Water Flows, and Climatic Variability in Maputo, Mozambique. *Ann. Am. Assoc. Geogr.* 1–20 (2021).
44. Alda-Vidal, C., Kooy, M. & Rusca, M. Mapping operation and maintenance: An everyday urbanism analysis of inequalities within piped water supply in Lilongwe, Malawi. *Urban Geogr.* **39**, 104–121 (2018).
45. Anand, N. Municipal disconnect: On abject water and its urban infrastructures. *Ethnography* **13**, 487–509 (2012).
46. Anand, N. PRESSURE: The PoliTechnics of Water Supply in Mumbai. *Cult. Anthropol.* **26**, 542–564 (2011).
47. Austin, K. F., Noble, M. D. & Berndt, V. K. Drying Climates and Gendered Suffering: Links Between Drought, Food Insecurity, and Women's HIV in Less-Developed Countries. *Soc. Indic. Res.* **154**, 313–334 (2021).
48. Chitonge, H. Cities Beyond Networks: The Status of Water Services for the Urban Poor in African Cities. *Afr. Stud.* **73**, 58–83 (2014).
49. Millington, N. Producing water scarcity in São Paulo, Brazil: The 2014-2015 water crisis and the binding politics of infrastructure. *Polit. Geogr.* **65**, 26–34 (2018).
50. Taylor, V., Chappells, H., Medd, W. & Trentmann, F. Drought is normal: the socio-technical evolution of drought and water demand in England and Wales, 1893–2006. *J. Hist. Geogr.* **35**, 568–591 (2009).

51. Kallis, G. Droughts. *Annu. Rev. Environ. Resour.* **33**, 85–118 (2008).

52. Heynen, N., Kaika, M. & Swyngedouw, E. *In the nature of cities: urban political ecology and the politics of urban metabolism*. vol. 3 (Taylor & Francis, 2006).

53. Rusca, M. & Schwartz, K. The paradox of cost recovery in heterogeneous municipal water supply systems: ensuring inclusiveness or exacerbating inequalities? *Habitat Int.* **73**, 101–108 (2018).

54. Kimari, W. & Ernstson, H. Imperial Remains and Imperial Invitations: Centering Race within the Contemporary Large-Scale Infrastructures of East Africa. *Antipode* **52**, 825–846 (2020).

55. Bakker, K. Neoliberalizing Nature? Market Environmentalism in Water Supply in England and Wales. *Ann. Assoc. Am. Geogr.* **95**, 542–565 (2005).

56. Lu, J., Carbone, G. J. & Grego, J. M. Uncertainty and hotspots in 21st century projections of agricultural drought from CMIP5 models. *Sci. Rep.* **9**, 1–12 (2019).

57. Maxmen, A. As Cape Town water crisis deepens, scientists prepare for ‘Day Zero’. *Nature* **554**, 13–14 (2018).

58. Biza, A., Kooy, M., Manuel, S. & Zwarteveen, M. Sanitary governmentalities: Producing and naturalizing social differentiation in Maputo City, Mozambique (1887–2017). *Environ. Plan. E Nat. Space* 2514848621996583 (2021) doi:10.1177/2514848621996583.

59. Jenkins, P. City profile: Maputo. *Cities* **17**, 207–218 (2000).

60. Vicente-Serrano, S. M., Beguería, S. & López-Moreno, J. I. A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. *J. Clim.* **23**, 1696–1718 (2010).

61. Vicente-Serrano, S. M., Beguería, S., López-Moreno, J. I., Angulo, M. & El Kenawy, A. A new global 0.5 gridded dataset (1901–2006) of a multiscalar drought index:

comparison with current drought index datasets based on the Palmer Drought Severity Index. *J. Hydrometeorol.* **11**, 1033–1043 (2010).

62. CSAG. *The Big Six Monitor Database from the Climate System Analysis Group CSAG*. https://cip.csag.uct.ac.za/monitoring/bigsix.html (https://cip.csag.uct.ac.za/monitoring/bigsix.html z).

63. Notisso, P. F. Aplicação do modelo weap na avaliação de alocação de água Do reservatório dos pequenos libombos, moçambique. (Universidade Federal de Goiás, 20AD).

