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Enhancing Water Management in the City of Umhlathuze Local Municipality in Kwazulu Natal by Analysing its Historic Metering Data

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ENHANCING WATER MANAGEMENT IN THE CITY OF UMHLATHUZE LOCAL MUNICIPALITY IN KWAZULU NATAL BY ANALYSING ITS HISTORIC METERING DATA

CIVN7019A: RESEARCH PROJECT

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DECLARATION FOR THE PROJECT

I declare that this research project for CIVN7019A except where otherwise indicated, is my original research which was carried out by myself without being aided by anyone else.

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I extend my sincere appreciation to my supervisor, Professor Akpofure Taigbenu, for his invaluable support. Your insightful guidance and constructive feedback have been instrumental in shaping this research. Your expertise and deep knowledge of the subject matter have been truly inspiring.

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This work is dedicated to my late parents, Nobantu and Mbuzeni Shinga. Though you did not have the opportunity to witness the man I have become, I live each day striving to make you proud. Your love, teachings, and spirit remain with me, and I promise to carry your memory forward. Shinga, Blose, Ndelu, Sosukwana, Majojobela, Maphosela kude, akuShinganga wena kwaShinga isbongo.

ABSTRACT

This study examines historical metering data from March 2016 to September 2020 for billed residential areas within the City of uMhlathuze Local Municipality to identify trends in residential water consumption and provide insights into sustainable water management. Understanding consumption patterns among billed customers is critical in assessing the extent of excessive water consumption and its implications for water resource sustainability. By analysing these trends, this research enables comparative assessments with other municipalities, offering valuable insights into the effectiveness of existing water management strategies and proffering recommendations to improve water usage.

The study employs Change Point Analysis and Water Demand Models, incorporating linear, log-log, and semi-log regression techniques. Change Point Analysis is utilised to detect significant shifts in water demand driven by policy interventions such as the introduction of drought tariffs, seasonal variations, and socio-economic factors. The analysis reveals that residential water consumption in the municipality remained relatively stable, averaging 23,190 kl/d between March 2016 and September 2020. Further, the Water Demand Model analysis identifies the log-log model as the most representative of the municipality's water usage trends, with an R-squared value of 70%, indicating a relatively strong fit. The number of service connections emerges as a key determinant of water demand, with a statistically significant P-value of 0.01, emphasising its impact on consumption patterns.

Non-revenue water (NRW) accounts for 27% (or 88 L/c/d) of the total system input volume (327 L/c/d). The study found that excessive residential water consumption is not currently a significant concern, with an average residential per capita consumption of approximately 143 litres per person per day, which is categorised as excellent water use management. The resulting total Revenue Water figure of 239 L/c/d reflects the total system's efficiency in billing all sectors (residential, commercial and industrial). However, network inefficiencies due to aging infrastructure remain. Addressing these inefficiencies requires infrastructure upgrades, improved metering accuracy, and enhanced leak detection measures. Additionally, incorporating unauthorised users into the billing system can contribute to reducing NRW and improving revenue generation.

The study recommends a series of targeted interventions, including infrastructure maintenance, smart metering deployment, public awareness campaigns, and optimisation of industrial water use. Implementing these measures will strengthen water conservation efforts, ensure long-term sustainability, and promote equitable water distribution within the municipality.

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LIST OF ACRONYMS

AADD	Average Annual Daily Demand
ADD	Average Daily Demand
CPA	Change Point Analysis
CoCT	City of Cape Town
CUSUM	Cumulative Sum
CW	Clarified Water
DWS	Department of Water and Sanitation
ILI	Infrastructure Leakage Index
kl	Kilolitres
KZN	KwaZulu-Natal
L/c/d	Litres per capita per day
MSE	Mean Square Error
NR	Non-Revenue Water
RDP	Reconstruction and Development Programme
SDGs	Sustainable Development Goals
SIV	System Input Volume
SWOR	Sampling Without Replacement
SWT	Special Water Tariff
WCC	Water Consumption (Commercial)
WCM	Water Credit Meter
WD	Water Dwelling
WDMs	Water Demand Models
WETC	Water Exxaro TSA Consumption
WR	Water Residential
WR	Water Rebate

LIST OF SYMBOLS

b_0: Model intercept

$b_1, b_2, b_3, \dots, b_n$: Coefficients of corresponding independent variables

CL: Confidence level

D_l: Bootstrap dataset

e_i: Random error correlated with the $i - th$ value

f: Function

i: Index for data points/time

j: Index for data points in bootstrap dataset

K: Number of bootstraps for which ${S_{diff}}^{i} > {S_{diff}}^{j}$

l_n: Natural logarithm

m: Furthest point from the zero value in the CUSUM chart, also index for data split

$m^3/annum$: Million cubic meters per year

m_i: Mean at time N

$MSE\ (m)$: Mean Square Error for a given sub-dataset D

N: Number of bootstrap samples executed

n: Size of dataset

n_0: Size of initial dataset

°C: Degrees Celsius (for temperature)

P-Value: Probability Value

R^2: R-squared value

$S_0, S_1, S_2, \dots, S_n$: Cumulative sum of the points

${S_{diff}}^{i}$: Magnitude of change

S_m: Furthest point from the zero value in the CUSUM chart

X_1: Number of Connections

X_2: Average Water Price Per Billing Period ($m3$ per day)

X_3: Average Seasonal Temperature (°C)

X_4: Seasonal Rainfall (mm or m)

$X_1, X_2, X_3, \dots, X_n$: Different relevant factors affecting the water demand

X_j: Data points for bootstrap dataset

x: Mean of data points

$x_1, x_2, x_3, \ldots, x_n$: n data points in a time series

Y: Total water demand

%: Percentage

1 INTRODUCTION

Water scarcity presents a pressing challenge globally, particularly evident in South Africa, where projections forecast a significant water deficit by 2030 (Viljoen & van der Walt, 2018). This scarcity is aggravated by factors such as climate change, rapid urbanisation, and inefficient water use and management practices. Efforts have been made to address these issues through initiatives such as water conservation strategies, infrastructure rehabilitation projects, and the implementation of advanced monitoring systems to detect leaks and inefficiencies (DWS, 2023). However, challenges such as significant leakage within aging water distribution networks, delays in infrastructure maintenance due to funding constraints, and inefficiencies in enforcement and policy implementation persist (Viljoen & van der Walt, 2018). These ongoing issues continue to strain municipal resources, emphasising the need for more effective and data-driven approaches to water management.

Referring to Figure 1, the 2021/22 national water balance produced by the Department of Water and Sanitation indicates a System Input Volume (SIV) of 4,282.50 million cubic meters per year, Non-Revenue Water (NRW) of 1,988.50 million m^3 per year (46.40%), and water losses of 1,744.70 million m^3 per year (40.70%) (DWS, 2023). Between 2021 and 2022, there has been a noticeable increase of 1.30% in NRW and 0.90% in water losses (DWS, 2023).

<table>
<tr><td rowspan="4">System Input Volume = 4282.532 (216 l/c/d)</td><td rowspan="2">Authorised Consumption = 2537.867 (59.3%)</td><td rowspan="2">Billed Authorised = 2294.071</td><td>Billed Metered = 1884.983</td><td rowspan="2">Revenue Water = 2294.071 (53.6%)</td></tr>
<tr><td>Billed Unmetered = 409.089</td></tr>
<tr><td rowspan="2">Unbilled Authorised = 243.796</td><td>Unbilled Metered = 41.67
Unbilled Unmetered = 202.128</td><td rowspan="3">Non-Revenue Water = 1988.460 (46.4%)</td></tr>
<tr><td rowspan="2">Water Losses = 1744.664 (40.7%)</td><td>Apparent Losses = 349.481</td><td>Apparent Losses = 349.481</td></tr>
<tr><td>Real Losses = 1395.183
ILI = 6.4</td><td>Real Losses = 1395.183
CARL=15 m^3/km/day</td></tr>
</table>

Figure 1: 2021/2022 National Water Balance (DWS, 2023)

Despite the national per capita consumption of water, as reported by the National Water Balance of 2023, being 216 litres per capita per day (L/c/d), a slight decrease from the national average of 217 L/c/d recorded in June 2021 (DWS, 2023), trends in non-revenue water (NRW) and overall water loss have shown a consistent increase over the past decade.

While existing literature emphasises the importance of leveraging data analytics and sustainable water management strategies, there is still a gap in understanding water consumption patterns and the efficacy of water-saving interventions.

Here are some examples of existing South African literature that discuss these gaps:

1. Mukheibir, P., & Ziervogel, G. (2007). *Developing a Municipal Adaptation Plan (MAP) for Climate Change: The City of Cape Town*. Environment and Urbanisation, 19(1), 143-158.
    - This study highlights data-driven planning in municipal water management and adaptation strategies in response to climate change. However, it acknowledges a gap in the detailed analysis of individual consumption behaviours and their long-term impacts on water conservation efforts.

2. Mukonavanhu, T. and Nel-Sanders, D. (2024). *Water Conservation and Water Demand Management Business Planning in South Africa*. International Journal of Development and Sustainability, 13(9), pp. 730-753.
    - The study identifies a gap in research concerning the comprehensive examination of the current state of Water Conservation and Water Demand Management business planning in South Africa.

This research aims to contribute toward addressing this gap by utilising historic metering data to analyse consumer behaviour. Based on the results targeted interventions for sustainable water resource management in South Africa, focusing on the City of uMhlathuze municipality of the province of KwaZulu-Natal, will be developed.

Figure 2 shows the water balance of KwaZulu Natal in 2023. The water balance data is largely influenced by the eThekwini, Msunduzi, Newcastle, and City of uMhlathuze municipalities, which collectively represent about 69% of the demand which 6% of that is represented by the City of uMhlathuze local Municipality (DWS, 2023). This water balance indicates non-revenue water (NRW) at 437.10 million m^3 per year (53.50%) and water losses at 365.40 million m^3 per year (44.80%) (DWS, 2023). According to DWS (2023) the rise in these figures is due to the aging infrastructure and issues that are associated with metering and billing.

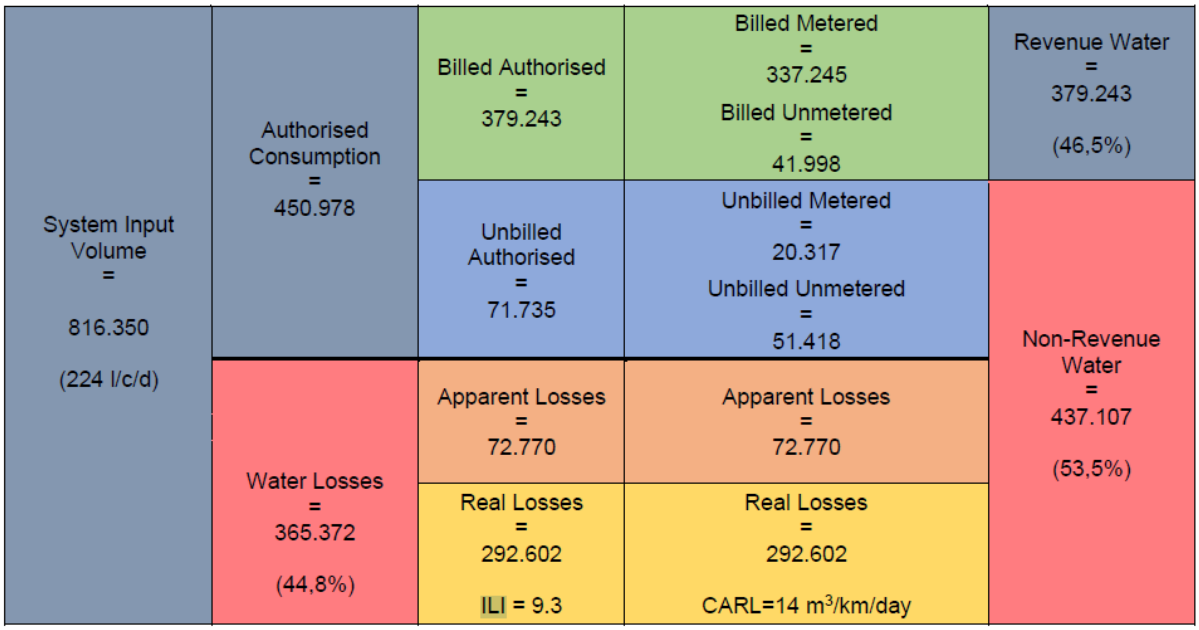

Figure 2: KwaZulu Natal Water Balance (million m^3 /annum) (DWS, 2023)

South Africa, particularly the KwaZulu Natal region, faces significant water losses and these losses stem from factors such as water theft, meter inaccuracies, and leakages within the distribution infrastructure (Netshitanini et al., 2023). Increasing demand places additional stress on aging infrastructure, increasing the likelihood of leaks and bursts. While consumers are billed for their recorded usage, the infrastructure delivering this water may suffer from inefficiencies that lead to further losses. As a result, non-revenue water (NRW), representing water that is produced but not billed, due to losses has become significant, accounting for 54% according to DWS (2023), which adversely affects both water availability and financial sustainability.

The Infrastructure Leakage Index (ILI) is a performance indicator that compares current real losses to unavoidable losses in a water distribution system and a higher ILI signifies greater inefficiencies (DWS, 2023). High ILI values indicate that overconsumption, coupled with infrastructure deficiencies, contribute significantly to water scarcity in the region (DWS, 2023). Table 1 presents the Infrastructure Leakage Index (ILI) for the region, as reported by DWS (2023). The ILI for the KwaZulu-Natal region stands at 9.30, which is considerably high, highlighting the urgent need for improved monitoring and significant investment in infrastructure repair, maintenance, and rehabilitation (DWS, 2023).

Table 1: Region Benchmark Summary Showing the Performance of Provinces in South Africa Using %NRW, L/c/d and ILI (DWS, 2023)

Region	SIV (m^3/annum)	RW (m^3/annum)	NRW (m^3/annum)	%NRW	L/c/d	ILI
EC	341,784,801	180,856,704	160,928,096	47%	203	5.30
FS	245,273,746	114,972,777	130,300,969	53%	224	5.60
GT	1,520,493,167	883,182,277	637,310,891	42%	253	7.90
KZN	816,349,522	379,242,693	437,106,828	54%	224	9.30
LP	297,623,119	128,801,298	168,821,821	57%	210	5.70
MP	287,781,407	140,491,650	147,289,757	51%	186	4.80
NC	108,607,828	47,554,453	61,053,374	56%	250	8.10
NW	232,123,394	114,267,940	117,855,454	51%	176	4.80
WC	430,141,867	302,936,992	127,204,875	30%	161	3.30
NATIONAL	4,280,178,851	2,292,306,784	1,987,872,065	46%	216	6.40

SIV	System Input Volume
RW	Revenue Water
NRW	Non-Revenue Water
L/c/d	Per Capita Water Consumption (Liters per capita per day)
ILI	Infrastructure Leakage Index

Aims and Objectives of the Research Project

This research project examines historical metering data for billed residential areas served by metered connections to identify trends in residential water consumption within the City of uMhlathuze Local Municipality. The study will utilise historical metering data for billed residential areas obtained from the City of uMhlathuze local municipality which is located in KwaZulu-Natal, spanning from March 2016 to June 2021.

By focusing on billed water consumption, the City of uMhlathuze Local Municipality can identify consumption trends, gaining a clearer understanding of who uses water and in what quantities. This analysis aids in pinpointing areas of excessive use and enabling targeted conservation efforts. Addressing discrepancies between produced and billed water can help reduce non-revenue water (NRW), ultimately improving overall water availability. Furthermore, analysing billed consumption provides valuable insights into user behaviour and system performance and this approach is essential for developing effective strategies to minimise water losses, manage overconsumption, and ensure the

sustainable provision of water resources within the City of uMhlathuze Local Municipality.

Research Questions

Four research questions that have be formulated to define the scope of this research project are:

1. What are the trends in water usage within the City of uMhlathuze Local Municipality in the province of KwaZulu-Natal based on historical metering data?

2. Is there evidence of excessive water consumption within the municipality relative to the population served by metered connections, and if so, what are the contributing factors?

3. How does the average water demand of the City of uMhlathuze Local Municipality observed in this research project compare with the average water demand observed in other studies focusing on the KwaZulu-Natal province?

4. In areas where excessive water usage is identified within the City of uMhlathuze Local Municipality, what educational and awareness campaigns can be recommended to promote domestic water conservation practices, and how can these campaigns be tailored to address specific community needs and challenges?

