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Shape of a water crisis: practitioner perspectives on urban water scarcity and 'Day Zero' in South Africa

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Abstract

The interruption of essential water services in Cape Town, foreshadowed as 'Day Zero,' is one of several recent examples of urban water scarcity connected to the language of urgent climate change. Johannesburg, with its larger and growing population and deeply enmeshed water and power infrastructures, is currently regarded as one drought away from disaster. As a result, the lessons to be learned from Cape Town are under active debate in South Africa. We used Q method to examine the structure of perspectives on urban water scarcity among South African water management practitioners. Our results illustrate distinct viewpoints differentiated by focus on corruption and politics, supply and demand systems, and social justice concerns as well as a distinct cohort of pragmatic optimists. Our analysis underscores the significance of public trust and institutional effectiveness, regardless of otherwise sound policy or infrastructure tools. As practitioners explicitly connect domains of competency to solvable and critical problems, integrated systems approaches will require deliberate interventions. Furthermore, urban water crises exacerbate and are exacerbated by existing experiences of racial and economic inequality, but this effect is masked by focus on demand management of average per capita water consumption and characterization of water scarcity as 'the new normal.'

Keywords: Cape Town; Day Zero; Q method; South Africa; Urban water; Water scarcity

Introduction

Ensuring safe, equitable and sustainable water supply is a critical global challenge. Worldwide freshwater withdrawals for agriculture, industry, and municipal use have grown at a greater rate than population, increasing nearly six-fold since 1900 to over 4 trillion cubic meters per year

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(World Bank, 2019). Even so, as much as two-thirds of the global population live under conditions of at least periodic water scarcity (Mekonnen & Hoekstra, 2016). Patterns of water availability – variability and distribution – are shifting as a function of global climate change (Milly *et al.*, 2005), and many regions are projected to experience more frequent and intense precipitation extremes, both wet and dry (IPCC, 2014). Concurrently, the increasing urbanization of the 20th century is projected to continue over the coming century (Jiang & O'Neill, 2017) with substantial implications for water-linked vulnerabilities (McDonald *et al.*, 2011). As a result of these converging trends, urban areas worldwide are facing the actual or imminent interruption of essential water services – a crisis termed 'Day Zero' in Cape Town, South Africa.

Along with Athens, São Paulo, Chennai, and Mexico City, Cape Town is among the most recent major urban centers to face a 'Day Zero.' Scarcity in Cape Town escalated across 2016, 2017, and 2018, culminating in highly publicized conservation measures, usage restrictions, and re-allocations, which in combination with 2018 winter rains forestalled the actual interruption of essential water services. In the process, Cape Town garnered national and international attention as a high-profile case of urban scarcity and adaptation planning. Experiences of scarcity within the City were varied, with ongoing public opposition to the form, scope, and efficacy of government interventions, critical examination of the 'Day Zero' narrative, and intense political fallout over culpability (Visser, 2018; Enqvist & Ziervogel, 2019; Vogel & Olivier, 2019). Competing problem definitions have been promoted along the way, centered on different aspects of the water system and with different implications in terms of valid and appropriate solutions (e.g. Muller, 2018; Wolski *et al.*, 2018). Against this backdrop, Cape Town is not alone among South African urban centers facing substantial water supply risks. The conurbation of Gauteng, centered in the metropolitan municipalities of Johannesburg, Ekurhuleni, and Tshwane, is itself one drought away from a devastating scarcity scenario. Lessons learned in Cape Town, and the utility of the 'Day Zero' framing, remain significant in this context.

Risk of interruption of essential water supply cannot be ascribed solely to the biophysical system – to meteorological or hydrological drought – even where the effects of anthropogenic climate change are manifest. Risk of a 'Day Zero' is instead the product of synergistic natural and social factors interacting across scales. While each city is unique in the details leading to any given scarcity crisis, many cities share some attributes: rising population, demographic or economic shifts that alter patterns of demand, reliance on inadequate infrastructure, changing rainfall variability, public demands for equity or efficiency, conflict between urban and rural consumptive uses, or a need to maintain environmental flows (e.g. Godinez Madrigal *et al.*, 2018; Millington, 2018). Underlying many of these drivers are technical, policymaking, or governance challenges – the domain of practitioners tasked with managing and maintaining supply.

This paper examines the structure and content of perspectives on urban water scarcity among South African water management practitioners. Our objective is to clarify how urban water scarcity challenges are understood among those tasked with developing and advancing alternatives. We focus on Cape Town's 2016–2018 crisis and evolving concerns in Johannesburg and the surrounding and interconnected Gauteng Province. In this paper, we use the term Gauteng City-Region, referring to the broader urban conurbation rather than Johannesburg alone. We then explore these perspectives in relation to the practice of water management, the water security of affected people, and prospects for equitable adaptation that advances common interests.

Context

South Africa is a semi-arid country, receiving less than 500 mm average annual rainfall (Terblanche *et al*., 2001). Patterns of precipitation vary substantially in time and space, with 60% of annual runoff originating from less than 20% of land area, and mean annual potential evaporation exceeding precipitation by a factor of at least three (le Maitre *et al*., 2018). South Africans have developed complex and extensive water supply systems in response to these conditions. Surface water sources comprise the vast majority of South Africa's supply, delivered through articulation networks that include trans-basin and international transfers.

South African water institutions are an expression of this context – technocratic, with an emphasis on expert management and engineered solution-building. Primary authority over water resources sits at the national level with the Department of Water and Sanitation (DWS), which has jurisdiction over bulk infrastructure and allocation decisions across catchment and metropolitan authorities, which are responsible for water treatment and end-user delivery as well as conservation and demand management. During scarcity, DWS sets supply restrictions, while implementation and enforcement are largely the purview of local and catchment authorities. This structure has engendered a complex and sometimes fraught cooperative governance landscape (Jonker *et al*., 2010).

