frontiers | Frontiers in Water

TYPE Original Research
PUBLISHED 07 September 2022
DOI 10.3389/frwa.2022.910149

OPEN ACCESS

EDITED BY
Amy Quandt,
San Diego State University,
United States

REVIEWED BY
Brighton Austin Chunga,
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Raffaele Giordano,
National Research Council (CNR), Italy
Alessandro Pagano,
Istituto di Ricerca Sulle Acque
IRSA-CNR, Italy

*CORRESPONDENCE
Suzanne C. Walther
swalther@sandiego.edu

SPECIALTY SECTION
This article was submitted to
Water Resource Management,
a section of the journal
Frontiers in Water

RECEIVED 31 March 2022
ACCEPTED 08 August 2022
PUBLISHED 07 September 2022

CITATION
Calverley CM and Walther SC (2022)
Drought, water management, and
social equity: Analyzing Cape Town,
South Africa's water crisis.
Front. Water 4:910149.
doi: 10.3389/frwa.2022.910149

Drought, water management, and social equity: Analyzing Cape Town, South Africa's water crisis

Cameron M. Calverley and Suzanne C. Walther*

Department of Environmental and Ocean Sciences, University of San Diego, San Diego, CA, United States

Climate change impacts on hydrologic systems, coupled with increasing water demand and a growing global population, has led to depleted water resources in semi-arid regions around the world. This increase in water shortages has significant implications for environmental justice and equity concerns. One such region impacted by both water scarcity and deep-seated inequality is the Western Cape of South Africa, whose drought crisis reached peak recognition when the City of Cape Town released its notice of "Day Zero" in 2018, the day the city would turn off the taps to residents. This study examines the changes in physical factors prior to and during the 2015–2018 drought in Cape Town and evaluates how policy decisions made in response to this event interacted with existing social injustices. Analysis of the physical data finds only a slight direct relationship between rainfall and dam levels ($r^2 = 0.3$), suggesting a more complex narrative for the decrease in water supply, including increased water use and management decisions. Of the many policies implemented to avoid Day Zero, some were found to be more effective and can be utilized long-term. The study also finds that the Cape Town water crisis has unveiled and heightened existing inequalities through placing a disproportionate financial burden on low-income communities. As droughts become more common, Cape Town provides a crucial case study for understanding the social, political, and environmental implications of drought management in the future.

KEYWORDS

drought, water policy, equity, Day Zero, Cape Town

Introduction

Climate change impacts on hydrologic systems, coupled with an increasing water demand from a growing population, have led to conflict over water resources in semi-arid regions around the world. Although water is critical to human health and survival as well as economic growth and production, over a billion people in developing countries lack adequate access to water (Ziervogel et al., 2010). Global climate change will undoubtedly be a major stressor on freshwater ecosystems, especially in arid and semi-arid regions in the latter half of the twenty-first century (du Plessis, 2019).

One such region is the Western Cape of South Africa, notably Cape Town, whose water scarcity recently reached a level that significantly threatened the freshwater supply of its citizens. Low levels of rainfall led to the worst drought in the region since 1904 (Otto et al., 2018). Annual rainfall in the Western Cape had been steadily decreasing in the last few decades, with 2017 having the lowest annual rainfall since 1933 (Morabito, 2018). Past research suggests that human-caused climate change made this drought five to six times more likely to occur (Tucker, 2020). Along with low rainfall, Cape Town's water resources are also under increasing stress due to a consistently increasing population. The city's population grew from 2.4 million people in 1996 to 4 million in 2017, a 67% increase. During the same time, the dam storage capacity only increased by about 15%, and rainfall remained highly variable (Nhamo and Agyepong, 2019). This forebodes further future water supply scarcity and the viability of future water access, a crisis seen around the world as more people move to urban centers, placing pressure on the water sources supplying these cities (Parker et al., 2018).

During the 2014–2017 drought, the overall dam levels supplying Cape Town dropped from 92.5 to 23% (Nhamo and Agyepong, 2019). Cape Town's water crisis reached peak recognition when the city released its notice of "Day Zero" in January of 2018. Originally predicted to be in April 2018, Day Zero was the point when the dam levels that supply the city's water would hit 13.5%, at which time citywide water rationing would be enforced (Millington and Scheba, 2020). At that point, taps would shut off to residents and water distributed through communal standpipes, limited to 25 l per person per day, as per the World Health Organization's minimum short-term emergency survival recommendations. In part due to management decisions and several subsequent high rainfall events in the winter of 2018, "Day Zero" never became a reality, though the city strongly felt the effects of water shortage during these years. Although much of the press focused on Cape Town as a major metropolitan area, this drought affected cities across the region.

Extreme events like Day Zero could become much more common by the end of the century (Tucker, 2020). Therefore, this multi-year drought in the Western Cape can serve as an example for other water scarce cities and regions to explore their changing drought risks. As climate change hazards worsen, it is crucial to understand the physical changes up to this point, and to evaluate the strategies and adaptations the city undertook in response. This includes assessing the changes in environmental conditions, but also the political, economic, and social implications of a reduced and variable water supply. Prioritizing water resources management is necessary, as decreasing water availability in these regions could easily lead to social unrest and conflict. South Africa has undertaken significant progress in their water policy and infrastructure, which provides a unique case study of changing management decisions. Understanding the crisis in Cape Town requires recognizing the role of the governance system, as it provides the foundation for the management and accessibility of water.

Further, water resource policy and management have significant implications for environmental equity and justice. Water access and allocation are deeply social processes; therefore, to explain the Cape Town crisis, it is crucial to recognize how they intersect with social justice issues. The World Economic and Social Survey found that poor and marginalized groups would likely experience the worst impacts of future water shortages (Savelli et al., 2021). The history of water access in South Africa mirrors its political history, divided along racial and class lines. Because South Africa has such a deep history of inequity, the policy outcomes from this event may also provide a test case for the justice concerns that accompany water scarcity in other regions.

Attempts at addressing and improving water resources management is not new. In fact, since the World Summit on Sustainable Development in 1992 (Rio), the concept of Integrated Water Resource Management (IWRM), defined by the Global Water Partnership as a process promoting the coordinated development and management of water resources to maximize economic and social welfare with considerations of equity and sustainability of vital ecosystems, and what it means in practice has been the topic of extensive discussion (Hassing et al., 2009). Numerous studies present case studies of integrated approaches in water management in drought prone areas, such as Australia (Mitchell, 2006) and Mexico (Wilder and Romero Lankao, 2006). While others examine policy linkages to equity in access in Namibia and Botswana (Thomas and Twyman, 2005) and incorporating equity into policy in watersheds in Texas and Arizona (Toledo, 2021). Further, Goff (2020) evaluated indigenous and non-indigenous approaches to water management in Australia for improved equity. However, Allouche (2020) notes that a divide between integration approaches and equity in water resource management remains and calls for interdisciplinary analysis interlinking equity, sustainability, and integration. Similarly, Keeler et al. (2020) developed a general toolkit for new approaches in order to advance water equity, seen as still lacking within sustainability science. Thus, the policies put forth in water-stressed regions around the world still need to be evaluated and assessed in the context of place, culture, and people so that lessons learned can inform small (or large) adjustments to achieve the goal of IWRM.

The aim of this study is two-fold. One goal is to determine the changes in the water bodies, rainfall, water usage, and population in the Western Cape over the last decade to better understand the water shortage. These findings may inform potential future impacts in other similarly populated cities and climates. The second goal is to evaluate the water policy actions taken in response to water scarcity in Cape Town through a socio-hydrological lens to determine the viability and justice of these adaptations. This study does not provide a systemic and all-encompassing analysis of the issue of water supply or governance as a whole, but rather presents a descriptive case study intended to continue the discourse on equity in water management that can be used in future analysis and discussion of freshwater supplies affected by climate change.

Specifically, the project aims to answer the following questions:

- How did physical factors (rainfall, population, dam storage, water usage) change within the last decade at the major supply dams leading up to the 2018 Day Zero drought event in Cape Town?
- What policies, adaptations, and management decisions did the government take to avoid Day Zero? What aspects of these policies remain today that could be adapted and/or sustained long term?
- How do the present policies address equitable access to water resources, and how can future adaptations ensure water access is environmentally just?

TABLE 1 Data sources (URLs provided in Appendix A).

Variable	Spatial and temporal resolution	Data source
Rainfall data	Daily totals from six rainfall stations from 2010 to 2021	South Africa National Weather Service
Dam level data	Daily Big Six Dam totals from 2012 to 2021	City of Cape Town Open Data Portal
Aggregated data on Big Six dam levels, rainfall, and water use	Monthly averages aggregated between all six]dams, 2008–2019	Climate Systems Analysis Group
Cape Town water usage data	Monthly totals for urban and agricultural use, 2008–2019	South Africa Department of Water and Sanitation
Population data	Census totals from City of Cape Town and Western Cape region from 1996, 2001, 2011, 2016 Annual totals from the City of Cape Town 1950–2020.	South Africa census data, United Nations World Population Prospects

TABLE 2 The Big Six dams and their corresponding rainfall gauge station.

