Transitioning towards water-sensitive resilient cities in urban South Africa; a study of Gauteng, Johannesburg

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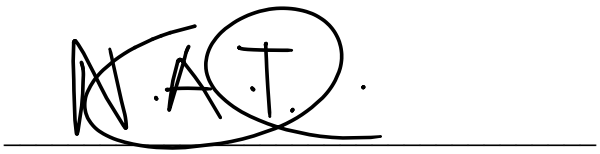
Candidate's declaration

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



(Signature of candidate)

15th day of November 2024 at Ladysmith.

Abstract

This dissertation examines water resilience in Johannesburg, focusing on the city's transition toward water-sensitive practices amidst social inequities in water access. As climate change and rapid urbanization intensify water scarcity, the research explores the significance of adaptive strategies and community engagement in promoting water resilience. A mixed-methods approach is employed, integrating qualitative interviews and quantitative data analysis to assess the challenges and opportunities within urban water management. The findings highlight the interconnectedness of social dynamics and environmental practices, revealing how inequity exacerbates vulnerability in water access. Ultimately, this study contributes to the understanding of sustainable urban water governance in South Africa and offers recommendations for enhancing water resilience through participatory and inclusive frameworks, aiming to inform policymakers and stakeholders in their efforts to build resilient urban environments.

By addressing immediate technical barriers alongside long-term social and governance transformations, Johannesburg can make meaningful strides toward becoming a water-sensitive, resilient city.

Dedications

Above all, I thank God for his grace and mercy that has sustained me through the challenging years, including the years of the COVID-19 pandemic; Thank you, God, for the gift of life, love, and light. Then I must thank my new supervisors for agreeing to supervise me at short notice and thank you for trusting me so that I can still finish and submit my dissertation and graduate. Thank you, Ms. Gillian, Prof Craig, and Prof Andrew for everything. I want to thank my daughter; Khuselo for being my light whenever I am on the verge of giving up; She kept my willpower going and getting this degree done. I would like to thank all the friends, family, and everyone who started or finished this MSc journey with me. Many thanks to Samke for really encouraging me to finish what I started. Thank you to my dad for texting me out of nowhere to just ask “When are you graduating, young lady?”. Thank you to Mom TK who always asked me, “Hey young lady, how far along are you with your schoolwork?” and for allowing me the ability to be honest with her and answer; not far at all. A special thanks to my younger sisters; Ntando, Linda, and Nadine for making me laugh evilly when asked when exactly I will graduate. A special thanks to all my Rhodes University friends for reminding me of what's important and always joking about my distractions; that made me want to push and move on from this milestone. A final special thank you to my partner for allowing me to rest, but in the end, we both knew what was important; and that was to do the work and finish. And to Simingazo I had to finish this one just so I can inspire you to do way more Ndabezitha. And to everyone else I couldn't name; thanks for the contribution.

TABLE OF CONTENTS

LIST OF FIGURES

List of tables

List of annexures

1. Introduction

Water is a universal solvent and the cornerstone of life on Earth, making its sustainable management crucial for both nature and people (Rogerson, 2018). South Africa, as a developing country, faces unique water management challenges exacerbated by rapid urbanization, climate change, and governance issues. The government must not only provide sufficient water to its growing population but also ensure access to other essential services, such as sanitation, food security, and energy supply (Carden et al., 2018). Water deficits in South Africa are often a result of physical scarcity, pollution of water resources, and poor water resource management, leading to failure in meeting both human and environmental needs (Brown & Wong, 2018).

Urban areas like Johannesburg are under significant pressure due to population growth and increasing demand for water. These cities face challenges related to physical water scarcity, climate change impacts, and governance failures (Bettini et al., 2015). The Day Zero crisis in Cape Town is a prime example of how poor management and drought conditions can lead to extreme water scarcity (Conradie, 2018).

In addressing these issues, there is a growing need to adopt water-sensitive urban design (WSUD) principles that promote water security, resilience, and sustainability. Cities like Johannesburg must transition toward becoming water-sensitive resilient cities, characterized by integrated approaches to water management, improved infrastructure, and community engagement (Fisher-Jeffes et al., 2012).

South Africa's urban water management is further challenged by social inequalities and political interference that affect decision-making and infrastructure investments. While the Lesotho Highlands Water Project provides some relief by transferring water to the Gauteng region, reliance

on external water sources is not sustainable in the long term (COJ, 2019). In addition, urban water systems in South Africa must account for the social dynamics that shape water use behavior, including community attitudes toward water conservation and perceptions of water availability (Anderson, 2016).

This study aims to explore the factors affecting Johannesburg's transition toward becoming a water-sensitive resilient city by examining current water management strategies, barriers to water security, and alternative solutions for improving the city's water system.

1.1. Research statement

Domestic water supply encompasses supply for use in homes, and institutions like schools, healthcare facilities, prisons, malls, etc., and at a household level, water is an important resource for daily usage, such as drinking, cooking, gardening, bathing, laundry, and general cleaning. Industrial water use encompasses usage for urban development, construction, business, tourism, mining, and agriculture. Therefore, the water supply must meet the water demand so that sustainable development can be achieved. Under normal circumstances, Rand Water's approved water allocation for Johannesburg is 1,493 megalitres/day, without considering a change in rainfall patterns and the spread of off-grid informal settlements (Rand Water, 2024). However, peaks of 1,710 megalitres/day are recorded in various weeks including July, September, and October, which is problematic; the city consumes more than the supply forecast (Rand Water, 2022). Excessive water use is making it difficult for water suppliers to meet growing demand, necessitating the introduction of Level 1 water restrictions. Figure 1 below shows the 10 water meters with the highest consumption in the City of Johannesburg. This shows that the highest consumption meters are located away from the community and in less affluent areas such as Alexander, Rosettenville,

and Ivory Park. Figure 1 also illustrates what the Level 1 restrictions entail and how long they will apply. In addition, options for saving water and thus reducing high usage are shown.

Figure 1: top 10 high-consuming meters, level 1 restrictions, and saving water tips. Source: www.johannesburgwater.co.za

Water in a developing country such as South Africa is important for economic growth. Johannesburg is South Africa's economic hub and water security affects economic growth and the quality of life hence the need for a transition that ensures water security. It is important to note that we are now in the 21st century which is characterized by climate variability which compromises a sufficient water supply from multiple sources (water security) leading to water-sensitive cities such as Johannesburg, and Gauteng (Tempelhoff, 2011). It is important when it comes to dealing with building resilience concerning water to first note that the achievement of the goal is dependent on the acknowledgment of the interconnectedness of the ecological, social, and economic systems as these are all parts of an integral system that influence water security which is embedded in the achievement of a water-sensitive city but in the past years, investments were focused on conventional ways (building more dams) of water management which have resulted in vulnerable cities (Wong & Brown, 2008). It is clear in Johannesburg that the vulnerability of the water system is influenced by more than just the challenge to meet the water demand but also by non-revenue for example pipe bursts and leaks that are unaccounted for.

Gauteng has been experiencing a shortage of water and as a result, the water storage facilities are being utilized more than they are being replenished leading to the compromise in water security hence the need for the current implementation of water restrictions. This state of affairs has resulted in the water demand not being met therefore the begging question arises; "how water-secure are we?". In a fast-developing province like Gauteng, other factors increase the vulnerability to water sensitivity; urban development to account for economic growth, the immigration of people due to job seeking or to tourism, the expansion of businesses and industries, limited funding allocation to the water department, weak institutional and policy framework combining into poor and ineffective systems of water resource management (Carden and Armitage, 2013). Although the

Lesotho highland water transfer project was initiated to try and manage water security due to delays in the implementation of the next phase Johannesburg now finds itself in trouble, the city is not able to meet the society's water demand and this is problematic.

To promote sustainable and innovative cities that focus on social, economic, and environmental transformation, it is important to move towards a water delivery system that can innovate and reorganize systems of water resource management (Fisher-Jeffes et al., 2017). This study, therefore, will aim to investigate how contemporary systems and processes of water resource management in South Africa can be modified or transformed to facilitate a transition towards sustainable and resilient water resource cities taking the City of Johannesburg as a case study.

1.2. Research Questions

In view of the above observations and arguments, the following questions will guide the research process:

I. How are the current management strategies, and identified institutions contributing to the achievement of water security in Johannesburg?
II. What barriers and constraints exist that can hinder efforts in achieving a water-secure city - a resilient City in Johannesburg?
III. What are the alternatives that can be explored to minimize the vulnerability (water sensitivity) of the City of Johannesburg?