2 LITERATURE REVIEW

2.1 Study Area

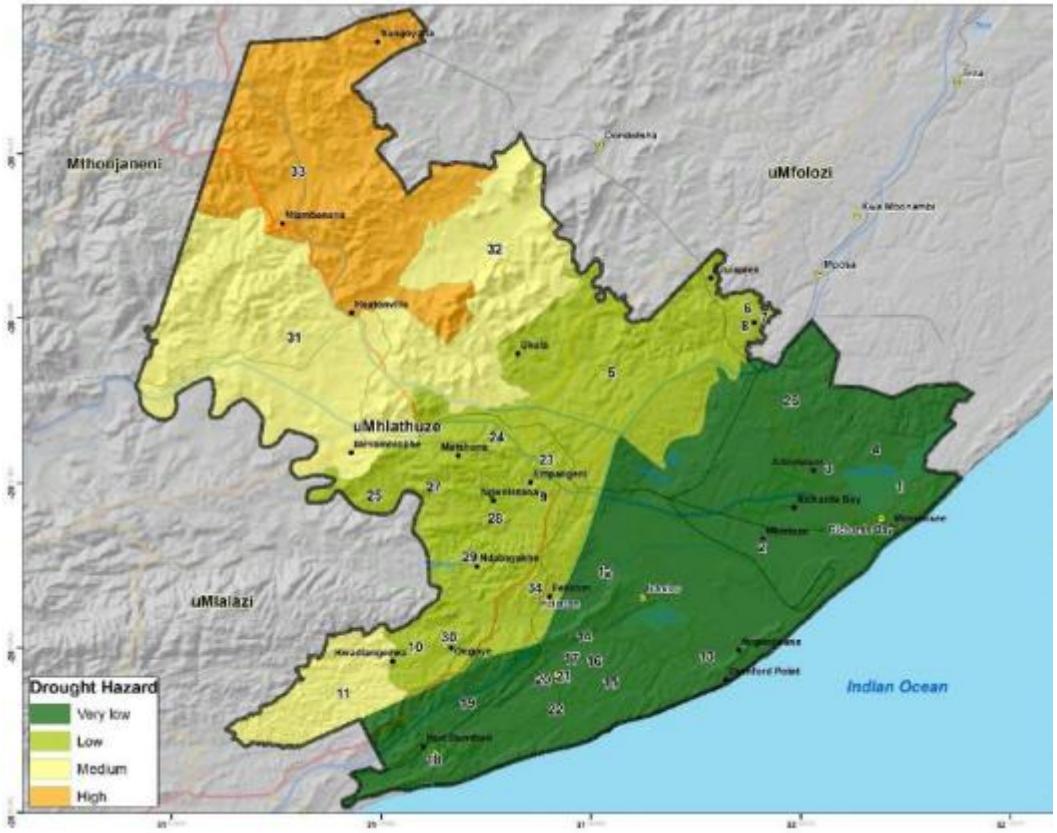

Figure 3: City of uMhlathuze Local Municipality Map (City of uMhlathuze, 2023)

The City of uMhlathuze Local Municipality which is shown in Figure 3 is situated within the King Cetshwayo District Municipality which is located on the north-east coast of the province of KwaZulu-Natal and is a rapidly developing area which plays a key role in the region's economic growth. As a strategic economic hub in KwaZulu-Natal, the City of uMhlathuze Local Municipality encompasses key urban centres such as Richards Bay and Empangeni, which attract industries, businesses, and a growing workforce (Tutu & Dlamini, 2024). This economic growth is accompanied by increasing water demand, as both industrial and residential sectors rely on a reliable and adequate amount of water supply to sustain operations and daily life.

The City of uMhlathuze Local Municipality is experiencing population growth of about 1% annually which is currently estimated to be approximately 412,075 and rapid urbanisation which further intensifies the demand for water resources (StatsSA, 2023). This issue is exacerbated by climate variability, with projected reductions in rainfall and

prolonged drought conditions further straining local water sources (Viljoen & van der Walt, 2018). Effective water resource management is therefore critical in the City of uMhlathuze Local Municipality, particularly in billed residential areas served by metered connections.

Billed residential areas served by metered connections in the City of uMhlathuze Local Municipality represent a significant portion of municipal water consumption and, ensuring that usage is monitored and controlled, can help mitigate excessive demand. Without targeted interventions, increased consumption will place additional pressure on an already aging infrastructure, making it even more challenging to provide reliable services. Addressing these challenges through improved consumption management, data-driven analytics, and infrastructure maintenance will be key to ensuring sustainable water supply for the municipality's growing population and economy.

2.2 Water Scarcity in South Africa

Water scarcity is a critical global challenge, closely aligned with the Sustainable Development Goals (SDGs), particularly Goal 6, which aims to ensure access to clean water and sanitation for all (Lehohla, 2016). South Africa faces significant water scarcity issues, with projections indicating a 17% water deficit by 2030 (Viljoen & van der Walt, 2018). The country's water scarcity is exacerbated by factors such as climate change, urbanisation, and inefficient water management practices (Viljoen & van der Walt, 2018). Historically, South Africa has struggled with water scarcity due to its status as one of the 30 driest countries globally, compounded by population growth and economic expansion (Wegelin, 2017; Al - Washali, 2020).

Recent studies highlight the importance of leveraging data analyses and predictive modelling to address water scarcity challenges in South Africa (Sousa et al., 2023; Huang et al., 2020). These studies emphasise the significance of understanding consumer behaviour and adopting sustainable water management strategies, such as water reuse and demand management initiatives (Mukherjee et al., 2018; Wang et al., 2021; Thakur et al., 2019; Ngcobo et al., 2023; Sousa et al., 2023).

Despite efforts to mitigate water scarcity, South Africa still faces prominent challenges, including leakage within water distribution networks and inadequate infrastructure

maintenance which are exacerbated by illegal connections, poor municipal billing systems and low revenue collection (Viljoen & van der Walt, 2018). Insufficient funding and aging infrastructure contribute to these challenges, necessitating innovative solutions for infrastructure maintenance (Viljoen & van der Walt, 2018; Netshitanini et al., 2023).

In South Africa, the implementation of metered connections for residential areas allows for more accessibility to accurate billing based on actual water consumption. This system highlights levels of water consumption, which alert residents to their consumption patterns in relation to the Department of Water and Sanitation's recommended per capita water consumption range of 150 to 200 litres per person per day for domestic use (DWS, 2023). When over-consumption is prevalent, it is linked to unsustainable water supply system, which is characterised by unreliability of supply, dissatisfied consumers, low revenue collection, and high input costs to the municipality. And if natural events such as drought occurs, coping mechanisms are greatly constrained.

A prominent example of this was the Day Zero crisis in Cape Town (CoCT) in 2018, when the city nearly ran out of water due to a combination of factors, including a prolonged drought, population growth, and excessive water usage (Calverley & Walther, 2022). Studies have shown that excessive water consumption was a key driver of the crisis, highlighting the need for more stringent water management policies in residential areas (Calverley & Walther, 2022).

Similarly, during the KwaZulu-Natal (KZN) drought in 2016-2017, over-consumption was observed as a contributing factor to water shortages in many areas including the City of uMhlathuze Local Municipality (Karlie, 2020). Municipalities in KZN had to implement water-saving measures and even restrict access to water to curb over-consumption (Ngwenya, Mabaso, & Mayisela, 2015).

While existing literature addresses various aspects of water scarcity in South Africa, there are notable gaps in understanding water consumption patterns, supply and demand challenges, and the effectiveness of water-saving interventions (Mutikanga, 2012; Murwirapachena, 2021). One key challenge is the management of municipal water

resources, particularly in regions such as the City of uMhlathuze Local Municipality, where insufficient funding and aging infrastructure hinder effective service delivery. The lack of financial resources for infrastructure maintenance and upgrades has led to frequent water supply disruptions, leakage issues, and a limited capacity to meet growing demand (Viljoen & van der Walt, 2018). Furthermore, aging infrastructure exacerbates these problems, making it increasingly difficult to implement efficient water conservation strategies and mitigate over-consumption.

The integration of metering data offers an opportunity to analyse consumer behaviour, identify inefficiencies and develop targeted interventions for more sustainable water resource management. This research aims to contribute to addressing these gaps by utilising historic metering data to assess consumption trends, using the City of uMhlathuze Local Municipality in KwaZulu-Natal as a case study to enhance water management practices and improve infrastructure resilience in the region.

2.3 Policy framework for Consumption Management

Effective management of water consumption in billed residential areas with metered connections is crucial for the City of uMhlathuze Local Municipality and this approach will not only ensure sustainable water use but will also align with South Africa's broader legislative framework for governing water resources.

South Africa's water resource management is primarily governed by the National Water Act (Act No. 36 of 1998), which emphasises the equitable allocation and sustainable use of water in the public interest (De la Harpe, 1998). The Act asserts that national government holds overall responsibility for and authority over water resource management, including the equitable allocation and beneficial use of water in the public interest (De la Harpe, 1998). This principle emphasises the necessity for municipalities to implement policies that promote efficient water use among all consumers, including residential sectors.

The Water Services Act of 1997 (Act No. 108 of 1997) serves as the primary legislative framework governing the provision of water supply and sanitation services in South Africa (De la Harpe, 1998). The Water Services Act of 1997 (Act No. 108 of 1997) governs the supply of water through billed metered connections, which is critical for managing water

resources, ensuring cost recovery, and maintaining sustainable service delivery which complements the National Water Act (De la Harpe, 1998). Recognising that water is a fundamental human right, the Water Services Act also accommodates differentiated service levels based on affordability and infrastructure availability, balancing universal access with financial and resource sustainability.

In response to the national directives, the City of uMhlathuze has instituted specific policies targeting water consumption in residential areas. One of the policies is the municipality's Metered Services Policy which outlines procedures for regular meter readings, aiming to provide accurate billing and monitor usage patterns effectively (City of uMhlathuze, 2019). This policy mandates that contractors should read water meters monthly and maintain intervals as close as possible to thirty days between readings (City of uMhlathuze, 2019).

The other policy is the municipality's Tariff Policy which incorporates consumption-based tariffs where residents are charged per unit of water they consume (City of uMhlathuze, 2019). This strategy serves as a financial incentive for consumers to reduce excessive usage by promoting water conservation (City of uMhlathuze, 2019). The policy also includes provisions for installing meters in appropriate cases and ensures that all consumers are billed accurately based on their consumption (City of uMhlathuze, 2019).

Despite these policies, challenges persist in managing water consumption effectively where aging infrastructure and funding constraints often lead to delays in maintenance, resulting in water losses and inefficiencies within the distribution network (City of uMhlathuze, 2019). Moreover, rapid urbanisation and population growth in the municipality exacerbate the demand for water and intensify the strain on existing resources and infrastructure (Parks et al., 2019). These factors highlight the critical need for robust policy implementation and continuous monitoring to ensure sustainable water management.

The relationship between policy and water consumption in the City of uMhlathuze is pivotal, and by adhering to national legislation and enforcing local policies that promote efficient water use, the municipality can address current challenges and work towards a sustainable water future for its residents.

2.4 Sustainable Water Resource Management Principles and Other Concepts of Water Management

Sustainable water resource management is a challenge which is emphasised by the United Nations' 2030 Agenda for Sustainable Development which includes Sustainable Development Goals (SDGs) aimed at ensuring access to clean water and sanitation (Lehohla, 2016). In South Africa, this challenge is compounded by factors such as water scarcity, historical inequalities and the effects of climate change (Viljoen & van der Walt, 2018).

The Water Services Act No. 108 of 1997 outlines the goals of ensuring access to basic water supply and sanitation along with establishing national standards, norms and tariffs for water services (Lehohla, 2016). Despite these efforts, challenges persist which includes regulatory, enforcement shortcomings, fragmented governance within the water sector and a lack of robust revenue management frameworks (Viljoen & van der Walt, 2018).

In South Africa, rising water demand, urbanisation, evolving lifestyles and climate change effects pose significant challenges to sustainable water resource management (Viljoen & van der Walt, 2018). The country's arid to semi-arid climate, coupled with an average annual precipitation of 465 mm, exacerbates water scarcity issues (Viljoen & van der Walt, 2018). Climate change effects, including prolonged droughts and intensified flooding events, further strain water availability and, if current demand trends continue, the projected disparity between water supply and demand by 2030 could be as high as 17% of available surface and groundwater resources (Viljoen & van der Walt, 2018).

Governance issues, including fragmented governance structures, regulatory and enforcement shortcomings, also hinder sustainable water management (Viljoen & van der Walt, 2018).

Factors contributing to the anticipated disparity between water demand and supply include low tariffs, inadequate cost recovery mechanisms, excessive consumption, inefficient utilisation, wastage, leakage, and unsuitable infrastructure choices (Viljoen & van der Walt, 2018). Water management policies and frameworks, such as the Water Services Act, aimed to address these challenges by guaranteeing access to basic water supply and sanitation, are not implemented (Lehohla, 2016).

The types of tariffs and associated connections used in the City of uMhlathuze Local Municipality for water billing over the years have been summarised in Table 2. A significant challenge in water demand models is the lack of uniformity of consumers served by the water distribution systems as is evident in Table 2. As the water distribution system expands, it incorporates more types of consumers and varied consumption patterns, which must be considered in the water demand models. Regional water demand model studies are limited and often apply a single model to a large area (e.g., supply area, county, basin), overlooking the lack of uniformity of consumption within the region (Avni et al., 2015).

Table 2: Tariff Type and Number of Connections Recorded

Tariff Description	**Number of Connections in March 2016**	**Number of Connections in June 2021**
Clarified Water	1	1
Special Water Tariff	7	10
Water Consumption (Commercial)	2,179	2,730
Water Credit Meter	1	3
Water Dwelling x 2	41	35
Water Exxaro TSA Consumption	2	2
Water Rebate < 0.2kl Per Day	45,366	1
Water Rebate < 0.4kl P/D Dwell x 2	41	0
Water Residential	26,697	47,889

While efforts to minimise water losses are crucial for sustainable management, challenges remain in estimating different aspects of the water balance and implementing effective meter and network management frameworks (Ncube and Taigbenu, 2018). Recent studies have also emphasised the importance of implementing effective management frameworks to address these issues and promote sustainable resource management (Ncube and Taigbenu, 2018).

2.5 Infrastructure Maintenance

World-wide, infrastructure maintenance presents challenges with profound implications for water resource management and delivery of water and sanitation services, and South Africa is facing difficulties in this regard. Historically, South Africa has struggled with

water loss due to aging infrastructure and inadequate maintenance practices (Viljoen & van der Walt, 2018).

South African municipalities lose an estimated 1,660 million cubic meters of water annually due to Non-Revenue Water (NRW), costing R9.90 billion per year (Viljoen & van der Walt, 2018). This accounts for approximately 35% of physical losses within municipal systems, significantly exceeding the global best practice benchmark of around 15% (Viljoen & van der Walt, 2018). Most communities in South Africa experience leaks like the one depicted in Figure 4. The response time to address these leaks varies depending on the availability of human resources, materials and budget allocations for maintenance within municipalities. However, leaks of this nature result in significant amounts of water loss when left unattended.



Figure 4: Physical Leakage, (Mckenzie et al., 2012)

According to Mckenzie et al. (2012), non-revenue water encompasses all water lost through physical leakage and apparent losses, such as meter under-registration, billing errors, theft, and any unbilled authorised consumption, and as well as activities like firefighting and flushing of rising main. Despite advancements in leak detection technologies, pinpointing leaks remains challenging, especially in larger diameter and non-metallic bulk water pipelines (Webb, et al., 2009). Even with best technology for leak

detection, no water distribution network achieves 0% losses, highlighting the ongoing challenge (Al - Washali, 2020).

The challenge of infrastructure maintenance in South Africa is exacerbated by factors such as funding shortages, inadequate capacity, and escalating unpaid bills (Viljoen & van der Walt, 2018). Aging infrastructure, coupled with reduced maintenance budgets, has led to increased water losses from various components of the distribution system (Netshitanini et al., 2023).

As illustrated in Figure 5, which depicts a catastrophic bust resulting from pipe failures, South Africa's water infrastructure is subject to frequent failures. In many areas, these failures occur daily, and in some cases, the time required to address and repair such damages can be significant. This highlights the ongoing challenges in maintaining and managing water distribution systems, emphasising the need for proactive infrastructure management and timely interventions to minimise water losses by municipal entities.



Figure 5: Physical Leakage Due to Pipe Failure, (Mckenzie et al., 2012)

Recent studies in South Africa highlight the importance of proactive leak management to reduce NRW. An example of these studies, include research on the Rand Water distribution network, which indicates that effective approaches can reduce avoidable NRW from 7% to 3%, potentially saving over R861 million annually as shown on Table 3 (Hlalele et al., 2023).

Table 3: Annual Profit on Repaired Leaks (Hlalele et al., 2023)

Profit on Repaired Leaks	
Cost of Sale in Rand/kilolitre	R11,62 /kl
NRW @ 7%	R1,480,213,700.00
NRW @ 3%	R618,439,640.00
Non - Revenue Water Savings on Repaired Leaks	R861,774,060.00

These studies also emphasise the effectiveness of implementing maintenance procedures in reducing non-revenue water, potentially saving municipalities significant amounts annually (Hlalele et al., 2023). However, challenges remain in assessing the condition of existing pipeline infrastructure and implementing well-planned maintenance programs (Webb et al., 2009).

