Understanding Water Consumption Trends Across Income Groups Before, During and After the 2015-2018 Cape Town Drought

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Abstract

This paper examines trends in household water consumption before, during and after the 2015–2018 Cape Town drought across different income groups. Using panel regression methods, the study investigates whether water consumption rebounded to pre-drought levels following the crisis and explores the key factors shaping consumption behaviour under conditions of scarcity and recovery. The empirical approach combines descriptive analysis with a static correlated random-effects model for the pre-drought period and dynamic fixed-effects models with lagged consumption for the drought and post-drought periods. Drawing on insights from the behavioural and environmental economics literature, the quantitative results are interpreted within a broader framework of habit formation and behavioural adjustment. Overall, the findings indicate that water consumption does not fully return to pre-drought levels across income groups. Income (proxied by quintile property value), seasonality, precipitation, temperature and past consumption behaviour are all found to significantly influence water use before, during and after the drought.

Plagiarism Declaration

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Introduction

Climate Change and the 2015-2018 Cape Town Drought

As a result of global warming, the world has seen a significant increase in natural disasters such as droughts in recent years (Dube et al., 2022). Droughts occur when the supply of water resources is insufficient to meet the needs of people or the environment in a manner which deviates from long-term normal conditions (Vicente-Serrano et al., 2022).

Between 2015 and 2018, the City of Cape Town (the City) experienced a drought which almost depleted its municipal water supply (Brühl & Visser, 2021). Previous studies have identified a prolonged lack of rainfall, attributed largely to global warming, as the primary cause of the drought (Pascale et al., 2020). In recent years, Southern Africa has been identified as a climate change hotspot by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 degrees Celsius. This highlights the region's heightened vulnerability to warming and drought risk (Engelbrecht et al., 2024).

Under normal conditions, Cape Town's climate is characterised by mild temperatures and an average annual rainfall of approximately 520 millimetres (Visser, 2018). Rainfall primarily occurs during winter between May and August, whilst the period from November to March is dry and marked by minimal rainfall and higher rates of evaporation (Brühl & Visser, 2021). Consequently, the City relies heavily on stored water resources to meet water demand during summer (Brühl & Visser, 2021). In 2015, however, Cape Town experienced a dry, hot summer followed by below average winter rainfall (Brühl & Visser, 2021). This pattern then persisted into 2016, exacerbating the strain on the City's water supply. As a result, between 2016 and 2017, dam levels decreased by 26%, reaching a record low in 2017 (Brühl & Visser, 2021).

Water Governance, Interventions Implemented to Conserve Water and Inequality

Even though global warming has been identified as the primary driver behind the drought, poor water management and insufficient infrastructure also played significant roles in exacerbating the crisis (Pascale et al., 2020). In Cape Town, water governance entails a complex interplay of factors which extend beyond climate change, including issues of inequality and informality, which undeniably influence resource management. Before the impact of these factors on water management can be examined, it is important to understand the legal frameworks which govern the supply and management of water in South Africa.

In South Africa, water governance is divided into two distinct areas: water resource management and water service delivery. Water resource management is regulated under the National Water Act (1998), which established water as a public resource managed by the government (Madigele, 2018). Water service delivery, on the other hand, is governed by the Water Services Act (1997), which outlines the responsibility of local government in ensuring access to basic water and sanitation services (Madigele, 2018).

The management of water resources in South Africa has changed significantly over time. Initially, water was considered private property in South Africa (Allan, 2003). However, in 1998, water was declared a public resource with the National Water Act (NWA) (Allan, 2003). In practice, water is managed at the local government level, meaning the municipalities are responsible for management and supply of water within their jurisdictions (Meissner & Jacobson, 2012). Despite this local management, emphasis remains on framing water as a common resource (Meissner & Jacobson, 2012).

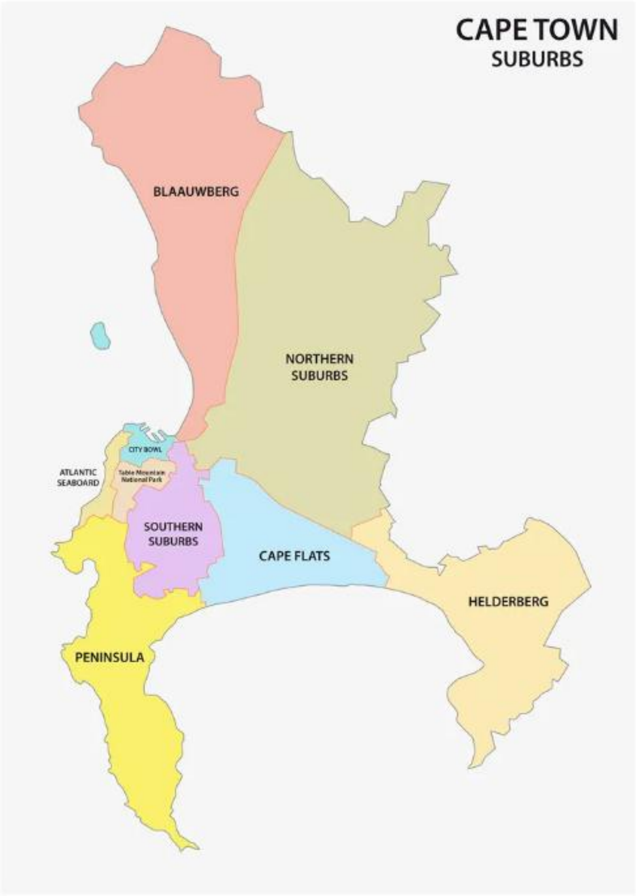
In Cape Town, the City holds the status of a Water Services Authority (WSA). This means that, under the Water Services Act, the City is legally responsible for ensuring reliable water service delivery to its residents (Madigele, 2018). Over time, the City's role as a WSA has evolved, from providing basic infrastructure post-1994 (Smith & Hanson, 2003), to implementing tariff structures and emergency drought interventions aimed at balancing equity and sustainability (Enqvist & Ziervogel, 2019).

The Department of Water Affairs and Forestry (DWAF) regulates water in Cape Town, while the City is responsible for managing water supply (Ribot & Larson, 2012). Both surface and groundwater are utilised, sourced from dams and reservoirs like Theewaterskloof, Voëlvlei, and Wemmershoek (Ribot & Larson, 2012). The water is then treated using filtration and disinfection processes before being distributed via a network of pipelines (Ribot & Larson, 2012). Groundwater from aquifers accessed via wells and boreholes further supplements the water supply (Ribot & Larson, 2012).

Water management challenges persist in South Africa, largely due to the legacy of Apartheid and its long-term impacts (Ribot & Larson, 2012). Apartheid systematically segregated racial groups, resulting in social, economic and residential inequalities (Mhuli & Salani 2015). 'Spatial Apartheid' was used to enforce segregation as different areas would be allocated for habitation by certain ethnic groups. 'Homelands' were rural areas of land created for Black people, far from the economic hub and the areas occupied by White people (Turok & Visagie, 2021). Often, Black people were forcibly removed to these 'homelands' which had little to no proper infrastructure and economic opportunities (Enqvist & van Oyen, 2022). Consequently, most people occupying these areas lived in shacks and other informal housing structures. Coloured communities were similarly relocated. However, given that they were seen as higher up in the racial hierarchy, the areas allocated to Coloured people were not as far removed, had better infrastructure and public service, and were also used as buffers between White areas and the 'homelands' (Enqvist & van Oyen, 2022; Turok & Visagie, 2021). Nonetheless, these areas still lacked sufficient infrastructure and service provision by the government (Turok & Visagie, 2021). Both Black and Coloured areas suffered from overcrowding, limited economic opportunities, and inadequate infrastructure. Examples of such areas within Cape Town include Mitchell's Plain (largely designated for Coloured people), and Khayelitsha (designated for Black occupation) (Turok & Visagie, 2021). *Figures 1 and 2* visually summarise Cape Town's suburbs and neighbourhood typologies, highlighting the spatial inequality which persists post-Apartheid.

Despite Apartheid having ended in 1994 and the post-Apartheid government implementing frameworks to redress past inequalities, inequalities persist and the long-standing effects of 'Spatial Apartheid' remain evident (Enqvist & van Oyen, 2022). The 'City Bowl', including affluent areas like the Northern Suburbs and Atlantic Sea Board, remains predominantly White, while areas like Mitchell's Plain and Khayelitsha remain impoverished and underdeveloped, and are still largely occupied by Black and Coloured communities (Enqvist & van Oyen, 2022). Informal settlements lacking basic water and sanitation infrastructure persist as vulnerable groups attempt to place themselves closer to economic opportunities, despite not having the financial means to do so formally (Turok & Visagie, 2021). These patterns highlight that historical spatial inequality continues to limit infrastructure development and service provision, particularly in overpopulated areas (Turok & Visagie, 2021).

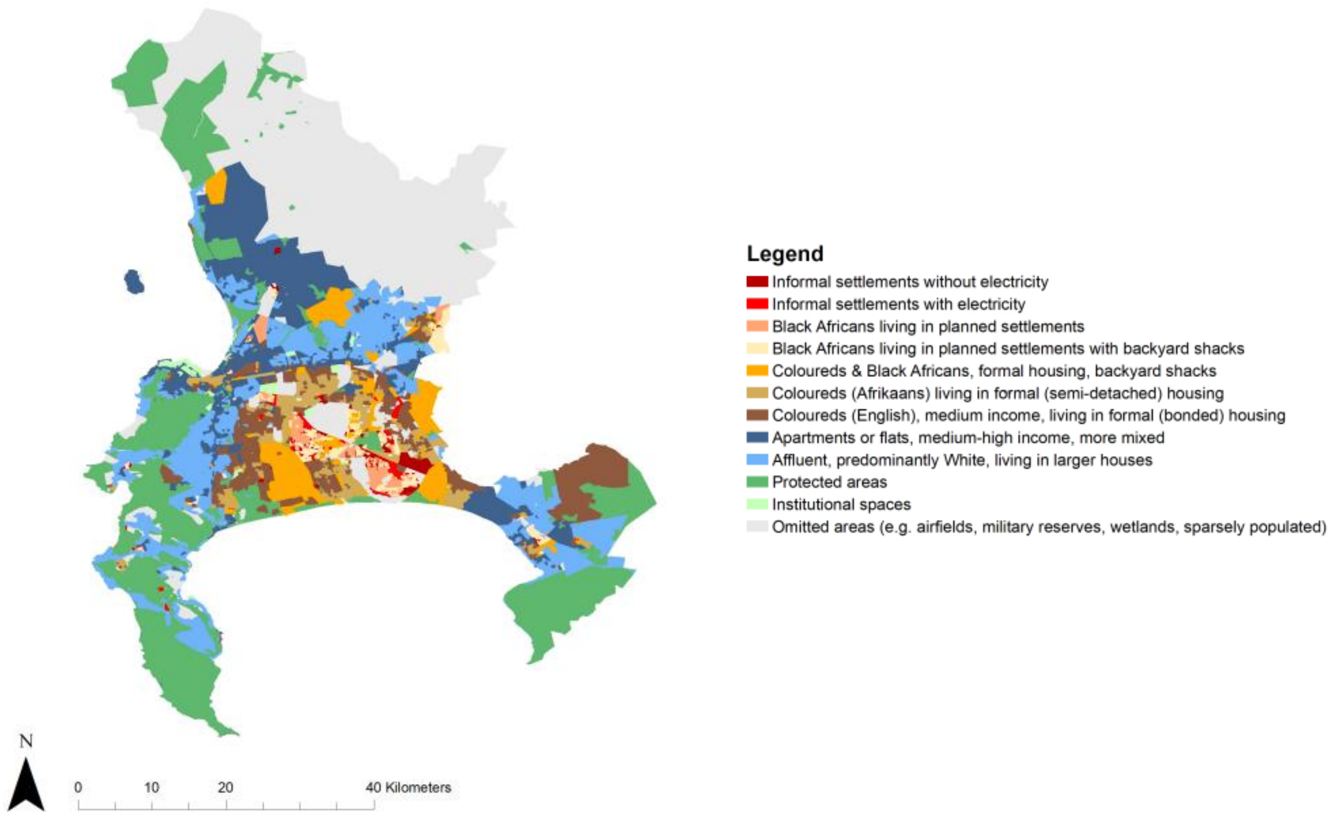
Figure 1: A Map Depicting the Different Suburbs which Comprise the City of Cape Town



Source:VectorStock.com

Following Gauteng, the Western Cape has the second-highest proportion of people residing in informal housing (Stats South Africa, 2018). According to Census data, 20.5% of households in Cape Town are located in informal settings, with 13.5% in settlements and 7% in backyard dwellings (City of Cape Town, 2023). In recent years, there has also been a surge in immigration to Cape Town which has increased the number of people residing in informal settlements, placing additional pressure on service delivery. In 2020, Cape Town hosted approximately 230,000 informal households across 204 settlements (City of Cape Town, 2020). Despite the significant number of people residing in informal settlements, informal settlements are responsible for only 4 to 5% of total water consumption in the City (City of Cape Town, 2018).

Figure 2: Cape Town's Neighbourhood Typologies



Source:http://www.centreforsustainablecities.ac.uk/

Residents in informal settlements are disproportionately affected by climate change and poor water supply due to persistent inequalities (Enqvist & van Oyen, 2022). Informal settlements are often at high risk of flooding, sometimes situated in hazardous locations like unplanned landfills or wetlands where the probability of flooding is high. Socially, informal settlements are primarily populated by some of the most vulnerable members of society: unemployed, impoverished individuals who are often exposed to elevated levels of crime (City of Cape Town, 2023). Although many informal settlements are located on City-owned land, there is a proportion of informal settlements which can be found on private property. These informal settlements pose complex challenges for the City, as service provision and regeneration initiatives are further complicated by difficulties faced by government employees when it comes to gaining access to the property to supply water (City of Cape Town, 2023). These challenges in service provision are further exacerbated when coupled with the fact that, as described above, most informal settlements are set up in areas with little to no existing infrastructure for service supply. Infrastructure development and implementation are costly and given the budget constraints of the government and the settlement occupants themselves, such development and implementation is oftentimes slow or entirely overlooked.