Dam name	Rainfall gauge station
Berg River	Franschhoek Robertsvlei
Steenbras Lower	Steenbras 11
Steenbras Upper	Grabouw Steenbras IV
Theewaterskloof	Rustenfein
Voelvei	Tulbagh
Wemmershoek	Stettynskloof

Materials and methods

In order to determine how physical conditions have changed in the past decade, we compiled data from various sources on rainfall, dam levels, water usage, and population growth over the specified timeframes in the Western Cape region (Table 1). After retrieving daily dam level data from the "Big Six" dams from 2012 to 2021, we selected the South African Weather Service's rainfall gauge stations that were closest to each dam (Table 2; Figure 1) and collected daily rainfall data 2010 to 2021 from those stations. To examine the relationship between these two variables, we calculated a regression analysis of rainfall and dam storage using monthly dam level averages and monthly rainfall totals (to account for the large variability in daily data), considering an approximated three month lag time that was identified as a best fit after exploring multiple timeframes.

Using ArcGIS 10.9 (ESRI, 2021), these various dam locations and rainfall stations were spatially analyzed in comparison to secondary and quaternary catchment areas, as well as water management areas, to identify spatial differences in physical factors as they relate to water management (Figure 1). Further, we examined the rainfall-dam level relationship between each of the dams.

Monthly water usage data for 2008–2019, aggregated between all six dams, and urban and agricultural use were graphed together to visualize the trends in water consumption over the past decade. Next, population data for the Western Cape and the City of Cape Town helped to quantify how population dynamics played into water consumption during the drought years. Finally, in order to determine connections to climate change, we reviewed the literature, including data that support the linkages between drought, water scarcity, and global climate trends.

For the policy and adaptation portion of the study, research first included an extensive literature review of published academic articles and government reports concerning the history of water policy in South Africa and similar semi-arid regions. This involved reading policy documents from South African law, including the post-apartheid water acts and the policy measures taken in response to the 2015–2018 drought. This also included collecting data from publications analyzing the environmental implications of these laws and other water laws in similar semi-arid regions. After compiling qualitative data on the management techniques implemented in 2015–2018 leading up to "Day Zero," we categorized the techniques as either temporary emergency measures or long-term policy changes. Next, we determined which of these policies remain today, and analyzed the long-term water infrastructure plans for Cape Town. Lastly, we reviewed the literature analyzing these policies

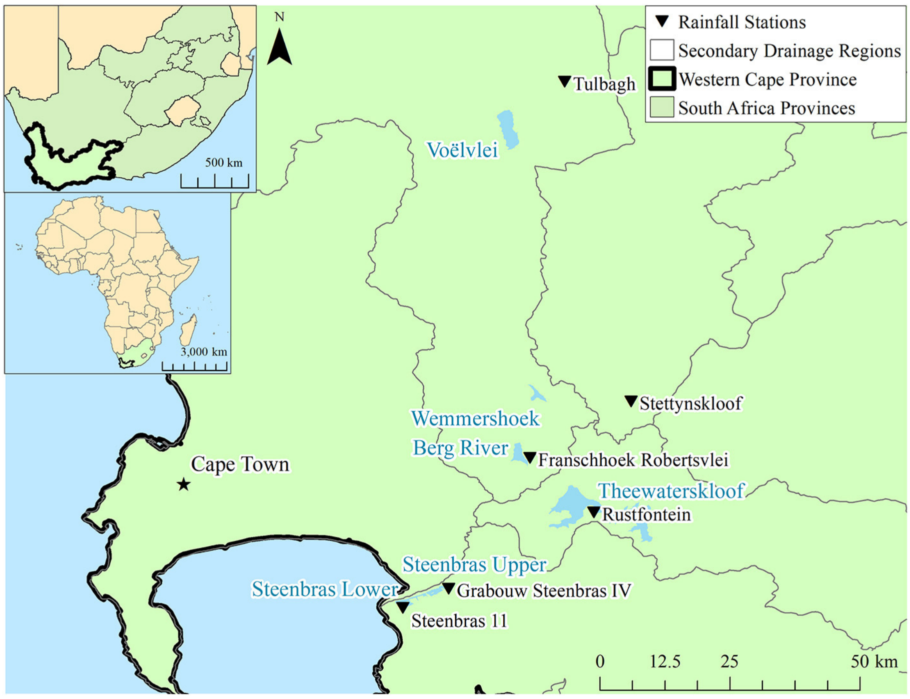

FIGURE 1
Big Six dams and rainfall gauge stations in comparison to secondary catchment areas in the Western Cape.

that identified which techniques were most successful and/or helpful in avoiding "Day Zero." Assessing the effectiveness of each policy consisted of reviewing analysis from past studies that examined each measure in detail, as well as reviewing the longevity of each action taken. It is crucial to consider the socioeconomic, institutional, and technological context of the policies taken, and while a number of these studies took into account some of these factors, we evaluated each measure through a holistic lens, following the framework of Integrated Water Resource Management (IWRM) and researching the history of each of these contexts in regards to each policy. This study is unique in that while several studies, cited in the introduction, evaluated policies similarly, those cases focused on specific projects or were not addressing a specific, intense drought event.

Evaluating Cape Town's management and policy actions provided an important opportunity to address equity issues in climate change adaptation, and to analyze whether the "Day Zero" responses to water scarcity could be implemented or adapted for long term use given these equity concerns. We reviewed articles, research, and testimony to determine how "Day Zero" policies affected different social groups and analyzed the policy measures through a social justice lens. From the findings, we summarized policies implemented and considered them through an environmental justice and equity perspective using the myriad of solutions offered by other studies.

This study begins with a background on the impacts of climate change on semi-arid regions, with detail on the Western Cape climate and water infrastructure system in order to establish the broader significance of the study, followed by an analysis of the possible factors of the water shortage based on the physical data. Next, the analysis of Day Zero policies identifies, first, their ability to curb overall consumption and, second, their long-term viability. A brief history of South African water policy as background on the current state of water infrastructure leads into a social analysis of past and current water policy in Cape Town. Using the results and analyses, some possible solutions for future water management are suggested to promote a more just and sustainable system. The study ends with conclusions on the Cape Town situation as well as implications for the broader region and other semi-arid areas.

Background

Water stress in semi-arid regions

Water scarcity is an urgent issue for countless communities around the world, especially in arid and semi-arid regions. In 2014, estimates showed one in four large cities were water stressed due to geographical or financial limitations (Brühl et al., 2020). Climate change will undoubtedly further exacerbate issues of water supply and availability, as droughts continue to shrink water supplies and urban populations further increase water demand (Environmental Protection Agency (EPA), 2019). The land area of semi-arid regions is expanding with climate change, which will increase the populations that are prone to water-related crises (Huang et al., 2016). With global temperature rise, projected droughts in these regions become extreme due to enhanced evaporation and lower amounts of precipitation (Huang et al., 2016).

Semi-arid regions are sensitive to changes made by human activities. Concurrently, these regions often support large human populations, who rely on rain-fed agriculture to survive; therefore, slight changes in precipitation patterns could significantly affect the livelihoods of those communities (Liu and Xia, 2004). Furthermore, a significant driver of water stress will come from population growth and development (Eales, 2011b). The UN estimates that cities will be home to an additional 2.5 billion people by 2050, 90% of which will be concentrated in Asia and Africa (Brühl et al., 2020). Given this increase, the impact of climate change on water resources in these regions will be especially severe, affecting a significant portion of the global population.

The Western Cape climate

South Africa is no exception to the changes brought on by climate change. Past studies found that the country has seen a warming trend of 0.16°C per decade since 1951 (South African Weather Service, 2021). The annual average temperature in South Africa for 2020 was around 0.5°C higher than the 1981–2010 average. Looking long-term, the estimated national trend for temperature increase is around 1.6°C, higher than the average global trend (South African Weather Service, 2021). In fact, predictions suggest that Southern Africa will face climate change and urbanization at a faster rate than most other places (Enqvist and Ziervogel, 2019).