There are gaps in recent literature particularly regarding the most effective strategies for managing water loss and promoting infrastructure maintenance (Netshitanini et al., 2023). While acknowledging the existing gaps in research areas, this study attempts to complement the existing body of research through the analysis of historical metering data. This research seeks to uncover primary challenges and potential avenues for enhancing water management practices.

2.6 Consumer Behaviour Towards Water Usage in South Africa

The data presented in Figure 6 illustrates the distribution of water usage in South Africa, with agriculture irrigation being the largest consumer at 61%, followed by municipal consumption at 27%, which includes industrial and commercial users (Viljoen & van der Walt, 2018). The remaining 12% is allocated to power generation, mining, bulk industrial usage, livestock farming, and conservation efforts, including afforestation (Viljoen & van der Walt, 2018).

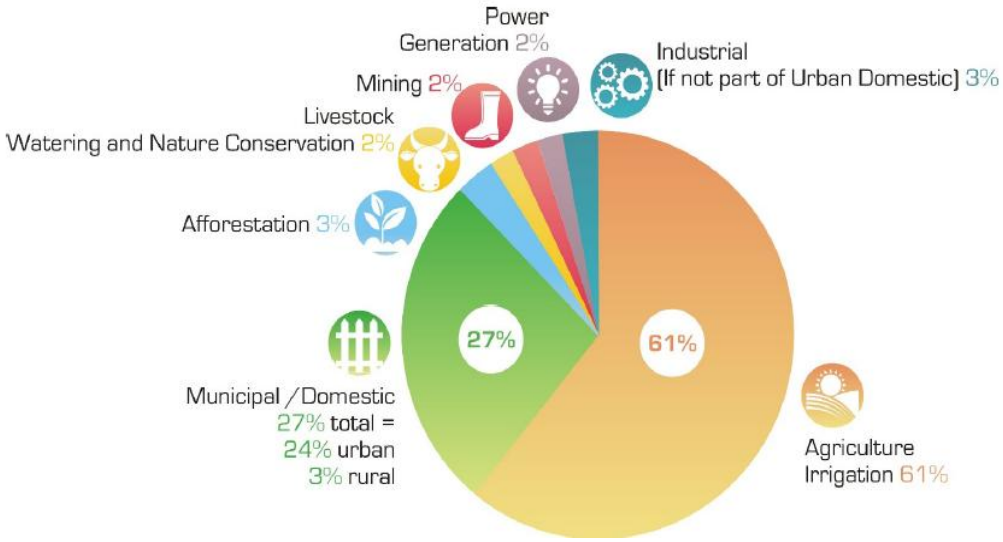

Figure 6: Current Water Use by Sector Based on South Africa's Total Population (Viljoen & van der Walt, 2018)

According to (Viljoen & van der Walt, 2018), the elevated domestic water consumption, averaging 237 litres per person per day, surpasses the global average by 64 litres per person per day, partly due to a high rate of municipal non-revenue water, currently at 41%.

Efforts to achieve water security in South Africa necessitate the adoption of more efficient water use practices across various sectors (Viljoen & van der Walt, 2018). A target has been set to reduce average domestic water consumption to 175 litres per person per day by 2025, with additional measures aimed at demand reduction (Viljoen & van der Walt, 2018). These measures prioritise water use efficiency and the adoption of low-flow and durable water and sanitation fittings, along with exploring rainwater harvesting potential in low-income areas (Viljoen & van der Walt, 2018). Behavioural change is very important because merely installing water-saving devices may not suffice; accompanying the installation with the adoption of water-efficient behaviours is crucial for achieving sustainable water-use behaviour.

Behavioural interventions play a crucial role in achieving sustainable water-use as can be seen in the information-motivation-behavioural skills model in Figure 7 presented by Ehret et al. (2019). Education plays a pivotal role in encouraging individuals to save water, highlighting its long-term benefits, and equipping them with practical tools for water conservation, even in communities where expensive water-saving devices are not widely utilised.

By raising awareness about water shortages and providing knowledge about simple yet effective water-saving practices, such as taking shorter showers and using cups when brushing teeth instead of running the tap, education can empower individuals to make meaningful contributions to water conservation.

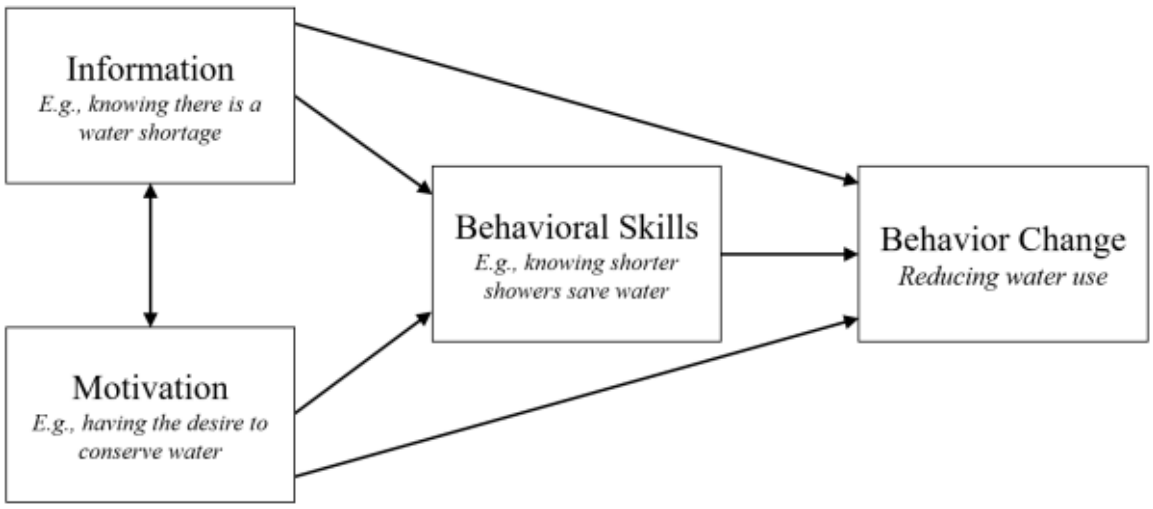

Figure 7: The Information-Motivation-Behavioural Skills Model with Water Conservation Examples (Ehret et al., 2019)

This behavioural change, when adopted collectively within communities, can significantly alleviate pressure on water resources and promote sustainable water management practices. Therefore, investing in water education initiatives can be an effective strategy for addressing water scarcity challenges at the grassroots level. While installing water-saving devices is essential, it should be accompanied by the adoption of water-efficient behaviours to yield positive outcomes (Ngcobo et al., 2023).

Studies highlight the importance of understanding water-use behaviour for proactive water demand management (Murwirapachena, 2021). While understanding household water-use behaviour is crucial for proactive water demand management, the literature lacks consensus on the most effective strategies for managing household water demand (Mutikanga, 2012). Additionally, factors such as non-payment for services and distrust in water authorities contribute to poor water management practices in South Africa (Thakur et al., 2019). Addressing these challenges requires effective community engagement and communication to educate residents about the importance of reducing water consumption (Thakur et al., 2019).

In summary, while progress has been made in understanding water consumption patterns and promoting water-saving behaviours, there is still a need for more targeted interventions and effective policies to address the challenges of water scarcity and inefficient water usage in South Africa. There is also a need for more research to identify effective strategies for managing household water demand and promoting water-efficient behaviours (Mutikanga, 2012).

Addressing behavioural change towards water conservation requires effective communication and community engagement, leveraging existing structures such as local councillors and traditional leaders to educate residents about the importance of reducing water consumption (Thakur et al., 2019). Providing individuals with accurate knowledge on water-saving practices is also crucial in fostering behavioural change (Thakur et al., 2019).

2.7 Summary of the Literature Review

The literature reviewed emphasises the urgent need for innovative approaches to water management in KwaZulu Natal, South Africa, as the region grapples with water scarcity exacerbated by various factors including climate change, population growth, and infrastructure challenges. Historic metering data emerges as a valuable resource in this endeavour, offering insights into consumer behaviour, and sustainable resource management.

Efforts to address infrastructure maintenance are crucial, given the substantial losses incurred by municipalities due to non-revenue water. Proactive strategies utilising predictive modelling and advanced leak detection technologies hold promise in mitigating these losses and improving infrastructure efficiency. Similarly, understanding consumer behaviour patterns is essential for designing targeted interventions aimed at promoting water conservation practices among residents.

Sustainable water resource management principles, including water reuse and demand management, are imperative for ensuring long-term water resource viability. Integrating diverse measures and leveraging historic metering data can aid in developing comprehensive strategies to address water scarcity challenges effectively.

Understanding water usage patterns among billed customers in the City of uMhlathuze is essential in determining whether over-consumption is occurring and to assess its impact on water resource sustainability. By analysing these consumption trends, it will become possible to compare consumer behaviours in uMhlathuze with those in other municipalities, providing valuable insights into the effectiveness of current water management strategies. Therefore, this literature review emphasises the importance of leveraging historic metering data and adopting multidimensional approaches to water management in KwaZulu-Natal. By integrating insights from data analyses, predictive modelling, and consumer behaviour, municipalities can develop more efficient and resilient water management practices. This will contribute to sustainable development, enhance resource efficiency, and improve the overall quality of life for residents.

3 METHODOLOGY

This chapter describes the methodology used in this research project. In this research project historical metering data from March 2016 to June 2021 was obtained from the City of uMhlathuze Local Municipality in KwaZulu-Natal and comprises information such as billing period, billed amount, water quantity, tariff description and billing date.

Based on this dataset, a methodology to detect instances of excessive water usage within the local municipality are assessed. The aim of the assessment is to analyse water usage trends within the municipality and ascertain whether excessive water consumption occurs within the metered population. A comparison of the findings with the average demand observed in eThekwini, Msunduzi, Newcastle which are the municipalities located in KwaZulu-Natal will be conducted. Subsequently, recommendations for educational and awareness campaigns will be proposed for areas identified with excessive water usage.

3.1 Data Preparation and Cleaning

The research begins with the collection and organisation of historical metering data, followed by data cleaning to address any inconsistencies.

3.2 Population of the Study Area

The population for this research project was obtained from Statistics South Africa Census (2021) and was also predicted based on the historical data available for the study.

3.3 Trend Analysis of Water Usage

The Change Point Analysis (CPA) was utilised in this study to identify shifts or significant changes in water consumption patterns of the City of uMhlathuze Local Municipality over the study period. CPA was used to identify when significant increases or decreases in water usage for residential areas occurred, particularly in response to external factors such as drought restrictions, tariff adjustments, or infrastructure failures.

Water Demand Models (WDMs) which can provide insights into water consumption behaviour and forecast water demand, aiding decision-making in water distribution system operations and infrastructure planning, was also utilised in this study (Avni et al.,

2015). The methodology for aggregating the data set relies exclusively on historical water consumption records. Other WDMs employ time-series analysis, which also use historical records and capture the inherent autocorrelation structure of water use patterns over time (Avni et al., 2015).

The approach outlined here represents a step toward utilising the growing volume of water consumption data and advanced data analysis techniques to model larger, heterogeneous regions with adequate resolution.

3.3.1 Procedure for Performing a Change-Point Analysis

The change-point analysis procedure involves an iterative approach that combines cumulative sum (CUSUM) charts with bootstrapping to identify changes. The change point analysis presented in this section is based on the works of Taylor (2018) and Naicker and Obagbuwa (2020).

The process starts by creating a CUSUM chart, which is done by calculating and plotting the cumulative sum of the data.

Let $x_1, x_2, x_3,\ldots, x_n$ represent n data points in a time series, and let $S_0, S_1, S_2,\ldots, S_n$ define the cumulative sum of the points. The change-point analysis is then performed by applying three steps to the initial dataset $D_0 = \{x_1, x_2, x_3,\ldots, x_n\}$, which has a size n (n_0=$|D_0|$). The mean $\bar{x}$ of $x_2, x_3,\ldots, x_n$ is given by

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n} \quad (1)$$

The cumulative sum begins at zero, meaning S_0 = 0. The cumulative sum for any subsequent point, S_i, is calculated using the following equation:

$$S_i = S_{i-1} + (x_i - \bar{x}), i = 1, 2, 3, \ldots . n \quad (2)$$

Prior to performing bootstrap analysis, it is necessary to estimate the magnitude of the changes to establish a boundary for the chart. The magnitude of the change can be determined using the following formula:

$$S_{diff}{}^{i} = \underset{i=0,..,n}{max} S_i - \underset{i=0,..,n}{min} S_i = S_{max} - S_{min} \quad (3)$$

After calculating the magnitude of the change, the bootstrap analysis is performed N times on D_0. Each individual bootstrap is carried out as follows:

I. A bootstrap dataset D_l of size n from data points of time series in dataset D_0 is represented as x_j $(j = 1,\ 2, 3, \ldots., n)$. This dataset is generated by original n values which are randomly reordered, which is also known as sampling without replacement (SWOR).

II. The bootstrap CUSUM is computed by following a similar method based on the bootstrap sample and is defined as S_j.

III. The magnitude of change for the bootstrap CUSUM is calculated based on Equation (3).

IV. Then, where the original magnitude of change is more than the magnitude of change of bootstrap CUSUM, ${S_{diff}}^i > {S_{diff}}^j$, the number of bootstraps is counted. Let N be the number of bootstrap samples executed and K be the number of bootstraps for which ${S_{diff}}^i > {S_{diff}}^j$, where the confidence level that a change has occurred as a percentage is defined as:

$$CL = \frac{\sum_{l=1}^{N} I({S_{diff}}^i > {S_{diff}}^j)}{N} \text{ x } 100 = \frac{K}{N} \text{ x } 100 \qquad (4)$$

The result of the bootstrapping process is a distribution free method that relies on only one assumption, the presence of an independent error structure. An independent error structure occurs when the data points are distributed in the following manner:

$$x_i = m_i + e_i \qquad (5)$$

where m_i is the mean at time N. Normally, $m_i = m_i - 1$ except for a small number of values of i that are called change points. Meanwhile, e_i is a random error correlated with the $i - th$ value and the independent e_i is assumed to have a zero-mean value, to be identically distributed and to be normally distributed.

Once a change has been detected, an estimate of when the change occurred can be made. This estimate, known as the CUSUM estimator, is calculated as follows. Let m be defined such that:

$$|S_m| = \max_{i=0,..,n} S_j |S_i| \qquad (6)$$

where S_m is the furthest point from the zero value in the CUSUM chart and the last point before the change occurred is estimated by point m while point $m+1$ estimates the first point after the change occurred. The mean square error (MSE) is used as the second estimator when the change happens:

Let $MSE\ (m)$ be defined as $MSE(m) = \min_{i=1,..,|D|} MSE(i)$ for a given sub-dataset D as follows:

$$MSE(i) = \sum_{j=1}^{i}\left(X_j - \overline{X}_1\right)^2 + \sum_{j=i+1}^{|D|}\left(X_j - \overline{X}_2\right)^2 \qquad (7)$$

Where $\overline{X}_1 = \frac{\sum_{j=1}^{i} X_j}{i}$ and $\overline{X}_2 = \frac{\sum_{j=i+1}^{|D|} X_j}{i}$

The MSE estimation is performed by dividing the data series into two parts: 1 as m and $m+1$ as n, before it is estimated how well the data in each part suits their equivalent mean. The value of m that minimises $MSE\ (m)$ represents the best estimator of the last point before the change, whereas $m+1$ represents the first point after the change.

When a change is detected, the data is split into sub-segments. The same method is then applied to each segment to identify additional change points, which further divide the segments into smaller sub-segments. By repeating the analysis, multiple significant change points can be identified at successive levels, with confidence limits and levels calculated using the bootstrapping technique.

After identifying the change points and their confidence levels, a backward elimination procedure is conducted to remove insignificant points. When a point is eliminated, the nearby change points and their significance levels are recalculated to minimise the occurrence of false detections. It is important to note that outliers are treated as isolated points. If the data contain outliers, this method ranks the data rather than using their actual values. As a result, the change-point analysis identifies less continuous changes with minimal interference from outliers. This method is effective in discovering significant change points in time series data related to rainfall, temperature, and relative humidity, which are the climate variables of interest in this study.

3.3.2 Statistical Method: Water Demand Model

Several studies focus on water demand modelling in larger areas. Babel et al. (2007) used multiple regression analysis to select a daily water demand function and relevant explanatory variables for water use in the Kathmandu Valley (Nepal), an area of 900 km^2. The multiple regression analysis used in their study is also utilised in this research project to analyse factors influencing water demand, understand their effects, and assess if there is excessive water usage in the local municipality of interest. Demand management aims to reduce water wastage due to overuse.

The simplified assumption in the single coefficient requirement model is that demand is constant for each person, regardless of lifestyle, income, and education level. This is not accurate. Domestic water use depends on:

i. Socio-economic characteristics: Population, household size, income, education level, etc,
ii. Climatic factors: Temperature, rainfall, and
iii. Public water policies and strategies.

A simple, user-friendly model has been developed to forecast water demand and analyse the effect of management measures in the domestic sector (Babel et al., 2007).