1.3. Research Aim & Objectives

The study aims to investigate ways to aid urban South Africa with the transition towards water-sensitive resilient cities in efforts to try and achieve some state of a water-secure city; considering Johannesburg as the case study.

The objectives of the study in light of the abovementioned aim will be to:

i) Examine current employed approaches or strategies that could aid facilitate the transition towards a water-sensitive resilient Johannesburg (accountability, adaptation, maintenance)

ii) Investigate the barriers to achieving water security in Johannesburg (infrastructure (green infrastructure and grey infrastructure) vs. water availability)

iii) Identify alternative ways in which the efficiency of the current water supply system can be improved to try to meet the growing water demand in Johannesburg.

2. Literature Review

2.1. Introduction to Literature

As globalization increases, population densities have become more concentrated in urban areas and this is putting pressure on finite resources, this paradigm shift of proportions came about with the dawn of the 21st century (Wong & Brown, 2009). According to the United Nations estimate, the population of people residing in urban areas is set to rise from 55% to 68% by 2050 (Chee & Neo, 2018). By the year 2030, it is estimated that 5 billion people (about 70% of the Earth's population) will be living in urban areas (Kotze, 2019, p. 4). Metropolitan cities in emerging economies have become attractive to both expatriates and rural-to-urban migrants. South Africa is among the countries that are listed as emerging migration destinations with a growth of two migrants per 1,000 people (Carden et al., 2016; World Economic Forum, 2017, p. 18). Reasons for expatriation to emerging metropolitan cities can be linked to increasing one's marketability, and as for locals, it will be linked to efforts of trying to curb financial inequality, poverty, unemployment, and social exclusion. The democratic transition in the late 20th century has markedly contributed to migration into cities like Johannesburg in the year 2011 the city had a population of 4.4 million and has grown to a population of 4.8 million in the year 2022 (STATSSA, 2022).

This section covers the relevant literature; outlines the impacts of urbanization as well as identifies the drivers of water scarcity. The section also elaborates on possible solutions that are available to minimize water scarcity, especially in Johannesburg, South Africa.

2.2. Water Security

The United Nations' definition of water security highlights the sustained ability of a population to safeguard access to adequate quantities and acceptable quality water for sustaining socio-economic well-being without compromising environmental water requirements. The UN definition of water security has later been supported by Anderson (2016), Ray & Shaw (2016), and Valiyaveettil (2017), who focused on water security as the availability of a reliable source of water with the capability of providing the right quantity and quality of water. Water security bolsters sustainable resilient cities (Leigh & Lee, 2019; Werbeloff & Brown, 2011). Water-secure environments minimize the effects of poverty and inequality (Johnson, 2015; Vairavamoorthy et al., 2008). The need for water security is not limited to the immediate shortage of water but also includes projecting supply and future demand (Darrel Jenerette & Alstad, 2010). According to USAID (2011), as shown in Figure 2, the integration of resilience, a healthy ecosystem, a productive economy, and minimization of water-borne diseases builds robust water security.

Figure 2: conceptual model showing pillars of water security (USAID, 2011)

Water security accounts for several needs which include:

1. Ability to supply potable water, sanitation and manage wastewater handling (Dubbeling et al., 2009; Radcliffe, 2018; Sharma et al., 2016; USAID, 2011)
2. Ability to support economic, agricultural, and power-generating activities (Dubbeling et al., 2009; Valiyaveettil, 2017)
3. Prevention of water-related natural disasters i.e. flooding (Armitage et al., 2013; Radcliffe, 2018; Sharma et al., 2016)
4. Coming up with adaptive strategies that cater to natural disaster mitigation and corrective plans (Ray & Shaw, 2016; Wong & Brown, 2009)

Water insecurity is rampant in areas mostly affected by low rainfall and has limited freshwater sources. Poor governance and increased water demand exacerbate the problem of water insecurity in metropolitan areas like Johannesburg, and due to the presence of concrete or tarred surfaces, maintaining the underground water table is a challenge caused by limited water infiltrating the ground (Armitage et al., 2013; Carden et al., 2016). Furthermore, concrete surfaces absorb heat and increase the evaporation rate of water. The signs of physical water scarcity include environmental degradation and declining groundwater resources (Ray & Shaw, 2016).

The world will not be able to meet the developmental challenges of the 21st century – human development, liveable urban communities, environmental change, food security, and energy security, without improving how countries manage their water resources and the same can be said about Johannesburg (Dubbeling et al., 2009; Johnstone et al., 2012; Radcliffe, 2018). Population growth, unsustainable development, and pollution are pushing water resources in many parts of the world to their limits and accordingly influencing water insecurity (Berry, 2008). Climate change leads to fluctuations in weather patterns, and increases the frequency of floods and droughts. It is also associated with the rise in risk of water resource mismanagement and it increases water demand (Li et al., 2018; Sharma et al., 2016; Valiyaveettil, 2017).

2.3. Sustainable and Resilient Urban Water Systems

Water is an example of a provisioning ecosystem service which means that the availability of potable water has a direct effect on food security, economic growth, and the health of a society; water is a necessity (Grey et al., 2013). Although due to climate change, it has now become a challenge for authorities to meet the water demands, therefore the importance of the transition to a water-sensitive resilient system (Ferguson et al., 2013). With the above mentioned, it is therefore important to first define what is meant by resilience and sustainability in the context of a water-sensitive city. Sustainability describes efforts to alleviate environmental impacts and advance the quality of life (Daniel et al., 2015; Vernon & Tiwari, 2009) whereas resilience of a water system in the case of a water-sensitive city can be defined as the capacity to buffer change, learn and develop; resilient systems can innovate and provide ecosystem services without depletion (e.g. Brown et al., 2008). The water system has to be able to absorb a magnitude of shock and remain within a given stable state and not necessarily the original state as per the understanding that socio-ecological systems are complex and evolving (Janse van Rensburg et al., 2016).

It is important to also note that a resilient water system is associated with the diversity of species, human opportunity, and economic options that encourage and maintain both adaptation and learning despite the interconnected systematic problems which include rapid population growth, industrialization, climate change and pollution (Wong & Brown, 2008). In the context of this study, to define a city as resilient, the city is expected to at least meet the water demands of its people including water for industry and water for domestic use, achieving the water secure status.

To alleviate the pressures of insecurity, there must be efforts to slowly transform Johannesburg into a water-sensitive resilient city. Water fluxes have been greatly reduced by the replacement and maintenance of the pipe network (COJ, 2019). Stormwater storage has been listed as one of

the methods cities can sustain resilience (Armitage et al., 2013; Kuller et al., 2017; Radcliffe, 2018). In response to the concept of water-resilient cities, Radcliffe (2018) mentions the concept of sponge cities. Sponge cities involve keeping rainwater within the city and ensuring evaporation takes place slowly, and as a result, cooling the city. Sponge cities harness and harvest rainwater as well as manage heat (Armitage et al., 2013; Kuller et al., 2017). Figure 3 below is a conceptual model showing the goals that sponge cities aim to achieve.

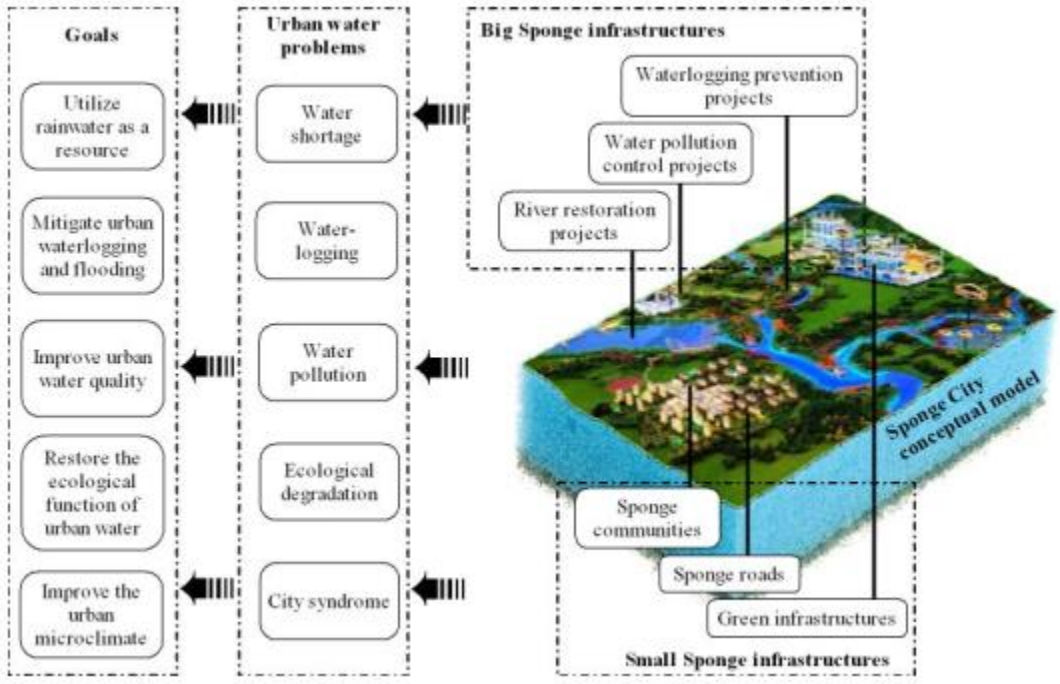


Figure 3: Diagram showing the goals and conceptual model of Sponge City (Li et al., 2018)