Following the advent of democracy in 1994, the DWAF and the City diversified their workforce in line with Affirmative Action initiatives and new legislative requirements, like the Employment Equity Act (1998), aiming to empower previously disadvantaged groups, including Black, Coloured, and Indian people (Ribot & Larson, 2012). Despite admirable intentions, Affirmative Action resulted in an abrupt loss of experienced professionals in the South African water management system, leading to disruptions in mentoring and the transfer of knowledge within the system. Consequently, the water management system in South Africa became less efficient and faced challenges when trying to build institutional capacity (Ribot & Larson, 2012). Affirmative Action also placed great focus on the internal composition of businesses, but overlooked the need for greater cooperation and policy harmonisation across businesses and institutions which would have allowed for the improvement of water delivery services (Ribot & Larson, 2012).

One of the earliest post-Apartheid initiatives in the water sector was the introduction of Free Basic Water (Enqvist & Ziervogel, 2019). This policy was rooted in the urgency to redress inequality after Apartheid by guaranteeing every household access to a minimum amount of safe water as a constitutional right. Initially set at 6 kilolitres per household per month, Free Basic Water became a cornerstone of South Africa's approach to water service delivery, linking water policy directly to social justice (Enqvist & Ziervogel, 2019).

The City's tariff structure has also been used as an attempt to address post-Apartheid inequality. Historically, water tariffs in Cape Town were set at levels too low to cover operational and maintenance costs (Brühl & Visser, 2021). In Cape Town, tariffs are structured such that wealthier consumers are placed in higher-priced tariff blocks (Enqvist & van Oyen, 2022). This is done with the intention of wealthier households subsidising free water for the poor to comply with the Free Basic Water Policy and constitutional requirements of providing basic services to all citizens (Enqvist & van Oyen, 2022). The problem, however, is that many poorer households accommodate larger families or provide housing to renters, resulting in a water bill that is often substantial enough to eliminate the intended redistribution mechanism (Enqvist & van Oyen, 2022).

When the 2015-2018 drought struck Cape Town, these challenges and inequalities in the water management system were not only highlighted, but exacerbated. To encourage residents to conserve water and avoid the complete depletion of municipal water reserves in Cape Town during the drought, the City implemented various interventions in the form of tariff increases, water restrictions, pressure reductions and information campaigns. Water restrictions were implemented at various levels to address the water crisis, with these restrictions being determined by the volume of available water in the major dams supplying the City (Brühl & Visser, 2021). Initially, during Level 2, garden irrigation was limited to specific days and times (Brühl & Visser, 2021). Consumers were also informed of the potential installation of pressure-reducing valves and media campaigns encouraged residents to install stopcocks between the municipal system and their households to take control of pressure reductions (Brühl & Visser, 2021). Level 3 restrictions began on 1 November 2016, limiting residents to the use of buckets for watering gardens and increasing tariffs. At this time, water inspectors were given the right to issue spot fines to residents who violated the water restrictions (Brühl & Visser, 2021). From 1 February 2017, Level 3B restrictions were enforced, combined with communication to households consuming relatively high amounts of water. All outdoor water use, including garden irrigation, car washing and the filling of swimming pools, was prohibited with the introduction of Level 4 water restrictions in June 2017. Residents were limited to 100 litres of water per person per day, including indoor usage (Brühl & Visser, 2021). Thereafter, Level 4B restrictions further limited residents to 87 litres per person per day (Brühl & Visser, 2021). Water management devices were installed in non-compliant households across the City in September and October 2017, with household water use being limited to 20 kilolitres per month.

In response to escalating water scarcity, the Critical Water Shortages Disaster Plan was introduced on 1 October 2017. Residents were informed that they could collect their daily water allocation from designated collection points controlled by the police and the army. These announcements garnered significant media attention (Brühl & Visser, 2021). In the months following the plan's announcement, the City aimed to improve transparency and public trust by providing timely and detailed information about the water crisis and management strategies. Various interventions were initiated, including the 'Water Dashboard', which provided weekly updates on water usage, dam levels and the approaching 'Day Zero' (the day the City was predicted to run out of municipal water). In January 2018, Level 6 restrictions were implemented, restricting residents to a monthly water consumption of 10.5 kilolitres per person, accompanied by increased pressure management and the announcement of the City Water Map (Brühl & Visser, 2021). At this stage of the drought, media coverage and drought-related campaigns were at an all-time high, increasing awareness of the severity of the water crisis. In February 2018, Level 6B restrictions limited residents to a water consumption of 50 litres per person per day (Brühl & Visser, 2021). In March 2018, 'Day Zero' was provisionally cancelled, followed by the official cancellation of 'Day Zero' in June 2018 (Brühl & Visser, 2021).

Because the City's tariff blocks rely on high water consumption by wealthier households to subsidise free water for lower-income residents, the reduction in water demand during the drought exacerbated existing inequalities in Cape Town, as the City generated significantly less revenue to fund these subsidies (Enqvist & van Oyen, 2022). To combat the reduction in revenue, free basic water was further limited to households which met the criteria of 'extreme impoverishment' (Enqvist & van Oyen, 2022). This approach, however, disadvantaged many lower-income residents as they were often unaware of the need to register for access to free basic water, did not meet eligibility criteria or did not have access to the resources necessary for registration (Enqvist & van Oyen, 2022). Consequently, the expenses of many low-income households increased during the drought, whilst expenses of higher-income households decreased because of mandated lower water use and therefore lower water bills (Enqvist & van Oyen, 2022). As many lower-income households struggled to afford the increased water expenses, the government was faced with a difficult decision: poorer residents either had to have their water cut off, thus violating their constitutional right to free basic water, or the government had to allow the debt of lower-income households to accumulate (Enqvist & van Oyen, 2022). Water management devices installed in lower-income households to monitor water use beyond basic need levels also often malfunctioned, resulting in lower-income households having their water supply cut off, further contributing to the exacerbation of inequalities facing the water sector in Cape Town (Enqvist & van Oyen, 2022).

Despite the interventions described above, one must acknowledge certain pre-existing challenges faced by the City which may have contributed to unequal outcomes in its attempt to manage the water crisis. A key challenge faced by the City was the lack of trust in the government as a consequence of Apartheid: Black and Coloured communities often tend to feel marginalised and unheard by municipal authorities (Mahlanza et al., 2016). Given that Black and Coloured people make up most residents in informal settlements, these communities often rely on informal support networks. This distrust in the government and reliance on alternative networks made it difficult for the City to encourage compliance with regulations and participation in water conservation programs (Enqvist & van Oyen, 2022).

Consequences of the Drought

Despite the City's efforts to manage the water crisis, the 2015-2018 Cape Town drought had widespread consequences, including a significant reduction in municipal revenue and spending (Cooke, 2019). During the drought, the City faced a complex trade-off between sustainable water practices and service delivery to the poor. Given the City's tariff model, the reduction in water demand posed serious challenges for maintaining service delivery (Cooke, 2019). Reductions in water consumption occurred as a result of successful conservation efforts by households, as well as private sector initiatives, such as decentralised and off-grid systems aimed at reducing reliance on municipal water (Simpson et al., 2019).

The reduction in water revenue was compounded by a reduction in electricity-related revenue generation, as hydroelectric power generation was negatively impacted during the drought period (Simpson et al., 2019). Water service related revenue, the third largest source of income for the City (after electricity and property rates) at ZAR 3.5 billion per year, was therefore significantly impacted, with serious consequences for the municipal budget as a whole (Simpson et al., 2019). The actual municipal budget during the drought fell significantly short of pre-drought estimates, leaving the municipality with little choice but to cut costs to avoid having to raise tariffs and rates exorbitantly (Cooke, 2019).

Beyond municipal revenue, the drought significantly impacted water dependent sectors in the South African economy. A key sector which took strain during the drought was the agricultural sector. Between 2017 and 2018, the agricultural sector in the Western Cape reduced its water use by approximately 60% (OECD, 2023). Like many other developing regions, the Western Cape relies heavily on the water-intensive agricultural sector for the functioning of its economy. In 2018, the agricultural sector in the Western Cape contributed approximately ZAR 530 billion and provided approximately 180,000 people with jobs, with an additional 126,000 jobs being provided in agri-processing (WWF, 2018). Collectively, the agricultural and agri-processing sectors accounted for 15% of employment in the Western Cape in 2018 (WWF, 2018). The Western Cape generates approximately 60% of agricultural exports in South Africa and contributes approximately 20% of the country's total agricultural production (Water Research Commission, 2014). Given the significant economic contribution of the agricultural sector, water reductions during the drought resulted in a severe knock to the economy as crop failures and livestock deaths increased substantially (Pili & Ncube, 2022). In the Western Cape alone, an estimated economic loss of ZAR 5.9 billion was recorded, resulting in the loss of approximately 30,000 jobs and a 13 to 20% reduction in exports (WWF, 2018).

The tourism industry was also significantly affected (Dube et al., 2022). In South Africa, tourism is responsible for approximately 10% of economic output and about 1.5 million jobs, accounting for 10% of total employment in the country (Parks et al., 2019). During the drought, tourist attractions like the waterfalls on Table Mountain dried up significantly, reducing the appeal of the City to tourists who tend to be drawn to Cape Town's picturesque views and nature-related experiences (Dube et al., 2022). These consequences, as well as potential future consequences of the drought were further emphasised through widespread negative media coverage, like the Day Zero campaign, with this negative media coverage playing a significant role in discouraging tourist arrivals in the City. Between April 2017 and April 2018, the number of tourists visiting from overseas decreased by 12.6%, followed by additional declines of 3.7% in May and 1.3% in June (WWF, 2018). Regarding popular tourist destinations, the drought resulted in 4% fewer visitors to the V&A Waterfront, a 2% reduction in visitors to Cape Point, a 12% decrease in traffic through Chapman's Drive and an 18% reduction in visitors to Robben Island (Dube et al., 2022). Tourists also booked shorter stays during the drought than in previous years, with the average duration of tourist bookings decreasing from 14.1 to 12.9 nights between 2017 and 2018 (Dube et al., 2022). As a consequence of decreased spending by tourists, the hospitality industry experienced notable revenue losses during the drought, with the average amount of money spent by international tourists on their trips dropping by 9% between 2017 and 2018 (Dube et al., 2022).

The Purpose of This Study

Evidently, the 2015-2018 Cape Town drought had significant socio-economic consequences for the City as a whole. Future droughts are increasingly likely due to the current trajectory of global warming: by 2100, warming rates are estimated to reach between 1.4 and 4.7 degrees Celsius in South Africa (Parks et al., 2019). Additionally, annual rainfall is predicted to decrease by up to 9% by 2100, with surface water supply estimated to reduce by approximately 20% (Parks et al., 2019). To better prepare for future droughts and develop more effective water conservation policies, it is important to better understand the driving forces behind water consumption behaviour during periods of water scarcity. In particular, gaining a deeper understanding of factors which influence long-lasting water consumption behaviour change is vital. In cities with high inequality like Cape Town, it is also important to examine how conditions of water scarcity, as well as measures implemented to combat them, affect residents differently according to socio-economic status to improve the effectiveness of future water conservation strategies.

This study examines how household water consumption in Cape Town evolved before, during and after the 2015–2018 drought, with a particular focus on differences across income groups. The central objective is to assess whether water use rebounded to pre-drought levels once the crisis ended, and to identify the key factors shaping consumption behaviour under conditions of scarcity and recovery. To do so, the study combines descriptive analysis with panel regression methods tailored to the structure of each period: a static correlated random-effects model is used for the short pre-drought period, while dynamic fixed-effects models with lagged consumption are estimated for the longer drought and post-drought panels. These models are used to evaluate the roles of income, seasonality, weather conditions and behavioural persistence in determining water consumption over time. Drawing on insights from economic and behavioural literature, the quantitative results are interpreted within a broader framework of habit formation, constraint-driven adjustment and behavioural change. Overall, the findings indicate that water consumption does not fully return to pre-drought levels across income groups, pointing to persistent reductions in demand. Income, seasonal factors, temperature, precipitation and past consumption behaviour all play statistically significant roles in shaping water use, with evidence of lasting behavioural adjustments following the drought.

Review of Literature

Overview of Water Scarcity and Drought Effects on Urban Areas

Water scarcity can be described as the excess of water demand over available supply (FAO, 2012). It can be categorised into three main levels: water stress (when annual water supply is below 1700m^3 per person), water scarcity (when annual water supply drops below 1000m^3 per person) and absolute scarcity (when the water supply drops below 500m^3 per person) (Falkenmark & Widstrand, 1992). As the economy of an urban area expands, so does the use of water, thus creating a shortage between the industrial, agricultural and urban sectors (Nairizi, 2017). When there is a shortage of water supply, one or more of these sectors must compromise, causing a knock-on effect which can result in a decline in the economic development of the area. As highlighted by Nairizi (2017), various factors come into play which affect the frequency of droughts, such as greenhouse gases, climate change and El Niño cycles. These periods of drought put strain on water systems creating prolonged periods of water scarcity in a region. Nairizi (2017) highlights impacts that occur due to droughts: agricultural impacts occur when crops do not receive the necessary water to ensure sufficient growth, creating food shortages; economic impacts arise when a country's GDP declines because rain-fed agriculture and livestock, which are vulnerable to drought, reduce export earnings. While this categorisation is useful, it may underplay the indirect social and behavioural consequences of drought, which are more evident in the Cape Town context. The following section of this paper will discuss the literature regarding various driving factors of water consumption behaviour during times of water scarcity compared to times of water abundance.

Seasonal Variations and Environmental Drivers of Water Consumption

There is an array of literature which highlights the roles of *rainfall and temperature* as key environmental drivers of water consumption (Beal et al., 2014). Several studies have explored the relationship between rainfall and water demand, particularly in the context of residential water use (Beal et al., 2014). The consensus of the literature is that water consumption tends to decrease as rainfall increases. For example, Beal et al. (2014) find that water consumption spikes during periods of low rainfall in residential areas. According to Beal et al. (2014), these spikes may be explained by an increase in outdoor irrigation as residents compensate for the reduction in natural irrigation with increased residential water use. On the other hand, the presence of rainfall is found to be correlated with a significant reduction in mean daily household water consumption (Beal et al., 2014). Additionally, Beal et al. (2014) suggest that it is not only the presence of rainfall or lack thereof which influences water consumption, but the number of consecutive days of below or above average rainfall. Regarding temperature, several studies like Beal et al. (2014) and Maidment and Miaou (1986) find water consumption to increase during warmer periods. This relationship has been explained by the increased demand for garden irrigation and more frequent showering during warmer weather (Beal et al., 2014). According to van Huyssteen (2021), the finding that increasing temperatures are associated with higher water consumption levels remains consistent across various geographic locations.