Following democratization in 1994, South Africa's constitution (Section 24) enshrined the principle of guaranteed access to water – a policy expanded and implemented through the National Water Services Act (RSA, 1997) and National Water Act (RSA, 1998) and known as Free Basic Water (FBW). Water service providers in South Africa largely operate according to a cost-recovery model with tariffs expected to cover the cost of supply and service delivery, often with a 'block tariff' (inclining block rate) structure such that high-volume users pay more to subsidize low-volume users and infrastructure. In practice, revenues are typically insufficient to cover operational costs, particularly rehabilitation and repair of infrastructure (e.g. McKenzie, 2014; Ziervogel, 2019). Access to water and water services has manifold significance in this context, implicated in experiences of equity and justice, health and wellbeing, and diverse ecosystem-linked values, including agriculture and tourism economies.

Water in Cape Town

The City of Cape Town sits at the foot of Table Mountain on South Africa's southwestern coast (Figure 1), with suburbs extending across the coastal plain to north and east, transitioning to a mosaic of agricultural lands and protected uplands containing the six rain-fed reservoirs that comprise over 95% of the City's water supply (CoCT, 2017a). Cape Town is the economic hub of Western Cape Province, a global tourism destination, and the center of South Africa's wine industry.

Access to water has played a focal role in human settlement and land use in Cape Town, and successive centuries of policy and practice have largely functioned to serve the White population while limiting access among peoples indigenous to the Cape, other Africans, and descendants of slaves brought from South Asia (Enqvist & Ziervogel, 2019). Water and sanitation service delivery to non-White communities was heavily circumscribed during Apartheid. Acts of protest against the perceived inadequacies of water services and infrastructure accelerated through the 1980s, and severe drought in the Cape in the early 1990s underscored the human ramifications of a water system predicated on the interests of White South Africans and white-owned commercial agriculture (Vogel & Olivier, 2019).

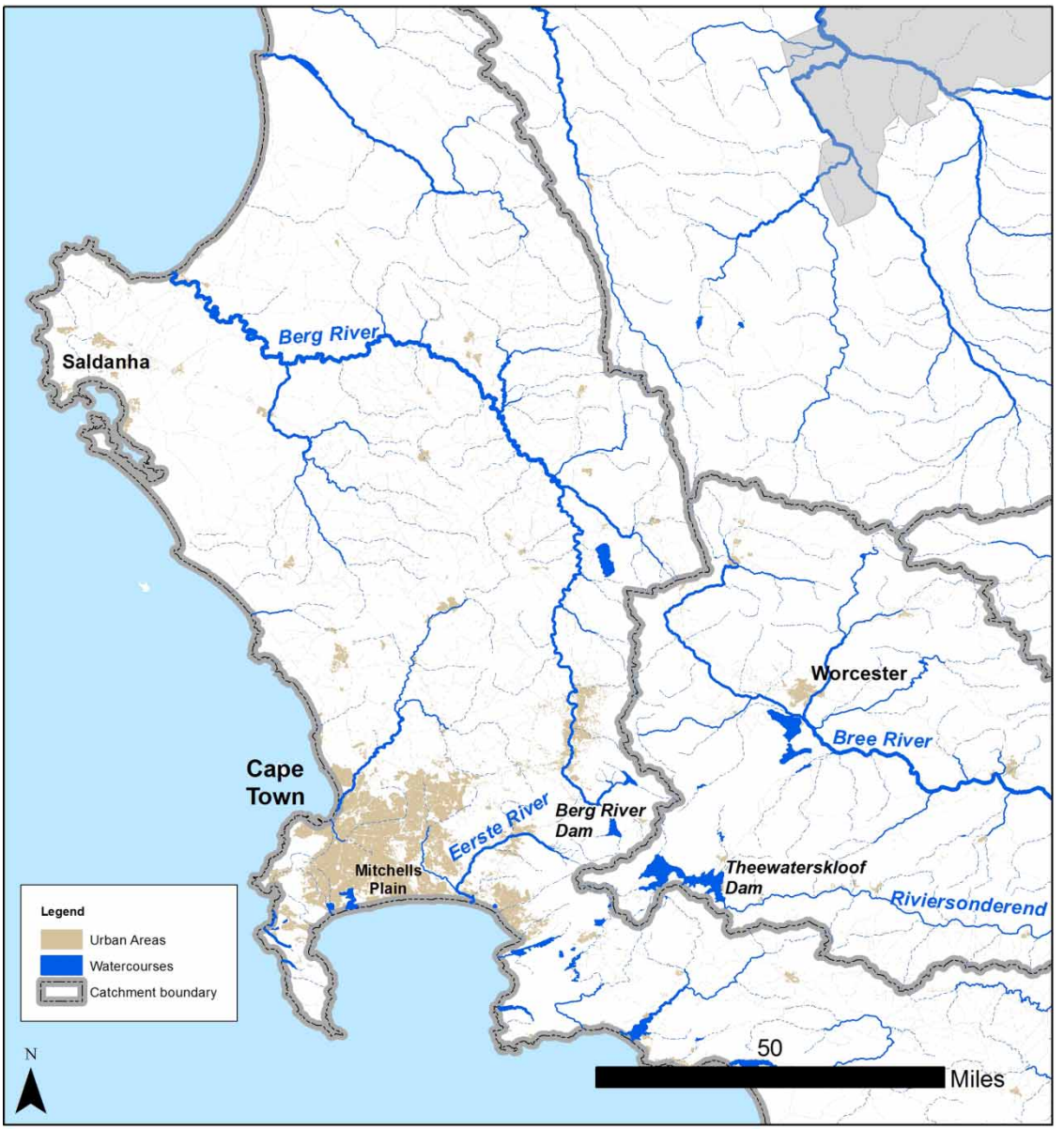

Fig. 1. Cape Town urban footprint with primary catchment boundaries and principal watercourses.