Suggestions by Li et al. (2018) allude sponge cities seek to mitigate; (1) water pollution, (2) ecological degradation, (3) city syndrome, (4) water shortage, and (5) water shortage. The Johannesburg Roads Agency (JRA) has the responsibility of planning and designing roads and stormwater infrastructure (COJ, 2019, p. 122). To date, stormwater run-off has been utilized by the City of Johannesburg for the management of rainwater (COJ, 2019). Minimal effort has been put in place to regulate city temperatures.

Sustainable water management is key to ensuring stability and water security (Kuller et al., 2017; Radcliffe, 2018; Wong & Brown, 2009). Though there is progress in implementing sustainability in Johannesburg, more needs to be done to completely mitigate issues of achieving water security (COJ, 2019). The challenge of water shortages arises from poor water governance (Anderson, 2016; Kuller et al., 2017; Vairavamoorthy et al., 2008). Good governance, transparent policies, and leadership involvement are essential in creating sustainability and resilience (Anderson, 2016). Furthermore, development strategies play a pivotal role in ensuring resilience (USAID, 2011). Without guiding principles and policies, resilience remains mystified.

Legacy forms of water management involve building water infrastructure that supplies more water and prevents natural disasters i.e. building dams and embankments (USAID, 2011). These approaches are not enough to be considered resilient measures. More needs to be done and thought out to mitigate situations like embankment failure and drought.

Water scarcity is an emerging challenge that is assumed to continue as population growth increases (Werbeloff & Brown, 2011). Water-sensitive designs and sustainable water management are key to ensuring consistent water supplies. When it comes to water scarcity, the problem is exacerbated by the lack of realization that water is a finite resource (LeRoy, 1995; Prathapar, 2000). The business side of society is starting to realize they have a role to play in promoting sustainability. Stakeholders need to figure out how to minimize the conversion of green water and blue water to grey water (Valiyaveettil, 2017). Green water is water that is present from rainfall, blue water is water that is available in oceans, aquifers, and reservoirs, and grey water is polluted water acquired from processes (Valiyaveettil, 2017). Water patterns are dependent on space and time – the geographical conditions in the surroundings influence water management (Mukherjee et al., 2010)

Water-sensitive design describes the appearance of an area and the creation of a conducive environment (Vernon & Tiwari, 2009). Water-sensitive design techniques include swales, living streams, compensation basins, stream rehabilitation, and natural and constructed wetlands, being used for drainage, and stormwater runoff treatment (Vernon & Tiwari, 2009).

Achieving complete water resilience is challenging (USAID, 2011). In a publication by USAID, a Water Security Improvement (WSI) process was developed, outlining steps in which water security can be achieved, attained, managed, and improved.

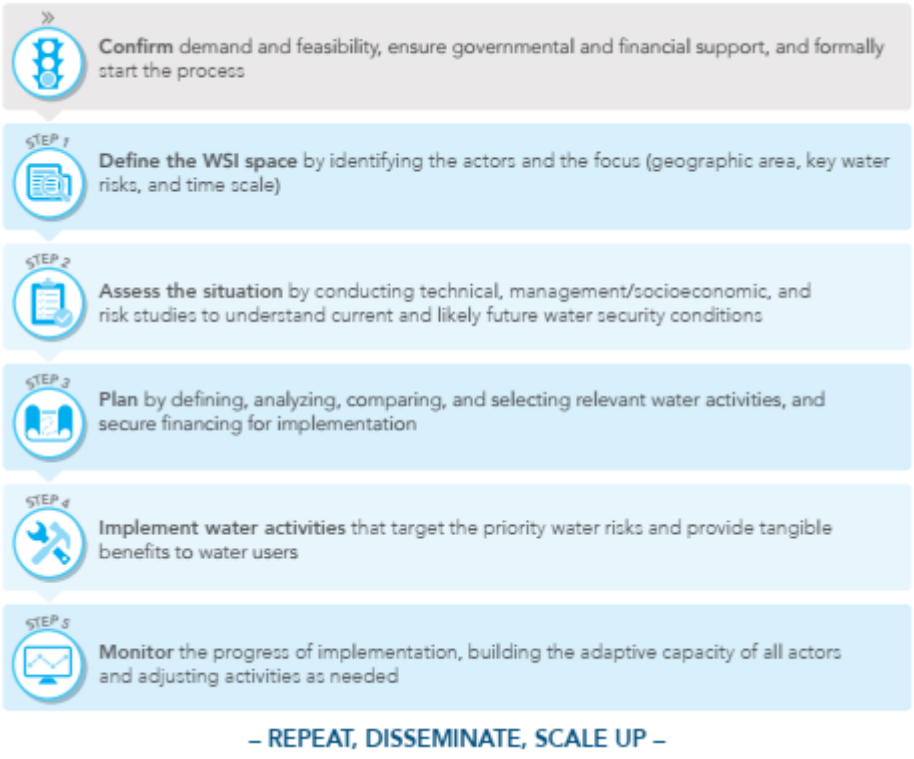


Figure 4: WSI process for achieving water security (USAID, 2011)

From the above-stated steps (figure 4), it is apparent that the deployment and implementation of the process require a substantial amount of knowledge management. This involves acquiring supporting data from each step to build onto the next step, as well as dissemination and communication of acquired knowledge.

2.4. The history of the water-sensitive resilient city

In reference to the diagram in Figure 5; the urban water management transition diagram was formulated for Australian cities to address their failing water infrastructure which was prevalent after they had to respond to the emergency of being hit by a drought and severe flooding within a small period. The drought resulted in mortality rate spikes and food price hikes therefore putting pressure on the governing institutions to find a way that will make them less vulnerable and more prepared for the future hence the realization of a transition (Wong & Brown 2008). The main drivers of change in water management that are highlighted in the case of Australian cities are service delivery and socio-political factors (Figure 5).

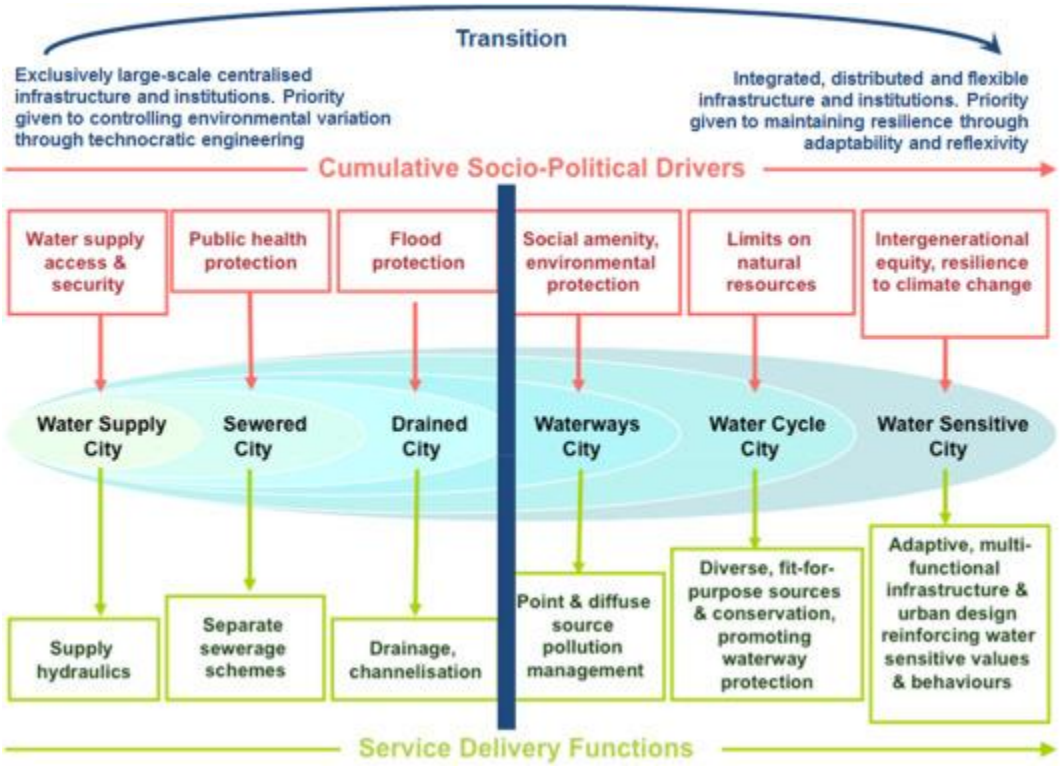


Figure 5: Diagram showing urban water management and the transition framework (*De Haan et al., (2016)).*