There is also evidence to suggest that the way in which rainfall and temperature affect water consumption is more complex than the straightforward linear relationships discussed above (Beal et al., 2014). There are several studies which recognise that this relationship can vary based on a number of contextual factors, such as geography, climate and socioeconomic factors. For example, Schulz and Jansen (2006) unexpectedly find rainfall to be positively correlated with water consumption. This relationship, however, is not found to be statistically significant, potentially due to other contextual factors such as cultural practices, water management policies and individual behaviours shaping water demand (Schulz & Jansen, 2006). On the other hand, even though Siebrits (2012) finds that, in Cape Town, water consumption is highest during the dry summer months and lowest during the wet winter months, the authors of this study acknowledge that there is a lack of conclusive evidence to support the claim that this relationship is causal.

Like rainfall, the relationship between temperature and water consumption has been found to be complicated by the way temperature interacts with other factors. The lack of a straightforward linear relationship between temperature and water use is highlighted by studies like Schleich and Hillenbrand (2009) which find temperature to have no significant impact on residential water consumption in certain scenarios. Additionally, studies like Viljoen (2015) highlight the fact that, in contexts like Cape Town, temperature-related water consumption trends can differ according to income. More specifically, in Cape Town, higher temperatures are associated with higher water consumption in low-income areas, as low-income households tend to have corrugated iron roofs and structures, increasing indoor temperatures and, consequently, demand for water (Viljoen, 2015). On the other hand, the relationship between higher temperatures, which are experienced in the dry Cape Town summer, and increased water consumption in high-income households can be explained by the fact that wealthier households tend to have larger gardens in need of irrigation during the dry summer months (Viljoen, 2015).

Moreover, the relationship between rainfall, temperature and water consumption is further complicated by the influence of *the tourist season* on water consumption dynamics (Reynaud, Pons & Pesado, 2018). Existing literature indicates an increase in water consumption associated with a surge in visiting tourists during the tourist season (Reynaud, Pons & Pesado, 2018). The acknowledgement of these dynamics is particularly important in locations like Cape Town which experience a significant influx of tourists at certain points during the year. Important to note is also the fact that the tourist season is context dependent, with different places experiencing an influx of visitors during different periods throughout the year. For example, whilst Cape Town might experience an influx of tourists during the summer because of its picturesque beaches, places like Andorra attract tourists during the winter months for the skiing season (Reynaud, Pons & Pesado, 2018). In Cape Town, the tourist-driven water demand coincides with peak summer scarcity, likely exacerbating the strain on local supply systems.

Given the significant role that tourism plays in the Cape Town economy, it is important to acknowledge the complex problem that places like this face when it comes to balancing sustainability with economic survival (Parks et al., 2019). Garidzirai and Nguza-Mduba (2020) emphasises the positive relationship between tourist arrivals and local economic development, suggesting that the solution to potential increased water consumption during the tourist season cannot be to simply reduce the number of tourists visiting the area. The study by Prinsloo (2019) explores the relationship between tourist season, the economy and water use during the 2015-2018 Cape Town drought. Despite the fact that tourists contribute to increased water consumption in the City, Prinsloo (2019) highlights that, during the drought, Airbnb hosts implemented water-saving practices and visiting tourists assisted in reducing the water consumption of Airbnb listings. According to Drummond (2019), media and government initiatives like 'Save Like a Local' played a significant role in mitigating the influence of tourist arrivals on water consumption in the City. Thus, seasonal influences on water consumption extend beyond the simple recognition of rainfall and temperature patterns, and require the acknowledgement of several socioeconomic factors.

Socio-Economic Drivers of Water Consumption

Income

One socioeconomic factor which plays an undeniable role in influencing water consumption behaviour is income. Under conditions of water abundance, several studies have found higher-income households to consume more water, on average, than lower-income households (Jansen & Schulz, 2006). Hussien et al. (2016) finds water consumption per capita to increase with income. As mentioned above, the positive relationship between income and consumption has been explained by the fact that wealthier households tend to have larger properties with more expansive gardens and swimming pools than lower-income households (Jansen & Schulz, 2006). Higher-income households also tend to be able to afford more expensive water-consuming appliances and technologies, thus increasing their water consumption on average (Jansen & Schulz, 2006). In the context of Cape Town, differences in water consumption across income groups are also likely influenced by historical inequalities in housing and access to services.

Interestingly, Hussien et al. (2016) finds that, although average per capita water consumption increases with income, the distribution of water used for various activities remains consistent across income groups. In developing countries like South Africa, the highest proportion of water consumption occurs via taps, regardless of income (Hussien et al., 2016). This contrasts with developed countries where toilet flushing is responsible for the highest proportion of water use (Hussien et al., 2016). According to Gato (2006), on the other hand, the way in which water is used for hygiene practices differs according to income group: higher income households tend to use more water for bathing and have more frequent showers than lower-income households. Additionally, although Gato (2006) finds hand washing to be responsible for approximately 32% of water consumption regardless of income, the study finds higher-income households to display lower flow rates from their taps. According to Gato (2006), the lower flow rates of wealthier households may be attributed to the adoption of water-efficient appliances in these households.

Similar to environmental drivers of water demand, the relationship between income and water consumption is not solely linear (Hussien et al., 2016). In some cases, lower-income households have been found to consume more water than higher-income households as a result of inadequate access to water-efficient technologies, reliance on water-intensive activities like agriculture for livelihoods, and a lack of awareness of conservation practices (Hussien et al., 2016).

In South Africa, spatial inequality in water access is an important factor to consider when it comes to understanding the complex relationship between income and water consumption. According to Cole et al. (2018), there are significant disparities in access to piped water across various geographic locations in South Africa, with a Gini index ranging from 0.06 to 0.57. More specifically, urban areas tend to have greater access to piped water than traditional/tribal areas (Cole et al., 2018). Despite the fact that one might expect water supply-related factors to significantly impact water consumption patterns, Cole et al. (2018) highlights a lack of correlation between water use and supply-related factors. Rather, Cole et al. (2018) emphasises a positive correlation between water consumption and demand-related factors like income. Income therefore does not independently determine water consumption behaviour. Rather, it interacts with a variety of other factors like geographic location and access to infrastructure.

Responses to Water Scarcity and Driving Factors

Under conditions of water scarcity like droughts, studies like Cook, Brühl and Visser (2021) find the relationship between income and water consumption to undergo notable changes compared to pre-drought times. Cook, Brühl and Visser (2021) examine the 2015-2018 Cape Town drought and discuss changes in the relationship between income and water consumption from before the drought to the drought period. During the initial phases of the drought, during the winter months, the correlation between income and water consumption is not notably strong. As the drought intensifies, however, higher income becomes more strongly associated with increased water consumption, most likely due to large gardens in need of irrigation. Following the implementation of various conservation measures, however, the correlation between income and water consumption becomes weaker until winter 2017, when income is found to be negatively correlated with water consumption (Cook, Brühl & Visser, 2021). These findings suggest that, by the height of the drought, higher-income households use less water than their lower-income counterparts.

The observed differences in response to water scarcity conditions may be explained by several diverse factors, one of which is the implementation of *conservation measures* by the government. During times of water scarcity, policymakers often attempt to encourage consumers to conserve water using various interventions (Brühl & Visser, 2021). These interventions can be price-based, targeting the money of consumers directly or non-price based, targeting consumer behaviour (Gössling, Scott & Hall, 2013). An example of a commonly used price-based intervention is water tariffs (Gössling, Scott & Hall, 2013). Studies like Colvin & Saayman (2007) find increased water tariffs to be effective in incentivising the reduction of household water consumption. Important to note, however, is the fact that, when water tariffs are increased, immediate adjustments to consumption behaviour are not observed. Rather, individuals tend to gradually adopt water efficient equipment and adjust their consumption behaviour over time (Martínez-Espineira & Nauges, 2004). According to Martínez-Espineira and Nauges (2004), tariff increases are effective in encouraging residents to reduce their water consumption until it reaches basic need levels. The effectiveness of tariffs is therefore expected to differ between households in cities like Cape Town which have high levels of inequality and large proportions of the population consuming close to basic need levels of water, even prior to the drought. Brühl and Visser (2021) reiterate this point, emphasising the fact that, in Cape Town, tariffs have a greater influence on the consumption of richer households compared to that of lower-income households. Interestingly, however, Jack et al. (2019) highlight that higher-income households have been found to be less motivated by price increases than lower-income households, as water bills form a smaller proportion of their income. Rather, wealthier residents have shown more responsiveness to social pressure and civic duty in the context of Cape Town.

Another intervention which policymakers commonly use is the implementation of water restrictions. According to previous studies, water restrictions are effective in reducing water usage by between 16 and 28% (Brühl & Visser, 2021). In California, mandatory water restrictions, coupled with tariff increases, have been found to reduce water consumption by 23 to 28% (Renwick & Archibald, 2018). During the 1985 to 1992 drought in Santa Barbara, the prohibition of outdoor water use was found to successfully reduce water consumption by 16% (Renwick & Archibald, 2018). Voluntary water restrictions, on the other hand, have not been found to significantly impact water consumption behaviour (Brent & Wichman, 2022).

Furthermore, pressure-reducing valves are often installed during times of water scarcity to lower water pressure and minimise water loss as a result of leaks in pipes and fittings (Brühl & Visser, 2021). In general, the installation of pressure-reducing valves has been found to be effective in reducing water consumption during times of water scarcity. According to Turner et al. (2016), investments in leakage and pressure management programs during the Millenium Drought in Australia successfully reduced the wastage of water as more leaks were reported and responded to more quickly due to the increased concern for water conservation. In the context of developing countries like South Africa, pressure-reducing valves are of particular relevance due to their cost-effectiveness in comparison to the expansion of water supply infrastructure (Brühl & Visser, 2021). It is important to note, however, that pressure-reducing valves have been found to reduce water wastage, but there is little conclusive evidence which indicates that the installation of pressure-reducing valves plays a significant role in influencing water consumption behaviour (Brühl & Visser, 2021).

In terms of non-price-based water conservation measures, information campaigns are often used by the government to encourage people to adopt water saving behaviours. In the short term, water conservation campaigns have been found to successfully reduce water usage by between 11 and 28% (Brühl & Visser, 2021). The success of information campaigns has been attributed to their emphasis on social responsibility among residents. For example, during the 2003-2005 Cape Town drought, it was found that 20% of respondents adhered to water restrictions because of a feeling of social responsibility, with 7% of these respondents conserving water in an effort to protect the environment (Colvin & Saayman, 2007). In a survey conducted during the same drought, 25% of respondents noted the use of groundwater for outdoor irrigation because of environmental concerns (Colvin & Saayman, 2007). Additionally, combining information campaigns with other conservation measures has been particularly effective in reducing water demand (Brühl & Visser, 2021). For example, during the Millenium Drought in Australia, the highest levels of water saving behaviour were observed during a period in which water restrictions were implemented alongside water saving information campaigns (Beal et al., 2014). Similarly, a combination of water conservation measures was found to be effective in reducing water consumption below basic need levels of 3 kilolitres per person per month during the 2015-2018 Cape Town drought (Brühl & Visser, 2021). Regarding the long-term cost effectiveness of information campaigns, studies like Quesnel and Ajami (2017) and Brühl and Visser (2021) question the durability of the effects of information campaigns relative to their cost. For example, Quesnel and Ajami (2017) find that, during the 2005-2015 San Francisco Bay drought in California, an increase of 100 drought-related media articles was only associated with a decrease in water consumption of between 11 and 18%. According to Brühl and Visser (2021), continued investments in information campaigns may be necessary to ensure their continued impact on water consumption behaviour.

Water consumption behaviour can also be significantly impacted by *household characteristics* such as financial situation, household size and education level (Hussien et al., 2016). In terms of finances, higher-income households have a greater capacity to afford water-efficient appliances like low-flow showerheads and water-efficient washing machines, therefore allowing wealthier households greater capacity to reduce their water consumption during times of water scarcity (Hussien et al., 2016). Lower-income households, by contrast, struggle to afford these water-efficient appliances as they often entail large upfront costs associated with the purchasing and fitting of the devices, thus limiting the capacity of poorer households to reduce their water usage in response to calls for water conservation (Ribot & Larson, 2012). Lower-income individuals also face the challenge of little access to credit or financing options which further hinders their ability to adopt the recommended water-saving technology (Ribot & Larson, 2012).

Not only do differing financial situations affect household response to water scarcity through practical channels, they also take effect through psychological channels. According to a broad literature on *the psychology of poverty*, there are several poverty-related cognitive and psychological factors which impact how lower-income households respond to water conservation efforts (Haushofer & Fehr, 2014). Maslow's Hierarchy of Needs gives an overview of how these poverty-related psychological factors may affect water conservation behaviour. According to Maslow's theory, people tend to prioritise basic survival needs over higher-level goals. In cities like Cape Town, the basic survival needs of access to clean water, food and safe housing are unmet for a large proportion of the poorer population (Marutlulle, 2021). According to Haushofer and Fehr (2014), the cognitive load placed on lower-income individuals by the constant juggling of limited resources and economic hardships consumes a large amount of cognitive bandwidth, leaving financially disadvantaged people with limited cognitive capacity for the consideration of long-term concerns like water conservation. Consequently, according to Maslow's theory, lower-income households will fixate on meeting their basic need to clean water, food and safety, otherwise known as 'tunnelling', with little attention being directed towards higher-level goals like water conservation (Rojas, Méndez & Watkins-Fassler, 2023). Though important to understand, one should be careful not to use the cognitive bandwidth narrative to underestimate the agency of lower-income individuals. Higher-income individuals, by contrast, tend to meet their basic needs relatively easily, thus leaving them with more cognitive bandwidth to direct attention towards environmental conservation and the social responsibility which that entails (Dodds, 1997).

These insights from the psychology of poverty can be linked to the broader psychological literature which allows one to better understand how water consumption behaviour is shaped during times of water scarcity. There is an array of previous literature which investigates the role that *attitudes* play in determining water consumption behaviour. Studies like Willis et al. (2011), Boylu and Gunay (2017) and Nancarrow et al. (1997) highlight the positive correlation between positive attitudes towards environmental concern and active efforts to conserve water. These efforts have been found to reduce overall water consumption via shorter showers, less frequent clothes washing, reduced tap use and decreased irrigation (Willis et al., 2011).