South Africa, broadly considered as a semi-arid region, sits under the high-pressure belt in the mid latitudes of the Southern Hemisphere, which is generally unfavorable for the formation of rain. The country's topography results in higher rainfall in the southeast, broadly decreasing in a westerly and northerly direction. The country's precipitation patterns experience a large amount of temporal variability, with the dry western areas such as Western Cape experiencing the most variation. The country as a whole is largely a summer rainfall region; however, the west coast, including Cape Town, receives more winter rainfall than other areas (van Rooyen et al., 2011). Large variations in rainfall result in even larger variations in river flow, that therefore require storage to provide for residents year-round. Overall, South Africa has characteristically low levels of rainfall, high levels of evaporation, a low rainfall to runoff ratio, and both

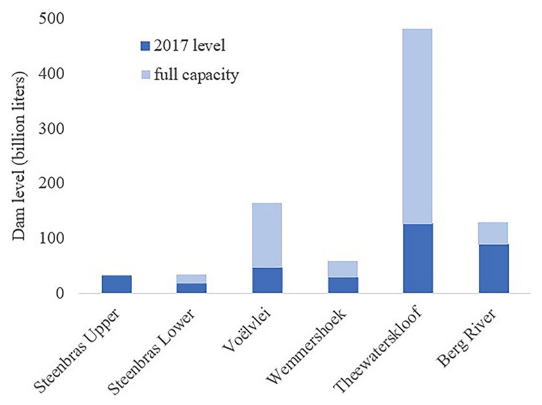

FIGURE 2
Total capacities (light blue) and 2017 levels (dark blue) of the Big Six dams that supply Cape Town, South Africa.

a spatial and temporal variation in water availability (Moseki et al., 2010). The country's average annual rainfall of 490 mm is much lower than the global annual average of 814 mm, while the average rate of potential evaporation is more than three times its rainfall (Edmond, 2019). Although South Africa is considered a water-scarce country, at the macro-level in 2011 there was sufficient water available for socio-economic development, but it is not distributed equitably across the nation (Moseki et al., 2010).

In this study, the area of focus is the Western Cape, which includes the major metropolitan city of Cape Town (Figure 1). The Western Cape's main catchment areas are the mountains to the East/Northeast of Cape Town, where rainfall is highest. Most of the rain in that region comes from winter cold fronts in the Atlantic (City of Cape Town, 2018). Fourteen dams, controlled and managed by the Western Cape Water Supply System (WCWSS), source the Western Cape. Six of these dams provide a majority of the water (referred to as the "Big Six" in publications and media). These six dams, which will be the focus of this study, include the Theewaterskloof Dam, the Berg River Dam, the Wemmershoek Dam, the Upper and Lower Steenbras Dams, and the Voelvlei Dam (Figure 1). The Theewaterskloof Dam is by far the largest dam, with a larger capacity than the other 13 dams in the system combined (Figure 2). The remaining eight dams not listed are much smaller than these six, and only contribute 0.4% to total capacity (City of Cape Town, 2018). Cape Town sources about 95% of their water from the WCWSS, accounting for $\sim$ 64% of the total WCWSS drinking water. The uses for the other WCWSS sourced water include agriculture (29%) and other municipal purposes (7%) (City of Cape Town, 2018).

The WCWSS system helps the region optimize their water resources by allowing for the transfer of water between dams and catchment systems. For example, if one dam is running low, another dam's supply can fill it, and excess water from river systems can be stored in one of the dams and then transferred back to the river in the dry season. Cape Town has twelve water treatment plants, which collectively provide a capacity of 1,600 million liters (Ml) per day. The city has 25 bulk reservoirs and over 100 smaller distribution reservoirs, which help provide treated water based on demand peaks and lags (City of Cape Town, 2018). The number of households with direct access to piped water is high in Cape Town (88%) compared to other parts of South Africa, with nearly all households having indirect water access through a public tap (Brühl et al., 2020).

This system provides service to over 4.1 million people and 650,000 properties in Cape Town, numbers that are rapidly increasing each year with population growth and migration into the urban center. In fact, there are 8,500 new customers added to this service each year (City of Cape Town, 2018). Water consumption from "formal properties" in the City is metered, and consumers are billed monthly for their water use. Average domestic consumption in 2018 was 660 L per day for households, and 460 L per day for flats and complexes (City of Cape Town, 2018). Household consumption in the city is greater than in many other metropolitan areas in South Africa.

Historical overview of South African water policy

Although the multiyear drought and climate change have certainly influenced the water crisis in the past decade, they do not tell the entire story. The political and social dimensions of water rights in South Africa influenced both the response to the drought and how it affected individuals in distinct ways. As noted by Enqvist and Ziervogel (2019), a "water crisis" is often at its roots a "governance crisis," where the institutions and infrastructure in place fail to adapt to changing conditions. Disasters such as droughts often affect people in different ways depending on their class, gender, and race, and the situation in South Africa was no exception (Grasham et al., 2019). It is not possible to analyze the drought without understanding the planning and construction of the infrastructure, and knowing who made these decisions (Mihalopoulos, 2021). Therefore, wholly understanding the water crisis in Cape Town requires a reflection on the history of water policy in order to provide important context in what led the city to this breaking point.

South Africa has a long history of water access inequalities as the country struggles with its legacy of racial segregation and inequities. The water sector in South Africa has gone through many progressive changes to attempt to remedy the largely socially unjust, environmentally destructive, and economically inefficient management practices dating back before the apartheid regime (van Koppen et al., 2011). The beginning of these harmful practices traces back to colonialism and imperialism that began in the 17th century. Racial conflict over water access began with the settlement of Cape Town (Enqvist and Ziervogel, 2019). During the period of colonization, Europeans attempted to use the agricultural rules of colonizing countries in Europe, which have very different environments, in the dry climates in Southern Africa (Dugard, 2010). Colonists exploited water and resource laws, as they had access and power when it came to controlling land, and therefore wealth (Dugard, 2010). The centuries after early colonization brought about mass resource appropriation through divide-and-rule alliances and warfare (van Koppen et al., 2011).

Broadly, colonialism led to the dispossession of most South Africans from their land and resources and introduced a long legacy of environmental racism in the country. This seizure of African resources provided a large amount of cheap labor through labor laws that ensured an exploitable Black labor force (van Koppen et al., 2011). For much of South Africa's history, racial politics determined the management of resources (Meissner et al., 2016). For example, colonists claimed that they were "predestined to possess the most fertile and temperate regions" because of the fact that they were not accustomed to the African climate, and that "the native people should be capable of living under more harsh conditions" (Darmofal, 2012). Europeans asserted that they were more deserving of these prosperous and fertile lands, which from the beginning established a sense of dominion, superiority, and racism that has influenced how South Africans interact with land and the environment today (Darmofal, 2012). Religious beliefs during colonialism, notably interpretations of Christianity, also played a large role in the way colonizers viewed their relationship to the land. One dominant Christian view during the colonial period was that of dominion over non-human nature, which led to many using resources simply for their own gain (Schuman et al., 2018).

During this colonial era, water laws often relied on water permit systems, in which required users to apply for permits, generating significant revenue for the governing colonies and putting water rights in the hands of wealthy colonists (van Koppen and Schreiner, 2018). The control of water and land by the colonial rulers displaced Black South Africans to unfertile areas that played into the growing racialized wealth inequalities that are still prevalent today. During apartheid, differential water rights and access were maintained divisions along racial lines. The apartheid government lacked a department to control and regulate universal water access; therefore, local governments ran their own infrastructures (Nnadozie, 2011). Given their lower socioeconomic status, poorer black communities had inefficient and underfunded government structures to provide clean water (Nnadozie, 2011). Water and sanitation services, primarily provided to whites, neglected informal settlements of Black South Africans (Enqvist and Ziervogel, 2019). In 1994, when Apartheid ended, an estimated 30% of South Africans did not have access to adequate water services and approximately 50% lacked access to adequate sanitation (Nnadozie, 2011).

After the apartheid era, the new neoliberal government attempted to make water access a priority as they created laws that aimed to provide water availability for all South Africans. For example, the 1994 Water Supply and Sanitation White Paper called for government subsidies for the cost of construction of basic water services (RSA, 1994). Furthermore, the 1998 National Water Act is recognized as one of the most wide-ranging and comprehensive water laws that has been passed worldwide (RSA, 1998). When these national water laws were passed in the late 1990s, they established and guaranteed water as a basic human right, which led to the formation of the free base water (FBW) program in 2001 (van Koppen et al., 2003). A baseline standard, developed by the Reconstruction and Development Program–known as the RDP standard, determined that 6,000 L of water per household of eight people per month would be sufficient–which comes out to 25 L per person per day (Calfucoy et al., 2009). They also established a maximum distance of 200 m from a source to a dwelling, and a minimum flow rate considered to be meeting the basic water standard (Department of Water Affairs Forestry, 1994). Under these laws, the national Department of Water and Sanitation acted as the main regulating body, the Water Boards at catchment levels would provide bulk water, and individual municipalities would deliver water and sanitation to end users (Enqvist and Ziervogel, 2019).

These national laws are highly acclaimed worldwide for providing an alternative method of managing water resources, promoting equity, and sustainability as core values in policy (Pollard and du Toit, 2019). Central to each of these acts is the concept of integrated water resource management (IWRM), defined by the Department of Water Affairs and Forestry as "a philosophy, a process and a management strategy to achieve sustainable use of resources by all stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and integrity of water resources at the catchment scale within agreed limits" (Pollard and du Toit, 2019). The National Water Act therefore focused on decentralization of water management and an increased emphasis on stakeholder engagement and consultation.