Figure 5 illustrates the past strategies represented on the left which include water supply, sewerage, and drainage services once provided flood protection, water access, and security as well as public health protection governed by centralized infrastructure and institutions (Figure 5). The governance ensured the supply of hydraulics, separate sewerage schemes, and drainage channelization (Figure 5). However, the introduction of innovation and development through industrialization resulted in rapid population growth, outdated infrastructure, economic pressures as well as climatic changes which gave rise to the need for a transition due to the vulnerability caused to the cities (Figure 5). This transition emphasizes social and environmental protection in the form of waterways which will result in better pollution management (figure 5). What is clearly illustrated is that natural resources such as water can be depleted if not sustainably utilized hence the importance of having multiple water sources including rainwater harvesting and waterway protection (Figure 5). In contrast to what is illustrated in Figure 5 is the case of contemporary societies particularly those in Sub-Saharan Africa they tend to undermine resilience because of a lack of ecological functionality therefore the implementation of the concept of water-sensitive resilient cities is overlooked until a state of a water crisis is reached. A recent case of reactive behavior to the importance of the consideration of transitioning towards water-sensitive resilient cities is the case of the day zero crisis in Cape Town, South Africa (Dobbie et al., 2016). An important adaptation strategy to ensure an intergenerational equity supply of water is adopting the concept of resilience and applying it to water-sensitive cities to deal with changes to the water cycle that have resulted from climate change and other pressures (Figure 5). In the case of Johannesburg, it is also said that the city's water sensitivity is a result of mainly changes in weather patterns and rapid population growth that has exerted pressure on outdated infrastructure and

institutional compartmentalization in terms of accountability towards service provision, operation, and maintenance (Folke et al., 2002).

The City of Johannesburg is the oldest modern urban settlement in the Republic of South Africa, with a population of about 15.1 million in the province, the City of Johannesburg has a very dense population city for its size (STATS SA, 2022). Geographically, the City of Johannesburg lies between the Vaal and Limpopo River catchments. Water supplies in Johannesburg are provided by an entity of the City of Johannesburg running under the trade name Johannesburg Water (JW) SOC Ltd (COJ, 2019). The majority of water supply to the City of Johannesburg is sourced from the Gariep basin that is fed by the Lesotho highlands inter-transfer system (COJ, 2019). One of the ways the City of Johannesburg delivers its corporate social responsibility is by ensuring households have access to water. In their efforts to curb poverty and inequality, more than 87.03% of informal settlements now have access to water (COJ, 2019). However, like most cities, Johannesburg has outgrown its ability to provide a sustainable water supply (Gwebu, 2002). Moreover, achieving sustainable water supply in South Africa is deterred by having a significant number of the population without access to water (Radcliffe, 2018). This phenomenon became apparent amid the 2018 Cape Town water crisis (Armitage et al., 2013; Beane et al., 2019; Conward Consulting & City of Cape Town, 2007).

The City is the largest consumer of the Integrated Vaal River System (IVRS) (COJ, 2019). Despite being the largest consumer of one of the largest dams in South Africa, the city remains vulnerable to water shortages considering it is a city that is built dependent on supplies from other catchment areas. The Vaal Dam was built as a result of the gold rush that occurred. Over time, the City of Johannesburg in conjunction with Rand Water has had to implement measures that sustain the community. Measures implemented included tunneling water through the Drakensberg mountains

and importing water into South Africa from Lesotho through the Tugela-Vaal Scheme (1974) and the Lesotho Highlands Water Project (1997), respectively (WRC, 2005).

In 2019, there was an evident overall decline in water levels at the Integrated Vaal River system and this was emphasized by the (DWS) as a warning to all users to use water sparingly and sustainably (DWS, 2019). Decreasing water levels across the dams meant deterred efforts by the City of Johannesburg in the achievement of water security as an operational capability that will ensure sustainability (COJ, 2019). Therefore, measures of sustainability and resilience become more important to try and close the widening gap between supply and demand. Due to erratic rainfall patterns and rapid population growth achieving sustainability has been difficult to achieve (Gwebu, 2002). Furthermore, continuous investment in conventional approaches to achieving sustainability has slowed down the deployment and execution of sustainable strategies (Wong & Brown, 2009). Both natural disasters and human-induced causes of water scarcity have made town planning a difficult task (Gwebu, 2002).

To date, the City of Johannesburg is in the process of developing the Climate Action Plan (CAP) (COJ, 2019). The CAP seeks to have an emission-neutral, climate-resilient city by 2050 (COJ, 2019, p. 265). This action plan was purposefully introduced to mitigate flash flooding and erratic rain patterns like those experienced in the 2010/2011 rainy season (Ngie, 2012). The expected time of implementation of the strategic plan is after the closure of the 2020 financial year (COJ, 2019).

2.5. Water Security in Urban South Africa

Ensuring sustainable urbanization is an emerging global imperative that cities, including those in South Africa, will increasingly face. With the global urban population projected to increase by an additional 2.5 billion people by 2050, South African cities, like Johannesburg, are grappling with

rapid urbanization and the challenge of equitable water access (Mguni et al., 2022; Patrick, 2021). Johannesburg exemplifies the duality of wealth and poverty, with urban development shaped by apartheid-era planning and an economy marked by inequality. As climate change intensifies, Johannesburg's water vulnerability could lead to increased risks for infrastructure, communities, and natural ecosystems. Nature-based solutions (NbS), particularly those focused on urban wetlands, offer an adaptable approach to enhance resilience, aligning Johannesburg with the global shift toward water-sensitive urban design (WSUD) (Mguni et al., 2022).

Water-Sensitive Urban Design (WSUD) and Resilience

Water-sensitive urban design has emerged as a critical approach to mitigate urban water challenges, especially in cities facing scarcity and environmental stressors. WSUD principles encourage integrated planning of green and grey infrastructure and advocate for restoring natural water cycles through NbS, such as wetlands and rainwater capture systems (Carden & Fell, 2021; Hasselaar et al., 2021). As Carden and Fell (2021) note, water-sensitive cities prioritize long-term sustainability over traditional urban development methods, which often lack resilience to climate extremes.

However, South Africa's limited investment in infrastructure and inadequate water systems complicate the transition toward WSUD. Current systems are unsuited to cope with the urban configuration of Johannesburg and other South African cities, leading to growing demands on overstressed water supply networks (Rogers et al., 2020). The National Water Resource Strategy (DWS, 2020) underscores the need for cities like Johannesburg to adopt WSUD and nature-based solutions as integral to sustainable urban planning and climate adaptation.

Social and Behavioral Dimensions in Water Security

A significant aspect of water security is the impact of social and behavioral factors on water conservation and equitable distribution. Research indicates that effective management strategies in water-sensitive cities rely on shifting social attitudes toward water as a finite resource (Greeff & Lawrence, 2019). In Johannesburg, unequal access to water perpetuates disparities across socio-economic groups, with wealthier areas often consuming disproportionately higher volumes of water compared to underserved communities (Satterthwaite et al., 2020).

Studies by Mphambukeli and Tsoeu (2018) and Hellberg (2018) further emphasize the need for public education on water scarcity and conservation practices, as well as regulatory measures that encourage sustainable water use. Community-level engagement and behavior change play essential roles in achieving sustainable water practices in urban areas. However, there is limited evidence of policy-driven behavior change programs in Johannesburg, highlighting a gap in both government initiatives and public awareness.