There are, however, times in which positive attitudes towards environmental conservation have not been found to translate into water-saving behaviour. For example, Koop et al. (2019) draws attention to the fact that people often have the desire to save water during times of water scarcity, but if these people do not perceive water conservation as feasible for themselves, they are less likely to translate the desire to conserve water into action. According to Schultz, Tabanico and Rendón (2008), behavioural *beliefs*, which refer to the perceived consequences of water conservation efforts, play a direct role in determining water conservation attitudes. Similarly, control beliefs influence a person's perceived behavioural control or self-efficacy in engaging in water conservation behaviours: if a person believes that they have the necessary resources, skills and support to implement water-saving practices effectively, they are more likely to take action (Schultz, Tabanico & Rendón, 2008).

On the other hand, normative beliefs, which relate to societal expectations, influence water conservation behaviour by shaping a person's subjective norms (Schultz, Tabanico & Rendón, 2008). In other words, if a person feels as though their social circle or community values water conservation, that person is more likely to feel a sense of social pressure to behave in a way which conserves water (Schultz, Tabanico & Rendón, 2008). According to Thakur et al. (2022), subjective norms have been found to play a more significant role than attitudes in determining behavioural outcomes, implying that collective beliefs within social groups influence water conservation decisions to a greater extent than individual attitudes alone. Abrahamse and Steg (2013) reiterate that individuals are more likely to adhere to requests to change behaviour if people they view as similar to themselves make the request.

A key way in which social connection influences behaviour change is via *knowledge transfer* (Koop et al., 2019). An example of knowledge transfer is education on the topic of water conservation. According to Koop et al. (2019), knowledge transfer plays a vital role in shaping attitudes around water conservation by encouraging the conscious processing of information. However, like Schultz, Tabanico and Rendón (2008), Koop et al. (2019) emphasises the importance of highlighting specific water-saving actions when sharing information regarding water conservation to promote self-efficacy, thereby increasing the likelihood that people will use their newly acquired knowledge to act. In the context of South Africa, Thakur et al. (2022) finds a significant disparity between knowledge of water conservation and actual water conservation action in low-income communities: despite 94.4% of respondents indicating awareness of water conservation techniques, only 74.1% of respondents translate this awareness into action. Although Thakur et al. (2022) attributes this disparity to a culture of non-payment and potential misuse of water as a result of the Free Basic Water Policy in South Africa, previous studies like those discussed above suggest that other factors like perceived self-efficacy and psychological stress in conditions of poverty should also be taken into account when commenting on a lack of water conservation behaviour in lower-income communities. Considering the viewpoints discussed above, it is important to give adequate consideration to the psychological pressures linked to poverty, rather than framing the issue as a simple outcome of policy misuse. Underestimating these barriers to behaviour change may hinder policy makers implementing effective solutions.

Social connection also influences behaviour change via *culture*. According to Fanteso and Yessoufou (2022), there is evidence to suggest that culture plays a significant role in determining water conservation behaviour. In a city like Cape Town which hosts a diverse range of cultures and ethnicities, the role of cultural and ethnic factors in influencing water consumption behaviour during times of water scarcity is particularly relevant (Chilaka, Torell & Ward, 2022). With reference to Chilaka, Torell and Ward (2022), ethnic differences like varying languages complicate the design of water conservation campaigns and affect the success rate of behavioural nudges. In Cape Town, Sipamla (2018) finds significant disparities in water-related knowledge, perceptions and behaviours across ethnic groups. For example, during the 2015-2018 Cape Town drought, Black respondents were found to display less acknowledgement of a water crisis compared to Coloured and White respondents (Sipamla, 2018). Additionally, Sipamla (2018) finds disparities in beliefs and water-related behaviours between ethnicities. More specifically, while Black respondents perceive the City's water supply as sufficient, they engage less in recreational water use than other ethnicities due to an association of water with labour (Sipamla, 2018). During the drought, Black respondents were also found to display a high willingness to reduce water consumption compared to other ethnicities. These findings suggest that, by addressing culture, policymakers could access untapped conservation potential. Policymakers must, however, remain wary of appropriating Black cultural norms for conservation campaigns (Sipamla, 2018).

In addition to the aforementioned factors, residential water consumption behaviours are significantly influenced by *habits and routines*. Habits are defined as stable patterns of behaviour which are reinforced over time and are executed automatically, bypassing deliberate decision-making (Aitken et al., 1994). According to Trumbo and O'Keefe (2005), habits may explain part of the differences in water consumption behaviour between income groups. For example, higher-income households tend to irrigate expansive gardens during times of water abundance, thus contributing to a significant amount of outdoor water use in wealthier households compared to lower-income households (Trumbo & O'Keefe, 2005). During drought periods, however, Brühl and Visser (2021) find that the conscious efforts to conserve water, like shorter showers and turning off taps when not in use, tend to become ingrained habits, contributing to sustained water-saving routines post-drought. The extent to which these water conservation habits persist once a drought has come to an end has, however, been widely debated.

Post-Drought Consumption Patterns and Long-Term Observations

Following a drought, when communities have adequate water supply, several studies suggest that water consumption *rebounds*. In this context, the term 'rebound' refers to an increase in water usage following a period of water scarcity (Beal et al., 2014). Rebounds in water consumption following a period of water scarcity have been observed in Queensland, Australia, as well as the Murray-Darling Basin (Beal et al., 2014; Loch & Adamson, 2015). In Queensland, Australia, for example, yearly average water consumption increased from 156 to 178 litres per day between 2010 and 2012 (Beal et al., 2014). Similarly, following the relaxation of conservation mandates, Nemati, Tran and Schwabe (2023) finds water consumption to increase by approximately 9% in Northern California between 2013 and 2019. Following the 2012-2016 California drought, Bolorinos, Rajagopal and Ajami (2022) finds approximately 25% of households which made active efforts to conserve water during the drought to rebound to pre-drought consumption levels five years post-drought. Notably, these studies were conducted in developed countries, meaning that they may not be indicative of developing country outcomes.

Despite the evidence which suggests that water consumption increases post-drought, there is also evidence to suggest that *water consumption remains depressed* relative to pre-drought levels, even after a drought has come to an end (Nemati, Tran & Schwabe, 2023). For example, even though water consumption increases by 9% following the relaxation of California's conservation mandate, overall water consumption is found to remain approximately 17% lower than the period prior to the implementation of the mandate (Nemati, Tran & Schwabe, 2023). These findings suggest that conservation mandates influence water consumption behaviour, not only during the drought period itself, but also when the drought has come to an end. The findings of Nemati, Tran and Schwabe (2023) align with previous studies like Bernardo, Fageda and Termes (2015) which makes use of a difference-in-differences analysis to prove that, following the end of a drought in Barcelona, lasting reductions in water consumption are observed. In Australia, although Gonzales and Ajami (2017) notes a rebound in water consumption following the drought, this study emphasises the limited significance of the rebound.

Interestingly, the rebound effect can differ according to various *contextual factors*. On average, Bolorinos, Rajagopal and Ajami (2022) finds conservation efforts to last approximately 8 years following a drought, with larger conservation efforts exhibiting longer lasting effects on water consumption behaviour post-drought. According to Nemati, Tran and Schwabe (2023), varying degrees of rebound have also been observed between groups of residents with certain characteristics. More specifically, the lowest percentage rebound has been observed in the highest water users, whilst lower water users have been found to exhibit large rebounds in consumption. Additionally, Nemati, Tran and Schwabe (2023) also draw attention to the finding that the most significant rebounds in water consumption post-drought tend to be observed in the summer months, potentially due to increased outdoor irrigation demand.

The level of innovation and development which takes place during a drought also plays a role in determining the extent to which water consumption rebounds following a drought. During the 2015-2018 Cape Town drought, water management infrastructure was significantly improved. For example, desalination plants like the V&A Waterfront Desalination Plant and the Strandfontein Desalination Plant were constructed to provide alternative water sources to supplement municipal supplies (Mihalopoulos, 2021). Efforts were also made to enhance water storage capacity in the City through projects like the Voëlvlei Dam and the Berg River Dam, while water recycling and reuse infrastructure was improved with projects like the Zandvliet Water Recycling Plant (Groot, 2019). Whilst these infrastructural upgrades assisted the City in addressing immediate water scarcity, they also played a significant role in assisting with sustainable water management practices post-drought. Studies like Zeff et al. (2016) and Jorgenson et al. (2009) reiterate the way in which infrastructure improvements contribute to a sustained reduction in water use following a drought. By strengthening the capacity of infrastructure to store and recycle water, the water supply system is made more resilient, thus enabling communities to maintain conservation efforts post-drought (Zeff et al., 2016).

Apart from infrastructural changes, *habits formed during the drought period* have been found to significantly impact water-saving behaviour post-drought. During the 2015-2018 Cape Town drought, for example, farmers adapted agricultural practices to make use of drought-resistant crops like rooibos tea and spekboom, employed water conserving farming techniques like mulching and no-till agriculture, and implemented water-efficient irrigation methods like precision irrigation systems (Theron et al., 2023). These farming techniques were integrated into agricultural routines over time, thus supporting sustained water conservation in the agricultural sector (Theron et al., 2023).

Moreover, *attitudes* prove to be crucial in understanding post-drought water consumption behaviour (Willis et. al., 2011). According to Willis et al. (2011), positive attitudes towards water conservation are associated with reduced water consumption following a drought. This may be attributed to the way in which the drought period fosters a sense of responsibility and consciousness around the need to conserve water which leaves a lasting impact in the minds of people even when the drought has come to an end (Willis et. al., 2011). According to Chen et al. (2023), the increase of risk perception following a drought is associated with a higher likelihood of behaving in a manner which conserves water to avoid the risk of another drought. On the contrary, studies like Carlton et al. (2016) find no significant shifts in climate change beliefs or adaptation attitudes following a drought, therefore challenging the idea that a single climate-related event has the power to change beliefs or attitudes. Even though droughts have been found to heighten risk perceptions, some studies find that these heightened risk perceptions do not lead to increased water conservation efforts post-drought (Carlton et al., 2016).

Having established a deeper understanding of the literature which exists on the relationship between water consumption behaviour in contexts of both water abundance and water scarcity, as well as the factors which influence this behaviour, this paper will go on to discuss the manner in which fixed effects panel regressions, as well as visual analysis, were used to investigate whether water consumption following the 2015-2018 Cape Town drought returned to pre-drought levels, as well as the extent to which income, seasonal fluctuations, the previous month's water consumption and other socioeconomic factors explain water consumption behaviour amongst varying income groups before, during and after the drought.

Methodology

Data Collection and Preparation

This paper utilises graphics and panel regression analysis to investigate whether water consumption following the 2015-2018 Cape Town drought returns to pre-drought levels for various income groups in Cape Town. Furthermore, the paper investigates the extent to which income, seasonality and previous consumption patterns explain changes in water consumption across the pre-drought (January 2015-December 2015), drought (January 2016-June 2018), and post-drought (July 2016-December 2022) periods in Cape Town. The analysis is conducted using a dataset comprised of a combination of the City of Cape Town's 2015-2022 municipal water data, the City of Cape Town's 2012 household property value data, a dataset provided by the City of Cape Town indicating which households are classified as indigent, and temperature and precipitation data for the 2015-2022 period in Cape Town.

The municipal water data utilised in this paper is available on the Comprehensive Knowledge Archive Network (CKAN), an open data portal. On CKAN, the municipal water data for each year is stored in shards (small datasets), with each year split into multiple shards. To create a comprehensive dataset spanning 2015-2022, all shards of data for these years were merged. The 2012 household property value data specifying the indigent status of households in Cape Town was provided to the Environmental Economics Policy Research Unit by the City of Cape Town on request. The temperature and precipitation data was obtained via web-scraping.

The final dataset contains 43,848,346 observations spanning the period from January 2015 to December 2022. The data include household-level monthly water consumption (kilolitres), Quintile Property Value (QPV) indicators, household indigent status, and contemporaneous temperature and precipitation measures. QPV is used as a proxy for household income. Although the property value data were collected in 2012, existing evidence suggests that relative spatial patterns in property values are highly persistent over time (Gil-Alana et al., 2013). Standard data cleaning procedures were applied, including the removal of duplicate observations and irrelevant variables. Seasonal indicators and drought-period indicators were constructed for use in the econometric analysis.

Descriptive Statistics

Descriptive statistics reveal a clear and internally consistent seasonal structure in household water consumption in Cape Town over the 2015–2022 period (*Appendix 1 Tables A–C*). In nearly every year, summer exhibits the highest mean daily consumption and winter the lowest, with autumn and spring falling between these extremes, reflecting predictable climatic drivers such as temperature-driven outdoor irrigation and evaporation demands. The sole exception occurs in 2018, when extreme behavioural and institutional responses associated with the approach of Day Zero substantially compressed seasonal variation. Comparing mean consumption across drought phases highlights a pronounced decline in water use during the drought, followed by only a partial recovery thereafter.

Relative to the pre-drought baseline, summer consumption fell by approximately 33 per cent during the drought and by nearly 40 per cent in the post-drought period, while winter consumption declined by about 23 per cent during the drought and 32 per cent thereafter. Reductions are largest in the warmer seasons, consistent with cutbacks in discretionary outdoor uses, targeted behavioural messaging and enforcement aimed at non-essential consumption. Although winter consumption declined by a smaller percentage, reflecting the higher share of essential indoor uses, post-drought consumption remains materially below pre-drought levels across all seasons. Taken together, these descriptive patterns suggest that the drought induced persistent reductions in household water use, consistent with longer-run behavioural adjustment and the adoption of water-saving practices and technologies.

Panel Data Analysis

This study employs household-level panel regression models to analyse changes in municipal water consumption between 2015 and 2022. The dataset links repeated monthly observations to individual accounts, which allows the empirical strategy to exploit both variation across households and variation within the same household over time. In a city such as Cape Town, where unobserved household characteristics such as dwelling size, garden presence, pool ownership and appliance stock are likely to be correlated with both baseline consumption and behavioural responses to drought measures, simple cross-sectional or pooled time-series regressions would produce biased estimates.