The concept of IWRM engrained in the post-apartheid water laws brought the blueprints for a system of Catchment Management Agencies (CMAs), which would be nineteen lower-level institutions in charge of managing and allocating water to individual users (Mackay, 2003). The intent of the CMAs was to ensure representation of local stakeholders in water policy decisions and management, and to guarantee that management power is not concentrated at the national level (Meissner et al., 2016). The plan aligned the CMAs with the nineteen established water management areas (WMAs), which divide the country along catchments that do not necessarily match government administrative boundaries. However, from the founding of the system in 2001 until 2012, only two CMAs have been created. Therefore, the number of planned agencies were reduced from nineteen to nine, and the boundaries of the Water Management Areas were adjusted to align with the new CMAs (Meissner et al., 2016). At present, only two of the nine CMAs are operational (Figure 3): the Inkomati-Usuthu and the Breede-Gouritz areas. The other seven CMAs are in various stages of development (Khorommbi, 2019). Cape Town falls under the Berg-Olifants CMA, which was not operational during the recent drought.

Despite the progressive water laws adopted post-apartheid, there continued to be issues with water availability and access for low-income communities. Many of the poorest households in South Africa did not have access to formal water services; therefore, they could not benefit from FBW until services were extended to them (Mackay, 2003). Although the intention of the FBW policy was to provide water to low-income households, in practice it became difficult to target poor households alone. Furthermore, in many municipalities the cost of providing FBW is greater than the resources allocated to fund it (Eales, 2011a). A successful rollout of free basic water requires significant local subsidies, or administrative support that exceeds that of the local municipality (Eales, 2011a). Most metropolitan areas have at least some capacity to manage water demands; however, many poorer or smaller towns/municipalities have varying degrees of challenges due to non-existent or dysfunctional infrastructure, low funds, and limited engineering capacity (Moseki et al., 2010). Post-apartheid, there was an inherent disconnect between national laws and local regulations, as uneven effort went into ensuring that the progressive laws and policies were enforced and complied with by local governments (Dugard, 2010). Therefore, in 2019, an estimated 37% of freshwater was lost *via* the existing urban infrastructure across the country (Edmond, 2019).

While the 1994 Water Supply and Sanitation White Paper called for subsidies of the cost of construction of services, subsidies were not available for the "operating, maintenance, or replacement costs" of these services (Dugard, 2010). This meant that when low-income communities that lacked the funds for operating and maintenance had infrastructure problems, service breakdowns and social unrest ensued (Eales, 2011a). The success of water legislation rests on the capacity to implement the resultant systems; this capacity is, in turn, limited by material and human resources, especially in technical fields such as water resource protection (Pienaar et al., 2010). The participation of citizens in the planning and overseeing of service delivery is essential but is also quite challenging in communities that have been historically excluded from local government systems in South Africa (Eales, 2011a).

Due to these issues, in 2006 just over 40% of households in the poorest 20% of the population had access to piped water in 2006 (Eales, 2011a). Because infrastructure in low-income communities was often not well-maintained or managed, water meters in these areas often over allocated water usage and

FIGURE 3
Water management areas in South Africa, with which each Catchment Management Area (CMA) would align.

added debt to thousands of Black and colored neighborhoods (Enqvist and Ziervogel, 2019). When these debts were not paid, authorities cut off the water supply to these consumers, which left some primarily Black communities without running water in 90% of the households (Enqvist and Ziervogel, 2019). The introduction of water management devices to households in 2007 helped with this issue, as it allowed for providing FBW while cutting off supply in case of leaks or excessive use (City of Cape Town, 2007). However, these devices did not forgive already accumulated water debt in these communities, and not all areas had access to these technologies.

A complex dynamic arose in the handling of water access in which a commitment to universal water availability coincided with a push toward the commercialization of water (Millington and Scheba, 2020). This issue of water governance dynamics in the post-apartheid era was deemed 'impossible terrain' by Gillian Hart, which describes a "complex, contradictory, and volatile relationship between scales of government, the need to address deep existing inequalities, and a simultaneous impetus to maintain fiscal solvency" (Millington and Scheba, 2020). This issue arises in South Africa where the local government placed in charge of water service delivery lacked the funds to do so adequately. Because of this, many local governments felt pushed toward the commercialization of these services in order to generate revenue. As water commercialization by municipal services increased throughout the country, poor communities experienced more and more water supply disconnections as they could not afford maintenance and repair (Dugard, 2010). Across South Africa, and especially in the urban cities where privatization occurred, water is less of a public service and more of a product allocated to maximize profits (Dugard, 2010). Despite its proposed intent to increase water access, water commercialization brought with it a "white urban-industrial water economy," serving wealthier whites who could afford privatized water (van Koppen et al., 2011). These issues left white urban areas with water services comparable to those in well-developed countries, and poor black townships with poor management and a lack of infrastructure (van Koppen et al., 2011).

Therefore, although FBW was made into law to provide water for low-income residents, the commercialization and lack of capacity of local governments led to the opposite, where low-income townships had less access to FBW (Millington and Scheba, 2020). Additionally, FBW often was insufficient for those low-income residents who managed to receive it. For example, the government in Cape Town has a *per household* per month water allowance, which failed to account for larger or multi-generational households, number of dependents, illnesses, or other factors that may disproportionately discriminate against poor urban areas (Dugard, 2010). With many households having large numbers of people, and many families struggling with HIV/AIDS, the FBW allowance was insufficient to meet basic needs and caused residents to forgo basic hygiene and health (Dugard, 2010). Water supply either cuts off automatically after the allocated amount runs out unless residents pay for additional water, an option many cannot afford. This

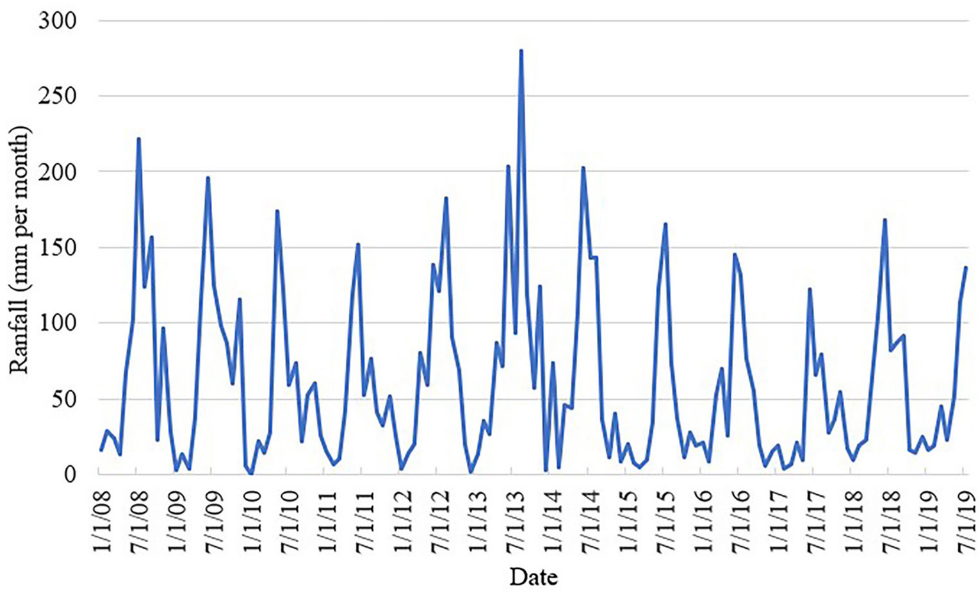

FIGURE 4
"Big Six" monthly rainfall from 2008 to 2019.

process therefore tends to punish low-income groups, as these households typically have higher than average number of individual residents. Similarly, those communities whose water did not automatically terminate often did not have individually metered water supplies, therefore each household was billed a monthly flat rate amount that was too high for the majority of households (Dugard, 2010).

Ultimately, the post-apartheid laws leading up to Day Zero, although well intentioned, arose in a system with historical socio-economic and racial inequalities. In 2017, South Africa had the highest Gini coefficient, a measure of wealth disparity, of the 154 countries surveyed by the World Bank, reflecting the deep-seated inequalities in the country (Sieff, 2018). Ten percent of the South African population owns over 90 percent of the wealth and this wealth inequality is broadly divided along racial lines, with white people more concentrated in wealthy areas (Sieff, 2018). The legacies of colonialism and apartheid have left a deep-rooted racial inequality that still affects the distribution of wealth today. This racial wealth gap has meant that Black people in the country have unequal access to water compared to White people, even decades after the passing of post-apartheid laws.