Equity and Governance in Water Access

Equitable water access remains a cornerstone of water-sensitive resilience. South African policies, including the National Water Act (1998), emphasize equitable distribution of water resources to correct historical imbalances. Despite these policies, urban areas like Johannesburg continue to experience significant disparities in water access, largely due to infrastructural limitations and governance challenges (Carden et al., 2018). Poor governance often exacerbates these inequalities, as municipal resources fail to meet the needs of a rapidly growing population.

Equity in water access requires a regulatory overhaul to support sustainable transformation, particularly in densely populated urban areas where demand outstrips supply (DWS, 2020). Patrick (2021) suggests that transitioning Johannesburg into a resilient city requires a collaborative

approach among all stakeholders, including municipal authorities, infrastructure providers, and communities.

Barriers to Water Security in Johannesburg

In Johannesburg, barriers to achieving water security include aging infrastructure, underfunded green and grey infrastructure, and inconsistent governance. As identified in the research, Johannesburg's water infrastructure is outdated and unable to meet current demands (Conradie, 2018). This inadequacy is compounded by inefficient water systems and the city's reliance on external water supplies, such as the Lesotho Highlands Water Project (COJ, 2019).

Additional barriers stem from urbanization pressures, poor infrastructure maintenance, and governance silos that fragment efforts to address water scarcity (Warner & Jones, 2013). Implementing WSUD requires both structural and policy adjustments, as well as financial investment to sustain resilient water systems (Rogers et al., 2020).

Strategies for Water Efficiency and Resilience

To improve the efficiency of Johannesburg's water supply, alternative water sources and enhanced infrastructure are crucial. Solutions such as rainwater harvesting, greywater reuse, and stormwater management have proven effective in other water-stressed regions and could offer similar benefits for Johannesburg (Mekonnen & Hoekstra, 2016). These approaches align with global WSUD principles and the vision of South Africa's National Water Resource Strategy to foster a resilient and sustainable urban water system (DWS, 2020).

In the context of climate change, nature-based solutions such as urban wetland restoration present a low-cost alternative for improving resilience and reducing reliance on external water resources.

Such Nature-based approaches contribute to Johannesburg's aim of achieving water sensitivity by maintaining ecological balance, supporting biodiversity, and providing recreational green spaces (Mguni et al., 2022; Rogers et al., 2020).

Conclusion

The literature underscores the importance of integrating WSUD and Nature-based solutions into urban planning to promote water security in Johannesburg. Achieving this requires addressing social inequalities, prioritizing infrastructure investment, and developing a comprehensive governance framework. By embedding these principles into Johannesburg's water management strategies, the city can advance toward becoming a truly water-sensitive, resilient city, setting a precedent for sustainable urban water management in South Africa.

3. Methodological considerations

3.1. Research philosophy

Methods can be defined as a systematic process of conducting research and this process allows for the replication of the method of study by other scholars should a need arise (Dawson, 2013). The epistemological standpoint employed in this research is that of empiricism. This means that all the knowledge construction that informed this research study is based on the knowledge and experience of the research participants (Leedy & Ormrod, 2005).

The methodological approach that was used for this study is that of applied research as this approach entails the solving of real-world problems focusing on facts this approach was more suited as water scarcity is a real-life problem that needs to be addressed as it affects the livelihoods

of people, the researcher consulted multiple stakeholders while conducting the research to try to minimize getting biased responses and get a holistic view into water security (Dawson, 2013).

3.2. Description of research site

Johannesburg is located in an area that doesn't have a water surplus but the water sources statistics show no diversified sources instead the majority of the population is dependent on water that is supplied by the municipality, hence the need for this research as it encourages the exploration of alternative sources to ensure sustainable water use measures and water availability for the future. About 77.1% of the total households in Johannesburg have access to piped water within their homes (STATSSA, 2022). Concerning water service delivery, 1.7% of the population of the City of Johannesburg has no access to piped water (STATSSA, 2022).

Climate influences water availability and Johannesburg has a subtropical highland climate, the city is characterized by hot, wet summers and dry, cold but sunny winters, the city is situated on the Highveld plateau resulting in its place-specific weather patterns due to the high elevation (STATSSA, 2022). It receives an average of 713 mm of rainfall annually from October to April (STATSSA, 2022). For the period 2015-2017, Johannesburg was experiencing a shortage of water following drought intensification in 2016 due to a change in rainfall patterns. Despite the rise in the dam level of the Vaal residents were still urged to use water sparingly as water continues to be a scarce resource. Rand Water implemented level 1 restrictions for September 2023 to the end of March 2024 for Johannesburg as an effort to ensure sustainable use and availability of water.

Johannesburg is the capital city of Gauteng province, it is therefore regarded as the economic hub and consumes a lot of water (STATSSA, 2022). It has a surface area of 1 645 km² and is the largest city in South Africa with a population of 4,803,262 (STATSSA, 2022). According to statistics

from the year 2011 to 2022 Johannesburg has had a growth rate of 0.8% (STATSSA, 2022) due to this increased population water demand also increases putting pressure on the already strained water resource.

The above-mentioned is important to note because these economic activities need water and currently the demand for water in the city is exceeding the supply, therefore one can argue that Johannesburg's initial purpose was not for residential purposes but economic purposes but due to development people have now flooded to the city to dwell therefore putting pressure on the water system which majority of it was initially for economic use. Therefore, the importance of this study is to facilitate the transition to a water-resilient city.

3.3. Research design

This study utilized a qualitative research approach to gain an in-depth understanding of the complexities involved in transitioning Johannesburg towards a water-sensitive resilient city. Qualitative research is particularly suited for exploring the social, environmental, and governance factors that impact water security and resilience in urban areas (Mguni et al. 2022).

The research adopted a case study approach, focusing on Johannesburg as the selected urban center due to its significance as a major city in South Africa with pertinent water-related challenges. Johannesburg's dependency on external water sources, rapid urbanization, and climate vulnerability make it an ideal case to examine the transition towards water-sensitive design and resilience. The case study approach allows for an in-depth exploration of the institutional structures, policy environments, and social behaviors that impact water-sensitive design.

3.3.1. Study population and sampling procedures

The research gathered is from attending the 4th Water Research Commission Symposium, attending the 1st Gauteng Environment Research Symposium hosted by GDARD, and interviewing seven research participants. Secondary sources were consulted during the study and they included; articles published in accredited journals, conference papers, newspaper articles and academic books, and official documents from the Department of Water and Sanitation (DWS) as well as Johannesburg Water; these documents include the national water and sanitation master plan as well as the water security framework.

The study used purposive sampling to target participants with expertise in water management, urban planning, and environmental governance. As Mguni et al. (2022) highlight, engaging with a range of stakeholders is crucial for understanding the broader implications of WSUD and identifying the enablers and barriers to adopting nature-based solutions in urban settings.
A total of seven research participants were interviewed, with snowball sampling used to identify additional experts, ensuring that the study captured a diverse set of perspectives. This aligns with Mguni et al.'s (2022) emphasis on the importance of multi-stakeholder engagement in developing resilient water management strategies.

Semi-structured interviews were conducted, the targeted research participants were Johannesburg Water, Rand Water, the Department of Water and Sanitation (DWS), the Environment and Infrastructure Services Department (EISD), Gauteng Department of Agriculture and Rural Development (GDARD), Johannesburg Roads Agency (JRA), the Water Research Commission (WRC). The snowballing technique was also used during each interview to identify other key stakeholders to be interviewed for the study (Bryman, 2016).

In terms of the budget; transport costs were considered for the researcher to be able to commute from one area of Johannesburg to another while conducting the semi-structured interviews at different departments, as well as travelling costs to attend any relevant symposiums to collect data relevant to the study.

Data collection tools

The primary data collection method consisted of semi-structured interviews with key stakeholders. This approach allowed for flexibility in questioning while ensuring that the main themes related to water security, governance, and infrastructure challenges were covered.

The document analysis method was also employed to review relevant policy papers, urban plans, and academic literature. Documents from institutions such as the Department of Water and Sanitation (DWS), Johannesburg Water, and Rand Water were analyzed to understand the existing water management strategies and challenges.

The researcher also needed printed interview scripts or guides, notebook and writing material as well as a voice recorder and a camera phone. For privacy, confidential data is stored in a locked laptop.

3.3.2. Data analysis

Using the results obtained from the study, data was grouped accordingly and represented using a table in the results section of the dissertation. The study utilized thematic analysis, consistent with the methodology outlined by Mguni et al. (2022), to identify recurring themes related to water-sensitive urban design. Predefined themes were based on core research questions, such as governance, social behavior, and infrastructure, while emergent themes arose from the data itself,

including the role of community-driven initiatives and political challenges in implementing nature-based solutions.