Access to water is more equitable in the region surrounding Cape Town than in many other areas of South Africa (Cole *et al.*, 2017). Nonetheless, economic inequality is very high and access to water services comparatively low in suburban townships and informal settlements outside the City core. While 86% of households citywide have piped water in the dwelling and 9% access piped water within 200 m of the dwelling, distribution of access and proportion of use is uneven; only 35% of residents in the predominately non-White suburb of Khayelitsha have access to water within the dwelling (Beck

et al., 2016; CoCT, 2017a). Water in this context is closely implicated in broader patterns of racial and economic inequality. Public perceptions of scarcity – and of demand management and conservation interventions – are shaped by this history.

Bulk supply to Cape Town is delivered through the Western Cape Water Supply System (WCWSS), with an unconstrained system allocation of approximately 570 million m^3, providing an unconstrained daily supply of nearly 1,350 million liters per day for more than 3.8 million people in Cape Town, adjacent municipalities, and to irrigators along the Berg, Eerste, and Riviersonderend rivers – an area generating approximately 14% of national GDP (CoCT, 2017b, 2018). In 2018, 77% of WCWSS water was allocated to urban use, with the remainder going to agriculture.

Reliance on rain-fed reservoirs for bulk supply means Cape Town is almost entirely dependent on winter season precipitation runoff, characterized by low-frequency, high amplitude variability. There is no statistically significant rainfall trend in the catchments supplying WCWSS, but significant increasing and accelerating trends in temperature have been documented over recent decades (Kruger & Nxumalo, 2017; Lynch & Bischoff-Mattson, 2018). Evaporative loss is expected to increase and soil moisture expected to decrease as a result, conditioning runoff water availability in any given year regardless of rainfall.

Water in Gauteng City-Region

Gauteng is the smallest province in South Africa by land area but contains the country's largest urban agglomeration (Figure 2), with over 15 million residents in the metropolitan municipalities of Johannesburg, Ekhuruleni, and Tshwane; satellite towns; and informal settlements (StatsSA, 2018). An ongoing process of consolidation has merged the physical, economic, and social fabric of these centers, which now form the urban core of the 18,000 km^2 province. Gauteng City-Region straddles the Witwatersrand, a scarp on the Highveld of South Africa's central plateau that forms the continental watershed divide. Water draining northward flows into the Indian Ocean via the Limpopo catchment, while water draining southward flows into the Atlantic Ocean via the Orange and Vaal catchments.

Early development in Gauteng was driven by mining, and the socioeconomic and environmental ramifications of this history are pervasive. Gauteng City-Region currently generates around 37% of South Africa's national GDP and is the country's financial, commercial, industrial, and government hub (Gauteng Provincial Government, 2019). It experiences a higher rate of in-migration than any other urban area in South Africa, with the projected population growth of more than 25% in the next decade. Increasing domestic and industrial water use has driven substantial environmental degradation, compounded by acid mine drainage, poorly managed and inadequate wastewater treatment infrastructure, and direct pollution into rivers and wetlands (GDARD, 2011).

Like Cape Town, Gauteng City-Region is characterized by high rates of poverty and inequality, and access to water services is shaped by entrenched patterns of racial segregation. Over 90% of Gauteng City-Region households have access to piped water, while 3.3% of households lack access to water that meets minimum standards for potability, and many of these residents rely on unsafe surface water sources (StatsSA, 2018). The principal challenge in Gauteng is not whether households are connected to the infrastructure network but rather the reliability and quality of service. Nearly a quarter of households (23%) report experiencing water interruptions every week or multiple times per month (de Kadt et al., 2019).