The panel framework addresses this by using models that difference out time-invariant household characteristics and focus on within-household adjustments in response to the drought, tariff changes, seasonal conditions and weather. In particular, fixed-effects (FE) specifications allow the analysis to control for all time-invariant unobserved heterogeneity at the account level, so that coefficients on income (as proxied by quintile property value), seasonality, weather and lagged consumption are identified from changes within households over time rather than from cross-sectional comparisons alone.

The choice between random-effects (RE) and FE estimators is important in this setting because there are strong reasons to expect correlation between unobserved household characteristics and the observed regressors. For example, higher-valued properties are more likely to have irrigated gardens and swimming pools and to occupy neighbourhoods with distinct micro-climates, which in turn influence both levels and dynamics of water use. As discussed in the following subsection, Hausman tests strongly reject the orthogonality conditions required for RE, supporting the use of FE and correlated random-effects (CRE) models as the preferred specifications.

Finally, because water use is highly persistent over time, the main models for the drought and post-drought periods are specified in dynamic form with lagged monthly consumption. This captures state dependence in household behaviour and allows the analysis to distinguish transitory shocks from more persistent changes in water use following the drought. The dynamic panel structure, combined with account-level clustering of standard errors, therefore provides an econometrically robust framework for assessing how income, seasonality, weather and past consumption jointly shape water demand before, during and after the drought.

Hausman Tests (Random Effects vs Fixed Effects)

To determine whether household-level unobservables can be treated as orthogonal to the regressors, both RE and FE panel models were estimated for each drought phase and Hausman tests were implemented on the overlapping coefficient sets. Both a static specification, including only QPV quintile dummies, seasonal dummies and weather controls, and a dynamic specification that additionally includes lagged monthly water consumption were considered. Throughout, the dependent variable is monthly water consumption at the account level.

For the static models, Hausman tests strongly reject the null hypothesis that the difference between FE and RE coefficients is not systematic in all phases. In the pre-drought period (2015), the test yields $\chi^2(5) = 502.38$, $p < 0.001$, based on the seasonal and weather coefficients that are identified in both models. During the drought phase (2016–September 2018), the test statistic rises to $\chi^2(7) = 13\ 558.97$ ($p < 0.001$), with substantial differences in the QPV coefficients between FE and RE. Post-drought (October 2018–2022), the Hausman test again firmly rejects RE, with $\chi^2(9) = 7\ 961.04$ ($p < 0.001$), reflecting large discrepancies in estimated QPV effects and precipitation responsiveness.

The dynamic models, which add lagged consumption to capture state dependence, reinforce this conclusion. For the pre-drought period, the Hausman statistic is $\chi^2(6) = 658\ 878$ ($p < 0.001$), with RE producing a much larger persistence parameter (approximately 0.87) than FE (approximately 0.64) and markedly different estimates for seasonal and weather coefficients. During the drought and post-drought phases, the Hausman tests again reject RE, with $\chi^2(10) = 738\ 319$ and $\chi^2(10) = 1\ 182\ 838$ respectively (both $p < 0.001$). In both phases, RE substantially attenuates the estimated reductions in consumption among high-QPV households and inflates the persistence of consumption relative to FE. Given these results, and the strong prior that unobserved household characteristics such as dwelling size, garden presence and appliance stock are correlated with both baseline consumption and responses to prices and restrictions, we treat the FE estimator as the preferred specification and rely on FE dynamic models for our main inference. *One must acknowledge that dynamic FE is subject to finite-sample bias in the pre-drought period, where T is small, and interpret the pre-drought lag coefficients with caution, while placing more weight on the longer drought and post-drought panels.*

Main results (*Table 1*) therefore draw on household fixed effects regressions with lagged consumption, QPV fixed effects, seasonal dummies and weather controls, estimated separately for the pre-drought, drought and post-drought periods. The FE estimator drops the QPV dummies entirely in the pre-drought period because QPV are constant for each household in 2015. More importantly, the seasonal and weather coefficients in this subsample are mechanically identified from only twelve calendar months and are therefore not meaningful structural estimates. For this period, we therefore rely on CRE (Mundlak) specifications to estimate cross-sectional QPV differences and reserve the dynamic FE model for the longer drought and post-drought periods, where genuine within-household variation exists. The CRE framework allows the QPV coefficients to be retained while still permitting correlation between household-specific unobservables and time-varying regressors, which avoids the untenable orthogonality assumptions of standard RE. *This approach keeps the empirical strategy coherent across periods: one obtains interpretable distributional patterns before the drought and preserves a strict within-household identification strategy once the panel becomes long enough to support it.*

Serial Correlation and Error Structure

Monthly household water consumption displays strong persistence over time, raising the possibility that the idiosyncratic error term in the panel-data models may exhibit first order serial correlation. To assess this formally, the study applies the Wooldridge (2002) test for autocorrelation in panel data. The test operates by first estimating a FE model and extracting the within-household residuals. These residuals are then first-differenced, and the test examines whether the differenced residuals are correlated with their one-period lag. Under the null hypothesis of no serial correlation, the coefficient on the lagged differenced residual should equal zero; rejection of this hypothesis indicates the presence of first order autocorrelation in the error structure.

Across the full sample and within each drought phase, the Wooldridge test strongly rejects the null of no serial correlation at conventional significance levels (*Appendix 2, Table D*). This finding is entirely expected given the nature of household water consumption data. Water use is a state-dependent behaviour, and dynamic FE models with lagged consumption naturally induce correlation in the composite error term. The presence of autocorrelation does not invalidate the FE estimator, nor does it imply misspecification of the behavioural model. Instead, it affects only the validity of standard errors.

To ensure correct statistical inference, all FE specifications (whether for the drought, post-drought or pooled periods) are therefore estimated with standard errors clustered at the household account level. Clustering in this way produces estimates that are robust to arbitrary forms of serial correlation and heteroskedasticity within households. For consistency, the pre-drought CRE model is also estimated using account-level clustered standard errors. This uniform approach allows the analysis to accommodate the high persistence inherent in consumption behaviour while maintaining valid inference for all estimated parameters.

Econometric Model Specification

To analyse household water consumption before, during and after the 2015–2018 Cape Town drought, three complementary panel-data models are estimated. These models reflect differences in the length of each period, the availability of within-household variation, and the requirements for identifying the key behavioural parameters.

Pre-drought model (2015): Static Correlated Random Effects (CRE)

Because the pre-drought period spans only one year, several key regressors - most notably property value - exhibit no within-household variation, rendering fixed-effects estimation inappropriate. For this period, household water consumption is therefore modelled using a **static correlated random-effects (CRE)** specification:

$$\text{consumption}_{it} = \alpha + \beta QPV_{it} + \gamma Seasons_{it} + \delta W_{it} + \theta \bar{W}_i + \mu_i + \varepsilon_{it},$$

where W_{it} denotes contemporaneous weather variables and $\bar{W}_i$ represents their household-specific means. Including $\bar{W}_i$ follows the Mundlak (1978) approach, allowing for correlation between the unobserved effect μ_i and observed covariates. This model is estimated using **random-effects with clustered standard errors** at the account level.

In the CRE model, household-specific averages of precipitation and temperature are included to allow correlation between time-invariant household characteristics and the time-varying weather regressors. This follows the Mundlak adjustment, which ensures consistent estimation of coefficients on QPV despite potential correlation between property value, unobserved household traits and typical local climate conditions.

Drought (2016–September 2018) and post-drought (October 2018–2022) models: Dynamic Fixed Effects (FE)

For the drought and post-drought periods, the time dimension is considerably longer (33 and 51 months respectively). In panels of this length, the Nickell bias is minor and does not materially distort estimates of the lagged dependent variable. The FE estimator therefore remains appropriate, particularly when combined with household-level clustering and the primary interest lying in seasonal and weather coefficients rather than the precise magnitude of the autoregressive parameter.

For the longer drought and post-drought panels, the empirical strategy therefore employs **dynamic fixed-effects (FE)** models to capture persistence in household water use:

$$\text{consumption}_{it} = \alpha + \rho\,\text{consumption}_{i,t-1} + \beta QPV_{it} + \gamma Seasons_{it} + \delta W_{it} + \mu_i + \varepsilon_{it}.$$

These models control for all time-invariant household characteristics through $\mu_i$and incorporate lagged consumption $(\rho)$to reflect dynamic adjustment in water-use behaviour. Estimation is carried out using **FE with standard errors clustered at the account level** to address serial correlation and heteroskedasticity.

Full Period: Fixed Effects (FE)

The pooled FE specification combines the entire 2015–2022 panel and includes QPV indicators, seasonal dummies, lagged consumption and contemporaneous weather variables. Because both weather and QPV vary across households and periods in this longer panel, these coefficients are identified despite fixed effects.

Model Features Common to All Specifications

- **Reference categories:**
  Summer is the omitted seasonal category, and Quintile Property Value 1 (QPV 1) is the omitted income category.
- **Outlier trimming:**
  The top 1% of daily consumption values are removed prior to estimation to reduce the influence of extreme observations.
- **Clustering:**
  In all models, standard errors are **clustered at the household account level** to account for strong serial correlation within households over time.

A priori expectations were as follows: Households in higher income quintiles were expected to consume more water than lower-income households. Drought conditions were anticipated to reduce water consumption across all income groups, with larger proportional reductions in higher-income areas where discretionary outdoor use is more prevalent. Higher temperatures were expected to increase water consumption, while higher precipitation was expected to reduce demand, particularly through reduced outdoor irrigation.

Seasonal patterns in **raw consumption** were expected to follow established climatological trends, with water use peaking in summer and declining during the wetter winter months. In the dynamic specifications estimated for the drought and post-drought periods, lagged consumption was expected to be positively correlated with current consumption, reflecting persistence in household water-use behaviour.

In the post-drought period, it was expected that households - particularly those in middle- and high-income areas - would gradually increase their water use as restrictions eased and supply conditions normalised. However, consumption was anticipated to remain below pre-drought levels, reflecting lasting behavioural adjustments and increased awareness of water scarcity.

Table 1: Water Consumption and Quintile Property Value, Season and Weather by Drought Phase

	(1) Pre-drought (CRE)	(2) Drought (FE)	(3) Post-drought (FE)	(4) Full period (FE)
Dependent variable: Monthly consumption (kL)				
Quintile Property Value (ref: QPV 1)				
QPV 2	2.016*** (0.044)	-0.694*** (0.058)	0.555*** (0.033)	0.275*** (0.025)
QPV 3	2.791*** (0.044)	-1.534*** (0.076)	0.801*** (0.039)	0.443*** (0.029)
QPV 4	5.780*** (0.047)	-3.897*** (0.099)	1.212*** (0.046)	0.520*** (0.033)
QPV 5	11.736*** (0.053)	-6.833*** (0.128)	2.035*** (0.060)	0.945*** (0.039)
Season dummies (ref: Summer)				
Autumn	0.917*** (0.008)	0.520*** (0.005)	-0.442*** (0.004)	0.156*** (0.003)
Winter	1.298*** (0.013)	1.722*** (0.014)	-0.430*** (0.010)	0.929*** (0.006)
Spring	0.610*** (0.010)	1.092*** (0.006)	-0.225*** (0.007)	0.535*** (0.005)
Contemporaneous weather				
Precipitation (mm)	0.360*** (0.005)	-0.231*** (0.003)	-0.073*** (0.002)	-0.356*** (0.004)
Temperature (°C)	0.715*** (0.002)	0.165*** (0.002)	0.044*** (0.002)	0.075*** (0.001)
Household mean weather (CRE only)				
Mean precipitation	2.243*** (0.306)	—	—	—
Mean temperature	-0.303 (0.221)	—	—	—
Dynamics				
Lagged consumption	—	0.562*** (0.004)	0.441*** (0.009)	0.573*** (0.005)
Constant	1.810 (4.174)	4.439*** (0.086)	4.959*** (0.071)	3.496*** (0.066)
Observations	5,723,927	15,188,533	23,419,947	43,848,346
Accounts	497,165	528,519	495,216	528,574
R-sq	0.075	0.492	0.365	0.514
Model	RE (CRE)	FE	FE	FE
Account	Yes	Yes	Yes	Yes
Clustered SEs	Yes (account)	Yes (account)	Yes (account)	Yes (account)

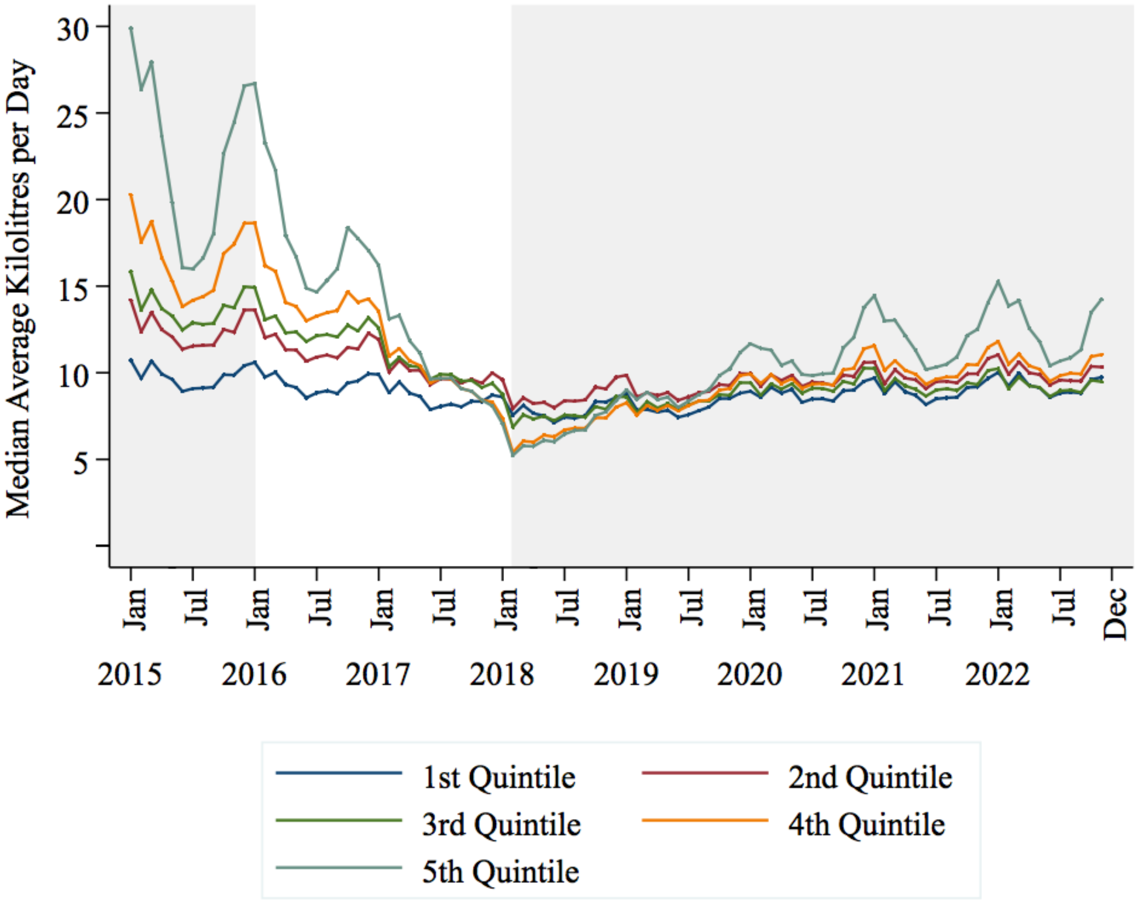
Notes: Dependent variable is monthly household water consumption in kilolitres. Column (1) reports correlated random-effects (CRE) estimates for the pre-drought period (2015), including household-specific means of weather variables. Columns (2) and (3) report fixed-effects estimates for the drought (2016-2018) and post-drought (2018-2022) periods, respectively, with standard errors clustered at the account level. Column (4) reports a pooled fixed-effects specification for the full 2015-2022 period. The top 1 percent of daily consumption observations have been excluded as high outliers in all models. Summer and the lowest property value quintile (QPV 1) are the omitted reference categories. Standard errors clustered at the account level to address serial correlation within households over time.