Predefined themes: These included water security, governance, infrastructure, and community participation.

Emergent themes: Key emergent themes included stakeholder accountability, the integration of nature-based solutions, and adaptive governance.

Additionally, a constant comparative analysis was applied, which allowed for continuous comparison within and across interviews to discern patterns and contrasts in perspectives. This approach helped refine the understanding of institutional barriers and opportunities for enhancing resilience through WSUD (Brown & Wong, 2009).

By the end of the study, the researcher aims to have fulfilled all the objectives of the study as set out in Chapter 2 above and have gathered insight on what could possibly be done to aid urban South Africa to transition towards water-sensitive resilient cities and mitigate the vulnerability.

3.4. Ethical considerations

i) Ethical clearance was applied for from the University of the Witwatersrand; Johannesburg Human Research Ethics Committee (Non- medical) and the application number was: R14/49 Shoba on 23/08/2018. The application was considered by the ethics committee on 14/09/2018 and it was signed and approved on 02/11/2018 by the chairperson and the study only commenced after the approval was received. The protocol number is H18/09/28. The ethical clearance certificate is attached to this dissertation as Annexure 1.

ii) In the study, it was ensured that all participants were of legal age (18 years and older)

iii) All participants were told of their rights before participation

iv) Informed consent was obtained from all participants, ensuring voluntary participation of all participants

v) All participants were told that they were allowed to withdraw from the study at any point

vi) All the literature engaged with to aid with the study was acknowledged

vii) Should participants wish for their identity to be kept anonymous their anonymity was ensured.

viii) The research was carried out in the form of structured interviews targeting water affairs authorities and academic figures or researchers and this might lead to some participants not being entirely transparent when answering some of the questions due to the urge to protect their jobs integrity arising from trust issues of who will have access to the research report.

ix) Also limiting the interviewing to authorities and experts in the field only may introduce bias.

x) Since the study is aimed at investigating ways in which urban South Africa can transition towards water-sensitive resilient cities limitations might include reluctant participation from the people due to different previous experiences with previous researchers, and since it's a people based study the participants might not be entirely truthful in their responses.

xi) The chosen topic has socio-political implications hence resistance to participation also withholding of some facts is prevalent in some instances where some decisions are more influenced by who is currently in political power.

xii) The study was carried out with scientific integrity (for example; data was correctly recorded, and respect for other disciplines was practiced at all times.

xiii) The researcher adhered to ethical guidelines, respecting cultural sensitivities and avoiding harm to participants

4. Results

In this section, the results are presented in line with the research questions as stated earlier on in this report. This section presents the findings aligned with the research questions, showcasing the current approaches, barriers, and opportunities surrounding the transition to a water-sensitive, resilient Johannesburg. The results provide an overview of key themes drawn from participant responses, ranging from current water security practices to challenges in governance and

infrastructure. The significance of these results, particularly their implications for policy and planning, will be examined in the discussion section.

Current Approaches and Strategies

Table 1 provides a summary of the current approaches and strategies employed by various departments to support Johannesburg's transition towards water resilience. These strategies include large-scale initiatives such as the Lesotho Highlands Water Project, alongside community-based efforts like workshops and campaigns aimed at reducing water usage. Across departments, there is a shared emphasis on the necessity of reducing water usage to manage the city's increasing water demand.

Table 1: Current approaches and strategies used by different water institutions in Johannesburg in the efforts to achieve water resilience

Different water actors	**Institutional Responsibilities**	**Efforts**
Department of Water and Sanitation (DWS).	**Primary Legislation:** The National Water Act (NWA) of 1998 and the Water Services Act of 1997. **Responsibilities**: • **Regulation and Oversight**: Ensures sustainable and equitable water resource management across South Africa. • **Licensing and Compliance**: Issues water use licenses, monitors compliance, and	Developed the National Water and Sanitation Master Plan, and is simultaneously striving to lower non-revenue to 15% by 2030. Lesotho Highlands initiative is underway, although it is facing delays in execution. **Water Security Planning**: Developed policies and frameworks like the National Water Resource Strategy to address water security, scarcity, and allocation.

	enforces regulations related to water use and water pollution. • **Infrastructure Development**: Manages large-scale water infrastructure projects, such as dams and inter-basin transfers, and works to improve national water infrastructure.	
Water Research Commission. (WRC)	**Primary Legislation**: Water Research Act (No. 34 of 1971). **Responsibilities**: • **Research and Development**: Funds and facilitates research	"Water Resilient Cities," a publication within the World Resources Institute's global series, examines urban transitions toward water resilience.

	on water management, water quality, and innovative solutions for water challenges. • **Capacity Building**: Develop tools, guidelines, and educational programmes to build expertise in water resource management and promote sustainable water use.	**Knowledge Dissemination**: Disseminate findings from funded research to policymakers, water sector professionals, and the public
Johannesburg Roads Agency (JRA)	**Primary Legislation**: Municipal Systems Act, Municipal Structures Act, and City by-laws. **Responsibilities**:	The City of Johannesburg formalised its approach to stormwater management through the publication of a dedicated manual.

	• **Stormwater Management**: Designs, constructs, and maintains stormwater drainage systems to manage runoff and prevent flooding. • **Road Infrastructure**: Manages road infrastructure within Johannesburg, including planning, construction, and maintenance. • **Disaster Mitigation**: Implements measures to reduce flood risks, particularly by maintaining and enhancing stormwater	

	systems as part of citywide disaster preparedness	
Johannesburg Water: City of Johannesburg (JW- CoJ)	**Primary Legislation**: Water Services Act (No. 108 of 1997) and City by-laws. **Responsibilities**: • **Water Supply and Distribution**: Manages water supply and distribution for Johannesburg, sourcing bulk water from Rand Water and ensuring it reaches communities. • **Sanitation Services**: Provides sanitation services,	Stormwater bylaws were formulated to align with the idea that storm water can be better utilised instead of being thrown away imposes varying degrees of water restrictions based on water availability and demand as required.

	including wastewater treatment and sewer system management, to promote public health and environmental protection.	
Environment & Infrastructure Services Department (EISD)	**Primary Legislation**: National Environmental Management Act (NEMA), Municipal Systems Act, and relevant City by-laws. **Responsibilities**: • **Environmental Management**: Oversees environmental policies and practices within Johannesburg, including	Efforts are underway to develop the National Water Security Framework and to implement the Climate Change Strategic Framework, both of which are pivotal in addressing pressing environmental challenges. Furthermore, the City of Johannesburg is actively working on executing its Climate Action Plan, which aims to mitigate climate impacts and enhance resilience within the city.

	waste management, pollution control, and green infrastructure development. • **Infrastructure Coordination**: Coordinates infrastructure planning related to environmental services, including water and energy management. • **Climate Action and Resilience**: Develop and implement the city's climate action plans to enhance resilience against climate	

	risks, such as droughts and floods.	
Gauteng Provincial Government (GPG) (office of the premier)	**Primary Legislation**: Provincial Government Administration and Constitution of South Africa. **Responsibilities**: • **Provincial Coordination**: Oversees coordination of provincial departments to ensure effective service delivery, including water and environmental services. • **Policy Implementation**: Ensures that provincial policies align with national	The Gauteng City-Region Observatory has been commissioned to develop a comprehensive Gauteng Water Security Framework, aimed at ensuring sustainable water management across the region. The Gauteng Provincial Government also promotes the integration of retrofitting and retention facilities in new developments, encouraging designs that support water conservation and resilience to water scarcity.

	mandates and address local needs in areas like water security, environmental sustainability, and disaster preparedness. • **Intergovernmental Relations**: Fosters collaboration between the provincial government, municipalities, and national bodies to enhance regional resource management and infrastructure development.	

Rand Water (RW)	**Primary Legislation**: Water Services Act (No. 108 of 1997). **Responsibilities**: • **Bulk Water Supply**: Supplies bulk potable water to municipalities and water utilities across Gauteng, including Johannesburg Water. • **Infrastructure Maintenance**: Maintains water pipelines, treatment facilities, and reservoirs to ensure a consistent water supply.	Rand Water promotes its environmental initiative, "Water Wise," aimed at fostering water conservation by educating the public through workshops, roadshows, and various outreach activities across different regions. This programme supports efforts to reduce municipal bulk water demand by 8%, ensuring compliance with licensed water supply agreements. Moreover, Rand Water's community-based projects department undertakes responsibilities such as leak repair initiatives, sustainable water use workshops, and awareness campaigns to further promote efficient water usage and conservation within communities.