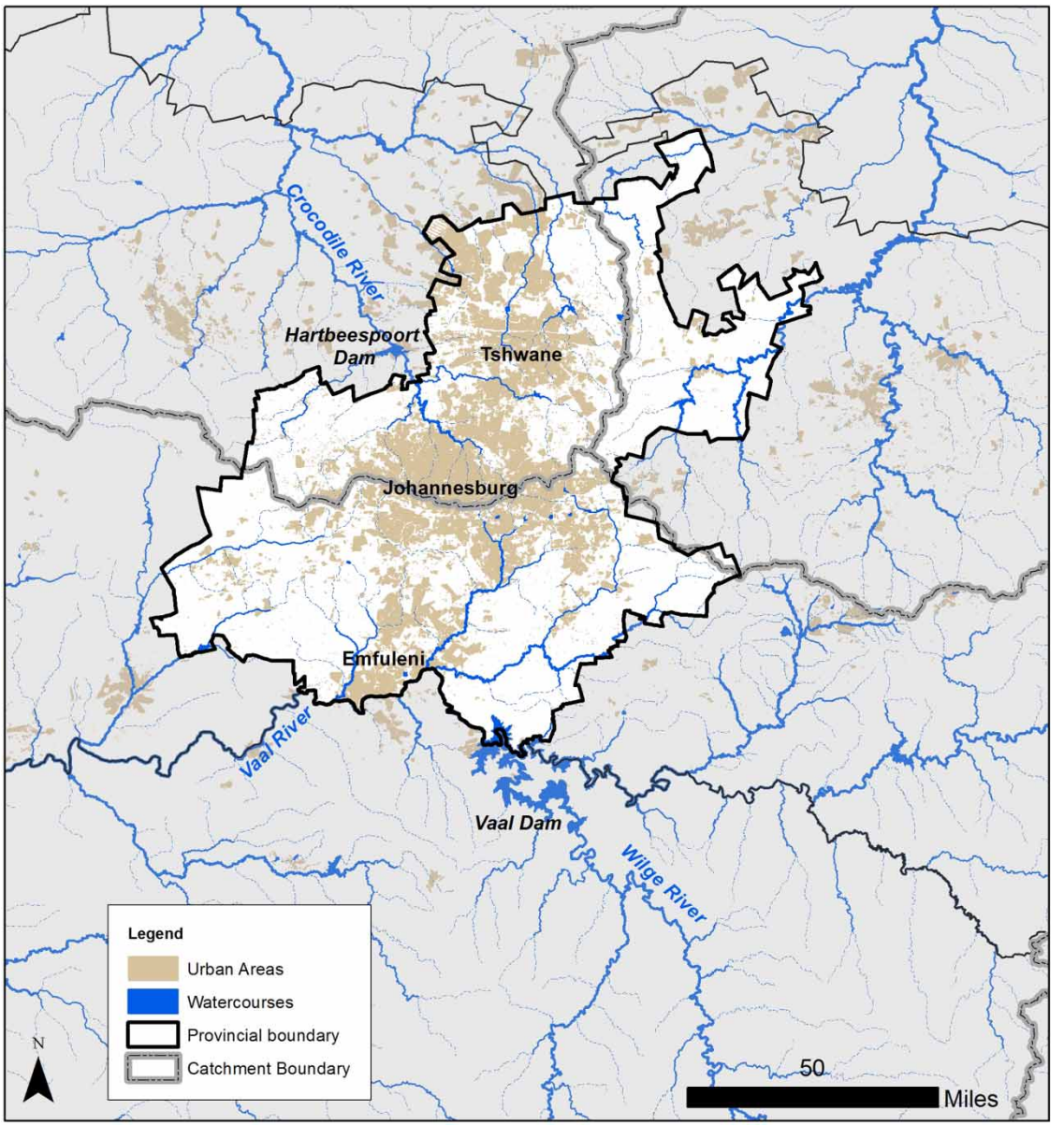

Fig. 2. Gauteng City-Region urban footprint with primary catchment boundaries and principal watercourses.

Bulk supply in Gauteng is provided through Rand Water, Africa's largest bulk water utility, via an extensive regional system of reservoirs and interbasin transfers. Most of Gauteng's potable water is supplied through the Integrated Vaal River System (IVRS), a network of rivers, dams, and bulk infrastructure connecting Gauteng to the Vaal catchment, the adjoining system of reservoirs and pipelines comprising the Lesotho Highlands Water Project, and other distant catchments within South Africa (Figure S1, Supplementary Materials). Gauteng currently obtains about 25% of its

water from Lesotho through the IVRS (DWS, 2019a). To the north, the Limpopo catchment spans four countries and comprises a smaller but strategically significant supply source, governed by a complex of interbasin agreements (Turton *et al.*, 2006). Demand is projected to increase substantially over the coming years, and plans are currently in place to extend the IVRS through the construction of a new major dam, though extended delays have pushed project timelines to 2030.

Against this backdrop, policy to address water scarcity in Gauteng City-Region and Cape Town over the last decade has largely focused on demand management and conservation rather than increased or diversified supply. This reflects a trend established by the National Water Act (RSA, 1998), which introduced conservation and demand management requirements alongside mandates for more equitable water access and broader participation in decision-making (Francis, 2005). Water management devices (WMDs) have been introduced in Gauteng City-Region and Cape Town as a means of managing demand and recovering costs, designed to provide a household's monthly FBW allocation before automatically cutting supply, historically targeted at lower-income households with high unpaid water bills (Yates & Harris, 2018). Perversely, inadequate infrastructure, poor maintenance, and pervasive leakage in non-White residential areas have frequently resulted in high metered 'use' and, by extension, inability or unwillingness among residents to pay fees (e.g. Smith, 2004). WMDs have been critiqued for their impact on proportionally low-income and low-volume per capita water users, particularly where leaking infrastructure goes unrepaired or where multiple households rely on a single WMD-capped dwelling for supply (Mahlanza *et al.*, 2016).

'Day Zero' in Cape Town

2016–2017 marked a period of intensifying urban water stress across South Africa. In the Western Cape, successive years of low rainfall and runoff translated into falling reservoir levels behind WCWSS dams: 74% of capacity at the end of the 2015 hydrological year, 62% in 2016, and 38% in 2017 (CoCT, 2019). By early 2016, the City of Cape Town and DWS imposed 20% restrictions on urban and agricultural water use – restrictions that increased steadily over the coming months, reaching 60% by January 2018.

Authoritative response to low rainfall and falling reservoirs accelerated across early 2017, culminating in a provincial declaration of emergency. By June 2017, Mayor Patricia de Lille referred to water shortage as 'the new normal' and in October, the term 'Day Zero' was first used (Visser, 2018). A citywide usage target of 500 megaliters per day was set (average daily use the prior year was greater than 1,000 megaliters or roughly 220 liters per person per day) and plans for supply augmentation were implemented, including small desalination facilities, expanded groundwater abstraction, and water recovery and recycling infrastructure (City of Cape Town, 2018). Concurrently, WMD installations were expanded, applied at the broad scale for the first time to low- *and* high-income households.