Results and Discussion

Income (Proxied by QPV)

Under conditions of water abundance, there is a large portion of literature which suggests that higher-income households tend to consume more water than their lower-income counterparts (Jansen & Schulz, 2006). Consistent with this evidence, property value quintile is strongly and monotonically associated with water consumption in the pre-drought period. Relative to households in the lowest property value quintile, those in QPV 2 and QPV 3 consume approximately 2.0 and 2.8 kilolitres more per month, respectively, while households in QPV 5 consume approximately 11.7 kilolitres more on average (Table 1). These differences reflect substantial structural heterogeneity in pre-restriction water demand across the wealth distribution, consistent with larger properties, more extensive irrigated gardens and higher ownership of water-intensive appliances in higher-value areas. The positive relationship between property value quintile and water consumption during the pre-drought period supports the *a priori* expectation that higher-income households consume more water than lower-income households, as illustrated in the first grey block of Figure 3.

Figure 3: Median Average Kilolitres Consumed per Day by Different QPVs over Time



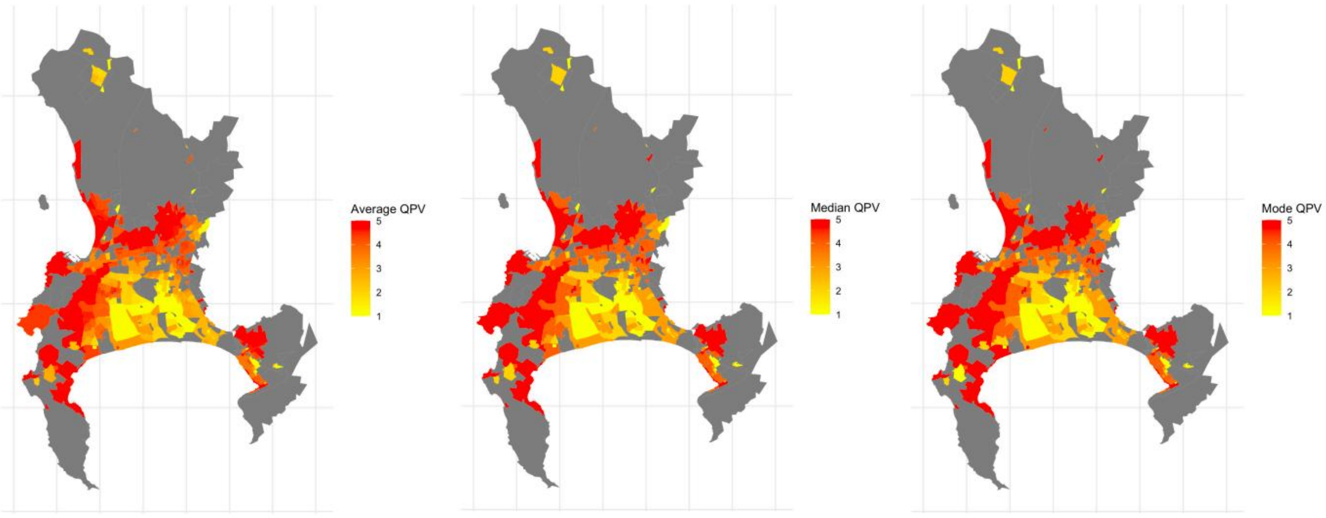
Quintile Property Value

According to previous literature, there are several factors which may explain why higher-income households tend to consume more water than lower-income households under conditions of water abundance. One explanation which is repeatedly mentioned in previous studies is that higher-income households tend to be larger in property size, with increased use of water-intensive amenities such as swimming pools and expansive gardens (Jansen & Schulz, 2006). The larger property sizes and expansive gardens of higher-income households also play a role in shaping habits which entail greater water consumption amongst wealthier households than lower-income households (Trumbo & O'Keefe, 2005). Additionally, under conditions of water abundance, the significantly higher water consumption by higher-income households may be explained by other psychological factors such as attitudes which play a crucial role in shaping water consumption behaviour. For example, according to Willis et al. (2011), higher-income households tend to display a lower regard for resource conservation during times of resource abundance.

In a city like Cape Town which has a large, impoverished population, however, it is important to acknowledge that, even during pre-drought times, water is not experienced as an abundant resource for a significant proportion of the population. More specifically, Cole et al. (2018) highlights the spatial inequality in water access in South Africa, with developed urban areas exhibiting significantly greater access to piped water compared to underdeveloped traditional/tribal areas. The importance of geographic location in determining a household's access to water is emphasised in this study. With reference to *Figures 4* and *5,* a series of GIS maps generated to show the mean, median and mode QPV per suburb, as well as the average water consumption for different suburbs in Cape Town for each year from 2015 to 2022, it is clear that, during 2015, which corresponds to the pre-drought period, affluent neighbourhoods including the Peninsula, the Atlantic Seaboard, the City Bowl, the Blaauwberg coast, the Northern Suburbs and Helderberg exhibit the highest water consumption levels in Cape Town. These regions are depicted with red and dark orange shading on the map. Notably, 2015 stands out as having the most red coloration compared to other time periods, indicating that the highest levels of water consumption are observed in the pre-drought period. Conversely, economically disadvantaged areas like the Cape Flats are represented by yellow shading in 2015, indicating the lowest levels of water consumption. Before assuming a relationship between geographic location and water consumption, however, one should consider studies like Cole et al. (2018) which find a lack of correlation between supply-related factors and water consumption. Rather, demand-related factors like income are found to be significantly correlated with water consumption behaviour (Cole et al., 2018). These findings reiterate the multifaceted nature of the relationship between income and water consumption, even under pre-drought conditions.

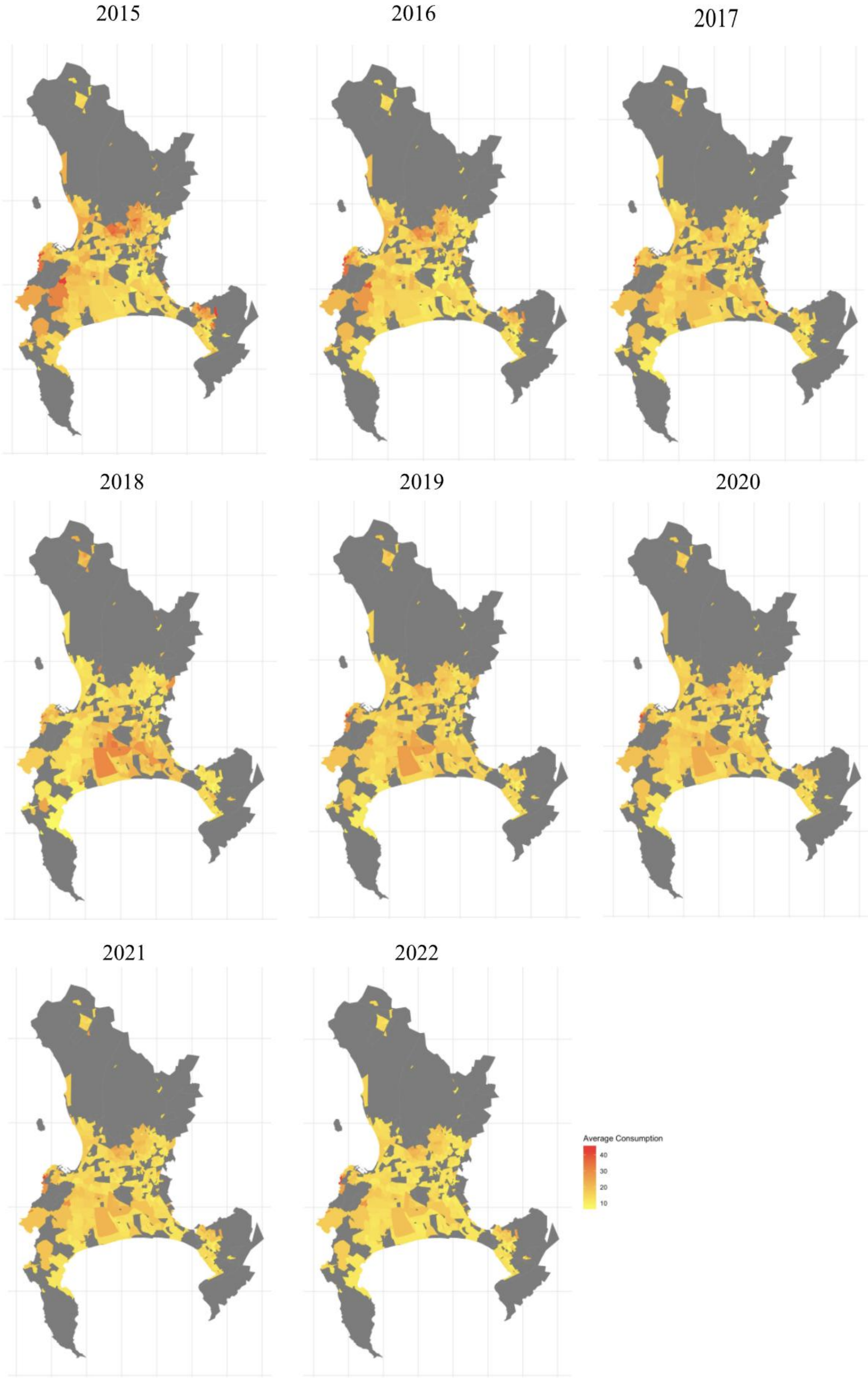
It is also important to acknowledge potential confounding factors which may arise as a result of the City's history of Apartheid. As a consequence of Apartheid, Black, Coloured and Indian populations remain economically disadvantaged (Seekings, 2011). Certain geographic locations tend to be populated by people of colour living in lower-income households, with their specific ethnic and cultural norms, as can be seen in *Figure 2*. These ethnic and cultural norms have been found to play a role in shaping water consumption behaviour, thus making it important to distinguish between income-related consumption patterns and consumption patterns which may be attributed to ethnic or cultural practices and beliefs (Sipamla, 2018). For example, Sipamla (2018) finds that Black participants tend to perceive the City's water supply as sufficient, but engage less in recreational water use as a result of a social construct associating water with labour in Black households. Overall, there is a lack of literature investigating the role of ethnicity and culture in Cape Town in shaping water consumption behaviour, even though a deeper understanding of this subject area could prove particularly useful in understanding water consumption behaviour before the drought presented itself.

Figure 4: GIS Maps Generated to Show the Average, Median and Mode QPV for Different Suburbs in Cape Town



When a drought presents itself, the imbalance between water supply and demand is highlighted. As such, one would expect the relationship between income and water consumption to change from a relationship predominantly shaped by demand to a more complex relationship, as communities are forced to adapt and encouraged to reshape their water consumption behaviours. In line with these expectations, as well as studies such as Cook, Brühl and Visser (2021), Wang et al. (2017) and Schulz and Jansen (2006), this study finds the relationship between QPV and water consumption to change from a positive one before the drought to a negative relationship during the drought period (*Table 1*). More specifically, relative to households in QPV 1, households in QPV 2, QPV 3, QPV 4 and QPV 5 experience statistically significant reductions in monthly water consumption of approximately 0.7, 1.5, 3.9 and 6.8 kilolitres, respectively, during the drought period ($p < 0.01$; *Table 1*). Interestingly, these findings, in line with those of Cook, Brühl and Visser (2021) suggest that, during the drought period, higher-income households, on average, consume less water than lower-income households. With reference to *Figure 3*, it is evident that higher QPVs maintain higher consumption rates until approximately July 2017 (mid-drought), when consumption levels of QPV 2, 3, 4 and 5 converge. In the latter half of 2017, QPV 3, 4 and 5 show reduced consumption levels compared to the two lowest QPVs, with the highest QPV consuming the least amount of water by the end of the drought in March 2018. *Figure 5* reiterates these findings: in 2016, at the onset of the drought period, there is a marginal decline in water usage observed in wealthier suburbs, as indicated by a shift from dark orange to a slightly lighter shade of orange compared to 2015. By 2017, a notable contrast from 2015 emerges: the map shows minimal red shading, and wealthier areas appear in a lighter orange colour, while economically disadvantaged areas like the Cape Flats exhibit a slightly darker shade of orange. This indicates a decrease in water consumption among wealthier suburbs but a rise in consumption among poorer suburbs. Interestingly, by 2018, during the peak of the drought period, the Cape Flats, previously represented in yellow, transitions to a darker shade of orange, with no red areas visible on the map.