The multivariate water demand model can utilise as many variables as necessary to account for factors that directly or indirectly affect water demand in site-specific conditions. Based on the literature, the commonly used variables are:

- Number of connections or population;
- Household size;
- Number of households;
- Income or factors representing the standards of living;
- Price of water, educational level; and
- Climatic factors such as temperature and rainfall.

The general form of the multivariate model is:

$$Y = f(X_1, X_2, X_3, \dots, X_n) \quad (8)$$

Where *Y* is the total water demand and X_1 to X_n are different relevant factors affecting the water demand.

The three options to analyse water demand are:

Linear Model: $Y = b_0 + b_1(X_1) + b_2(X_2) + b_3(X_3) + \cdots + b_n(X_n)$ (9)

Log-Log Model: $lnY = b_0 + b_1 ln(X_1) + b_2 ln(X_2) + b_3 ln(X_3) + \cdots + b_n ln(X_n)$ (10)

Semi-Log Model: $lnY = b_0 + b_1(X_1) + b_2(X_2) + b_3(X_3) + \cdots + b_n(X_n)$ (11)

Where, b_0 is the model intercept and $b_1, b_2, b_3, \ldots, b_n$ are the coefficients of corresponding independent variables. The three options can all analyse water demand but have different functionalities as illustrated below:

- Linear demand functions are often chosen for their ease of estimation. However, they do not produce constant elasticities at all points on the demand function.
- The log-log functional form provides direct estimates of the elasticities of the independent variables with respect to the dependent variable.
- The Semi-Log function is frequently used to compare the results with those of the linear and log-log functions (Garcia et al., 2001).

The intercept and coefficient values for all three functional forms are obtained through multiple regression analysis using the built-in regression tool of Microsoft Excel.

The other important output from the regression analysis is the R-squared value which indicates the "goodness of fit" for the model, showing how much of the variability in water demand is explained by the independent variables (Ozili, 2023). The R-squared value is the percentage of the dependent variable variation that a model explains and is represented by the following equation (Ozili, 2023).

$$R^2 = \frac{VARIANCE\ EXPLAINED\ BY\ THE\ MODEL}{TOTAL\ VARIANCE} \quad (13)$$

The R-squared value Indicates the strength of the relationship between water demand and the chosen variables. R-squared is always between 0 and 100% (Ozili, 2023).

where,

- 0% represents a model that does not explain any of the variation in the response variable around its mean. 100% represents a model that explains all the variation in the response variable around its mean.

The P-Value for each coefficient indicates whether the corresponding variable significantly explains water demand and is also an output from the regression analysis (Ott et al., 2016). Typically, P-Values below 0.05 are considered statistically significant, meaning that the variable has a substantial impact on water demand (Ott et al., 2016).

3.3.3 Determine Overall Trajectory of Water Usage

This section of the research determines and assesses the overall trajectory of water usage trends. Any notable changes or anomalies are recorded, analysed, and reported accordingly.

3.4 Assessment of Excessive Water Consumption

Criteria or thresholds are developed to define excessive water consumption relative to the metered population size of the local municipality:

1. Per Capita Water Consumption Baseline:

- National/Regional Standards: Establish a baseline using national or regional standards for per capita water consumption. Guidelines typically recommend a specific range.
- Local Historical Average: Calculates the municipality's historical average water consumption per capita over a defined period which serves as the local baseline.

2. Threshold for Excessive Consumption:

- Percentage Above Baseline: Defines excessive water consumption as any usage that exceeds the established baseline by a specific percentage which can be determined based on the available water resources in the area.
- Absolute Consumption Limit: Sets an absolute limit on per capita consumption (e.g., 300 Liters per person per day) and any usage beyond this limit can be categorised as excessive, regardless of the baseline.

Analyse the historical metering data to identify instances of excessive water consumption based on the established criteria:

- Baseline Comparison: Compare historical water usage data against the established baseline. Identify periods where water consumption exceeds the threshold defined as excessive.
- Anomaly Detection: Use statistical methods (e.g., moving averages) to identify significant deviations from the norm.

Investigate potential contributing factors to excessive water usage, such as demographic characteristics, socio-economic factors, and infrastructure limitations:

- Population Growth: Assess the impact of population growth on water consumption. Rapid increases in population can lead to higher overall water demand.
- Household Size: Larger households may consume more water, so analysing household size trends is important.
- Metering Accuracy: Ensure that water meters are accurate and properly maintained to avoid misidentification of excessive usage due to meter faults.

The Human Settlement Neighbourhood Planning and Design Guide specifies 230 L/c/d for house connections. The general assumption in the aforementioned statement is that all residential connections in this local municipality are house connections. This section aims to assess whether the actual residential water demand of the local municipality exceeds the allowable or design water demand as indicated by the findings of DWS (2023).

3.5 Water Demand of the City of uMhlathuze Local Municipality Compared to that from other Studies of the KwaZulu-Natal Province

The starting point of this exercise will be to gather the relevant data such as the average water demand figures from the research project specific to the City of uMhlathuze. Concurrently, it is essential to look at other studies that focus on other parts of the province to determine water demand in the broader KwaZulu-Natal province. Key metrics

to extract include daily water consumption per capita, annual water usage, and any reported trends over time.

With the collected data, a comparative analysis is performed. This involves statistically comparing the average water demand of the City of uMhlathuze with the averages reported from studies in other municipalities. One could use methods such as calculating the mean, median, and standard deviation to understand the central tendency and variability of water demand in both contexts. Additionally, visual tools like graphs and charts can help illustrate differences and similarities. It is also beneficial to consider factors that might influence water demand, such as population density, industrial activities, climate conditions, and water management practices, to provide a comprehensive analysis. This comparative approach will highlight any significant deviations or alignments in water demand between the City of uMhlathuze and the broader KwaZulu-Natal province.

3.6 Recommendation of Educational and Awareness Campaigns

The identified areas within the local municipality where excessive water usage is prevalent, based on the analysis, are those that targeted educational and awareness campaigns can be developed. These campaigns can be tailored to specific communities to address specific community needs and challenges related to water conservation practices, leveraging on insights from the data analysis.

3.7 Summary of the Methodology

This chapter outlines the methodology used in this research project, which involves analysing historical metering data from a local municipality in KwaZulu-Natal, covering March 2016 to June 2021. The methodology aims to detect excessive water usage and analyse water consumption trends relative to the population. Key steps include data preparation and cleaning, and the development of a water demand model using multiple regression analysis. Various functional forms, such as Linear, Log-Log, and Semi-Log Models, will be utilised to assess water demand.

The research will also involve the review of how the average water demand of the City of uMhlathuze Local Municipality compares with the average water demand observed in other studies focusing on the KwaZulu-Natal province. Suggestions on how to develop

targeted educational and awareness campaigns will be developed to address areas with identified excessive water usage.

By carrying out these tasks, the research project will effectively address the research questions outlined and contribute to enhancing water management practices for domestic consumers in the City of uMhlathuze Local Municipality.

4 RESULTS AND DISCUSSION

4.1 Data Preparation and Cleaning

To clearly identify all water users in the City of uMhlathuze Local Municipality, tariff types were utilised. These tariff types were recorded for every suburb in each town within the City of uMhlathuze Local Municipality. The following tariff types were documented:

- Clarified Water (CW)
- Special Water Tariff (SWT)
- Water Consumption (Commercial) (WCC)
- Water Credit Meter (WCM)
- Water Dwelling X2 (WD)
- Water Exxaro TSA Consumption (WETC)
- Water Rebate < 0.20 kl Per Day (WR < 0.20)
- Water Rebate < 0.40 kl Per Day
- Dwell X2 (WR < 0.40)
- Water Residential (WR)

With the identified tariff types, all locations with available metering data from March 2016 to June 2021 were consolidated by tariff type and presented in Table 4. As reflected in Table 4, inconsistencies in the recording of the data were observed in some of the tariff types such as incorrect recording of data, unrecorded periods as well as huge changes in the number of recorded areas. The observation of these inconsistencies led to the decision to focus more attention on the Water Residential tariff type during the analysis because of the consistency of the data and the fact that it can be utilised to represent the water usage trends of the study area.

Additionally, the study's timeframe was updated from March 2016 to June 2021 to the period from March 2016 to September 2020 because poor recording of the meters was observed from September 2020 and their inclusion in the analysis skewed the results. For the purpose of this research the study period from March 2016 to September 2020 will be applied.

Table 4: Identification and Analysis of Water Users in the City of uMhlathuze Local Municipality Based on Tariff Types (March 2016 - June 2021)

DATE	CW (kl)	SWT (kl)	WCC (kl)	WCM (kl)	WD (kl)	WETC (kl)	WR< 0.2 (kl)	WR <0.4 (kl)	WR (kl)
Mar-16	638,004	243,623	1,814,668	17,250	2,332	114,400	1,552,019	2,332	1,743,756
Jun-16	660,594	321,397	1,413,001	24,460	3,271	96,540	1,803,148	3,271	1,860,430
Sept-16	781,382	249,353	1,594,827	38,700	3,682	0	1,295,110	3,681	1,984,910
Mar-17	884,614	276,715	1,706,124	30,120	3,594	0	1,532,659	3,594	2,075,023
Jun-17	819,804	391,259	2,456,999	30,830	3,075	270,340	0	0	2,165,135
Sept-17	1,021,688	343,091	1,861,904	53,300	3,113	0	1,309,609	3,073	2,164,401
Dec-17	1,091,274	367,893	2,302,012	87,560	3,244	365,520	1,070	0	2,163,666
Mar-18	387,496	406,722	4,083,182	27,350	3,391	502,700	1,032	0	2,179,688
Jun-18	907,999	395,788	4,563,680	36,490	3,093	574,403	1,149	0	2,219,068
Sept-18	786,567	375,575	5,236,927	47,860	3,085	392,320	1,053	0	2,026,222
Dec-18	829,995	402,601	4,870,888	49,600	3,098	339,900	1,161	0	2,030,217
Mar-19	1,023,424	399,829	5,961,965	43,940	3,468	375,000	1,108	0	2,034,220
Jun-19	981,800	416,523	5,012,466	51,846	3,141	428,010	19	0	2,223,151
Sept-19	1,027,279	455,847	4,967,773	119,829	3,480	256,970	26	0	2,221,739
Dec-19	1,147,871	546,191	5,493,851	1,852	3,235	344,960	47	0	2,216,229
Mar-20	1,272,759	1,193,849	5,081,608	3,261	3,217	329,340	52	0	2,236,008
Jun-20	888,656	1,284,025	4,869,934	2,360	3,541	264,930	62	0	2,255,965
Sept-20	1,149,533	1,264,425	4,561,296	9,468	3,107	380,800	70	0	2,276,099
Dec-20	944,010	1,344,294	4,858,573	1,109	3,191	394,900	81	0	1,743,756
Mar-21	0	0	233,703	0	0	0	0	0	1,860,430
Jun-21	1,123,964	1,264,527	4,748,395	2,127	3,068	449,500	54	0	1,984,910

4.2 Population of the Study Area

The population of the City of uMhlathuze Local Municipality in KwaZulu-Natal is estimated in this section. The first step of this exercise involved examining the population

data for the City of uMhlathuze Local Municipality as presented by the Statistics South Africa Census count of 2011 and 2022.

Table 5 illustrates the population growth for the municipality, with an average annual growth rate of 0.92% between 2011 and 2022 (StatsSA, 2022). In 2022, it was reported that the municipality had 100,441 households, and the total population was 412,075, with an average of 4 people per household (StatsSA, 2022).

Table 5: Estimation of Population Growth in the City of uMhlathuze Local Municipality Based on Census Data from 2011 and 2022 (StatsSA, 2022)

Statistics South Africa Census 2011 – 2022		
Name	**2011**	**2022**
Total Population	370,256	412,075
Number of Households	94,010	100,441
Average Household Size	4	4
Average Annual Population Growth	0.92%	

Subsequently, the household count focusing on the residential areas of the City of uMhlathuze Local Municipality which are served by billed metered connections was carried out and presented in Table 6. This household count as represented in Table 6 was compiled from March 2016 to September 2020, using historical metering data that was obtained from the City of uMhlathuze Local Municipality.

Table 6: Population Estimation of Residential Areas in the City of uMhlathuze Local Municipality Using Historical Metering Data (March 2016 - September 2020)

Measurement Timeline	Residential House Count with Metered Connections	Population Count
		4 People Per Household
Mar-16	26,697	106,788
Jun-16	28,483	113,933
Sept-16	30,389	121,556
Mar-17	32,355	129,418
Jun-17	34,320	137,280
Sep-17	39,483	157,930
Dec-17	44,645	178,580
Mar-18	44,647	178,586
Jun-18	44,648	178,592
Sep-18	44,909	179,636
Dec-18	44,998	179,990
Mar-19	45,086	180,345
Jun-19	46,769	187,076
Sept-19	47,346	189,384
Dec-19	47,607	190,428
Mar-20	48,032	192,128
Jun-20	48,461	193,842
Sept-20	48,893	195,572
Average	41,543	166,170

An analysis of population trends in the City of uMhlathuze Local Municipality, based on Statistics South Africa Census data from 2011 and 2022, reveals that the average recorded population exceeds the population of residential areas served by billed metered connections. Estimates derived from historical data show that the population of residential areas served by billed metered connections is approximately 40% of the entire population of the municipality.

Therefore, the average population for this study is 166,170; the number of residential households with metered connections is 41,543, and the household size is 4.

4.3 Procedure for Performing a Change-Point Analysis

Before analysing the results from the Change-Point Analysis model (CPA), it is crucial to understand how to interpret them. The findings are presented using two types of graphs.

The first graph is a modified control chart, where changes in the background colour signal potential change-points (Arif et al. 2017). This chart includes control limits that define the expected variability of the data. In this graph, the y-axis shows the variable under investigation, such as water usage volume, while the x-axis represents the time range in three-month intervals.

The second graph displays the Cumulative Sum (CUSUM) chart, which pinpoints the exact occurrence of change-points (Arif et al. 2017). Each variable or socio-economic indicator for a particular area is shown through a CPA graph, like the modified control chart, including control limits and background changes (Taylor 2018). The corresponding CUSUM chart confirms the timing of identified change-points (Arif et al. 2017). Thus, each analysed variable includes two graphs for comprehensive review.

In the modified control chart, change-points are indicated by background colour shifts, with the blue region showing a background change (Arif et al. 2017). Control limits, marked by red lines, defining the upper and lower bounds of expected variation. Points that exceed these limits are referred to as outliers and they represent significant deviations, suggesting a change. However, these control limits are based on a normal distribution and may not apply to all datasets and if all data points fall within this range, it implies the model adequately captures the data's variability (Taylor, 2018). Any background shifts from yellow to blue indicate changes in the data.

Figure 8 presents the Change-Point Analysis (CPA) results for water consumption in residential areas with billed metered connection within the City of uMhlathuze Local Municipality. The analysis reveals that there were no change-points that occurred between March 2016 and September 2020 as it is shown by the consistency of the background colour. This effectively means that there were no shifts or significant changes in water consumption for residential consumers with billed metered connection patterns in the City of uMhlathuze Local Municipality over the study period.

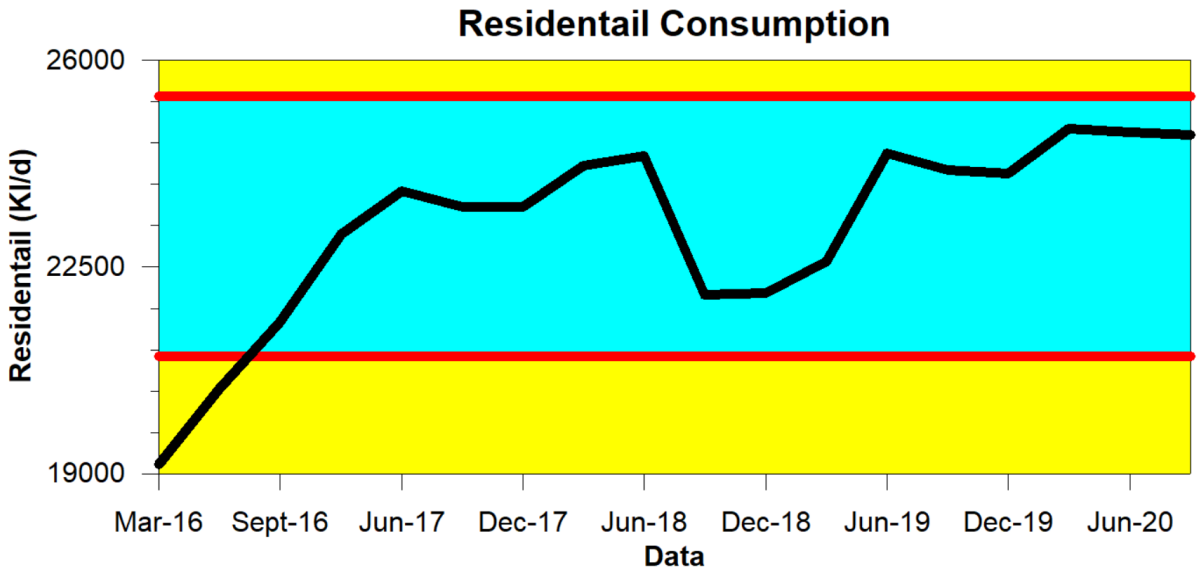

Figure 8: Change-Point Analysis of Residential Water Consumption in the City of uMhlathuze (March 2016 - September 2020)

The cumulative sum (CUSUM) chart illustrates the cumulative sum at each time point or data point, with change-points represented by shifts in the background colour from yellow to blue (Monyeki et al., 2020). An upward trend in the chart indicates a period when data points are above the overall average, while a downward trend suggests the opposite (Monyeki et al., 2020). Straight-line trends indicate periods without notable change, whereas abrupt shifts in direction signal changes in values (Taylor, 2018).