Given this inequality, a significant portion of Cape Town's poor citizens' access water *via* a communal tap. Therefore, a sort of "Day Zero" remains a constant reality for many residents. Formal households consume 66% of the City's water, whereas informal settlements, where 14% of households in Cape Town are living, use only 4% (Ziervogel, 2019). The average daily water consumption for units in informal settlements is 40 L per day, and these units can often host up to 15 residents (Savelli et al., 2021). There is a wide difference between the water consumption of high-income and low-income residents in Cape Town. For example, some neighborhoods consume between 774 and 8,560 L per person per day, lower middle-class neighborhoods average between 90 and 350 L per person per day, and informal settlements average around 10 L per person per day (Savelli et al., 2021). Therefore, while water access has increased in the past few decades, water use still divides along socio-economic and racial lines.

Results

Physical changes

Analysis of physical factors indicate no single driver of the water shortage event, but rather that a combination of factors drove the "Day Zero" event in Cape Town. Each of the physical factors examined played a role in the water shortage event in 2018, including rainfall, water use, and population. For example, average rainfall in the Big Six dams over the 2015–2017 drought was 45.11 mm/month, a 34.5% decrease from the pre-draft monthly average (2008–2014) (Figure 4). There were no observed differences in rainfall within different catchment areas. The regression analysis of monthly rainfall and dam levels at each of the Big Six dams over an 11 year period yielded a slight positive relationship (R^2 values ranged between 0.26 and 0.43) (Table 3). This indicates that at the Big Six dams, 26–43% of the dam level can be explained by rainfall

TABLE 3 Daily rainfall/dam level regression (R^2) values at Big Six dams from 2010 to 2021 (using a 3-month lag time).

Dam Location	R^2 Value
Berg River	0.27
Steenbras Lower	0.43
Steenbras Upper	0.26
Theewaterskloof	0.26
Voelvei	0.28
Wemmershoek	0.32

in the three months prior (Figure 5). This leaves 57–74% based on other factors. These factors may consist of both physical changes, including temperature, runoff, and evaporation, and human influences, such as dam management and changes in water usage. When the Big Six dams were aggregated to account for local geographic variability, there was also a slight positive relationship between monthly rainfall and dam levels ($R^2 = 0.30$).

Spatially, there were only slight differences observed between dam levels in different catchments or in different water management areas. The Steenbras Upper dam's water levels were highest during the drought. The Theewaterskloof and Voelvlei dams' levels were the lowest, the two dams with the highest capacities. The relationship between rainfall and dam levels were also lowest at these high-capacity dams, and highest at the Steenbras Lower dam, which has a relatively small capacity (Table 3), indicating other influences on the dam storage at high-capacity locations. Steenbras Upper Dam also had a low correlation between rainfall and dam levels, although this dam has one of the lowest capacities.

In evaluating other factors influencing water levels, agricultural water use peaked (2016) one year after urban water use (2015), both during years of drought (Figure 6). Urban and agricultural water use has been decreasing since 2016, with a slight increase in urban water use in 2019 compared to the year prior (Figure 7). The population in both the Western Cape and in Cape Town has been steadily increasing for the past several decades, with Cape Town's population averaging an annual increase of 2.6% over the drought period (2015–2017) (Figure 8).

Policy implications

The City of Cape Town utilized a variety of different tactics in their attempt to curb water use during the drought period, especially as "Day Zero" drew nearer (Table 4). The city developed the Critical Water Shortages Disaster Plan in October 2017, which included three phases of water rationing, disaster restrictions, and disaster implementation. These tactics can be categorized into either temporary limitations and restrictions in response to the threat of emergency, which have been largely discontinued since the avoidance of "Day Zero," or long-term policy improvements that can be sustainably adapted and implemented going forward. Short-term emergency measures included water restrictions on urban use by way of water management devices, water pressure regulations, and eventually quotas on water use after the announcement of "Day Zero". Water management devices set a daily limit of water for individuals' properties, and steadily reduced water pressure in municipal pipes (Parks et al., 2019). Short-term measures also included a number of communication campaigns, including mobile apps that provided water saving tools and incentives, a water map to show heavy-users, and the scare-tactic education campaign revolving around "Day Zero." The city also collaborated with the University of Cape Town to develop a map that acknowledged the households saving the most water as a tool for positive reinforcement (Martinus and Naur, 2020). Additionally, hard quotas on water use were set for the nearby agricultural sector in 2018, which allowed more water transfer to the city, with some water brought in from other regions in South Africa to supplement the supply. Finally, water tariffs increased temporarily, and the free basic water policy ended for all households not considered indigent (as defined by the government) (Millington and Scheba, 2020). These measures were undertaken and defined by the City of Cape Town's Department of Water and Sanitation, which took the primary role in Cape Town's water management during the crisis.

In contrast, there were certain measures used in response to the water shortage that are still in use and/or can be adapted for long-term use. These include better water management and infrastructure, including the implementation of smart water meters in schools, increased data monitoring, and a weekly water dashboard released by the city to keep residents informed on the status of dams and water usage. Long-term measures also include an increased investment in diverse new water sources, including desalination and groundwater. Although the new tariff system continued past the drought period, as of November of 2020 tariffs are back to pre-drought levels. Additionally, there are new permanent water saving regulations in the city. These include restrictions on outdoor water use, such as only allowing watering during certain hours and regulating the positioning of sprinkler systems, maximum flow rates for showerheads and washbasins, recycling and re-use for car washes, mandates for swimming pool covers, and regulations on water use for construction sites (City of Cape Town, 2020b). These measures were carried out by the city government and have been added to the City of Cape Town water bylaw. The extent to which these regulations were or are still enforced by the city government is not entirely clear.

In May of 2019, in response to the "Day Zero" event and the ongoing regional drought, the city approved the Cape Town Water Strategy. This strategy outlines the city's path toward a "sustainable water future," which considers impacts due to climate change. The plan makes five main

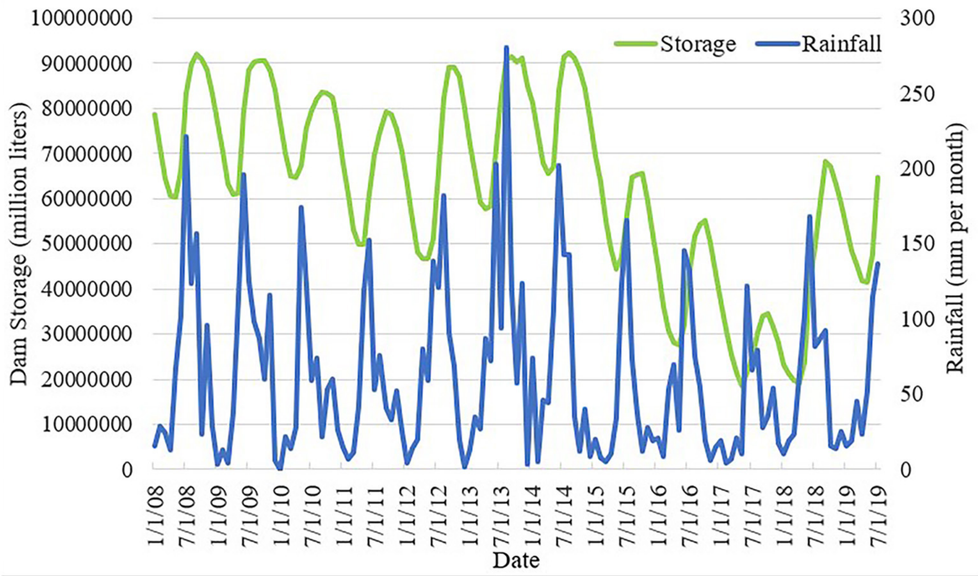

FIGURE 5
Big Six-monthly rainfall and dam levels from 2008 to 2019 ($R^2 = 0.30$ with a 3-month lag-time).