Within this context, the 'Day Zero' narrative was understood by municipal leaders as a means of shifting the tone of public communications, underscoring severity and urgency. Crucially, this functioned to reframe the scope of responsibility beyond the City government and onto individual residents (Ziervogel, 2019). Concurrently, the City launched a publicly accessible database reporting real-time individual household usage, along with citywide use and supply updates and statements on the City's actions. Public communication by the City emphasized water conservation and reuse. By January 2018, at the height of the drought, the daily individual allowance was set at 50 liters per person per day. Private efforts to augment supply among high-income households accelerated alongside tightening restrictions,

with the number of registered private boreholes rising from 1,500 to 23,000 across 2017 (Visser, 2018). In concatenation with increased tariffs, increasingly sophisticated system pressure management to reduce consumption, and intensifying community efforts to conserve water, substantial 2018 winter rains led to rising reservoir levels and, as of 2019, substantially eased water restrictions.

This crisis had extensive synergistic impacts on Cape Town and its economy (notably tourism and agriculture; e.g. Pienaar & Boonzaaier, 2018). According to some observers, severe scarcity was both predictable and avoidable – a function of insufficient supply relative to expanding population, exacerbated by deferred investment in essential infrastructure (Muller, 2017; Olivier & Xu, 2019). The primary responsibility for managing the crisis shifted between different authorities within the City. This reflected an intensely politicized operating environment as well as a perceived need for more holistic decision-making but may have eroded collaborative trust among participants (Ziervogel, 2019). Further, a siloed departmental landscape (within the City as well as across regional and national authorities) may have stifled communication and a more effective integrated response to the emerging crisis. Fractious intergovernmental relations may also have delayed access to critical resources. The Democratic Alliance (DA) is politically dominant in Cape Town and Western Cape Province, whereas the African National Congress (ANC) holds broad national power, and requests by the City for national emergency assistance were declined during the crisis. This may have been a matter of politics as well as limited available resources as a result of systemic financial mismanagement at DWS (Visser, 2018). At a local level, reduced usage as a function of demand management led to dramatic revenue shortfalls in the context of Cape Town's block tariff system, and proposals to adjust fees to recoup costs were heavily contested on the grounds they would penalize already-efficient residents. Lack of government transparency and limited substantive community involvement in decision-making emerged as substantial concerns in this broader context (Vogel & Olivier, 2019). Further, communication on demand management and supply restrictions was not consistently coordinated, frequently resulting in confusion and an erosion of confidence in government (Enqvist & Ziervogel, 2019). WMDs (re)emerged as a symbolic issue in this context – particularly where they were installed without the informed consent of residents and applied to households with relatively limited scope to reduce water use (e.g. Booysen *et al*., 2019).

Scarcity has catalyzed substantial revision of public water practices in Cape Town (Robins, 2019), though it remains unclear whether emergent community-based capacities for conservation and demand management will be sustained (Ziervogel, 2018). Within this context, different perspectives on events in Cape Town will shape adaptation pathways across South Africa. In Gauteng City-Region in late 2019, a planned two-month maintenance shutdown of the Lesotho Highlands Water tunnel system exacerbated diminishing supply due to unusually high temperatures and low rainfall. Government officials were reactive, discussing a range of measures to address ongoing scarcity, including demand management and use restrictions, new infrastructure, and groundwater development; the question of 'Day Zero,' and the efficacy of existing approaches, are under active debate (e.g. Muller, 2019).

Methods

Q method (Brown, 1980) is an approach for studying the structure of perspectives around an issue. There are as many subjectivities as there are people in a context, and Q method is an approach for orienting with tractable granularity to the diversity and complexity of those viewpoints. The empirical basis of

Q method is the Q sort, in which participants map their individual viewpoint by rank ordering a set of statements pertaining to the issue under study. The rank-ordered sorts of participants are factor analyzed, and resulting factors represent clusters of subjectivity; each factor represents a distinguishable group of viewpoints, and these results describe the latent structure of perspectives (Brown, 1993). A Q study does not describe the frequency or distribution of perspectives in a population, and results are not statistically generalizable. Unlike methods of the factor analysis that examine relationships between objective attributes, Q method examines patterns across whole individuals, providing a descriptive typology of perspectives around a given issue and context (Steelman & Maguire, 1999). A limited number of participants is appropriate (e.g. 25–60) so long as the participant sample captures sufficient diversity of perspectives (Watts & Stenner, 2012). Q method has been used to understand viewpoints across a range of water resource issues and is a useful means of exploring the interplay of policy and practice (e.g. Raadgever *et al*., 2008; Strickert *et al*., 2016; Bischoff-Mattson *et al*., 2018).

We used an online survey tool (FlashQ) to lead participants anonymously through the process of mapping their viewpoint by responding to a series of 23 statements pertaining to urban water scarcity in South Africa, with specific reference to the 2016–2018 Cape Town crisis and evolving challenges in Gauteng City-Region (Table S1, Supplementary Materials). This set of statements comprised the Q sample and was derived from the wider concourse of public debate (see below). Participants were instructed to rank order the statements according to a forced distribution from 'most disagree' to 'most agree' (Figure S2, Supplementary Materials). The use of a forced distribution aids in identifying the most strongly held elements of perspective (Brown, 1980).

Q sample

The Q sample was developed through a comprehensive review of literature and media document sources to identify thematic patterns in public statements pertaining to urban water scarcity in South Africa. Source documents included: government agency statements and reports; local and national news coverage, including opinion-editorial content; non-government organization statements and reports; and academic literature. Representative statements were recorded and then iteratively consolidated to clarify recurrent patterns and remove duplicate content. This process of consolidation yielded a set of 89 statements we judged representative of the essential breadth of public dialog. From this pool, we selected a final set of 23 – the Q sample – chosen to maximize conceptual breadth while remaining a manageable number of statements for participants to interrelate.