Figure 5: GIS Maps Depicting Average Water Consumption Levels between 2015 and 2022 in Cape Town



2015

2016

2017

2018

2019

2020

2021

2022

According to previous literature like Brühl and Visser (2021), the negative relationship between QPV and water consumption during the drought may validate the effectiveness of conservation measures and water-saving campaigns implemented during the drought period. Given that during the 2015-2018 Cape Town drought various conservation measures were implemented in short succession of one another, one cannot comment on the effectiveness of specific measures on water conservation efforts, but rather the effectiveness of measure bundles (Brühl & Visser, 2021). Moreover, this paper's findings may contribute to the evidence found in studies such as Wang et al. (2017) which suggests that the response to different conservation measures during a period of drought varies according to income. In general, the literature suggests that conservation measures are more effective in reducing the water consumption in higher-income households compared to lower-income households. This study reiterates these findings as the drought period regression analysis shows a greater decrease in water consumption associated with a change in QPV to higher property values than lower property values (*Table 1*).

According to Martínez-Espineira and Nauges (2004), tariff increases can successfully incentivise households to reduce water consumption until they are consuming close to basic need levels of water. In a city like Cape Town, where inequality is rife and large proportions of the lower-income households already consume close to basic need levels of water prior to the drought, it is logical for conservation measures to result in larger reductions in water consumption for higher-income households, as the consumption starting point of these households lies significantly above levels of water necessary for survival. Interestingly, however, Brühl and Visser (2021) highlight the fact that, during the drought, residents were incentivised to consume below the basic need threshold of 3 kilolitres per person per month.

When examining differences in water conservation behaviour amongst income groups during the drought, it is important to acknowledge the role of financial limitations. When adapting to drought conditions, higher-income households have a greater capacity to afford water-efficient technologies, such as low-flow showerheads or water-efficient washing machines, which assist in reducing water consumption (Hussien et al., 2016). On the other hand, lower-income households face limitations in the extent to which they can reduce their water consumption whilst maintaining daily functioning as they cannot afford these more expensive water-efficient appliances (Hussien et al., 2016). Water-efficient infrastructure also often requires a large upfront investment, with many households having to take out loans to be able to afford such infrastructure. According to previous research, lower-income households are less likely to be granted the loans they may require to be able to invest in this infrastructure, thus further limiting the capacity of lower-income households to reduce their water consumption to an extent which may be compared to that of higher-income households (Ribot & Larson, 2012).

According to previous studies, differences in conservation efforts by different income groups may also be attributed to psychological factors. For example, according to Koop et al. (2019), the degree to which people perceive a change in water use behaviour as feasible is correlated with the degree to which actual water conservation is observed. Given the fact that, as a consequence of a lack of financial resources, lower-income individuals may perceive their ability to afford water-saving devices as less feasible than higher-income individuals, lower-income individuals may be less likely to take action when it comes to water conservation efforts. Additionally, lower-income individuals may perceive their ability to use less water as less feasible than higher-income individuals as a result of the fact that they are already consuming close to basic need levels of water, thus making it less likely for lower-income households to attempt to conserve water more than they usually would.

Knowledge transfer is also an important factor to consider when trying to understand the differing water conservation behaviour amongst different income groups in Cape Town. According to Koop et al. (2019), knowledge transfer plays a crucial role in shaping water conservation attitudes which significantly impact water conservation behaviour. In Cape Town, a large proportion of the population is impoverished, lacking access to adequate schooling and technology through which information is shared. As such, large proportions of lower-income households in Cape Town may have lacked access to consistent reputable information regarding the severity of the drought, as well as feasible recommendations regarding water conservation efforts in poorer areas. Although there is evidence of a knowledge gap regarding water conservation, it is important to consider the findings of Thakur et al. (2022), which suggest that low-income households in South Africa do, in fact, have high awareness of water conservation techniques, but this high awareness does not necessarily translate into practical water-saving behaviour.

On the note of the impact of poverty on water conservation efforts, it is important to acknowledge the large body of literature on the psychology of poverty which provides information that is imperative in understanding the differences in drought-response behaviour between lower and higher-income households. According to Haushofer and Fehr (2014), individuals living in poverty face a cognitive load as a result of the challenges of juggling limited resources and navigating economic hardships, with this cognitive load consuming mental bandwidth, resulting in the impoverished individual lacking the capacity to experience concern over longer-term issues like the importance of water conservation efforts. While lower-income individuals are forced to 'tunnel' their attention towards urgent needs for survival, higher-income individuals tend not to have to worry about the necessities for survival, and thus have the ability to direct their attention towards activities which are perceived as less urgent, like water conservation (Shafir, 2017). Although the present study does not directly measure cognitive load or attention, these findings from the broader literature offer a plausible behavioural mechanism for why higher-income households might respond more strongly to conservation campaigns than lower-income households.

In addition to the aforementioned factors, social norms must be examined for their vital role in determining conservation efforts during periods of water scarcity. There is a large body of literature which suggests that if an individual perceives their social circle or community to value water conservation, that individual is more likely to partake in water-saving behaviour (Schultz, Tabanico & Rendón, 2008). The present panel data do not include direct measures of social norms or perceived community expectations, so these mechanisms cannot be tested explicitly. Nonetheless, they provide useful context for interpreting the heterogeneous responses observed across neighbourhoods and income groups. Given that different areas in Cape Town tend to be populated by specific racial groups with their distinct cultural norms, attitudes and beliefs, one has to consider the potential role of ethnic and cultural factors in determining water conservation efforts during the drought. According to Sipamla (2018), Black residents tend to acknowledge the crisis of the drought to a lesser extent than Coloured and White residents in Cape Town, with these differences in outlooks during the drought suggesting a correlation between ethnicity and water-related attitudes during times of water scarcity.

Moreover, there is an abundance of literature which suggests that water consumption behaviour exhibits a rebound when a period of water scarcity comes to an end (Beal et al., 2014). In line with this literature, following the 2015-2018 Cape Town drought, this study finds that QPV is significantly ($p<0.01$) positively associated with water consumption (*Table 1*). Relative to households in the lowest property value quintile, households in QPV 2, QPV 3, QPV 4 and QPV 5 consume approximately 0.6, 0.8, 1.2

and 2.0 kilolitres more per month, respectively, in the post-drought period (*Table 1*). With reference to the second grey region in *Figure 3*, following the drought, water consumption increases gradually across all property value quintiles, with the exception of QPV 1, although consumption levels remain subdued relative to the pre-drought period. This pattern aligns with the *a priori* expectation that water use would recover as restrictions eased, but would not fully return to pre-drought levels.

Notably, QPV 2 remains the highest consumer until the second half of 2019, after which QPV 5 overtakes all other quintiles. QPV 3 closely tracks the consumption levels of the lowest property value quintile throughout the post-drought period, remaining similar until December 2022. Overall, consumption levels across QPVs (excluding QPV 5) are considerably more compressed in the post-drought period than before the drought. Although property value quintile remains positively and significantly associated with water consumption during the post-drought period, as in the pre-drought period, the magnitude of this relationship is substantially weaker (*Table 1*). Together, these patterns suggest a lasting behavioural adjustment towards lower water use across income groups following the 2015–2018 Cape Town drought.

Figure 5 builds on the visual summary of post-drought water consumption patterns observed across income groups. In 2019, post-drought, less affluent areas like the Cape Flats exhibit a decrease in water usage, indicated by the lighter orange shade on the map, possibly due to persistent tariff increases (Brühl & Visser, 2021). The map predominantly displays yellow, representing low water consumption levels, with the exception of a small red area noted at the top of the Peninsula coast. Additionally, in 2019, wealthier suburbs like the Northern Suburbs begin to show a slight increase in water consumption. Moving to 2020, water usage remains relatively low across Cape Town, as can be seen from the extensive yellow shading on the map. Compared to 2015, the amount of red visible on the map in 2020 remains minimal. Notably, in 2020, poorer areas such as the Cape Flats demonstrate a reduction in water consumption, as indicated by the lighter orange shade, while wealthier suburbs like the Northern Suburbs continue to experience a slight increase in water consumption. Subsequently, in 2021 and 2022, less affluent areas like the Cape Flats persist in reducing their water consumption, while the majority of Cape Town shows no significant increase in water usage, as illustrated by the sustained presence of yellow and light orange shading on the map.

Thus, *Figure 5* reiterates that although water consumption slightly rises in wealthier areas post-drought, water consumption remains subdued compared to pre-drought levels for all QPVs. According to Nemati, Tran and Schwabe (2023), higher-income households tend to show lower levels of rebound following a drought compared to lower-income households. Additionally, studies such as Nemati, Tran and Schwabe (2023) highlight the fact that a rebound in water consumption behaviour is predominantly observed in the summer months. Finally, when examining the post-drought relationship between income and water consumption, it is also important to acknowledge the role of infrastructure and water-efficient technologies which were installed during the drought in shaping post-drought consumption patterns.

Seasons, Precipitation and Temperature

One cannot examine the relationship between socioeconomic factors such as income and water consumption without accounting for the role of seasonal fluctuations. In Cape Town, seasonal variation is a fundamental determinant of water demand, reflecting predictable changes in temperature, rainfall, outdoor water use and tourism patterns.

It is useful to distinguish between two different notions of ‘seasonal effects’ used in this study. The first is the unconditional climatological pattern documented in the descriptive statistics, which simply compares mean consumption across seasons. The second is the conditional, regression-based seasonal effect, which measures how consumption in a given season deviates from a household’s own predicted level once weather, past consumption and fixed household characteristics have been taken into account. The descriptive statistics speak to the former, while the panel models estimate the latter.

Consistent with the existing literature (Beal et al., 2014), this study finds that seasonal indicators are statistically significant at the 1% level across the pre-drought, drought and post-drought periods (*Table 1*). Importantly, however, the seasonal coefficients in the regression models do *not* represent raw or unconditional seasonal consumption patterns. Because the specifications control for temperature, precipitation, lagged consumption and household-specific effects, the estimated coefficients capture *residual, behaviourally driven seasonal variation within households*, rather than absolute seasonal differences.

Descriptively, raw consumption follows a stable climatological structure throughout the entire sample period. Summer consistently exhibits the highest mean daily consumption and winter the lowest, with autumn and spring falling in between. This pattern is observed in every year from 2015 to 2022 and reflects temperature-driven outdoor irrigation, evaporation needs and seasonal occupancy. The regression results do not contradict this pattern; rather, they isolate how households adjust water-use behaviour *within seasons* once weather conditions and persistence are held constant.

In the pre-drought period, the positive coefficients on autumn, winter and spring indicate that, conditional on weather and lagged use, the residual component of consumption is higher in non-summer months than in summer. Put differently, once the part of consumption that is systematically driven by temperature and rainfall is stripped out, households use somewhat more water than the model predicts in autumn, winter and spring, and somewhat less in summer. This does *not* mean that winter or autumn have higher total consumption than summer. Instead, it reflects the fact that much of the summer peak is already captured by the explicit weather controls, so there is relatively little additional seasonal variation left for the summer dummy to pick up.

Weather variables behave as expected during the pre-drought period. Temperature is positively and strongly associated with water consumption, while precipitation exhibits a statistically significant effect reflecting the complex interaction between rainfall, indoor demand and property characteristics. The household-level means of precipitation are strongly significant in the CRE specification, indicating meaningful cross-sectional heterogeneity in long-term hydrological exposure, billing-cycle effects and household occupancy patterns.

During the drought, the interpretation of seasonal effects becomes particularly important. Although summer continues to exhibit the highest absolute levels of consumption, it experiences the largest proportional reductions due to severe restrictions on outdoor irrigation and discretionary use. Winter consumption, which contains less discretionary demand, declines by less. As a result, the residual component of summer consumption falls sharply relative to other seasons. This behavioural compression of the summer peak produces fixed-effects coefficients in which winter and spring appear positive relative to summer, even though summer remains the season of highest absolute use. At the same time, the elasticity with respect to rainfall becomes negative, indicating that households exploit rainfall events to further reduce metered consumption. Temperature remains positively associated with demand but with a substantially attenuated effect, consistent with constrained outdoor use under binding policy restrictions (Brühl & Visser, 2021). These results are also consistent with broader contextual changes during the drought. WWF (2018) documents a sharp decline in tourist arrivals - typically concentrated in summer months - which further reduces seasonal demand pressures during this period.

In the post-drought phase, seasonal patterns evolve again. Rainfall continues to depress consumption slightly, while temperature effects remain positive but smaller than in the pre-drought period. A one-degree Celsius increase in temperature is associated with an increase in monthly consumption of approximately 0.044 kilolitres (*Table 1*), indicating a persistent, though muted, responsiveness to heat. Notably, summer consumption does not fully return to its pre-drought seasonal uplift. The persistence of drought-era conservation norms, alongside the adoption of water-efficient technologies, appears to concentrate lasting reductions in historically high-use summer months. Consequently, the fixed-effects estimates yield negative residual coefficients for winter and autumn relative to summer. These coefficients do **not** imply that winter consumption exceeds summer consumption in absolute terms. Rather, they indicate that the *seasonal premium associated with summer* is smaller than before the drought once weather conditions and lagged usage are controlled for.

To clarify the interpretation of the seasonal coefficients, *Appendix 3 Table E* reports FE specifications estimated without temperature and precipitation controls. Once weather is omitted, the estimated coefficients recover the canonical seasonal ordering, with summer exhibiting the highest conditional consumption and winter the lowest across all periods. This confirms that the sign reversals observed in some of the fully specified models in *Table 1* are a mechanical consequence of conditioning on temperature and precipitation, rather than evidence that the underlying climatological pattern has changed. Together, the descriptive tables, the fully specified models, and the no-weather robustness checks therefore present a coherent picture: summer always has the highest absolute water use, but the residual component of seasonal variation is reshaped by the drought and by the inclusion of explicit weather controls.

The literature emphasises that the relationship between seasonality and water consumption is highly context dependent. While rainfall is often negatively associated with consumption, studies such as Schulz and Jansen (2006) document positive or insignificant relationships, underscoring the role of geographic, climatic and socioeconomic factors. Income interacts with seasonal drivers in complex ways: Viljoen (2015) shows that temperature increases have larger effects in lower-income households due to heat-retaining housing materials, while higher-income households respond more strongly to low rainfall because of garden irrigation demands. Tourism further complicates seasonal demand patterns. In cities such as Cape Town, peak tourist inflows during summer months contribute to higher seasonal water use (Reynaud, Pons & Pesado, 2018), amplifying the importance of summer demand management in water-scarce contexts.