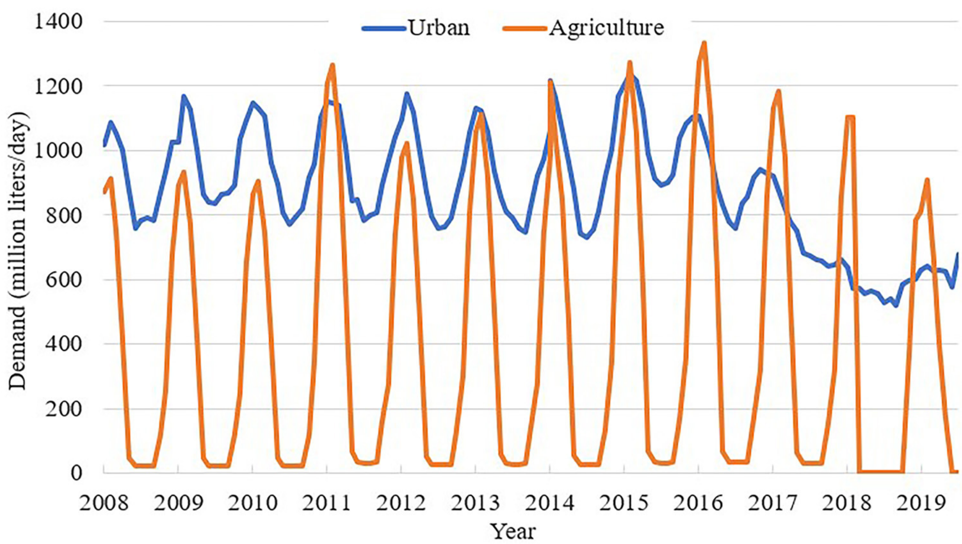

FIGURE 6
"Big Six" urban and agricultural water use 2008–2019.

commitments to their citizens: Safe access to water and sanitation, wise water use, sufficient reliable water from diverse sources, shared benefits from regional water resources, and becoming an overall water-sensitive city. The vision for the city is to "(optimize) and integrate the management of water resources to improve resilience, competitiveness and livability for the prosperity of its people" by 2040 (City of Cape Town, 2019). The city claims that through their investments in new water sources, which include wastewater, desalination, and groundwater, there will only be a slight increase in cost, still making water costs per month much less than the cost of a water bottle. As of 2019, water resources were 96% sourced from surface water and 4% from groundwater. In the water strategy, they plan to grow desalination to 11% of the resource

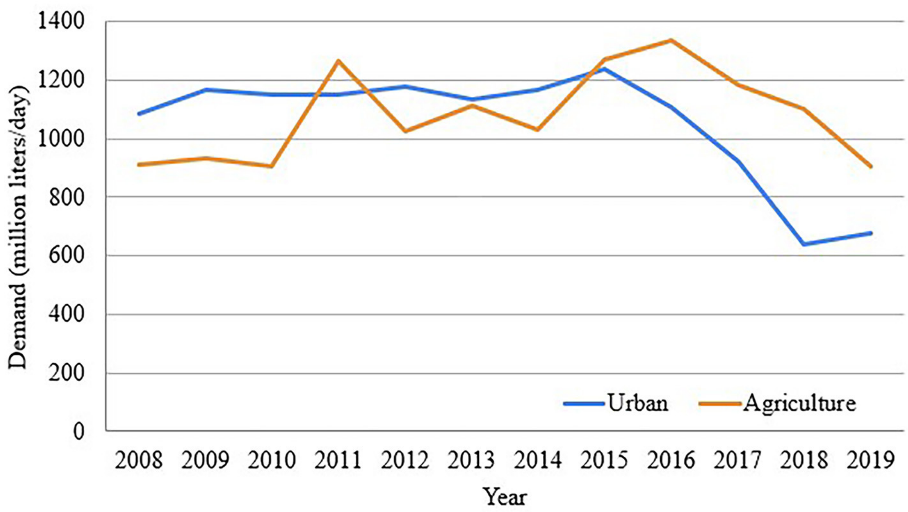

FIGURE 7
"Big Six" dams monthly peak water use from 2008 to 2019.

supply, increase groundwater to 7%, and source 7% through recapture for industrial, commercial and landscaping uses, and aquifer recharge. Today, the city continues to monitor their water levels daily, and remains conscious of where water use occurs.

Discussion

Physical changes

Given that there was weak positive correlation in rainfall and dam levels at each of the Big Six dams, it appears that more factors contributed to the water shortage in Cape Town beyond simply a decrease in rainfall. Many factors could affect this link, including evaporation, runoff, increased water usage, and dam management (e.g., dam water release policies). For example, a past study found that in South Africa the large variations in rainfall result in greater variations of river flow due to the typical lack of soil moisture in need of replenishment. This means that much of the rainfall does not likely reach each dam due to this soil replenishment (van Koppen et al., 2011).

Moreover, two different governing entities manage the dams in the WCWSS. The National DWS manages the three largest dams in the system—Theewaterskloof, Berg River, and Voelvei (City of Cape Town, 2020a). The City of Cape Town is responsible for the other three: the Steenbras Upper and Lower, and Wemmershoek. Steenbras Upper typically maintains as full a level as possible, as this dam provides water to a large area and runs the Steenbras hydroelectric power station. This strict management explains why this dam storage had such a low correlation with rainfall. The Steenbras Upper Dam also received augmentation during the drought years from another region in South Africa, which justifies why its storage levels were so high while the rest of the "Big Six" dropped to such low levels during the drought. The overall differences in management at each of these dams likely contributed to the differences in R^2 values.

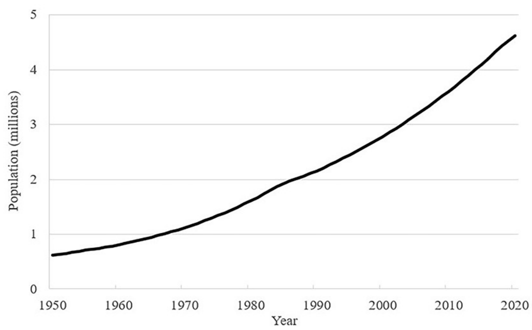

FIGURE 8
Cape Town population from 1950 to 2020 (www.macrotrends.net). According to census data, the percent increase in Cape Town's population mirrors that of the Western Cape between 1996–2016 (Statistics South Africa, 2016).

The City of Cape Town (2020a) reported that dam levels drop from water use by agriculture, the city, and other municipalities, as well as evaporation. The high-capacity dams, such as Theewaterskloof, cover a large surface area, therefore greater evaporation at these dams can alter the relationship between rainfall and dam storage. The increase in both

TABLE 4 City of Cape Town measures put into place in 2017/2018 to avoid "Day Zero."

Temporary measures – limitations/restrictions	Long term measures – Policy improvements and/or efficiency
Water restrictions	**Continued water management**
- Water management devices (no longer in use)	- Smart water meters implementation
- Reduced water pressure	- Dam level monitoring, weekly water dashboard
- Enforcement of prohibitions on heavy users	
Communication campaigns	**Investment in new water sources**
- Behavioral nudges	- Desalination, Groundwater, Water recycling and re-use, Aquifer recharge
- Mobile apps	
- City-wide water map	
Agricultural restrictions	**Reformed tariff system**
- Hard quotas to agricultural water use introduced	- Lowest (no restriction) tariff is in effect from November 1, 2020
Temporary tariff increases	**Permanent water restrictions/regulations**
- Free allocation of water removed for non-indigent households, and a fixed monthly connection charge introduced	- Outdoor water use and groundwater - Efficiency of taps, toilets and showers - Swimming pools, car washes, construction sites

agricultural and urban water use at the beginning of the drought in the Big Six dams would indicate that consumption habits also contributed to the drop in water levels. Further, the steady increase in Cape Town and Western Cape population suggest that dam storage will likely be under increased stress going forward as more urban users tap into these resources, regardless of rainfall patterns. Overall, these physical analyses indicate that while a decrease in rainfall was a driver of the water shortage, it was not the sole cause of the crisis. Media throughout the drought event focused heavily on the drought (i.e., lack of rainfall) as the instigator of the shortage; however, this was just one aspect of a complex dynamic. When evaluating water management going forward, it is crucial to not only consider rainfall, but to monitor the other factors as well. This highlights the importance of water policy in adapting to climate change, as successful management can have a significant impact on dam levels (water supply) despite the precipitation in a given year.

Policy implications

Overall, the management decisions employed to avoid "Day Zero" were successful in curbing consumption and allowing the city to prevent further temporary measures, such as turning off residential water taps and bringing in water from sources outside the Western Cape. "Day Zero" never came to be in part due to these consumption reductions. Dam levels have been rising since 2019 and have stabilized above 95% in the past few years. While there were a wide range of policy techniques used to accomplish this, some measures were more impactful than others. Several studies indicate that residents responded most actively to the communication campaigns put out by the city, including the publication of the City's Disaster Plan, the threat of "Day Zero," and the publication of neighborhood water use (Matikinca et al., 2020; Visser et al., 2021). Among the methods of water restrictions, tariffs, and communication campaigns, the Day Zero campaign ranked highest in raising awareness of the issue, and water restrictions ranked highest in terms of encouraging water savings at the household level (Matikinca et al., 2020).

Results of these studies indicate that water tariffs did not have a significant impact on water consumption, but rather that non-pricing mechanisms were more effective in encouraging consumption change. This has important implications for water governance techniques in Cape Town and other drought-prone regions going forward, as prioritizing social pressures and restrictions on heavy users seem to be effective in managing consumption in the future, while pricing mechanisms are less so. However, while behavioral interventions were very effective in reducing water use, this may be diminished by inadequate water infrastructure to implement these solutions, as this requires significant funding (Visser et al., 2021). The long-term impact of these policies on consumption patterns will be seen in the next few years, as these restrictions have since been lifted, and communication campaigns have slowed since Day Zero was avoided.