	• **Water Conservation**: Runs educational programs, like the "Water Wise" initiative, promoting efficient water use and conservation across the communities it serves.	
Gauteng Department of Agriculture and Rural Development (GDARD)	**Primary Legislation**: National Environmental Management Act (NEMA), the Conservation of Agricultural Resources Act (CARA), and the Water Act. **Responsibilities**: • **Environmental Conservation**: Regulates and promotes sustainable use of	An important initiative is the annual Gauteng Environment Research Symposium, launched in 2019, which addresses critical topics, including strategies to enhance water security in the region. Among the recommendations emerging from these discussions is the promotion of rainwater harvesting at the household level. This practice aims to diversify water sources, particularly for non-potable uses, thereby reducing pressure on the primary water supply system.

	natural resources, focusing on water conservation, land use, and biodiversity. • **Rural Water and Food Security**: Ensures access to safe water for agricultural and rural development, supporting food security and sustainable farming practices. • **Environmental Research and Education**: Conducts research and educational outreach to promote sustainable environmental	

	practices within rural and agricultural sectors.	

Source: Field data collected by researcher

The themes below highlight some of the barriers and constraints faced by the different water sectors when it comes to the planning and the implementation of new ideas that encourage the transition to a water- sensitive resilient city. The prominent issues were that of funding, rapid population growth that cannot be accounted for and the outdated infrastructure as well as the lack of maintenance to ageing infrastructure. When doing research, it is always important to reflect on what has already been done in the field of study and make a decision on what is more likely to be the solution to the problem presented at hand (Mguni et al., 2022).

Emerging themes

Current Water Security Status

Participants noted the pressing issue of non-revenue water, with 41% of supplied water lost due to factors such as theft and leaks. A representative from the Department of Water and Sanitation (DWS) highlighted the need for a "mind set change regarding water usage efficiency" to improve water security. This aligns with the growing literature on urban water management, which emphasizes behavioural shifts as critical to sustainable water use (Mguni et al., 2022).

Stakeholder Accountability

Responses emphasized the need for accountability among stakeholders, with representatives from GDARD highlighting the importance of professional capacity and participatory approaches. However, they noted that political resistance often obstructs these efforts. These findings echo the challenges identified by Mguni et al. (2022), who suggest that participatory governance can be undermined by political barriers, thus hindering effective water management.

Priority in Budget Allocation

Participants expressed concerns over the lack of adequate budget prioritization for water security initiatives, with political interference affecting funding and the implementation of essential projects. Similar issues have been noted in the South African literature, where studies reveal the tension between political agendas and the need for sustained financial commitment to water security (Muller, 2021).

Barriers to Achieving Water Security

Key barriers cited include climate change, non-revenue water, political interference, and outdated infrastructure. Respondents also highlighted a maintenance backlog, a lack of stakeholder collaboration, and disparities in water access. These barriers are compounded by socioeconomic factors, such as population growth, economic demands, and the lingering effects of apartheid on infrastructure maintenance (Swilling & Annecke, 2021).

Alternative Water Sources

To supplement Johannesburg's water supply, participants suggested options like rainwater harvesting, storm water capture, grey water reuse, and acid mine drainage for non-potable use. These approaches, advocated by Rand Water, are in line with broader initiatives in South Africa to diversify water sources (Rand Water, 2020).

Policy and Planning

Respondents emphasized the need for comprehensive water management strategies, inclusive of bylaws, long-term planning, and inter-governmental collaboration. Integrating community input into decision-making was deemed essential. According to recent studies, this inclusive approach

is increasingly recognized as a way to overcome governance fragmentation in urban water management (Janse van Rensburg et al., 2016).

Behavioural Change and Education

Educating the public on water conservation was highlighted as a priority, with participants recommending incentives, penalties, and water-sensitive design to promote responsible use. Literature supports these strategies, suggesting that public awareness and education are critical to reducing urban water wastage ().

Technological and Innovative Solutions

Investments in green infrastructure, smart water management, and advanced water treatment technologies were recommended by respondents. Integrating spatial planning with water supply planning is seen as essential for sustainable urban water management. These findings reflect broader trends in environmental policy, where innovative solutions are encouraged to improve efficiency and resilience (Swilling & Annecke, 2021).

Trans disciplinary Approach

Participants advocated for collaboration across disciplines and sectors, bridging academia and industry, and establishing communities of practice for knowledge-sharing. This approach is increasingly regarded as a valuable strategy for addressing complex water management issues (Carden & Fell, 2021).

Socioeconomic and Environmental Considerations

Participants expressed concern about inequalities in water access, environmental impacts, and the balance between economic growth and sustainable water use. Rapid urbanization further

complicates water management. These considerations are echoed in South African literature, which underscores the importance of addressing social inequities in environmental planning (Swilling & Annecke, 2021).

Recommendations and Conclusion by Research Participants

Participants recommended prioritizing practical solutions, community involvement, and a paradigm shift toward valuing water to reduce high water use. Emphasis was also placed on changing governance approaches to address water challenges effectively. This aligns with the need for a holistic approach that integrates community and institutional perspectives in water management (Muller, 2021).

Overall, these results underscore the complexity of achieving water security in Johannesburg. The participants' insights highlight the importance of reducing water wastage, improving infrastructure, and fostering collaborative governance as key components in the transition to a water-sensitive resilient city.

5. Discussion

This section delves into the implications of the study's findings, connecting them to the broader literature on water security in urban South Africa. The research aimed to investigate ways to aid urban South Africa with the transition towards water-sensitive resilient cities in the efforts to achieve water security; considering Johannesburg as a case study.

The reviewed literature emphasizes the importance of considering local context when addressing socio-environmental issues as there is no one universal answer to such problems or challenges and in this case, first-world-country solutions are not entirely relevant to third-world countries

(Radcliffe, 2018). The research revealed that budget allocation, political dynamics, and public perceptions of water significantly influence the effectiveness of environmental sector plans. People's values and behaviors related to water vary based on their background and understanding of water scarcity, adding complexity to the issue.

The prioritization and funding of water sustainability projects vary significantly between developed and developing countries. As Carden et al. 2016 point out, developed countries often have the resources to invest heavily in water security measures. In contrast, developing countries may face competing priorities, such as poverty and crime, which can limit their ability to allocate funds for water security. This reactive approach, as observed in the research findings, often leads to a focus on water security only during crises, such as the Cape Town "Day Zero" event or the water restrictions implemented in Johannesburg.

It's crucial to recognize that solutions effective in developed countries may not be directly transferable to developing contexts. As Rogerson 2018 highlights, this disparity often stems from differences in expertise and resources. Developed countries can readily engage specialists for complex projects, while developing countries may face limitations in accessing such expertise due to financial constraints or skills shortages, particularly in areas like sustainable water management.

The objectives of this study were as follows:

i) Examine current employed approaches or strategies that are put into place to facilitate the transition towards a water-sensitive resilient Johannesburg (accountability, adaptation, maintenance)

ii) Investigate the barriers to achieving water security in Johannesburg (infrastructure (green infrastructure and grey infrastructure) vs. water availability)

iii) Identify alternative ways in which the efficiency of the current water supply system can be improved to try to meet the growing water demand in Johannesburg.

Objective 1: Evaluate Current Approaches and Challenges to Water Resilience

The findings of this study underscore the pressing need for Johannesburg to address critical issues in its current water management strategies, particularly related to high non-revenue water rates and infrastructure inefficiencies. The revelation that 41% of supplied water is lost to wastage, as described by respondents, is significant. Literature echoes this concern, showing that aging infrastructure and insufficient maintenance are pervasive issues in South Africa, often worsening water security (Mguni et al., 2022). This reflects a broader concern about water conservation within urban South African contexts, where high water loss affects not only the immediate water supply but also creates disparities in water access, as underserved communities tend to experience more significant shortages (Carden & Fell, 2021).

The qualitative responses from participants suggest that overcoming these infrastructural and technical barriers is challenging under the current governmental structures, where political interference and limited budget allocation further constrain the implementation of sustainable water solutions. This aligns with Chee & Neo 2018 findings on governance challenges in water management, where local political dynamics often obstruct timely and effective interventions. Thus, the results reinforce the argument that greater accountability and reduced politicization are essential for fostering a water-sensitive, resilient Johannesburg. The researcher found that most departments noted that one of the challenges with implementation of new approaches or strategies that aim to facilitate the transition towards water- sensitive resilient cities is that all these different water sectors are working in silos.