Lagged Consumption

Intuitively, current water consumption behaviour is influenced by past consumption patterns. A substantial body of literature on habits and routines suggests that repeated behaviours, formed over time, tend to persist and shape future actions (Aitken et al., 1994; Trumbo & O'Keefe, 2005). Once established, such habits are often executed automatically, reducing the role of active deliberation in day-to-day consumption decisions.

Consistent with this literature and with *a priori* expectations, this study finds that the previous month's water consumption is significantly ($p < 0.01$) and positively associated with current water consumption in both the drought and post-drought periods. This indicates a high degree of persistence in household water-use behaviour over time, even after controlling for weather conditions, seasonality and household fixed effects.

The magnitude of the lagged consumption coefficient is slightly larger during the drought period, suggesting that behavioural persistence strengthens under conditions of scarcity. This pattern is consistent with the idea that repeated exposure to restrictions, heightened monitoring and social pressure during drought conditions reinforces water-saving routines. In the context of the 2015–2018 Cape Town drought, extensive public awareness campaigns and the social stigmatisation of high water use may have contributed to the consolidation of more conservative consumption habits (Willis et al., 2011).

Importantly, the persistence of a strong and significant lagged effect in the post-drought period suggests that these behavioural adjustments did not fully dissipate once restrictions were lifted. This finding aligns with existing evidence that droughts can generate durable changes in consumption behaviour, as water-saving practices adopted under scarcity become embedded as longer-term habits (Brühl & Visser, 2021). Rather than a complete return to pre-drought usage patterns, households appear to retain elements of the conservation behaviours learned during the drought.

Limitations

Even though this study provides valuable insights into the changes in water consumption patterns before, during and after the 2015-2018 Cape Town drought, it is important to acknowledge ways in which the study may be constrained. Given that this study makes use of the City of Cape Town's municipal water data, there may be a significant portion of low-income informal households which are not taken into account as a result of their lack of access to municipal water (City of Cape Town, 2023). Rather than relying on municipal data, these informal households often make use of communal taps and borehole water, with this water use being difficult to document in the official data (City of Cape Town, 2023). This limitation of the data should be kept in mind when drawing conclusions regarding the overall water consumption of the City, as well as the water consumption patterns of lower-income households in Cape Town as the results may not be fully representative of the lowest income group in Cape Town.

In addition, quintile property value (QPV) is used as a proxy for household income and wealth, which may not perfectly reflect current disposable income or household composition, particularly in cases where households are asset-rich but income-constrained.

During the drought, many households also turned to alternate sources of water beyond the municipal supply to maintain their preferred water-related routines. For example, wealthier households were able to drill boreholes and purchase water from external sources. As such, one must acknowledge the possible inaccuracies in the capturing of holistic water consumption data, even amongst higher-income households. The results of this study may speak more to municipal water use than water use in general, meaning that one should be careful as to the conclusions drawn from this paper surrounding water consumption patterns.

Additionally, even though this paper makes use of approximately five years of post-drought data, a longer period of time may need to be studied in order to accurately comment on the extent to which water consumption rebounds to pre-drought levels following a drought. This study finds that water consumption gradually increases following the drought, but data over a longer period of time would be necessary to comment on whether water consumption returns to pre-drought levels or stabilises at a new equilibrium.

Furthermore, while the inclusion of lagged consumption captures persistence in water-use behaviour over time, it does not allow for a clean separation between habit formation, technological adoption and ongoing institutional or policy constraints.

One also has to acknowledge the potential of omitted variable bias in the regressions. Despite the effort to include a number of relevant variables, certain factors which have been found in previous literature to influence water consumption trends were not included in the panel regressions. For example, variables like household size, infrastructure quality and culture were not included in the regression analysis. In addition, municipal water tariff data could not be incorporated in a comparable panel format. Given that tariffs were frequently adjusted during the drought, their omission may affect the extent to which changes in consumption are attributed to price effects versus behavioural or climatic factors. The omission of these variables may result in the regression failing to capture the complex interplay between income, seasonal factors, previous consumption patterns, other socioeconomic variables and water consumption.

With regards to the data, there are sections of the southern Peninsula, eastern Helderberg, parts of the Northern Suburbs and Blaauwberg which lack publicly available data on water consumption, as can be seen from the grey areas in *Figure 4*. The data omitted from the Northern Suburbs and Blaauwberg is omitted as it is either airfield, military reserve, wetland or sparsely populated territory (Turok et al., 2020). This omitted data should be taken into consideration when drawing conclusions regarding water consumption patterns in Cape Town.

Conclusions and Policy Recommendations

Conclusions

This study analyses household water consumption patterns across income groups before, during and after the 2015–2018 Cape Town drought, with the primary objective of assessing whether consumption rebounded to pre-drought levels following the crisis. The analysis combines descriptive evidence with panel regression methods tailored to the structure of each period, using a static correlated random-effects model for the pre-drought period and dynamic fixed-effects models for the drought and post-drought periods. Insights from the economic and behavioural literature are used to contextualise the empirical findings.

The results indicate that water consumption does not fully return to pre-drought levels following the drought. Although consumption increases gradually in the post-drought period, levels remain materially below those observed prior to 2015 across income groups. This suggests that the drought was associated with persistent reductions in municipal water use rather than a temporary deviation from long-run trends. While the analysis cannot identify the precise mechanisms underlying this persistence, the findings are consistent with a combination of structural adjustments - such as reduced outdoor water use and the adoption of water-efficient technologies - and longer-lasting behavioural changes.

Regression results show that income (proxied by quintile property value), seasonality, temperature, precipitation and lagged consumption are all statistically significant determinants of monthly water consumption. Prior to the drought, higher-income households consume substantially more water than lower-income households, consistent with greater access to water-intensive amenities. During the drought, this relationship reverses: higher-income households reduce municipal water consumption more sharply than lower-income households. This pattern likely reflects differences in the capacity to respond to restrictions and conservation measures, although the data do not allow for a definitive separation of behavioural, technological and institutional factors. In the post-drought period, income is again positively associated with water consumption, but the magnitude of this relationship is considerably smaller than before the drought, indicating a compression of consumption differences across income groups.

Seasonal and weather-related effects remain important throughout the sample period. Descriptive statistics confirm a stable climatological pattern in which summer exhibits the highest consumption and winter the lowest. However, the regression estimates capture conditional, within-household seasonal effects once weather conditions and persistence are controlled for. Prior to the drought, temperature is strongly positively associated with consumption, while precipitation reduces demand. During the drought, these relationships weaken as restrictions limit discretionary outdoor use. In the post-drought period, temperature and precipitation resume their expected roles, but with attenuated effects, suggesting a lasting change in the responsiveness of consumption to weather conditions.

Lagged consumption is positively and significantly associated with current consumption during the drought and post-drought periods, indicating substantial persistence in water-use behaviour. While this persistence cannot be unambiguously attributed to habit formation, technological adoption or continued institutional constraints, the results are consistent with evidence that consumption patterns established during periods of scarcity may endure over time.

Policy Recommendations

Several policy implications follow from these findings. First, the persistence of reduced water consumption suggests that droughts may generate durable changes in demand if conservation measures are sufficiently salient and sustained. Policies implemented during periods of scarcity should therefore be designed with an explicit view towards longer-run behavioural impacts, rather than solely short-term demand reduction.

Second, the differential responses across income groups highlight the importance of distributional considerations in water policy. Higher-income households appear better able to reduce consumption during drought conditions, likely reflecting greater access to water-saving technologies and flexibility in water use. Expanding access to water-efficient technologies among lower-income households (through targeted subsidies or support programmes) may improve equity in conservation outcomes and enhance overall demand management.

Third, the findings suggest that information and behavioural interventions should be carefully tailored to local socioeconomic contexts. Uniform messaging may be less effective in heterogeneous urban settings such as Cape Town. Community-specific approaches that account for differences in resources, constraints and social norms may improve the effectiveness of conservation initiatives.

Finally, the persistence of consumption behaviour highlights the relevance of broader socioeconomic conditions. For households facing binding material constraints, the capacity to engage with conservation initiatives may be limited. Complementary policies that reduce economic insecurity and improve access to basic services may therefore play an indirect role in supporting sustained water conservation.

Future research could extend the post-drought horizon to assess whether consumption stabilises at a new long-run equilibrium or gradually converges towards pre-drought levels. Further work could also explore the interaction between income, cultural norms and conservation messaging, as well as the role of cognitive and material constraints in shaping environmental behaviour.

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Appendices

Appendix 1

Table A: Mean Daily Water Use by Year and Season (litres per household per day)

Year	Summer	Autumn	Winter	Spring
2015	727.0	657.9	541.9	617.9
2016	635.4	556.7	497.0	532.2
2017	456.0	440.5	386.8	363.5
2018	340.8	286.0	314.9	358.2
2019	394.9	325.3	322.7	358.5
2020	426.2	393.4	380.3	403.5
2021	469.7	428.4	400.8	429.7
2022	495.4	455.3	413.1	452.6

Table B: Mean Daily Water Use by Drought Phase and Season

Drought Phase	Summer	Autumn	Winter	Spring
Pre-drought (2015)	727.0	657.9	541.9	617.9
Drought (2016–Jun 2018)	488.2	427.6	418.9	447.8
Post-drought (Jul 2018–2022)	440.6	399.0	371.1	398.8

Table C: Percentage Change Relative to Pre-drought Baseline (%)

Phase	Summer	Autumn	Winter	Spring
Drought	−32.9%	−35.0%	−22.7%	−27.5%
Post-drought	−39.4%	−39.4%	−31.5%	−35.5%

Appendix 2

Table D: Wooldridge tests for first order serial correlation in panel data

Sample / Period	**F-statistic**	**p-value**	**Conclusion**
Full sample (with covariates)	9 596.05	0.0000	Reject H_0: strong serial correlation
Pre-drought (2015)	3 090.32	0.0000	Reject H_0: strong serial correlation
Drought (2016 – Jun 2018)	11 111.37	0.0000	Reject H_0: strong serial correlation
Post-drought (Jul 2018 – 2022)	3 499.10	0.0000	Reject H_0: strong serial correlation

Appendix 3

Table E: Water Consumption Models: Pre-drought, Drought, Post-drought and Full Period

	(1) Pre-drought (FE)	(2) Drought (FE)	(3) Post-drought (FE)	(4) Full period (FE)
Dependent variable: Monthly consumption (kL)				
Quintile Property Value (ref: QPV 1)				
QPV 2	—	-0.800*** (0.058)	0.575*** (0.033)	0.334*** (0.025)
QPV 3	—	-1.742*** (0.077)	0.843*** (0.039)	0.570*** (0.029)
QPV 4	—	-4.216*** (0.101)	1.274*** (0.046)	0.700*** (0.033)
QPV 5	—	-7.254*** (0.129)	2.116*** (0.059)	1.175*** (0.039)
Season dummies (ref: Summer)				
Autumn	-1.350*** (0.009)	-0.180*** (0.009)	-0.636*** (0.007)	-0.288*** (0.005)
Winter	-4.089*** (0.013)	-0.231*** (0.010)	-0.954*** (0.015)	-0.554*** (0.010)
Spring	-2.132*** (0.010)	0.225*** (0.008)	-0.452*** (0.011)	0.027*** (0.008)
Dynamics				
Lagged consumption	—	0.565*** (0.004)	0.441*** (0.009)	0.575*** (0.005)
Constant	19.028*** (0.007)	8.066*** (0.111)	5.812*** (0.101)	4.786*** (0.072)
Observations	5,723,927	15,188,533	23,419,947	43,848,346
Accounts	497,165	528,519	495,216	528,574
R-sq	0.075	0.492	0.365	0.514
Model	FE	FE	FE	FE
Account	Yes	Yes	Yes	Yes
Clustered SEs	Yes (account)	Yes (account)	Yes (account)	Yes (account)

Notes: Dependent variable is monthly household water consumption in kilolitres. Column (1) (2) and (3) report fixed-effects estimates for pre-drought (2015), drought (2016-2018) and post-drought (2018-2022) periods, respectively, with standard errors clustered at the account level. Column (4) reports a pooled fixed-effects specification for the full 2015-2022 period. The top 1 percent of daily consumption observations have been excluded as high outliers in all models. Summer and the lowest property value quintile (QPV 1) are the omitted reference categories. Standard errors clustered at the account level to address serial correlation within households over time.

Table E reports a set of fixed-effects models estimated without explicit temperature and precipitation controls. While *Table 1* presents the preferred specifications - including contemporaneous weather variables and dynamic fixed effects for the longer panels - the inclusion of weather controls complicates the interpretation of the seasonal coefficients. In those models, seasonal dummies capture residual within-household seasonality conditional on temperature and precipitation, rather than the underlying climatological seasonal pattern.

To disentangle these effects, *Table E* presents parallel fixed-effects specifications for the pre-drought, drought, post-drought and pooled periods that retain seasonal indicators, quintile property value (QPV) controls and, where applicable, lagged consumption, but omit weather variables. These models provide a reduced-form characterisation of within-household changes in water use that abstracts from explicit weather variation and therefore yields a clearer depiction of the seasonal structure.

As expected, QPV indicators are omitted in the pre-drought fixed-effects specification due to the absence of within-household variation in property value over the single-year panel. This reinforces the rationale for the correlated random-effects approach used for the pre-drought period in *Table 1*. During the drought, QPV coefficients are strongly negative and exhibit a clear gradient, indicating that higher-value properties reduced consumption more sharply relative to their own baselines. In the post-drought period, QPV coefficients become positive and ordered, reflecting the re-emergence of cross-sectional differences in consumption once restrictions eased. The pooled estimates consolidate these patterns and confirm persistent heterogeneity in household demand across the property value distribution.

The seasonal coefficients in *Table E* follow the expected climatological ordering, with autumn, winter and spring exhibiting significantly lower consumption relative to summer across all periods. The contrast with *Table 1* demonstrates that the sign reversals observed in some fully specified models are a mechanical consequence of conditioning on temperature and precipitation. Once weather controls are removed, the canonical seasonal hierarchy is restored, confirming the internal consistency of the empirical strategy.

Finally, the coefficients on lagged consumption remain stable across specifications, indicating that the dynamic persistence of household water use is robust to the inclusion or exclusion of weather variables. Overall, *Table E* provides a robustness check that supports the main empirical findings and clarifies the role of weather controls in shaping seasonal coefficients.