64. AdP. *Medidas a implementar para minimização dos impactos da falta de água no sistema de abastecimento de água à Área Metropolitana de Maputo no âmbito da missão técnica da ADP a Maputo*. (2017).

65. AdeRM. *Boletim Infromativo*. (2018).

66. Rusca, M. Visualizing urban inequalities: The ethics of videography and documentary filmmaking in water research. *Wiley Interdiscip. Rev. Water* **5**, e1292 (2018).

67. Bayona-Valderrama, A., Acevedo-Guerrero, T. & Artur, C. Cities with Mosquitoes: A Political Ecology of Aedes Aegypti's Habitats. *Water Altern.* **14**, 186–203 (2021).

68. Rusca, M. *et al.* Space, state-building and the hydraulic mission: Crafting the Mozambican state. *Environ. Plan. C Polit. Space* **37**, 868–888 (2019).

69. Zuin, V. & Nicholson, M. The Impact of Pro-Poor Reforms on Consumers and the Water Utility in Maputo, Mozambique. *Water Altern.* **14**, 158–185 (2021).

70. CDD, C. para D. e D. Governo sufoca fornecedores privados que garantiram água por muitos anos nos bairros de expansão do Grande Maputo. *Política Moçambicana* vol. Year 3 (2021).

71. Robins, S. ‘Day Zero’, Hydraulic Citizenship and the Defence of the Commons in Cape Town: A Case Study of the Politics of Water and its Infrastructures (2017–2018). *J. South. Afr. Stud.* **45**, 5–29 (2019).
72. Scheba, S. & Millington, N. Crisis temporalities: Intersections between infrastructure and inequality in the Cape Town Water Crisis. *Int. J. Urban Reg. Res.* (2018).
73. WWF. Cape Town’s groundwater under the spotlight. https://africa.panda.org/?32522/Cape-Towns-groundwater-under-the-spotlight (2020).
74. Peñaloza, R. A. & Alzaté González, Laura Daniela. Day Zero: the role of social movements in the face of Cape Town’s water crisis. (Linnaeus University Master Thesis, 2019).
75. Ellis, E. Maverick Citizen: Victory in court for Philippi Horticultural Area. *Daily Maverick* https://www.dailymaverick.co.za/article/2020-02-18-victory-in-court-for-philippi-horticultural-area/ (2020).