Social impacts

Day Zero policies and equity

When the government introduced the "Day Zero" plans to handle the water crisis, the management steps seemed to solve the issue and appeared to be beneficial to the common good of the city. For example, the city ramped up water tariffs to place limits on water use of heavy users. Additionally, the city prohibited use of municipal water for lawns, swimming pools, and other non-essential uses. The government also put a water-pressure system into effect that reduced water flow, which cut down on about 10% of municipal water consumption (Alexander, 2019). In this system, the city adjusts the water flow through the reticulation network when an area is using above the daily limit of water and restores the pressure when water usage reduces back to below the daily limit.

However, after analyzing the policies in respect to the existing inequalities in the city, these measures made it even more difficult for certain neighborhoods and income levels to access drinkable water. The policies failed to resolve the contradictory water governance dynamics, but rather displaced the effects onto future generations and harmed already marginalized residents. The techniques used throughout the drought, although they succeeded in reducing consumption levels overall, primarily focused on reducing consumption of wealthier residents, which historically provided the tariff funds that served to cross-subsidize the usage of the poorer communities (Millington and Scheba, 2020). In fact, the city lost an estimated R6.1 billion in revenue due to reduced water consumption during the drought (Brühl et al., 2020). The fees and water management devices placed on high-volume users were controversial, as 10 ML saved per day would cost the city 40% of its revenues (Enqvist and Ziervogel, 2019). This highlights a contradiction in the water governance system, in the government having a commitment to equitable water distribution while also trying to ensure full cost recovery. This drought exposed one of the flaws of the current tariff system, as sufficient revenues are reliant on the overuse of water by wealthy residents. With the tariff increases during the drought, since low-volume users had less room to reduce their consumption, they had to bear a higher-than-normal water bill while high-income households paid the same due to their consumption decreases (Enqvist and Ziervogel, 2019). Further, during a drought revenue is lost due to the necessary reduction in usage. Thus, development of a tariff/rate structure that better balances fixed and variable costs with marginal pricing is needed, along with investigating other potential sources of revenue so that the basic functions of the system are consistently funded. Consumption habits changed more due to communication campaigns and restrictions than tariff increases (Matikinca et al., 2020; Visser et al., 2021), proving this policy change was both ineffective and unequitable.

Furthermore, when the city withdrew the universal FBW provision, those who did not quite qualify as being indigent or were unable to register therefore had to pay new high tariffs for all water and had water management devices installed. The process for registering as an indigent household is difficult, especially for poor residents. Many households fail to register as indigent due to lack of awareness, socioeconomic restrictions, fear, political motivations, or inconvenience (Enqvist and Ziervogel, 2019). Therefore, this decision caused many low-income families to have to pay higher tariffs than they were accustomed to pre-drought. The lowest tariff water price bracket increased by 600% in February of 2018 (Brühl et al., 2020). While high-income households could not retain their high standards of water consumption, these low-income families could not meet their basic water needs. A 2018 report also found that the majority (64%) of water management devices were installed in poor communities rather than high-consumption homes, which was both an inefficient use of resources and placed further water stress on these low-income residents (Mlaba, 2020).

Moreover, while many wealthy residents could afford to find individual solutions to the crisis for their residence, low-income residents lacked the funds to be proactive and independent in their solutions. As many wealthy residents could afford buying large quantities of bottled water, digging wells, or buying desalination machines, poor residents were left with few options but to cut back on food to buy bottled water at inflated prices (Morabito, 2018). In fact, most of the reductions of water uses occurred because of the pursuit of alternative water sources (World Wildlife Fund, 2020). Over 60% of high-income households installed rainwater tanks on their properties during the drought (Brühl et al., 2020). This made it clear that when the public utility fails to provide the desired amount of water, wealthy private citizens will secure their own water in ways that may not be equitable or sustainable. Therefore, although water consumption by high-income residents was lower through the public utility, the drought brought further privatization and commercialization of water, which exacerbated the inequality of water access.

Overall, Cape Town's policies provide an example of the potential harms of policies created at the national level that do not establish mechanisms to accommodate and seek equity for the demographics of the local area (Nhamo and Agyepong, 2019). Despite media and government perception, water insecurity in low-income areas, both in townships and informal dwellings, was more intense than that for the middle- and upper-class areas. Once restrictions were introduced, although water consumption changes were slightly less drastic for lower income citizens, these changes lasted longer for township dwellers, while consumption habits reverted back to previous levels more quickly for the city's wealthier residents (Savelli et al., 2021). Therefore, the drought cannot be generalized as one citywide societal impact or response. Rather, the crisis revealed contradictions in water governance that has deepened existing socio-economic inequality, which may continue given the likelihood of new policies due to climate change in the near future.

Some solutions

Several limitations affected this study. With respect to the physical data, these include the lack of availability of specific spatial data to analyze the differences between management at specific dams, and the lack of data on both the history (pre-1990s) of the climate and water management in South Africa.

Due to the increased drought risk with climate change and the growing urban population in Cape Town, there is a need for continued monitoring of the Day Zero policies long term, especially their impacts on vulnerable groups, to determine the sustainability of these management decisions into the future.

Additionally, although some research exists using first-hand interviews with residents to evaluate perceptions (Matikinca et al., 2020; Savelli et al., 2021), there is a need for follow up interviews several years after the drought to better understand the effectiveness of communication campaigns, how the culture has shifted, and what residents remember from the event. We could not conduct interviews following the drought due to COVID-19 travel restrictions, limiting a full evaluation of the success and failure of the policies, intertwined with the socio-economic, institutional, and technological contexts. This ultimately affects the overall completeness of the results. In an attempt to address this, we added examples of some successful practices in other drought prone regions such as California and Australia [Cahill and Lund, 2013; California Natural Resources Agency (CNRA), 2021], including how reduction success varies depending on the type of rate structure and implementation (Zerrenner and Rambarran, 2017) and on the combination of education and awareness campaigns, water restrictions, and other development programs in Australia and Spain (Bryx and Bromberg, 2009). We hope that additional studies conduct interviews related to the short-term and long-term policies before peoples' memories begin to fade. It is clear that a combination of practices and policies are needed to be prepared for future droughts, and with this study we hope to further the discourse into these different policies so that improvements can be made.

Given the equity and sustainability issues with current water management in South Africa and the contradictions exposed through the Day Zero policy measures in Cape Town, it is clear that there needs to be a change in water governance in order to ensure justice in management practices, particularly as rainfall becomes less reliable and extreme droughts more common due to climate change. A review of existing measures and management efforts reveals several recommendations that seem well-suited to handling the crisis in Cape Town. In their analysis of South Africa's water management, Schreiner and Hassan (2011) identify three key factors that good water governance can be paired down to: "predictable, open and enlightened policy making, a professional bureaucracy acting in the public interest, and a strong civil society active in public affairs." They also identified a key challenge in water services and resource management: the translation of policy into practice, no matter how well-intentioned the legislation is at the macro-level. The 2017–2018 crisis in Cape Town emphasized these two conclusions. Using this framework, we suggest several solutions to aid Cape Town, and other drought-prone regions, in building a water governance system that considers these factors in order to withstand the impacts of climate change and increased demand going forward.

Integrated water resource management

Many of the suggestions below relate back to the idea of Integrated Water Resource Management (IWRM), as recognized in the 1998 National Water Act. One result of the post-apartheid water legislation was the formation of the previously mentioned CMAs, though most of these agencies were never established. The Cape Town drought response was worsened by many factors, including a lack of trust and collaboration between political entities and different stakeholders, issues in data monitoring and access, competition between different sectors, and an absence of expert knowledge and expertise (Munnick, 2020). These issues could be addressed at least in part by fully functional CMAs. Therefore, the completion of these agencies should be a priority. These agencies will be better equipped to respond to the needs of local residents and stakeholders, especially those impacted most by water shortage. The South Australian Environmental trend and condition report card 2018 for Water Management highlights an example of a high (86 on as of 0–100) degree of integrated water resources management and improved water allocation planning, with the implementations of water allocation plans (WAPs) in the State increasing 79% over 10 years [Department of Environment and Water (DEW), 2018]. This more integrated approach in Cape Town would include a diversification of water sources to accommodate fluctuations in rainfall, since the city is highly reliant on rain-fed dams, such as more sustainable urban drainage and capture, wastewater treatment, water reuse, water efficiency efforts, and other solutions that are mindful of adverse environmental impacts (Oral et al., 2020).

Connection between levels of government

Similarly, greater collaboration between national, provincial, and municipal levels of government, already needed prior to the drought, may have reduced or prevented many of the water management issues that occurred (Pienaar et al., 2010). During the drought, the national government was slow to react, especially regarding agricultural restrictions (Wallace, 2021). In 2015, the Western Cape provincial government requested funds from the national government for investment in water infrastructure and that they declare the Western Cape as a disaster area (Brühl et al., 2020), both were turned down. These funds, finally approved in late 2017, were not available to the provincial government at the time of greatest need. Also, as groundwater use is regulated by the national government's DWS, the city lacked the power to prevent the drilling of private boreholes (Brühl et al., 2020). The national government will continue to play a crucial role in water management given its responsibility to ensure equitable allocation of water at the broader level. Therefore, unless the city, province, and state work together to ensure that water is distributed efficiently and equitably, emergency responses will continue to be delayed and ineffective.