Figure 9 illustrates the Cumulative Sum (CUSUM) chart for water usage in residential areas with billed metered connection of the City of uMhlathuze Local Municipality. The chart visualises the cumulative sum over time, helping to identify trends in water usage. The absence of a change-point is indicated by the consistently yellow background. The graph also shows a slight increase in the cumulative sum, suggesting a period of relatively steady growth in water usage within residential areas up to September 2020.

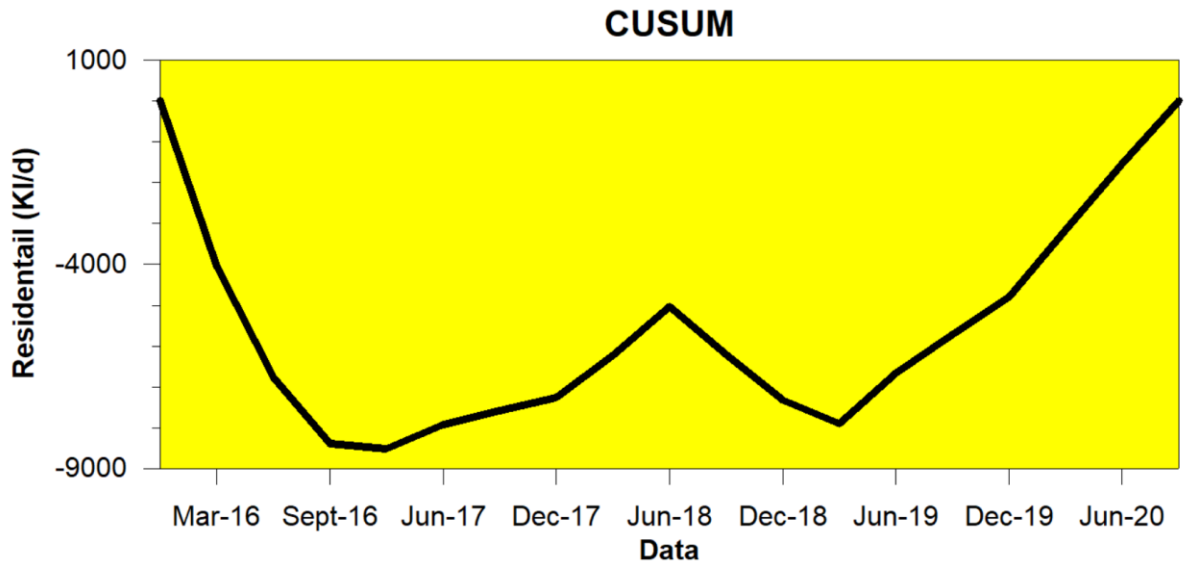

Figure 9: CUSUM Analysis of Residential Water Usage in the City of uMhlathuze (March 2016 - September 2020)

Since this analysis did not obtain any significant changes in the average water consumption for residential area with billed metered connection in the City of uMhlathuze Local Municipality, there is no bootstrap analysis. The water consumption for residential consumers with billed metered connection maintained the average consumption of 23,190 kl/d between March 2016 and September 2020.

In October 2014, the KwaZulu-Natal (KZN) Department of Cooperative Governance and Traditional Affairs recommended the declaration of a state of disaster in the affected areas of KZN following prolonged periods of below-average rainfall which resulted in a decline in dam and reservoir levels, leading to water scarcity in the region (Ngwenya, Mabaso, & Mayisela, 2015). The reduced availability of water resources led to increased reliance on municipal water supplies, contributing to an increase in the average water consumption, as shown by the results of the Change Point Analysis.

Despite the introduction of water restrictions, enforcement challenges and compliance issues hindered their effectiveness, resulting in continued high consumption. Many residents and businesses did not immediately adjust their water usage habits, further exacerbating water demand in areas such as the City of uMhlathuze. However, a noticeable reduction in water consumption was observed between June 2018 and September 2018, followed by a rapid increase from September 2018 to June 2019. This

decline in water consumption suggests a response from water users to the restrictions imposed by the municipality during this period. The subsequent rise in consumption may indicate that residents quickly adjusted to these restrictions resulting in a gradual return to previous consumption patterns, highlighting the need for sustained water conservation efforts and long-term demand management strategies.

The Change Point Analysis highlights the water usage trends in residential areas with billed metered connection of the City of uMhlathuze Local Municipality. As water demand surged while resources declined, the City of uMhlathuze implemented drought tariffs between 2017 and 2018 (City of uMhlathuze. 2024). These tariffs were designed to curb excessive water use, promote conservation among residents, businesses, and industries, and generate additional revenue to support municipal water supply operations and infrastructure maintenance during the crisis (Ngwenya, Mabaso, & Mayisela, 2015). The adoption of these measures was crucial in ensuring the continued provision of water services while enhancing the long-term sustainability and resilience of the municipal water supply system.

4.4 Statistical Method: Water Demand Model

When analysing historic water metering data of the City of uMhlathuze for the period between March 2016 and September 2020, Water Demand Models (WDMs) were used. A step-by-step process of the Water Demand model analysis, and results are presented below.

Variables such as total water consumption, average water price per billing period, average seasonal temperature and seasonal rainfall were used in this analysis to generate regression outputs such as b_0 (Intercept) and the coefficients b_1 , b_2, b_3 and b_4 (Pradhan et al., 2006). These regression outputs were thereafter used as coefficients in the Water Demand Models that represented the water usage trends of the study area. In this section Water Demand Models such as the Linear Model, Log-Log Model, and Semi-Log Model, were developed and used to represent the historic water demand trends.

Coefficients such as b_0 (Intercept) and the coefficients b_1 , b_2, b_3 and b_4, represent the relationship between the water demand (Y) and each variable (X_1 , X_2, X_3 and X_4)

- Total Water Consumption (Y)

- Number of Connections (X_1)
- Average Water Price Per Billing Period (m^3 per day) (X_2)
- Average Seasonal Temperature (°C) (X_3)
- Seasonal Rainfall (mm) (X_4)

The Water Demand Models employed in this research allow for the incorporation of multiple variables to model the likely behaviour of water usage trends in specific areas (Pradhan et al., 2006). For the analysis of water demand within the City of uMhlathuze Local Municipality, only the variables discussed in this section were utilised to model the water usage trends of the area. These variables were carefully selected based on their relevance to the local context and the available data.

However, for future investigations or more detailed analyses, additional variables could be explored to further refine the model and enhance the understanding of water consumption patterns. This would allow for a more comprehensive analysis of the factors influencing water demand, and such a study could provide valuable insights for improved water management strategies.

4.4.1 Variables for Water Demand Models

Table 7 presents details of all the variables, that include total water consumption, average water price per billing period, average seasonal temperature and seasonal rainfall, which were used in the WDM analysis.

Water connection data for domestic areas was obtained from the historical metering data from the City of uMhlathuze Local Municipality for the period from March 2016 to September 2020. Since the records for the historical data were available in 3-month intervals, water connection data in this research project was also presented in the same intervals. It is important to note that the City of uMhlathuze Local Municipality conducts water meter readings on a monthly basis. As a result, the three-month water consumption data reported by the municipality represents the cumulative total water usage over the 3-month period, rather than an average.

The water tariff data for domestic areas were obtained from historical metering records provided by the City of uMhlathuze Local Municipality, covering the period from March 2016 to September 2020. Additionally, the drought tariff data for the period between

October 2017 and September 2018 were sourced from the official uMhlathuze website and was used for the above-mentioned period (City of uMhlathuze, 2024).

Maximum temperatures for the Richards Bay area and surrounding regions within a 55 km radius were sourced and used in the analysis of the WDMs (Climate Engine, 2024). To retrieve this data, the Climate Engine website was utilised, covering the assessment period from January 2016 to December 2020. The results obtained were used to calculate the seasonal average maximum temperature for the area, which was subsequently applied in the water demand analysis.

The daily precipitation data collected between January 2016 and December 2020 was also sourced from the Climate Engine website and subsequently utilised in the water demand analysis (Climate Engine, 2024). The daily precipitation figures were converted into seasonal averages and incorporated as a variable in the water demand model. The precipitation readings are specific to the Richards Bay area and cover all locations within a 55 km radius (Climate Engine, 2024). The observed average precipitation, over the study period was 245.56 mm (Climate Engine, 2024).

Table 7: Domestic Water Prices, 2014 to 2022 (City of uMhlathuze, 2024)

Date	X_1	X_2	X_3	X_4
	Number of Connections	**Average Water Price Per Billing Period (m^3 per day)**	**Average Annual Temperature (°C)**	**Rainfall (m)**
Mar-16	26,697	6.57	27	0.28
Jun-16	28,483	7.25	25	0.28
Sept-16	30,389	5.75	27	0.28
Mar-17	32,355	8.83	27	0.42
Jun-17	34,320	11.61	25	0.16
Sept-17	39,483	12.46	27	0.06
Dec-17	44,645	13.31	30	0.21
Mar-18	44,647	15.67	26	0.30
Jun-18	44,648	17.07	25	0.33
Sept-18	44,909	18.61	28	0.13
Dec-18	44,998	12.55	30	0.32
Mar-19	45,086	14.60	27	0.33
Jun-19	46,769	12.72	26	0.13
Sept-19	47,346	12.56	28	0.12
Dec-19	47,607	12.27	30	0.43
Mar-20	48,032	13.39	26	0.31
Jun-20	48,461	12.44	25	0.14
Sept-20	48,893	12.51	28	0.17

4.4.2 Analysis Using the Linear Model

The linear model shows the direct change in water demand for a unit change in the variable (Pradhan et al., 2006). The Linear Model assumes that water demand is a linear function of the influencing variables (X_1 , X_2, X_3 and X_4).

The linear Water Demand Model is a statistical model that is based on the regression analysis in Microsoft Excel (Pradhan et al., 2006). Once the regression output is generated, the following variables are obtained b_0 (Intercept) and the coefficients b_1 , b_2, b_3 and b_4 which are associated with each independent variable.

Table 8 presents the actual water consumption, and corresponding water consumption obtained using Equation 14, which describes the linear model for water demand. Equation 14 below illustrates the water usage trends in the City of uMhlathuze, employing the linear model across the span of the study period.

$$Y = 22395.80 + 0.21(X_1) - 84.03(X_2) - 249.61(X_3) - 73.47(X_4) \quad (14)$$

Table 8: Actual Water Consumption and Linear Modelled Water Consumption

Date	Y	Y
	Total Water Consumption (m^3 per day)	**Linear Model**
Mar-16	19,162	20,638
Jun-16	20,444	21,405
Sept-16	21,575	21,423
Mar-17	23,056	21,550
Jun-17	23,793	22,173
Sept-17	23,526	22,642
Dec-17	23,518	22,951
Mar-18	24,219	23,773
Jun-18	24,385	23,963
Sept-18	22,024	23,167
Dec-18	22,068	23,206
Mar-19	22,602	23,781
Jun-19	24,430	24,554
Sept-19	24,149	24,215
Dec-19	24,089	23,608
Mar-20	24,845	24,794
Jun-20	24,791	25,219
Sept-20	24,740	24,355

The R-squared value for the Linear Model is 68%, indicating a reasonably good fit but also suggesting some substantial discrepancies of about 32% between the observed data and the fitted values as illustrated in Figure 10 below. This figure plots the water usage trend against the historical data for Total Water Consumption in kilolitres per day for the City of uMhlathuze Local Municipality. The sensitivity of the water usage trend to the P-Value for

each coefficient is crucial, as it determines the statistical significance of the variables in explaining water demand.

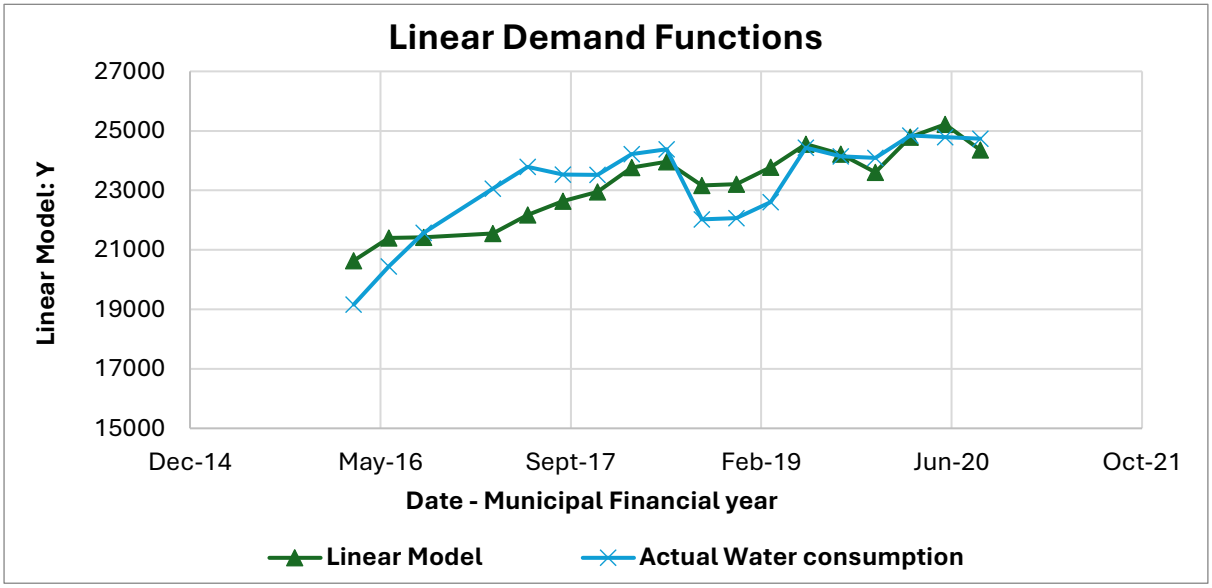

Figure 10: Linear Model - Curves for the Total Water Consumption (kl per day)

Table 9 below presents the P-Values for each variable, which will aid in assessing the significance of these variables in influencing water demand. The P-Value for each coefficient indicates whether the corresponding variable significantly explains water demand and is also an output from the regression analysis (Ott et al., 2016). Typically, P-Values below 0.05 are considered statistically significant, meaning that the variable has a substantial impact on water demand (Ott et al., 2016).

An examination of the P-Values reveals varying degrees of significance among the variables. For instance, the rainfall has a P-Value of 0.98, the highest among the variables, indicating that changes in the rainfall will influence water usage trends in the area of interest but it is not a crucial variable. Conversely, the average number of connections has the lowest P-Value at 0.002, a value that is also below 0.05, suggesting that it significantly affects residential water demand. Therefore, changes in the number of connections have a considerable impact on the water usage trend of the City of uMhlathuze Local Municipality.

Table 9: P-Values for the Linear Model

Variables	**P-Value**
Number of Connections	0.002
Average Water Price Per Billing Period (m^3per day)	0.49
Average Annual Temperature (°C)	0.13
Rainfall (m)	0.98

The Linear Model for water demand is relatively straightforward to estimate. However, it is important to note that this model does not provide constant elasticities at all points along the demand function. Consequently, the results derived from the Linear Model should be interpreted with caution, as their accuracy may be limited.

4.4.3 Analysis Using the Log-Log Model

To analyse the Log-Log Model, both the dependent variable (Y) and the independent variables (X_1 , X_2, X_3 and X_4) were log-transformed. This was achieved by creating new columns in Excel to calculate the natural logarithms of all relevant variables, including the dependent variable *Y* and the independent variables (X_1, X_2, X_3 and X_4) (Pradhan et al., 2006). After the transformation, regression analysis was performed to derive the coefficients, including b_0 (Intercept) and the coefficients b_1 , b_2, b_3 and b_4, which correspond to the log-transformed variables for both the dependent and independent variables.

In the Log-Log Model, the coefficients b_1 , b_2, b_3 and b_4 represent the elasticity of water demand with respect to the independent variables which means that each coefficient quantifies the percentage change in water demand in response to a 1% change in the respective variable (Bernardo and Termes, 2015).