Tables

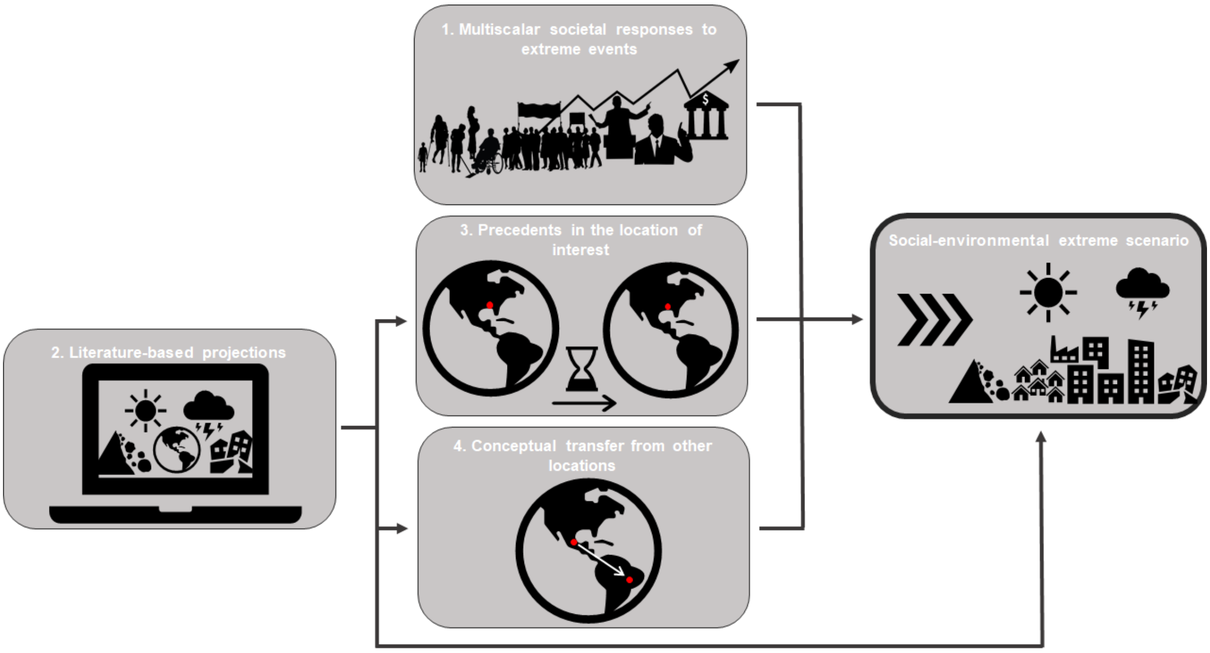

Figure S1 Schematic of the Social-Environmental Extremes Scenarios Approach[1].

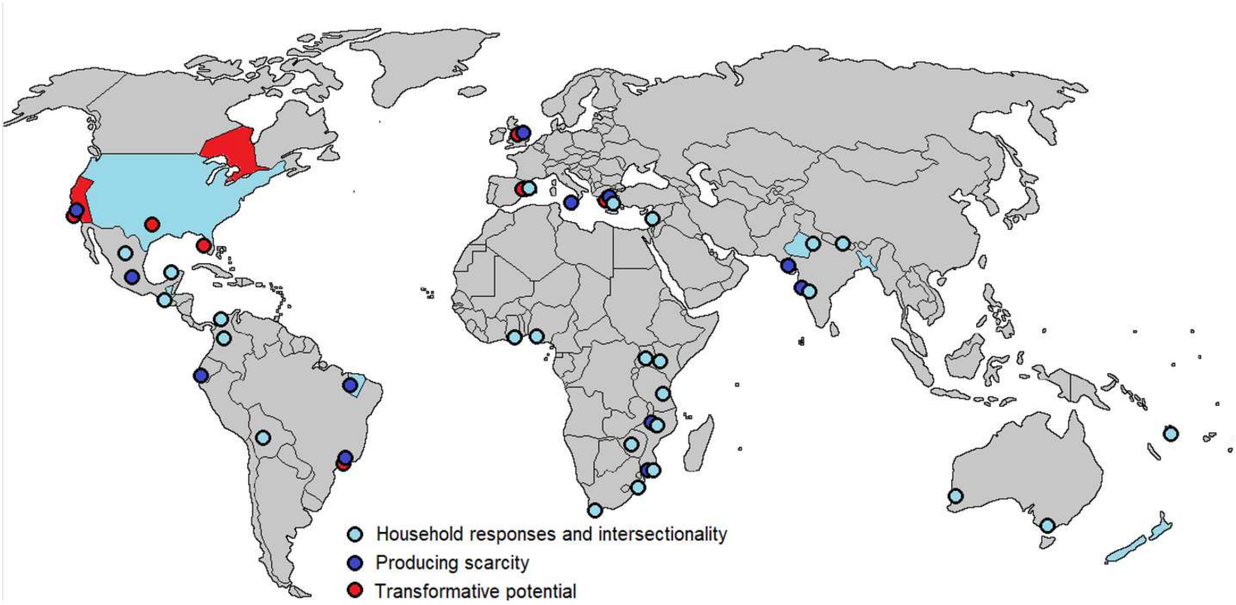

Figure S2 Map of the case studies examined for the Theoretical Synthesis (Pillar 1).