Increased collaboration with the public, especially vulnerable groups, to build back trust

A lack of trust between residents and government authorities was a significant issue for Cape Town during the crisis, especially given the long history of discrimination faced by black and colored residents and the failure to redress these injustices (Ziervogel, 2019). This tense relationship is one of the most needed and crucial areas for improvement for the city (Edmond, 2019). One key focus should be on building a relationship with Cape Town citizens and recognize them as legitimate stakeholders in water management. This could lead to increased citizen participation in water governance, which would help reduce resistance to water laws (House, 1999; Priscoli, 2004; Rodina, 2019). An inclusive water management will consider the experiences and needs of the vulnerable communities within its governance.

Reformed financial model

A major equity concern with the Day Zero policies was the imbalance of financial burden, through the increase in tariffs and removal of the FBW from non-indigent households that ultimately disproportionately affected low-income communities. Because low-income household usage did not contribute as significantly to the water crisis, maintaining FBW for a portion of the population based on income level could help avoid new water costs that many poorer families faced. Further, there is a need for new funding sources that do not rely on the overconsumption of wealthy residents. Enqvist and Ziervogel (2019) suggest a "rainless day fund" to help buffer tariff funds during a crisis. In some cases, a fund provides subsidies in disadvantaged communities in California (U. S. Water Alliance., 2017), with varying degrees of success (Elmer, 2021). More established long-term funding would be required to supplement tariff revenues, especially as future droughts place a strain on water resources. Needed are both an investment in water infrastructure and a reduction of water consumption by wealthy households, and the financial system should make both of these more feasible.

Continued focus on cultural shift through communication targeted at wealthy residents

With climate change likely making water scarcity more common, there ultimately needs to be a shift in the relationship that wealthy urban residents have with water. Although the communication campaigns were successful in curbing water consumption, targeted campaigns like that of "Day Zero" do not always have long-term impacts, as people tend to forget about hazards after a few years (Matikinca et al., 2020). Cape Town cannot sustain its residential water consumption, which is 35% above the global average (Heggie, 2020). While increased water rates can result in conservation in residential water consumption in similarly drought prone regions such as California, as seen in the 2021–2016 drought [California Natural Resources Agency (CNRA), 2021], and Australia (Cahill and Lund, 2013), reduction success varies for different types of rate structures (Zerrenner and Rambarran, 2017). Because tariff increases did not have a significant impact on household water consumption in this Cape Town crisis and can carry equity issues, other solutions must be found or improved. Several studies suggest that education and awareness campaigns, in combination with water restrictions, and other development programs, reduced water consumption significantly in Melbourne, Australia, and in Zaragoza, Spain, during nine- and five- year droughts, respectively (Bryx and Bromberg, 2009). While numerous urban water use efficiency and conservation actions exist, further improvement in consumption changes can come through education and a long-term mindset shift, a difficult task. However, without this paradigm shift, even with the investment into new water sources and other efficiency solutions, the country will eventually run out of drinkable water, as wealthy citizens will resume water overuse, while low-income people in the city will continue to lack affordable access to water and sanitation services.

Conclusion

There are many lessons learned from Cape Town's Day Zero event that can inform water management and decision-making of the South African government and other governments in drought-prone regions. Overall, while the response made to the water crisis in Cape Town avoided the worst-case scenario in the short-term, policies and management decisions exposed the framework of injustice that exists in water management in South Africa, and further heightened many of the existing inequalities. Future preparation for and response to water shortages need to acknowledge the implications of policy on various social groups, as well as the systemic issues that have plagued low-income communities of color over the past few decades. Governance processes designed to promote trust and collaboration between citizens and government will only be achieved through recognizing and working through the challenges that all social groups face.

Additional studies are needed to dive deeper into the impact of these policies on different social groups, different locations, and different uses. For example, water restrictions likely had a disproportionate impact on women, as domestic workers had to wash laundry by hand and travel farther for water (Wallace, 2021). And as populations are segregated spatially in different areas in and around the city, study on how the policies affected different areas could also inform future water management. Furthermore, full analysis of land use changes and agricultural water usage is needed. Approximately 30,000 agricultural jobs were lost during the drought, and production for major crops was down 20.4% from the 2017 to 2018 harvesting season (Parks et al., 2019). Research into the social impacts on these different groups, would shed light on how the drought event continues to affect vulnerable communities and necessary industry (agriculture/farming), and how these communities and farms are adapting. It is recommended that any future work on this event, and other similar events, approaches the subject through a framework of Integrated Water Resource Management (IWRM). Thus, an evaluation of policy measures should include the deeply intertwined social, economic, institutional, and technological contexts.

Perhaps most importantly, there is a need to further study the impacts of water shortage in South Africa as a whole, as the Western Cape is South Africa's most equitable province in terms of water access among social groups (Enqvist and Ziervogel, 2019). Although water infrastructure is relatively well-established in Cape Town, there is a need for increased attention given to low-income areas in other parts of the country that often have issues with water access and sanitation. In 2018, over five million South Africans lacked access to reliable drinking water and 14.1 million people lack access to safe sanitation, and less than half of households nationwide have piped water in their homes (Department of Water Sanitation, 2019).

Although the Western Cape and Cape Town were the main area of focus for "Day Zero," other parts of South Africa were hit hard by this drought and overall low water supply in the past decade. For example, in 2019, rural communities in the KwaZulu-Natal province were forced to go weeks without municipal water, while the drought kept rainfall low and 35% of municipal supply was being lost to theft and illegal connections (Heggie, 2020). The Eastern Cape similarly saw thousands of residents without water in 2019, with five municipalities declaring drought disasters. The Gauteng province, where Johannesburg and Pretoria are located, is dealing with a decreasing water supply and a rapidly increasing population, as the region's daily consumption is rising rapidly—a daily increase of 264 million gallons—while their next large dam will not be completed until 2026 (Heggie, 2020). The Northern Cape is facing serious drought implications for its agricultural sector, with hot weather and low rainfall leading to desertification, crop failures, and the wipeout of two thirds of the province's game. At least $40 million is needed in the province to alleviate the impacts of the drought and to secure the more than 60,000 jobs that are dependent on agriculture (Heggie, 2020). Finally, the Eastern Cape is currently dealing with record-level water shortages due to multi-year drought and poor management (Rakhetsi, 2021). Water scarcity is a concern all over the country and therefore must be a policy priority at all levels. Addressing the future water problem for Cape Town should be a component of the wider region, formulated as a national-scale strategy.

Lessons learned from Cape Town's water crisis have significant implications for other semi-arid regions around the globe as they learn how to manage their own regional "Day Zeros." Cape Town may have been the first major metropolitan city to almost run out of water, but undoubtedly, it will not be the last. As local and national governments plan for future water management, they can learn from the Cape Town crisis about the importance of equitable water management, clear and consistent communication with all stakeholders, and proactive adaptation to climate change. Sustainable water policy must consider all people, and disadvantaged communities cannot be left behind. Water access is a worldwide issue, and all regions must ensure that policy actions promote both long-term sustainability and social equity, and do not prioritize water access for the wealthy at the expense of the disadvantaged.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CC conceived and designed the analysis, collected the data, performed the analysis, and wrote the paper. SW conceived and designed the analysis, contributed data and analysis tools, and edited the paper. All authors contributed to the article and approved the submitted version.

Funding

Research was supported by a University of San Diego Office of Undergraduate Research travel grant to present at the 2021 Fall Association of Pacific Coast Geographers meeting where CC was awarded the Best Undergraduate Student Paper at a Regional Conference, and funding to present at 2022 American Association of Geographers Annual conference in NYC.

Acknowledgments

The authors acknowledge the University of San Diego Lost River Otters research group for fruitful discussions and input on this and related topics, especially during the pandemic. We are especially grateful to Dr. Andrew Tirrell for reviewing the manuscript prior to submission and to the reviewers for suggestions that improved the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

Appendix A Data links.

Daily rainfall: https://www.weathersa.co.za/home/aboutclimateatsaws

Daily dam levels: https://web1.capetown.gov.za/web1/opendataportal/DatasetDetail?DatasetName=Dam%20levels

Aggregated data on Big Six dam levels, rainfall, and water use: https://cip.csag.uct.ac.za/monitoring/bigsix.html

Cape Town water usage data: https://www.gov.za/sites/default/files/gcis_document/201911/national-water-and-sanitation-master-plandf.pdf

Population data: https://www.capetown.gov.za/Family%20and%20home/education-and-research-materials/data-statistics-and-research/cape-town-census;
https://population.un.org/wpp/.