Table 10 presents the actual water consumption, and corresponding water consumption obtained using Equation 15, which describes the Log-Log Model for water demand. Equation 15 below illustrates the water usage trends in the City of uMhlathuze, employing the Log-Log Model across the span of the study period.

$$lnY = 7.37 + 0.35(X_1) - 0.04(X_2) - 0.29(X_3) - 0.01(X_4) \quad (15)$$

Table 10: Actual Water Consumption and Log-Log Modelled Water Consumption

Date	lnY	lnY
	Total Water Consumption (kl per day)	**Log - Log Model**
Apr-16	9.86	9.92
Jun-16	9.93	9.96
Sept-16	9.98	9.97
Mar-17	10.05	9.97
Jun-17	10.08	10.01
Sept-17	10.07	10.04
Dec-17	10.07	10.04
Mar-18	10.09	10.08
Jun-18	10.10	10.09
Sept-18	10.00	10.06
Dec-18	10.00	10.05
Mar-19	10.03	10.08
Jun-19	10.10	10.11
Sept-19	10.09	10.10
Dec-19	10.09	10.06
Mar-20	10.12	10.11
Jun-20	10.12	10.14
Sept-20	10.12	10.10

The R-squared value for the Log-Log Model is 70%, indicating a relatively high "goodness-of-fit", which suggests discrepancies of about 30% between the observed data and the predicted values, as shown in Figure 11 below.

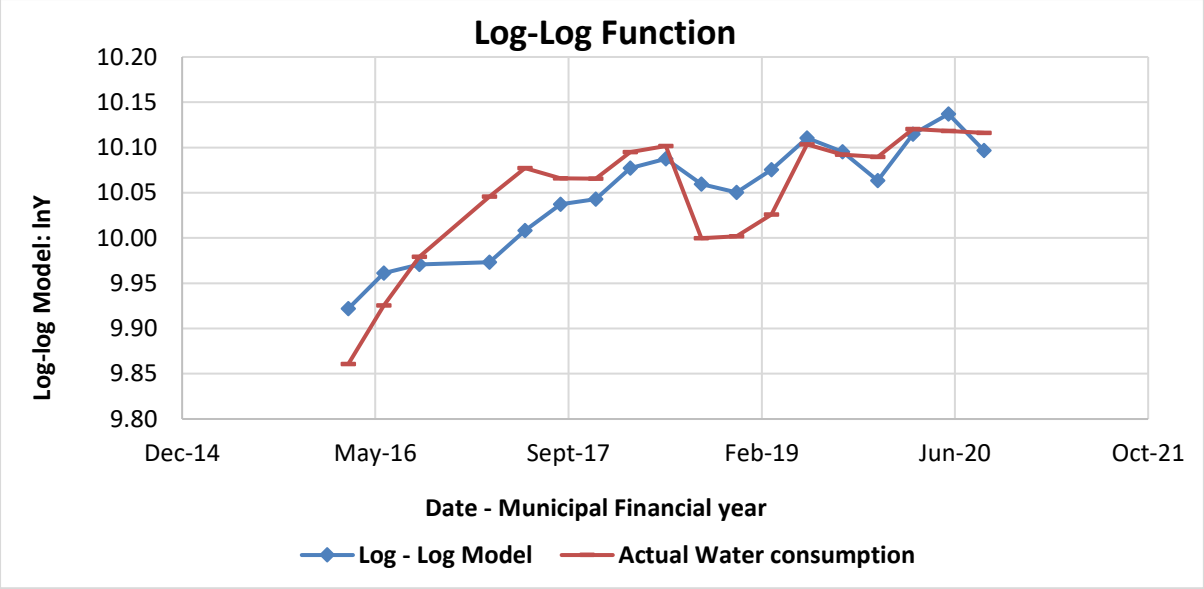

Figure 11: Log-Log Model - Curves for the Total Water Consumption (kl per day)

Table 11 below presents the P-Values for each variable, assisting in evaluating their significance in influencing water demand. As shown in the table, only the number of connection's P-Value is less than 0.05, indicating that this variable is statistically significant and thus have a substantial impact on water demand.

The number of connections has the lowest P-Value at 0.01, suggesting that it significantly affects water demand relative to the other variables and changes in number of connections have a considerable impact on the Log-Log Model used to predict water usage trend of the City of uMhlathuze Local Municipality.

Table 11: P-Values for the Log-Log Model

Variables	**P-Value**
Number of Connections	0.01
Average Water Price Per Billing Period (m^3 per day)	0.57
Average Annual Temperature (°C)	0.13
Rainfall (m)	0.78

The log-log functional form directly provides estimates of the elasticities of the independent variables in relation to the dependent variable. However, it is important to interpret the results from the Log-Log Model with caution, as they may present limited accuracy due to potential variations in elasticity across different points in the model.

4.4.4 Analysis Using the Semi-Log Model

To analyse the Semi-Log Model, only the dependent variable, Total Water Consumption, is log-transformed. This was accomplished by creating a new column in Excel to calculate the natural logarithm of the total water consumption (Y). Following this transformation, the regression analysis was conducted to obtain the coefficients, including b_0 (Intercept) and the coefficients b_1 , b_2, b_3 and b_4, which correspond to each independent variable X_1 , X_2, X_3 and X_4 (Pradhan et al., 2006). In this analysis, the log-transformed water consumption served as the dependent variable.

The interpretation of the output followed a similar approach to that of the linear model, while noting that the dependent variable is now in logarithmic form.

Table 12 presents the actual water consumption, and corresponding water consumption obtained using Equation 16, which describes the Semi-Log Model for water demand. Equation 16 below illustrates the water usage trends in the City of uMhlathuze, employing the Semi-Log Model across the span of the study period.

$$lnY = 10 + 9.09E-06(X_1) - 0.003(X_2) - 0.011(X_3) - 0.003(X_4) \quad (16)$$

Table 12: Actual Water Consumption and Semi-Log Modelled Water Consumption

Date	$\boldsymbol{lnY}$	$\boldsymbol{lnY}$
	Total Water Consumption (kl per day)	**Semi-Log Model**
Mar-16	9.86	9.93
Jun-16	9.93	9.97
Sept-16	9.98	9.97
Mar-17	10.05	9.98
Jun-17	10.08	10.00
Sept-17	10.07	10.03
Dec-17	10.07	10.04
Mar-18	10.09	10.08
Jun-18	10.10	10.08
Sept-18	10.00	10.05
Dec-18	10.00	10.05
Mar-19	10.03	10.08
Jun-19	10.10	10.11
Sept-19	10.09	10.09
Dec-19	10.09	10.07
Mar-20	10.12	10.12
Jun-20	10.12	10.14
Sept-20	10.12	10.10

The R-squared value for the Semi-Log Model is 67%, indicating a relatively high "goodness-of-fit", and suggesting 33% discrepancies between the observed data and the fitted values, as illustrated in Figure 12 below.

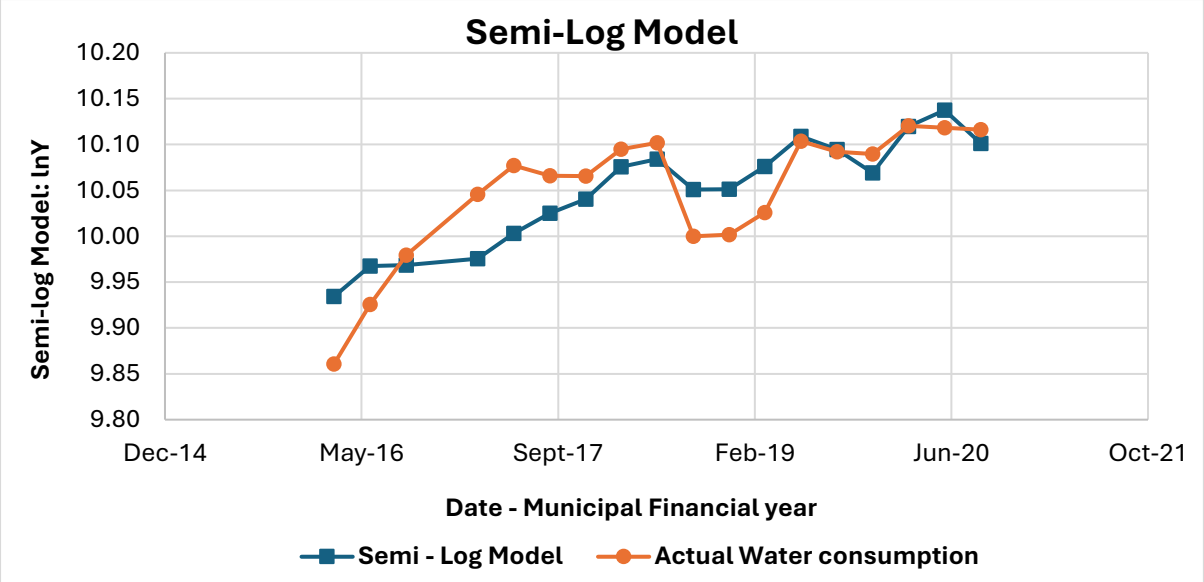

Figure 12: Semi-Log Model - Curves for the Total Water Consumption (kl per day)

Table 13 below presents the P-Values for each variable, which will aid in assessing the significance of these variables in influencing water demand. The number of connections has the lowest P-Value at 0.003, suggesting that it significantly affects water demand relative to the other variables. Changes in number of connections have a considerable impact on the Semi-Log water usage trend of the City of uMhlathuze Local Municipality.

Table 13: P-Values for the Semi-Log Model

Variables	**P-Value**
Number of Connections	0.003
Average Water Price Per Billing Period (m^3 per day)	0.55
Average Annual Temperature (°C)	0.15
Rainfall (m)	0.98

The Semi-Log function is often used to compare results with those obtained from linear and Log-Log Models (Pradhan et al., 2006). Consequently, the findings from the Semi-Log Model should be interpreted in relation to the linear and Log-Log Models, as this comparison can provide valuable insights into the strengths and limitations of each approach. While the Semi-Log model's accuracy may be constrained due to differences between the models, it still serves as an important reference point for evaluating the accuracy and behaviour of the other models in the analysis.

Table 14 presents the outputs of the Water Demand Model for various selected variables, which were combined to assess their significance in influencing water demand. The objective of this analysis was to evaluate the strength of the relationship between water demand and these variables while identifying discrepancies between the observed data and the fitted values. This assessment provided valuable insight into the most appropriate model for describing water usage trends within the City of uMhlathuze Local Municipality and determining the key variables that exert the greatest influence on water demand.

Based on the results of the Water Demand Model analysis, the Log-Log Model was found to best represent the water usage trends of the City of uMhlathuze Local Municipality. Additionally, the analysis highlights that the number of connections plays a significant role in determining water demand within the study area. This finding aligns with the observed historical consumption patterns, which indicate that over the years, water demand has steadily increased due to multiple contributing factors. However, one of the most prominent factors is the rise in the number of households connected to the municipal water supply network, directly impacting overall water consumption.

Table 14: Water Demand Model Outputs for Different Variables

Variables	Linear Model		Log-Log Model		Semi-Log Model	
	P-Value	**R Square**	**P-Value**	**R Square**	**P-Value**	**R Square**
Number of Connections	1.65E-04	66%	1.1E-04	69%	1.8E-04	66%
Average Annual Temperature (°C)	0.14		0.14		0.17	
Rainfall (m)	1.00		0.81		1.00	
Number of Connections	0.02	55%	0.03	58%	0.02	55%
Average Water Price Per Billing Period (m^3 per day)	0.99		0.88		0.95	
Number of Connections	0.17	60%	8.9E-05	63%	7.4E-06	60%

With the available Water Demand Models, further adjustments can be made to the independent variables, such as increasing the number of connections in order to forecast

future water demand trends or evaluate various policy scenarios. By following the steps outlined above, Excel can be used to effectively project water demand and analyse the influence of socio-economic, climatic, and policy-related factors. This approach allows for a more comprehensive understanding of how different variables affect water demand trends.

4.5 Assessment of Excessive Water Consumption

This section investigates whether excessive water consumption exists within the uMhlathuze Local Municipality by applying established criteria for per capita consumption. By evaluating historical water usage and identifying thresholds for normal and excessive consumption, this assessment aims to highlight current challenges and provide recommendations for sustainable water management.

As illustrated in Figure 13, in response to the escalating global water shortages, there is a pressing need to develop realistic estimates of water consumption based on actual water-use activities, rather than relying solely on imposed top-down restrictions. According to a study by (Crouch et al., 2021), the estimated non-wasteful water usage focusing specifically on indoor, essential activities was found to be approximately 175 litres per person per day. This value represents a more practical benchmark for typical daily water consumption across all primary water-use locations. These findings highlight the importance of aligning water usage estimates with real world activities to better inform water management strategies and ensure sustainable consumption practices (Crouch et al., 2021).

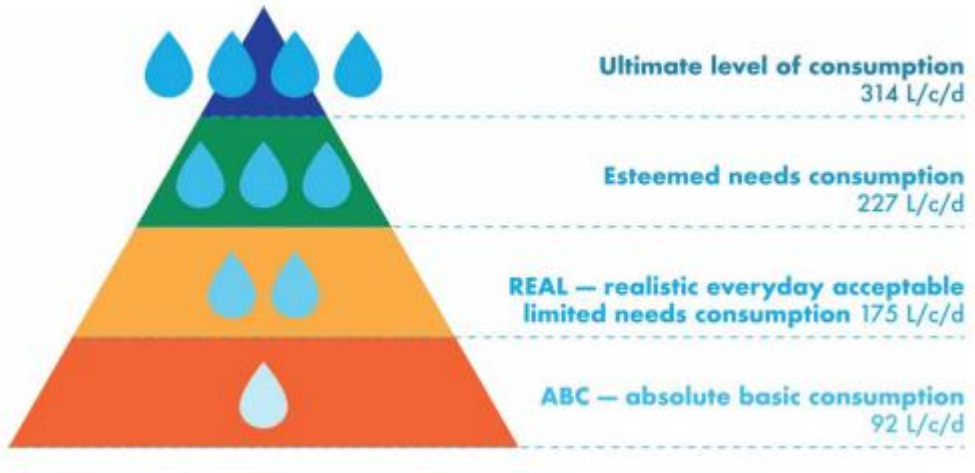

Figure 13: Grounded Actual Water-Use Activities in Litres Per Capita Per Day (Crouch et al., 2021)

The Department of Water and Sanitation (DWS) in South Africa recommends a per capita water consumption range of 150 to 200 litres per person per day for domestic purposes (DWS, 2023) as shown in Table 15. This recommended range serves as a basis for setting water consumption standards within the City of uMhlathuze Local Municipality, providing a benchmark to guide sustainable water usage and inform water resource management practices.

Table 15: Water Use Efficiency performance categories in L/c/d (DWS, 2023)

Water Use Efficiency (L/c/d) Performance Categories	
>300	Extremely high per capita water use
250-300	Poor per capita water use
200-250	Average per capita water use with potential for marked improvement
150-200	Good per capita water use but some improvement may be possible subject to economic benefit
<150	Excellent per capita water use management

Water use efficiency is commonly regarded as a key performance indicator and is reported at the national government level, with the average national per capita water consumption currently standing at 216 litres per capita per day (L/c/d) across South African provinces (DWS, 2023). This average significantly exceeds the international benchmark of 180 L/c/d (Wegelin et al., 2017). According to the Department of Water and Sanitation (DWS, 2015), municipalities were advised to aim for improvements targeting an average consumption of below 200 L/c/d. However, recent data from DWS (2023)

indicates that the KwaZulu-Natal region has reported a higher water consumption rate of 224 L/c/d, highlighting the ongoing challenge of aligning local usage with both national targets and international efficiency standards.

An examination of historical water consumption data for the City of uMhlathuze Local Municipality indicates an average per capita consumption of approximately 143 litres per person per day over the past five years, establishing a local baseline for comparative purposes. The average per capita consumption in the City of uMhlathuze Local Municipality was achieved through the implementation of various demand management strategies, including a three-tier rising block domestic tariff. This tariff structure encourages water conservation by charging higher rates for increased consumption, thereby promoting efficient water use among residents. This structure includes a lifeline tariff for consumption below 25 litres per day, a standard tariff aligned with average historical costs for consumption between 25 and 250 litres per day, and a marginal tariff, which reflects long-run marginal costs, for consumption exceeding 250 litres per day (DWAF, 2002). This tariff structure was designed to support low-income households, and it is based on household consumption rather than per capita usage which means that the allocation of the lifeline tariff is determined by the total water consumption of the household, not by individual per person usage (City of uMhlathuze. 2024). This approach aims to promote water use efficiency while ensuring equitable access across varying consumption levels.

Table 16 presents data on the historic residential average daily demand (ADD) for the study area over the five-year period. This study focuses on areas with billed metered house connections for residential households within the City of uMhlathuze Local Municipality. The observed average daily demand for residential areas with billed metered connections in the City of uMhlathuze Local Municipality was 143 litres per capita per day, which is below the typical demand range for residential households served by house connections which generally falls between 120 and 400 L/c/d, as outlined in Table 17 (DHS, 2019).