Participant sample and survey administration

We identified participants according to a semi-targeted sampling method, approaching practitioners involved in water resource management in South Africa and encouraging them to share a link to our survey with colleagues in their professional network. The survey was administered anonymously online, though participants were encouraged to ask clarifying questions if necessary. Online administration is typically an effective approach for Q method (Reber *et al*., 2000), and we judged that an online survey would support broad and inclusive participation given the geographic distribution of water practitioners in South Africa. The survey was open for 45 days from 29 May to 13 July 2019, and 40 survey responses were recorded. In addition to rank ordering the Q sample statements,

participants were asked to comment on the statements they reacted most strongly toward (i.e. the statements with which they agreed and disagreed most strongly), followed by a series of optional demographic questions (Table S2, Supplementary Materials).

Analysis

The purpose of our analysis was to generate a set of factors describing the latent structure of perspectives on urban water scarcity among South African water management practitioners, identify characteristic elements of each factor, and discuss functional differences in terms of policy and practice. We conducted the principal components analysis on a correlation matrix (Pearson's r) of the 40 participant Q sorts and used varimax rotation to maximize the variance between factors. We then used the normalized weighted average statement scores (Z scores) of respondents significantly associated with each factor (α 0.05) to generate model Q sorts representative of each factor, for purposes of comparison (Figures S3–S6). We extracted four factors explaining 64% cumulative variance. Interpretability was our primary criteria for factor extraction – for resulting factors to be clearly distinguishable while capturing sufficient contextual nuance and interpretive detail.

Most of our 40 participants identified as a senior manager/executive ($n = 17$) or middle manager ($n = 15$). Engineers ($n = 13$) and policy/management specialists ($n = 13$) were dominant job categories, followed by scientists ($n = 6$). The private sector ($n = 13$) was the dominant institutional affiliation, matched by the combined number of participants from the government (local government $n = 4$, provincial government $n = 3$, national government $n = 6$), followed by the research sector ($n = 6$). Categories of primary responsibility or interest were evenly distributed, and there was no discernible pattern of response *across* our demographic questions (e.g. no significant association between job category and institutional affiliation).

Results

Factor 1: corruption and politics

Factor 1 reflected a focus on corruption, mismanagement, and poor leadership; governance failures, with a characteristic emphasis on the people in power being the problem. Practitioners associated with this factor felt strongly that poor leadership and corruption are significant barriers to effective water management, particularly during times of scarcity, exacerbated by a siloed agency landscape. 'The appointed [sic] of technical staff is not based on competence, but political preferences' (participant 6200611) and 'criteria, other than aspects of excellence, are apparently utilized when appointing senior managers' (participant 7030810). As a consequence, senior managers are perceived to lack effective insight, vision, and ability to lead. Mismanagement of public finances is one of the many recognized consequences. According to these practitioners, 'political will is key to the matter' (participant 5300853) of improved leadership sufficient to provide essential 'change management [that] will be an important part of adapting to the changing circumstances of water demand (population growth, changes in living standards, food security, climate, etc.)' (participant 7030816). Perhaps by extension, urban planning and policy as currently structured were viewed as ineffectual at ensuring safe and reliable supply, and local governments are not seen to communicate effectively with communities. With these

issues in mind, political leadership was perceived to need guidance from stronger water institutions. 'The DWS should provide this function but it has been stripped of capacity and is just a shell' (participant 7030816). Perhaps given this group's focus on mismanagement and poor leadership, neither urban population growth nor climate change was seen as essential drivers of the 2018 Cape Town crisis. At a regional scale, these practitioners felt strongly that environmental regulations on extractive use should be maintained during periods of scarcity, and that the environmental impacts of expanded bulk infrastructure should be weighed carefully against benefits. Notably, these participants did not feel that agricultural water users consume an appropriate proportion of available resources. Participants associated with this factor largely identified as scientists, engineers, and consultants.

Factor 2: pragmatic optimism

Factor 2 reflected a cautiously optimistic assessment of water policy delivery, emphasizing the success of FBW but tempered by the awareness of failures in urban planning and the use of technical demand management tools. Participants associated with this factor felt strongly that FBW functions effectively to ensure essential supply; FBW is viewed as a policy that 'ensured that there was no argument about the baseline' (participant 7020255). Alternative and diversified water sources should be explored, according to this perspective, perhaps in part because inadequate bulk water infrastructure is perceived as a central contributor to the 2018 Cape Town crisis. Practitioners associated with this factor also felt strongly that environmental regulations should be set aside to ensure supply during scarcity – something that sets this factor apart from others. Climate change was not seen as a primary cause of Cape Town's crisis, and nor was urban population growth. From this perspective, population change was perceived as predictable and therefore manageable. Perhaps by extension, practitioners associated with this factor felt that Cape Town was never truly at risk of a 'Day Zero' total supply failure. These participants were actively unconcerned about power and wastewater infrastructure, generally disinterested in issues of governance, including corruption and mismanagement, and did not perceive a siloed departmental landscape as a substantial problem. Enforcement of regulations was largely seen as equitable, though participants associated with this factor felt strongly that the implementation of technical demand management tools had been ineffective. Many of the participants associated with this factor identified as senior managers or policy consultants.