	THEORETICAL EXPLANATIONS	AUTHORS
HH 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	9,14,15,40,41
	Vulnerability is tied to the levels of water (in)security experienced before the event	3,14,42,43
	Water (in)security is also experienced by residents connected to the centralised water supply network	7,9,22,44–46
	Water shortages have a cascading effect on other urban inequalities (health, safety, food security)	2,18,47
	Water shortages have a cascading effect on gender inequalities	6,9,14,15,41
	Water rationing and demand management measures exacerbate inequalities in access to water	6,48,49
	THEORETICAL EXPLANATIONS	**AUTHORS**
Producing Scarcity	Droughts are generated by combined physical and human-produced water scarcity	42,50,51
	Uneven, exclusionary development trajectories determine unequal impacts of the drought	20,21,51–53
	Colonial segregation, racial capitalism, patriarchy shape uneven drought impacts	10,19,27,54
	Water (in)security is generated by investment priorities, housing policies, market-based water pricing regimes	21,26,27,36,49
	Development-oriented interests, politicians and water providers might profit or politically benefit from droughts	3,9,28–30
	Market-based reforms have increased vulnerability to droughts	31,55
	Water (in)security is also generated by overconsumption of water by elite users	5,8,21,32,33,42
	THEORETICAL EXPLANATIONS	**AUTHORS**
Transformative potential	Droughts are framed as a natural and unpredictable, deflecting attention from political responsibility	3,29
	Framing nature as the problem generates consent for unlimited infrastructure development and consumption	3, 28, 29, 31
	Demand management measures can pave the way to managerial approaches and privatization of water utilities	28,52
	Drought generates new coalitions and trigger multiple moral claims on water beyond its economic value	33,34,36
	Droughts intensify protests against the privatization and bottled water	35
	Powerful and affluent residents often contest and do not comply with water restrictions	28,32,32,37
	Social pressure is exerted on overconsuming users to reduce their use during droughts	38,39

Table S1 Summary of the phenomena, case study locations on authors of the studies mapped in Figure S2. The Theoretical Synthesis rests on several case studies on household responses to drought events and intersectionality, the construction of drought disasters and the transformative potential of drought events.

	THEORETICAL EXPLANATIONS	AUTHORS
HH Responses and Intersectionality	Vulnerability mediates the impacts of the drought on different social groups and individuals	All
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Table S2 Summary of findings of the Theoretical Synthesis. The table outlines the main theoretical findings on: i. Household Responses and Intersectionality; ii. Producing Scarcity; and iii. Transformative Potential of a drought.

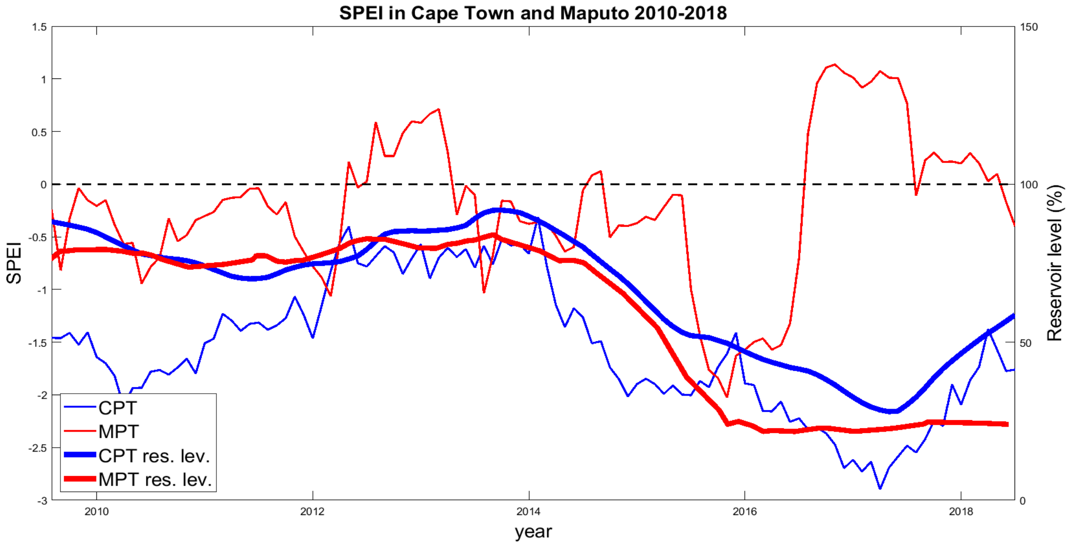

Figure S2 12-month SPEI index for the cities of Cape Town (thin blue line) and Maputo (thin red line). The thick lines show the 13-month running mean of filling levels (%) of the reservoirs supplying Cape Town[62] and Maputo[63]. The labels on the x-axis indicate the center point of each year.