Table 16: Historic Residential Average Daily Demand Litres Per Capita Per Day

Measurement Timeline	Residential House Count	Population Count	Total Water Consumption (kl/d)	Per Capita Consumption (L/c/d)
		4 People Per Household		
Mar-16	26,697	106,788	19,162	179
Jun-16	28,483	113,933	20,444	179
Sept-16	30,389	121,556	21,575	177
Mar-17	32,355	129,418	23,056	178
Jun-17	34,320	137,280	23,793	173
Sept-17	39,483	157,930	23,526	149
Dec-17	44,645	178,580	23,518	132
Mar-18	44,647	178,586	24,219	136
Jun-18	44,648	178,592	24,385	137
Sept-18	44,909	179,636	22,024	123
Dec-18	44,998	179,990	22,068	123
Mar-19	45,086	180,345	22,602	125
Jun-19	46,769	187,076	24,430	131
Sept-19	47,346	189,384	24,149	128
Dec-19	47,607	190,428	24,089	127
Mar-20	48,032	192,128	24,845	129
Jun-20	48,461	193,842	24,791	128
Sept-20	48,893	195,572	24,740	127

Table 17 illustrates the residential average annual daily demand (AADD) per capita, as outlined in the (DHS, 2019). The historical data indicates that house connections have been implemented within the municipality, as the actual residential water demand of the City of uMhlathuze Local Municipality ranges from 123 to 179 L/c/d. However as per Table 17, the City of uMhlathuze Local Municipality's average annual daily demand of 143 l/c/d is less than the average annual daily demand of 230 L/c/d for house connections for residential areas.

Table 17: Residential AADD (per capita) as per the (DHS, 2019)

Land Use		Persons Per Unit	Typical AADD L/c/d	AADD Range L/c/d
Standpipe		5	25	10 to 40
Yard Connection	With dry sanitation	5	50	40 to 60
	With low-flow (LOFLO's) sanitation	5	60	50 to 70
	With full-flush sanitation	5	70	60 to 80
House Connection	Low-income housing	5	90	60 to 120
	Residential	5	230	120 to 400
	Group/cluster housing	3 to 5	120	120 to 130
	Flats	1 to 4	150	110 to 252

In this study, the average annual daily demand for the City of uMhlathuze Local Municipality was calculated to be 143 litres per capita per day. This value is an average observed in the historical data for the study area over the study period and provides a consistent benchmark for analysis.

The DHS (2019) provides a guideline for real water losses, suggesting an allowance of 15% to 25%. The historical water consumption data selected for analysis in this research project for residential areas served by house connections, indicates that an average annual daily demand range of 120 to 400 litres per capita per day was to be expected, as outlined in Table 17. Consequently, an absolute consumption limit of 175 litres per person per day has been established (Viljoen & van der Walt, 2018). Any usage surpassing this limit will be classified as excessive; however, it is noteworthy that there have been no observations of the absolute consumption limit being exceeded within this area which suggests that the residential areas with metered connections of the City of uMhlathuze Local Municipality do not use water excessively.

The KwaZulu-Natal province faced a severe drought during 2015 and 2016, which caused critical declines in dam levels. For instance, Midmar Dam dropped to its lowest level since 1983 during the 2015 drought (Karlie, 2020). Climate change is widely acknowledged to influence the frequency and severity of droughts and is likely to have exacerbated the drought conditions experienced in KZN during this period.

The marked improvement in water usage efficiency observed in subsequent years could be attributed to the municipality's proactive measures in response to the drought. Table 18 below shows a drought tariff structure that was introduced on the 01 July 2017 and remained in effect throughout that year. This structure included four stages, with water tariffs increasing by up to 60% for residential areas and 15% for other categories. These measures incentivised more efficient water usage and contributed to the observed reduction in consumption.

Table 18: Drought Tariffs for the City of uMhlathuze Local Municipality (City of uMhlathuze. 2024)

Drought Tariffs 2017/19				
Stage 0	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Before Reduction	10% Res & 5% Other Reduction	20% Res & 10% Other Reduction	30% Res & 15% Other Reduction	60% Res & 15% Other Reduction
01/07/2017	2017/2018	2017/2018	2017/2018	2017/2018
R 4.90	R 5.76	R 6.28	R 6.85	R 7.47
R 5.88	R 6.92	R 7.54	R 8.22	R 8.96
R 13.76	R 16.19	R 17.65	R 19.24	R 20.97
R 18.24	R 21.46	R 23.39	R 25.50	R 27.79
R 23.79	R 27.99	R 30.51	R 33.25	R 36.25

The uMhlathuze area has experienced considerable population growth and according to Stats SA the population increased by 0.92% annually between 2011 and 2022. However, the actual population growth of people with billed metered connections in the residential areas that are served by the City of uMhlathuze Local Municipality was found to be 14% per annum when utilising historical metering data between 2016 to 2020. The population growth of 14% directly correlates with rising overall water demand as more house connections were implemented, placing additional pressure on local water resources. Analysis indicates that the number of households with billed metered connections in uMhlathuze increased from 26,697 in March 2016 to 48,893 in September 2020.

An assessment of water meters within the municipality revealed that some meters were not recorded which resulted in some water tariff types being excluded in this analysis. The absence of meter readings in residential areas can be attributed to several factors,

including but not limited to malfunctioning or broken meters, periods of no water usage, and restricted access to the meter. These challenges impact the accuracy and completeness of water consumption data. A closer look at the historical metering data records between December 2020 to June 2021 indicate that there were no records for most tariff types, and this raises concerns about the reliability of consumption data and the potential misclassification of excessive usage due to recording inconsistences that can be seen in Table 4.

The assessment indicates that current water consumption for residential areas with billed metered connections does reflect any excessive usage in the uMhlathuze Local Municipality. However, as water demand continues to rise due to factors such as population growth, increasing household sizes, standards of living, requiring an increase from standpipes to yard connections to household connections, the municipality is likely to face challenges related to excessive water usage in the future. Proactive measures, including improved metering accuracy, demand management strategies, and sustainable water resource planning, will be essential in mitigating these future challenges and ensuring the long-term sustainability of the water supply system. The established threshold for excessive consumption provides a framework for better management of water resources.

Conducting regular audits of water meters and taking regular meter readings are essential to ensure the accuracy and reliability of water consumption data. Municipalities hold the responsibility for planning, implementing, and monitoring water demand management initiatives (Mthethwa, 2017). However, as noted by McKenzie (2014), budgeting for water conservation and demand management projects such as infrastructure replacement, leak detection and repair poses a significant challenge for many municipalities. This difficulty often stems from a lack of recognition of the importance and benefits of addressing water losses within municipal reticulation systems (Mthethwa, 2017). Effective water conservation and demand management strategies necessitate adequate budgetary allocation by municipalities. Consequently, it is critical to evaluate whether municipalities allocate sufficient funding for such initiatives, particularly for projects involving pipe replacement, pressure management, leak detection, and repairs (Mthethwa, 2017).

A study conducted in the Mkhwanazi Tribal Area within the City of uMhlathuze Local Municipality recommended water awareness campaigns through visual displays at public venues such as health clinics, shops, and churches to instil the value of water in the community (Magwaza, 2011). Magwaza further suggested engaging school learners through projects, debates, and competitions as an effective method of spreading water conservation messages. Given the authoritative role of teachers, educating children about water conservation could indirectly influence household practices, ensuring the message permeates the broader community.

Regular water awareness campaigns should be conducted, particularly in schools, to maximise outreach. By educating children about the importance of potable water supplies, municipalities can cultivate an informed generation capable of contributing to the sustainability of water resources in the future (Magwaza, 2011). Additionally, challenges such as water losses and non-payment for water services in the Mkhwanazi Tribal Area can be addressed holistically by involving all governing bodies in water awareness initiatives.

Reassessing local water consumption policies is essential to ensure their alignment with established thresholds and to encourage responsible water use. According to Kgomotso et al., 2005, during South Africa's apartheid era, government policies primarily served the interests of a privileged minority, and water resource development was no exception. The focus was on supporting the progress of the wealthy sector, often at the expense of addressing the needs of impoverished, rural communities (Kgomotso et al., 2005).

With respect to issues of water governance, there are positive indications in areas like the uMhlathuze District Municipality where 81% of respondents demonstrated a clear understanding of the municipality's intentions. This indicates effective municipal awareness campaigns or an informed public (Nkutha, 2022). However, capacity-building initiatives are of immense importance, particularly for members of forums such as the uSuthu and Mhlathuze Catchment Management Forums (Nkutha, 2022). These initiatives should include public education and awareness workshops on water governance (Nkutha, 2022).

The free basic water policy, which provides six kilolitres of water per household per month, has faced criticism for being inadequate. There are analysts who argue that many low-income households require more than this amount due to larger household sizes, and aging and leaky infrastructure inherited from the apartheid era (Kgomotso et al., 2005).

Furthermore, policymakers must take into account the unintended consequences of emphasising household water consumption reductions. Efforts to minimise domestic use could inadvertently shift consumption to external locations such as offices, shopping centres, and recreational facilities, where individuals do not bear the cost of water use. This displacement could result in increased overall water consumption per capita (Crouch et al., 2021).

Holistic and equitable approaches to policymaking, alongside capacity-building efforts, are therefore crucial to fostering sustainable water use while addressing socio-economic disparities.

4.6 Water Demand of the City of uMhlathuze Local Municipality in relation to the KwaZulu-Natal Province

Water demand is a critical issue for urban planning and resource management, especially in regions facing water scarcity. This report investigates the average water demand in the City of uMhlathuze and compares it with trends across KwaZulu-Natal. The aim is to identify any significant deviations in water demand between the city and provincial averages.

Table 19 below shows the benchmark summary for different provinces for periods 2017 and 2022 as reported by (Wegelin et al., 2017) and (DWS, 2023) respectively. The benchmark for the province of KwaZulu Natal was found to be 225 L/c/d in 2017 and 224 L/c/d in 2022. This benchmark shows an improvement of 1 L/c/d being saved. However, the biggest improvement was observed in the Western Cape province where the benchmark reduced by 40 L/c/d. A province like Gauteng still falls short of achieving water usage to an amount of about 200 L/c/d (DWS, 2015).

Table 19: Benchmark Summary for Different Regions, 2017 and 2022 by (Wegelin et al., 2017) and (DWS, 2023)

Region Benchmark Summary for 2017 and 2022		
Region	**2017: L/c/d**	**2022: L/c/d**
EC	200	203
FS	209	224
GT	305	253
KZN	225	224
LP	182	210
MP	205	186
NC	238	250
NW	186	176
WC	201	161
National	233	216

A review of the system input volume in municipalities within KwaZulu-Natal was conducted. The selected areas were the eThekwini, Msunduzi, Newcastle, and City of uMhlathuze municipalities, which collectively represent about 69% of the demand utilised to produce the water balance of the KwaZulu-Natal province (DWS, 2023).

Table 20 shows the system input volume of eThekwini, Msunduzi, Newcastle, and City of uMhlathuze municipalities between 2011 and 2023. The system input volume for the City of uMhlathuze Local Municipality is higher than that of other municipalities in the region. This suggests that, on average, the City of uMhlathuze Local Municipality has a higher per capita water consumption rate compared to its counterparts. This trend may indicate increased water demand driven by multiple factors such as industrial activity, population dynamics and metering inefficiencies.

Table 20: System Input Volume (L/ c/ d) for Municipalities in KwaZulu Natal, 2011 to 2023 (DWS, 2023)

KwaZulu Natal System Input Volume (L/ c/ d) 2011 to 2022				
Year	**City of uMhlathuze Local Municipality**	**Newcastle Local Municipality**	**Msunduzi Local Municipality**	**Ethekwini Metropolitan Municipality**
2011	357	293	327	297
2012	359	312	347	297
2013	349	308	340	293
2014	340	304	334	289
2015	331	300	328	285
2016	322	295	322	281
2017	319	292	318	278
2018	315	289	314	274
2019	311	285	310	271
2020	307	282	307	268
2021	304	279	303	265
2022	324	227	269	246
2023	318	221	263	242

Table 21 shows the average System Input, Non-Revenue and Revenue water for multiple municipalities in KwaZulu Natal. The City of uMhlathuze Local Municipality has the lowest Non-Revenue Water per capita consumption and the highest Revenue Water per capita consumption among the municipalities analysed. Table 21 suggests that the City of uMhlathuze Local Municipality effectively recovers costs associated with water consumption, generating more revenue from water services compared to its counterparts. The high Revenue Water per capita may indicate efficient billing and metering practices, reduced water losses and a higher proportion of industrial and commercial water users contributing to overall revenue generation.

Table 21: Average System Input, Non-Revenue and Revenue Water for Municipalities in KwaZulu Natal, 2011 to 2023 (DWS, 2023)

Average Per Capita Consumption (L/c/d) from 2011 to 2023				
Data Collection Area	**System Input Volume Consumption (L/ c/ d)**	**Non-Revenue Water %**	**Non-Revenue Water (L/ c/ d)**	**Revenue Water (L/ c/ d)**
City of uMhlathuze Local Municipality	327	27%	88	239
Newcastle Local Municipality	284	45%	128	156
Msunduzi Local Municipality	314	48%	152	162
Ethekwini Metropolitan Municipality	276	35%	97	179

A basic water consumption requirement of about 25 litres per person per day within a 200 metres radius from the public standpipe is a requirement in South Africa (DHS, 2019). To comply with this requirement, the City of uMhlathuze Local Municipality developed a social package to assist households that are indigent. The social package includes free water for households that consume 200 litres and less per day for a month or the first 6 000 litres of water per month (City of uMhlathuze, 2018). When a consumer uses more than 200 litres per day for a month, the excess is charged by the Municipality.

The analysis of the historical meter data revealed that between the periods March 2016 and September 2020 the average demand for the City of uMhlathuze Local Municipality was 143 litres per capita per day. This daily water consumption per capita suggests that the municipality falls in the B3 category as shown in Table 22 (DWS, 2023). In the B3 category, the average consumption above RDP level is 150 L/c/d, with the design guideline suggesting a moderate to high development level ranging from 80 to 145 L/c/d and yard connections with the water consumption of 55 L/c/d (DWS, 2023).

Table 22: Average L/c/d Consumption Above and Below RDP Level (DWS, 2023)

Municipal Category	Average L/c/d Consumption Above RDP** Level	Average L/c/d Consumption Below RDP Level	Design Guideline*	Billing Efficiency
A	300	55	Very high development level = 260 to 480 L/c/d Yard connections = 55 L/c/d (typical)	90%
B1	250	55	High development level = 130 to 280 L/c/d Yard connections = 55 L/c/d (typical)	70%
B2	200	55	High development level = 130 to 280 L/c/d Yard connections = 55 L/c/d (typical)	50%
B3	150	55	Moderate to high development level = 80 to 145 L/c/d Yard connections = 55 L/c/d (typical)	30%
B4 and C2	100	25	Yard connections = 50 to 100 L/c/d Standpipe = 10 to 50	10%
* The Neighbourhood Planning and Design Guide (Part II) - Section J: Water supply (DHS, 2019)				
** Reconstruction and Development Programme				

Several factors influence water consumption patterns in the uMhlathuze Local Municipality, including population growth, industrial activity, climate conditions, and socio-economic changes. However, the assessment of the average daily water demand for residential areas with billed metered connections in the City of uMhlathuze Local Municipality, which was found to be 143 litres per capita per day indicates that there is no excessive water use. Therefore, other water users need to be evaluated to identify where excessive water use occurs in the City of uMhlathuze Local Municipality.

The municipality's population grew significantly from 370,256 in 2011 to over 412,075 in 2022, reflecting a 11% increase during the intercensal period (StatsSA, 2022). As can be observed in Figure 14 below, of this population, 58% reside in tribal areas, 39% in urban

areas, and 3% on farmland. This demographic composition emphasises the need for targeted rural development initiatives and collaboration with traditional leaders to enhance service delivery in tribal regions (City of uMhlathuze, 2022).

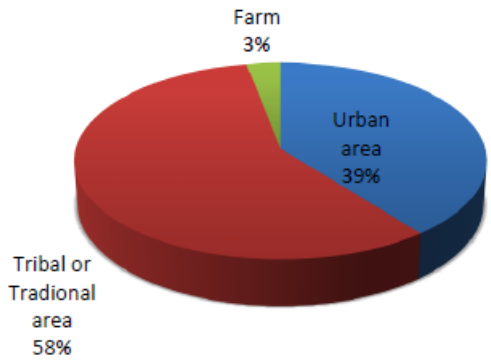

Figure 14: Population Demographic (City of uMhlathuze, 2022)

Rising water demand can further be driven by lifestyle changes associated with the expanding middle class, shifting demographics, and the impacts of climate change (Mthethwa, 2017). Efforts to improve the socio-economic well-being of historically disadvantaged communities also contributes to increased water consumption as living standards rise (Mthethwa, 2017). Projections indicate that at a steady growth rate of 1.5% per year, the municipality's population will exceed 500,000 by 2030 and with a higher growth rate of 5%, this threshold could be reached much sooner, doubling the number of households by 2030 (City of uMhlathuze, 2022).