Factor 3: supply and demand

Factor 3 reflected a focus on supply-demand synergies in relation to intergovernmental dysfunction and the inadequacies of existing infrastructure. Urban population growth was seen as a defining issue. 'With or without drought, the rising population (whether it be through migration, birth rate or tourism) was always a time bomb re: water supply. This point for me weighs the heaviest of all … ' (participant 7020307). However, participants were careful to note that framing scarcity as a function of population growth is fraught in the context of Apartheid history. 'This [issue of population growth] was a nice theory put forward on social media, which somehow made out that the Western Cape was not part of South Africa and those from the Eastern Cape had no right to migrate to the urban areas in search of improved livelihoods (as if Apartheid and the restrictions in the Western Cape on black migration never existed)' (participant 7020338). Further, prospects for migration ' … should have been picked up in reconciliation strategies and fed into demand scenarios' (participant 7030910). As a related

facet of their focus on demand, practitioners associated with Factor 3 also emphasized the perceived inadequacy of bulk water infrastructure and the necessity of diversified supply. 'With increasing pressure on water resources, we need [to] spread risk by having access to a diversity of water source supply types' and '… we don't recycle nearly as much water as we should' (participant 7020307). With regard to construction or expansion of reservoirs and interbasin transfers, 'decision-making is severely delayed and implementation is lacking' (participant 7030910). Perhaps by extension, these practitioners felt that existing urban planning and policy structures do not contribute sufficiently to safe and stable water access. Nor did they feel that the economic impacts of scarcity are factored sufficiently into decision-making. Intergovernmental dysfunction and limited coordination across siloed departments were perceived as overarching challenges. Lack of investment in wastewater infrastructure was a substantial concern, as to a lesser extent was an overburdened power system. While these practitioners felt that there is room for more productive communication with affected communities and for improved implementation of technical demand management tools, they felt strongly that decision-making authority should not be vested at the community level during scarcity. Participants associated with this factor largely identified as engineers and senior managers.

Factor 4: social justice

Factor 4 captured a nuanced characterization of institutional weaknesses, with a defining concern for equity and a wider framing of problems. According to practitioners associated with this factor, intergovernmental coordination failures are a crucial barrier to effectively managing scarcity, systemically amplified by lack of leadership and chronic financial mismanagement. 'Decision-making in times of crises is hampered by dysfunctional relationships between different levels of government' and the existing '… way of doing business is expensive and prone to corrupt activities' (participant 6180247). Concerning social stratification, 'serious [in]equalities in SA is a significant barrier to equitable enforcement … the poor carry a disproportionate burden' (participant 7050747). As a related issue, these practitioners felt that wealthy residents routinely circumvent restrictions, and that enforcement of demand management regulations is neither equitable nor very effective. Notably, these practitioners felt that water institutions are generally too reliant on consultants to make up for capacity gaps. Bulk water supply and urban population growth were not perceived as essential contributors to Cape Town's crisis, and these practitioners emphasized that climate change was also not the root cause. Rather, the problem is a more diffuse institutional one – a stance manifest in comments concerning equity, corruption, and incompetent leadership rather than the rejection of climate change as a phenomenon per se. Within that context, these practitioners felt that alternative water sources should be explored, that lack of investment in wastewater infrastructure is a substantial ongoing concern, and that the economic impacts of scarcity are poorly represented in decision-making. Many of the practitioners associated with this factor identified as research scientists.

Common ground

Four statements did not significantly distinguish any pair factors; these statements represent points of agreement or at least non-contention among the study participants. While practitioners associated with Factor 1 felt *most* strongly that the benefits of expanded bulk water infrastructure should be weighed carefully against environmental impacts, all participants agreed on this point. 'The environmental impact of

our decisions is not taken seriously enough' (participant 7030532), and 'we need to balance between use of resources and protection of goods and services that sustain those resources. If we develop physical water infrastructure that the country needs without regard to the green infrastructure (e.g. biodiversity) then our efforts would be unsustainable' (participant 7030645). Notably, however, stance on this issue did not track consistently with perspectives on the suspension of environmental limits on water extraction during periods of scarcity, nor did it relate uniformly to support for diversification of supply.

Notwithstanding these nuances, all participants generally agreed that diversification of supply was a good idea, though practitioners associated with Factors 2 and 3 felt most strongly that alternative water sources should be explored. 'It is not possible to provide adequate water to a growing population without the use of alternative water sources' (participant 6051207) and 'diversification of water sources is essential if we are going to build resilience into water management systems' (participant 6180247). Ultimately, 'given climatic and non-climatic stress factors, South Africa cannot rely on surface water […] alternative sources are not only necessary but economically and socially essential' (participant 7030645). In part, supply diversification was seen to provide co-benefits of raising awareness and mobilizing local problem-solving capacity. 'Bulk systems leave municipalities and communities detached from the importance of water as a resource. Alternative sources closer to home should be included in the water supply system so that local impacts on water systems are felt locally' (participant 7030816). However, key governance barriers exist and 'there has been very little done on the regulatory framework for desalinization and water reuse' (participant 6280847).

Suggestively, there was broad agreement that local governments do not communicate effectively about water scarcity with their constituent communities, though practitioners associated with Factor 1 felt most strongly about this. This is perceived as a matter of approach and timing. 'It does not come through effectively until it is 'too late'' (participant 7030953). There was also strong consensus that the implementation of technical demand management tools has been ineffective. Perceived failures relate to poor communication and outreach as well as broader structural and planning issues. 'The fact that although 95% of South Africans have piped water within 200 m of their homes only 64% have a safe reliable supply reflects a water *supply* crisis' [emphasis added] (participant 6281127) and 'efforts on leak management appear to be largely reactive, suggesting there is no plan in place' – if Johannesburg water 'is not held accountable for poor performance, then why have an agency?' (participant 7030816).

Interpretation

This survey of practitioner perspectives reveals several insights relevant to urban water scarcity in the South African context and beyond. Notably, our results suggest a worldview divide between those who ascribed problems to a variety of specific implementation issues (Factor 2 – *pragmatic optimism* and Factor 3 – *supply and demand*) and those concerned with broader governance questions (Factor 1 – *corruption and politics* and Factor 4 – *social justice*). To some extent, this reflects the South African context, where institutional capture and racial inequality dominate political discourse; we would expect these concerns to define the factor arrays.

However, the roles and affiliations of practitioners associated with each factor are suggestive of a siloing that is not unique to South Africa. For example, participants associated with the perspective that water crises result from poor governance, with critical ramifications for social justice, tended to identify

as research scientists. Participants associated with the view that infrastructure is the crux of existing water challenges tended to identify as engineers. Participants associated with the perspective that current water systems are functioning adequately tended to identify as senior managers or consultants – people with an implicit record of personal success in the existing system. That is, practitioners appeared to emphasize issues that fell within their domain of expertise or interest. While each perspective may be valid, this reflects a de facto emphasis on isolated aspects of an integrated water system and a tendency to regard that aspect as the most critical point of intervention.

Perceptions of crisis are shaped by bounded perspectives on the past behavior of a system. In the case of Cape Town, for example, many commentators emphasized that 2015 and 2017 saw the lowest annual precipitation of the past three decades (Lynch & Bischoff-Mattson, 2018). However, droughts of comparable or greater magnitude and extent are evident in long-term records, as recently as the early 1970s; many individual years over the last century were drier than 2015 or 2017. As in other contexts, perceptions of the crisis were aligned with empirical evidence but only boundedly (e.g. Lynch *et al*., 2004).

Against this backdrop, there was consensus that public communication was both reactive and slow as well as poorly targeted with too much reliance on climate change as a symbol. As a result, it was largely ineffective in the Cape Town case (Vogel & Olivier, 2019). This was ascribed to failures at all levels of government – a pattern repeated in more recent communications from national authorities in response to mounting water scarcity in Gauteng City-Region in late 2019. Water and Sanitation Minister Lindiwe Sisulu announced a forthcoming master plan for water savings in Gauteng only after the Vaal Dam was below 45% capacity and still dropping. The master plan, revealed a month later, included demand management strategies emphasizing 'stringent application of the law' under Drought Operating Rules (DWS, 2019b). This stands in contrast with, for example, the highly consultative approach taken in Melbourne, Australia, during the 1997–2009 Millennium Drought, in which over 600 public meetings resulted in an urban demand management system with such successful public uptake that no fines were ever issued for breaking water saving rules (Brunner & Lynch, 2013). This reflects a distinct social and political context, manifest in particular assumptions about community involvement in decision-making. Suggestively, some practitioners in this survey were skeptical of community-based decision-making (Factor 3 – *supply and demand*). As a result, 'effective public communication' may mean different things to different people, along a spectrum from clear and coordinated information-delivery to shared and deliberative governance.

We also encountered consensus around the perceived failures of technical demand management tools, exacerbated by this ineffective public outreach. To some practitioners, particularly those associated with Factor 4 (*social justice*), reliance on demand management tools such as WMDs appears to underscore a chronic mischaracterization of the problem. That is, a supply problem grounded in a complex climatic context, failing physical infrastructure, and ineffective institutions is misframed as a demand management problem, with substantial implications in terms of the locus of accountability. In particular, a focus on average per capita water consumption masked large disparities in access to and use of water. Further, climate change and its associated implications regarding 'the new normal' were not emphasized as a core challenge by practitioners; three of four factors actively dismissed it as a driver of the Cape Town crisis. This may also reflect practitioner sensitivity to the placement of accountability. Institutional function and the effective use of technical and policy tools are understood to transcend climate, particularly in a context where political leaders may be perceived to invoke climate change as a way of deflecting accountability for governance failures.

All participants agreed on the importance of diversified supply, and that water supply should not in principle undermine environmental values, but consensus on these themes may belie more nuanced

perspectives. For example, the degree of emphasis on expanded and diversified supply varied relative to concern for ecological impacts as well as stance on the suspension of environmental extraction limits during scarcity. Specific environmental values will inevitably need to be balanced against more immediate health and wellbeing values, but these results suggest distinct underlying assumptions about relevant thresholds and the scope of appropriate tradeoffs between supply and environment.

Conclusions

Our analysis illustrates bounded perceptions of crisis, shaped by de facto domain-specific viewpoints as well as assumptions that the form of resource management challenges will tend to remain stable. This suggests transdisciplinary and integrated systems approaches are unlikely to emerge spontaneously and will require deliberate institutional strategies (as in other contexts; e.g. Stave, 2003). In the face of future systemic shocks, from climate change or any other factor, bounded perspectives and siloed problem definitions may be a key vulnerability.

Neto *et al*. (2018) explored the OECD Principles on Water Governance by theorizing four main target areas for improving water governance: policy coherence, financing, managing tradeoffs, and ensuring integrity and transparency by decision-makers and stakeholders. Our findings align with this structure, with emphasis on two domains of key relevance to urban water scarcity in the South African context: Trust and Engagement (integrity and transparency, stakeholder engagement, and reliable monitoring and evaluation); and Effectiveness (clear roles and responsibilities, policy coherence, and functional inter-agency and inter-government relations). The crisis in Cape Town elevated public engagement around water and functioned as a boundary object around which some segments of the population were able to construct a shared narrative and revise their water practices. It *also* exacerbated existing experiences of racial and economic inequality, and illustrates the destabilizing potential for scarcity to amplify existing divisions and patterns of conflict. With this in mind, practitioner emphases on institutional dysfunction and social justice are particularly salient representations of Trust and Effectiveness concerns. A well-integrated and well-communicated institutional response grounded in shared governance is essential regardless of otherwise sound policy- and infrastructure-based strategies.

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Supplementary material

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