The municipality's industrial base, including the Richards Bay Industrial Development Zone, heavily influences local water usage and generation of income. The Mhlathuze catchment is regarded as a critical area for future industrial development, necessitating the safeguarding of its water resources to ensure sustainability (Nkutha, 2022). Economic opportunities in industrial and agricultural sectors may further drive population growth through in-migration from neighbouring regions (City of uMhlathuze, 2022). Seasonal variations, such as increased demand during summer, and climate change-induced challenges, including temperature extremes and erratic rainfall patterns will in turn exacerbate the pressures on water resources (Dlamini, 2018; City of uMhlathuze, 2022). The region experiences a warm, humid subtropical climate, with average annual rainfall

of 1,228 mm, 80% of which occurs between September and February (City of uMhlathuze, 2022).

To address these challenges, the municipality has implemented policies promoting sustainable water use, including a sliding-scale tariff system. This system exempts households consuming less than 0.2 kilolitres per day (up to 6 kilolitres per month) from charges, while higher consumption levels incur progressively higher rates (Mthethwa, 2017). While this initiative has shown promise, additional efforts are required to maximise its effectiveness in achieving water conservation goals. Public awareness campaigns play a pivotal role in fostering sustainable water use and encouraging both willingness and ability to pay for water services (Simasiku, 2010). Schools, churches, and other community spaces offer opportunities for educational initiatives to instil the value of water conservation and sustainable practices in households.

4.7 Promoting Water Conservation Through Targeted Educational and Campaigns

The assessment of water consumption demand for residential areas with billed metered connections in the City of uMhlathuze Local Municipality, which was found to be 143 litres per capita per day, indicates that there is no sufficient evidence of excessive water use. This conclusion is based on the benchmark set by Viljoen & van der Walt (2018), which defines an absolute consumption limit for estimated non-wasteful indoor water usage at 175 litres per person per day. The observed consumption falls well within this threshold, suggesting that residential water usage in the municipality remains within sustainable and efficient levels.

Therefore, to ensure that the City of uMhlathuze Local Municipality as a whole adheres to the non-wasteful indoor water usage limit of 175 litres per person per day, it is essential to implement targeted educational and awareness campaigns. These initiatives should focus on promoting sustainable water conservation practices, fostering behavioural change, and enhancing public awareness of efficient water use.

By engaging communities and providing practical guidance on reducing unnecessary consumption, the municipality can work towards long-term water sustainability while maintaining adequate service delivery. Such campaigns should be specifically tailored to address the unique needs and challenges faced by different communities.

Increased water usage within the municipality can be identified through a combination of population growth trends, water consumption data, infrastructure performance analysis and increased number of connections. The number of connections of the residential areas in the City of uMhlathuze Local Municipality has grown significantly, with the an estimated 41,543 connected residential houses in 2020, a 83% increase from 2016. The highest density areas, including urban and industrial zones, tend to have higher water demand due to both residential and commercial needs. Furthermore, tribal areas, which house 58% of the population, also face challenges related to poor infrastructure and service delivery making them crucial areas for intervention (City of uMhlathuze, 2022).

Excessive water usage is also influenced by lifestyle changes, socioeconomic factors, and seasonal variations. Areas with large industrial bases, such as Richards Bay and Empangeni, have increased water demand due to both domestic and industrial needs, further stressing the existing water resources (Nkutha, 2022). To address excessive water consumption, educational campaigns must be strategically designed to meet the diverse needs of various communities and in this section tailored strategies based on community-specific challenges are presented.

In urban and industrial regions, elevated water consumption is frequently attributed to the combined demands of residential and commercial activities. Targeted campaigns in these areas should prioritise the promotion of water-efficient technologies and sustainable practices among both households and businesses. Strategies could include advocating for the use of water-saving appliances, implementing responsible irrigation methods and minimising water wastage in industrial processes.

To encourage businesses and industries to adopt water conservation measures, incentive-based approaches could be implemented, such as providing rebates for the integration of water-efficient systems or financial support for infrastructure upgrades (City of uMhlathuze, 2022). These measures would not only foster responsible water use but also contribute to long-term sustainability in water resource management.

Public engagement initiatives should leverage local media outlets, social media platforms, and community centres to effectively disseminate information on water-

saving practices and the significance of responsible water usage. Emphasising the environmental consequences of overconsumption alongside practical solutions can foster greater awareness among residents and businesses. A study by Dlamini (2018) highlights the need for enhanced communication strategies within the uMhlathuze municipality. According to an official from the Project Management Unit, the lack of effective communication, transparency and public awareness regarding the municipality's plans and challenges in water provision has contributed to significant animosity within communities, leading to frequent service delivery protests. The study highlights a consensus among respondents that such protests could be mitigated through strengthened community engagement and the implementation of more accountable governance practices (Dlamini, 2018).

Rural and tribal areas often face challenges related to inadequate infrastructure and a lack of awareness regarding water conservation practices. Tailored awareness campaigns should address these challenges by incorporating local languages and actively engaging traditional leaders, local councillors, and other key stakeholders, including women, who play a significant role in water resource management.

A study by Murwirapachena (2021) highlights that in South Africa, women are primarily responsible for household water usage due to their roles in managing domestic affairs. Consequently, water conservation awareness campaigns should prioritise women while also targeting the general population. Women should be integral to programs addressing excessive water consumption and should be encouraged to assume leadership roles. Empowering and equipping women with the necessary skills and knowledge will enhance their ability to implement these initiatives effectively.

Research conducted by Thakur et al. (2019) emphasises the importance of education and communication in raising awareness about critical issues such as climate change, water scarcity, and sustainable water use practices. Participants in the study stressed the need for community involvement and the utilisation of existing structures, such as local councillors, to promote water conservation. Moreover, the findings advocate for education and communication programs aimed at reducing water consumption in poor communities. These programs could focus on disseminating water-saving techniques and promoting awareness of personal water consumption practices (Thakur et al., 2019).

Given the agricultural orientation of many rural communities, targeted campaigns should incorporate water-saving practices specifically designed for both formal and informal small scale farming activities. These practices may include promoting rainwater harvesting, drip irrigation, and efficient crop irrigation methods to optimise water usage. Implementing water loss prevention strategies is crucial to reduce institutional expenditure on water resources (Netshitanini et al., 2023). As suggested by Hill, (1997), a comprehensive water management approach should involve maintaining a logbook to record key metrics such as rainfall, evaporation rates, and irrigation schedules. This logbook would enable farmers to identify long-term trends in water use and evaluate irrigation efficiency by benchmarking the performance of their farms against local and industry standards (Hill, 1997).

Routine inspections should be conducted to identify and address leaks in taps, and faulty meters as part of a six-monthly audit, with prompt replacement of washers when required (Hill, 1997). Additional measures include minimising water use by reusing and recycling water wherever possible, particularly in cases where high-quality water is not essential or can be treated and reused for critical applications. Adopting the most efficient irrigation methods and avoiding midday irrigation to reduce evaporation are vital strategies (Hill, 1997). Rainwater harvesting should be promoted for irrigation and cleaning purposes to reduce dependency on freshwater resources, minimise environmental impacts, and lower costs. Rehabilitation of tanks and renovation of water harvesting structures may also be necessary. Storing runoff water during rainy periods using tanks, ponds, cisterns, and earth dams can ensure availability during dry spells, enhancing sustainability in agricultural water management (Hill, 1997).

Implementing on-the-ground workshops in tribal areas to demonstrate water-saving techniques is crucial for promoting sustainable water use, particularly for households and small-scale farmers. Leveraging respected community members, such as teachers, traditional leaders, and local councillors, to facilitate these sessions can ensure that the messages are effectively communicated and well-received. This approach enhances trust and encourages participation within the community.

Behavioural change is more likely when individuals possess accurate knowledge about a problem and its consequences. A lack of understanding of how certain behaviours

contribute to negative outcomes can hinder efforts to change those behaviours (Ehret et al., 2019). Therefore, interventions should focus on not only raising awareness but also motivating water users and equipping them with practical skills to reduce water consumption effectively (Ehret et al., 2019).

Organisations ranging from government entities to non-profits and businesses play a pivotal role in addressing water issues by raising awareness and providing solutions to those most affected by water scarcity. In South Africa, the Water Research Commission is an example of such an organisation (Ehret et al., 2019). A participant in a study conducted by (Dlamini, 2018) emphasised the importance of educating school children to instil an appreciation for the value of water, which could ultimately lead to positive behavioural changes.

Schools serve as a vital platform for educating future generations about water conservation. Educational campaigns in schools can involve students in water-saving initiatives, debates, and competitions, empowering them to act as advocates for water conservation in their households. Collaborating with teachers to design engaging activities and involving parents in these campaigns ensures that the message reaches entire families. By engaging children in these discussions, the principles of water conservation can permeate households and foster broader community-wide behavioural change.

In regions experiencing extreme weather conditions, such as high summer temperatures and unpredictable rainfall patterns, public awareness campaigns should emphasise the importance of adapting water usage during peak demand periods. Such initiatives can include practical guidance on water conservation during dry seasons, such as minimising outdoor water usage, optimising irrigation practices, and promptly addressing leaks to prevent unnecessary water loss (Dlamini, 2018).

Seasonal variations in water demand highlight a notable increase in outdoor water usage during summer months, while indoor consumption remains relatively stable. Research by Beal et al. (2011) demonstrates that indoor water usage is largely unaffected by seasonal changes, whereas outdoor consumption is closely linked to environmental conditions, including temperature, rainfall, and humidity. This distinction emphasises

the need for targeted interventions to manage outdoor water demand effectively during periods of high consumption.

To minimise water usage in the uMhlathuze Local Municipality, targeted educational and awareness campaigns must be implemented to suit the specific needs of different communities. By focusing on both residential and commercial sectors, leveraging traditional leadership, and integrating water conservation into local schools and agricultural practices, the municipality can foster a culture of responsible water use. Furthermore, addressing climate impacts and infrastructure challenges will ensure that the municipality can meet the growing demands of its population while promoting sustainability.

5 CONCLUSION

This research project aimed to examine historical metering data for billed residential areas served by metered connections to identify trends in residential water consumption within the City of uMhlathuze Local Municipality between March 2016 to June 2021.

The literature review revealed that even though progress has been made in understanding water consumption patterns and promoting water-saving behaviours, there is still a need for more targeted interventions and effective policies to address the challenges of water scarcity and inefficient water usage in South Africa.

The research methodology adopted in this project aimed to produce trends for water usage within the City of uMhlathuze Local Municipality using the Change Point Analysis and Water Demand Models. The Change Point Analysis was employed to identify critical periods when water demand patterns shifted, highlighting the potential influence of external factors such as policy changes, seasonal variations, and broader socio-economic trends. These insights were then integrated into Water Demand Models, which were developed using multiple regression analysis techniques, including linear, log-log, and Semi-Log models. By combining these analytical approaches, the study aimed to establish a comprehensive understanding of the factors driving water consumption trends, enabling more accurate predictions and targeted interventions for sustainable water management.

Through the application of linear, log-log, and Semi-Log models, this study assessed the impacts of key variables, including the number of connections, household size, water pricing, temperature, and rainfall. The linear model revealed direct relationships but demonstrated limitations in accurately fitting the data. The Log-Log Model provided elasticity estimates but exhibited accuracy constraints, while the Semi-Log model, though imprecise, served as a useful comparative tool, highlighting the complexities of water demand prediction.

Estimates derived from historical data obtained from the City of uMhlathuze Local Municipality for the period between March 2016 to September 2020 show that the population of residential areas served by billed metered connections is approximately 166,170 which is 40% of the entire population of the municipality. The number of

residential households with metered connections in the City of uMhlathuze Local Municipality between March 2016 to September 2020 is 41,543, and the household size is 4. The analysis of this study is based on these estimates as they represent the population of residential areas served by billed metered connections which the study focused on.

The Change Point Analysis water usage trend in residential areas with billed metered connection of the City of uMhlathuze Local Municipality show that the reduced availability of water resources led to increased reliance on municipal water supplies, contributing to an increase in the average water consumption. The Change Point Analysis revealed that the water consumption for residential consumers with billed metered connection maintained the average consumption of 23,190 kl/d between March 2016 and September 2020. A reduction in the water consumption trend was observed between June 2018 and September 2018, followed by a rapid increase from September 2018 to June 2019. This trend suggests that residents quickly adjusted to restrictions imposed by the City of uMhlathuze Local Municipality during the drought resulting to a gradual return to previous consumption patterns, highlighting the need for sustained water conservation efforts and long-term demand management strategies.

The Water Demand Model analysis revealed that the Log-Log Model is the best model that represents the water usage trends of the City of uMhlathuze Local Municipality.

The Log-Log Model revealed that the number of connections had the P-Value of 0.01, suggesting that it significantly affects water demand relative to the other variables and changes in number of connections have a considerable impact on the water usage trends of the City of uMhlathuze Local Municipality. The R-squared value for the Log-Log Model was found to be 70%, indicating a relatively high “goodness-of-fit” between the observed data and the predicted values.

The assessment of water consumption in residential areas with billed metered connections indicates that, at present, excessive water use is not a major concern for the uMhlathuze Local Municipality. However, factors such as population growth, increasing household sizes, and the transition from standpipes to household connections are likely to increase demand in the future, presenting potential challenges for water supply

management. Additionally, inaccuracies in water metering could further complicate demand management. To mitigate these risks, proactive measures, including improved metering accuracy, demand management strategies, and sustainable water resource planning, are essential to ensure the long-term viability of the water supply system.

The analysis of water loss revealed that Non-Revenue Water (NRW) remains a significant issue, primarily due to aging infrastructure. Currently, about 27% (88 L/c/d) of the total System Input Volume (SIV) (327 L/c/d) is lost as NRW. This means the total Revenue Water (RW) for the system is 239 L/c/d. While this total RW figure is significantly higher than the residential average, it reflects the high total system efficiency in billing all sectors, including substantial consumption from the municipality's non-residential sectors (commercial, industrial, institutional, etc.), driven by the City's role as a major economic hub.

The City of uMhlathuze Local Municipality demonstrates the lowest NRW per capita and the highest Revenue Water per capita among the municipalities analysed. This high performance in revenue recovery indicates effective billing and metering practices across the whole municipal supply system.

To address the core research question on residential excessive consumption, the average consumption derived from historical metering data for billed residential areas is 143 litres per capita per day. This figure is categorised as Excellent per capita water use management (less than 150 L/c/d), confirming that excessive consumption is not an issue in this specific sector.

Therefore, the conclusion that the municipality exhibits low water demand must be explicitly refined to reflect low residential per capita water consumption. Attention should now be directed toward other water users (Commercial and Industrial) to identify areas of excessive use, since the residential sector performs efficiently.

Despite lower NRW levels compared to other regions, infrastructure challenges and unauthorised water use remain pressing concerns. Expanding the effective billing system to include unauthorized users could significantly reduce NRW and enhance revenue generation. To maintain water supply efficiency, uMhlathuze must prioritize

infrastructure upgrades, maintenance, and the inclusion of unauthorised users in the billing system.

To enhance water conservation and efficiency, the City of uMhlathuze Local Municipality should implement the following key recommendations:

- Identify and Integrate Unauthorised Users into the Billing System - The municipality's billing system has proven effective in managing water consumption among billed metered residential users. Therefore, a thorough assessment should be conducted to identify unauthorised water users and integrate them into the billing system. This would not only reduce non-revenue water (NRW) losses but also ensure equitable contributions to municipal water costs.
- Improve Infrastructure Maintenance and Leak Detection - Aging infrastructure remains a significant contributor to water losses. Regular inspections, timely repairs, and proactive maintenance of pipelines, reservoirs, and metering systems should be prioritised to prevent leakages and reduce NRW.
- Enhance Metering Accuracy and Monitoring - Installing advanced smart meters and conducting regular audits on water usage can help detect discrepancies and prevent water losses. Ensuring that meters are functioning correctly will improve billing accuracy and encourage responsible water consumption.
- Implement Public Awareness and Conservation Campaigns - Educating residents and businesses on sustainable water practices is essential. Awareness programs should emphasise the importance of reducing wastage, fixing leaks, and using water-efficient appliances to help maintain consumption within sustainable limits.
- Strengthen Water Demand Management Strategies - Implementing water-saving incentives, promoting the use of greywater systems, and enforcing water restrictions during drought conditions can help regulate water demand. Encouraging industries and businesses to adopt water-efficient practices will also contribute to overall water conservation efforts.
- Optimise Industrial and Commercial Water Use - As the analysis indicates high total Revenue Water (239 L/c/d) driven largely by non-residential consumption, the municipality should prioritize working with industrial and commercial users to

implement water recycling and efficiency programs. Encouraging the adoption of alternative water sources, such as rainwater harvesting, can help reduce reliance on municipal water supplies

- By implementing these measures, the City of uMhlathuze Local Municipality can significantly reduce water losses, improve revenue collection, and ensure the long-term sustainability of its water supply system.

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