What was said by the representative from JRA is that most of the approaches or strategies are developed by a certain department for example the stormwater manual to the best of their knowledge without consulting the next institutions on a feasible, working solution. There is no collaboration because of a lack of communication between different the different water management institutions just because the people believe that for example, if the JRA is tasked with the management of stormwater so that it doesn't cause flooding in the city then even though someone from DWS might have a working solution but they will not collaborate their efforts with JRA because there is no working relationship between key stakeholders and this is what is meant by working in silos mentality. The problem is that the system of water supply assumes cooperative governance when solutions are being explored and this is not the case therefore lack of implementations equates to lack of addressing challenges therefore no real solution being achieved and the poor end up at the receiving end because at the end of the day the affluent community can afford boreholes and Jojo tanks at for their households.

According to the DWS participant interviewed addressing adequate water supply is going to be expensive but reducing the 41 % waste due to non-revenue would be the better approach to take. Institutions can achieve this by having a paradigm shift in water supply; he stresses that it is important for us to not solely rely on the Lesotho highlands project but to consider a multiple waters approach (Carden & Fell, 2021). He says that there is a need to supplement the current water supply by considering other water sources such as rainwater harvesting and grey water re-use for non-potable uses such as watering of the garden. We can also explore storm water or ground water but both of these will be more expensive for Gauteng because of the lack of suitable infrastructure for example concrete jungle and pollution.

According to the symposium hosted by GDARD the Lesotho highlands projects only bring 23% of the overall water supply in Gauteng which is not enough for the municipality to rely on as a solution to adequate and sustainable water supply for the growing population of Gauteng and the government is not the solution the community needs to be involved in influencing the stable state required. The DWS representative stresses that there needs to be a paradigm shift in consumer behaviour, he emphasises that we need to minimise the wastage of water due to leaks and gives an example of automated taps that can be utilized to help contribute to the minimization of water leaks. The Gauteng government representative says that political conflict delays projects when it comes to ageing infrastructure and maintenance, projects end up taking longer to complete and end up costing more than what was budgeted for them because every politician wants to have an opinion on what needs to be achieved and how it must be achieved. There is also a challenge of infrastructure reliability versus infrastructure availability when it comes to the provision of water and these are influenced by maintenance or repairs of infrastructure as well as insufficient capacity of the infrastructure (Carden & Fell, 2021).

The DWS representative says that in his opinion water is emotive and political but this shouldn't come ahead of the community needs. Water is influenced by different spheres of government including national, provincial, and local government but all these spheres have a mentality of working in silos whereas they actually should be putting community needs and collaborating so that their efforts can be effective in the sustainable provision of water.

During an interview with a representative from Johannesburg Roads Agency (JRA), it was said that the government has recently tasked the GCRO to put together a document titled ''Gauteng water security perspective". It is in this document where Gauteng's water situation is explained as well as its challenges and possible solutions are highlighted. However, the JRA representative

pointed out that they are worried about whether the information that has been brought to light will make a difference to the current approach and attitude towards water security. The participants wonder if anything will be done to try and implement a working idea that will aid in the transition towards a water-secure Gauteng or will the plan or perspectives always be like any other effort before it, it will be just good on paper and lack in implementation. Again, this is another example of where the different authorities and departments see a problem but they still will not collaborate to address the problem as a collective rather they just realize that there is a problem with communication and implementation but they still go about doing business as usual and not addressing issues inter-departmentally.

Objective 2: Identify Stakeholder Involvement and Accountability in Water Management

The need for improved stakeholder collaboration and accountability emerged as a key theme, which aligns with national calls for participatory water governance (DWS, 2017). Respondents highlighted that fostering partnerships among government departments, private entities, and local communities is crucial for integrated water resource management. However, this collaborative effort is often hampered by insufficient accountability, which has been identified as a root cause of operational inefficiencies and project delays (Moyo, 2019). In a South African context, this challenge is exacerbated by systemic inequities that impact decision-making processes, as communities with lower socioeconomic status generally lack representation in water management dialogues (Carden & Fell, 2021). Alternative water sources emerged as a potential solution to supplement traditional water supply systems. Participants discussed options such as rainwater harvesting, groundwater use, and grey water reuse. A representative from Johannesburg Water highlighted the importance of educating the community about these alternatives.

The responses further suggest that the inclusion of local communities and regular stakeholder engagement could enhance transparency, as seen in successful community-based water projects across South Africa (Moyo, 2019). Community empowerment and equitable decision-making processes could create a governance structure that prioritizes both technical solutions and the social dimensions of water security, facilitating a more sustainable transition toward water resilience.

A representative from the Gauteng government emphasized that Johannesburg residents often take water availability for granted, leading to wasteful water use practices. This sentiment was echoed by a representative from Johannesburg Water, who noted the high levels of water use in the city, especially among less affluent households due to standpipes and lack of reporting of leaks. These findings align with existing literature on water scarcity and wasteful water use patterns (Satterthwaite et al., 2020).

The argument is that how can people say that there is a water shortage when Rand Water is meeting their target of supplying the municipality with the agreed and licensed amount of megalitres of water instead some departments are saying it is a water use problem; communities are wasting water instead of valuing water as a precious resource and using it with conservancy. Research participants pointed out that some of the barriers and constraints to achieving water security include funding issues because water security projects are not a priority to the government's budget allocation, political interference is also seen as a huge issue since in South Africa a political party can only rule for so long and different parties make different promises to its people hence if one political regards water security projects as a priority the next ruling party might not and then there will be a delay in implementation of such projects depending on the priorities of the ruling party at a certain period in time. An excellent example to demonstrate the

lack of maintenance and outdated infrastructure as a barrier to a water-secure city is the case of the Emfuleni municipality.

Infrastructure challenges were identified as a major obstacle to sustainable water management. A representative from the Johannesburg Roads Agency discussed the lack of water retention infrastructure in the city, contributing to runoff and flooding issues. Similarly, a representative from the Environmental Infrastructure and Services Department highlighted the backlog in infrastructure maintenance and the need for upgrades to meet growing demand. These findings resonate with research on aging infrastructure and its impact on water supply systems (Mguni et al., 2022).

Governance issues were brought to light by several participants. A representative from Rand Water emphasized the importance of collaboration among different governing institutions for effective water management. A representative from the Water Research Commission underscored the role of political will and policy coherence in addressing water challenges. These observations align with studies on the importance of integrated governance frameworks in water resource management (Chee & Neo, 2018; Warner & Jones, 2013).

Objective 3: Analyse Socioeconomic and Behavioural Factors Impacting Water Resilience

The study’s emphasis on behavioural change and education reflects a critical understanding that transitioning to water-sensitive practices is not merely a technical task but also a societal shift. South African literature emphasizes the role of public education in fostering a water-conscious culture, especially in urban settings like Johannesburg, where high water demand and population growth strain limited resources (Carden & Fell, 2021). The participants' suggestions for community workshops and educational campaigns are consistent with strategies outlined by Khan

et al. (2015), which argue that promoting a societal value shift around water usage can significantly reduce water use.

Moreover, respondents highlighted socioeconomic inequities that affect water access, an issue documented widely in South African literature. Lower-income communities are disproportionately affected by water shortages, non-revenue water loss, and inadequate infrastructure maintenance (Mguni et al., 2022). These disparities often stem from apartheid-era policies that left certain communities under-resourced (Carden & Fell, 2021). As a result, marginalized communities in Johannesburg bear a heavier burden of water scarcity, further underscoring the need for equitable water policies that address both systemic and immediate water access issues.

Lastly, the need for collaboration and behavioural change was emphasized by multiple participants. The symposiums attended stressed the importance of a collaborative mindset among stakeholders to achieve sustainable water provision. They highlighted the role of community empowerment in promoting behavioural change. These findings resonate with studies advocating for participatory approaches and community engagement in water management (Khan et al., 2015).

Assessing Technological and Policy Innovations for Sustainable Water Management

The data indicates strong support for innovative, decentralized approaches, such as rainwater harvesting, greywater reuse, and smart water management systems, to improve water resilience in Johannesburg. This aligns with findings from Carden et al. (2018), who advocate for alternative water sources to reduce reliance on conventional water supply systems, particularly in urban areas susceptible to climate variability. These findings are consistent with research on the potential of alternative water sources to enhance water security (Mekonnen & Hoekstra, 2016; Sharma & Begbie, 2015).

However, implementation is hindered by outdated policies and regulatory frameworks that do not prioritize innovation (Mguni et al., 2022). For South Africa, adapting policy to embrace these technological solutions while maintaining regulatory standards is critical to developing a resilient urban water system (Khan et al., 2015).

Additionally, participants expressed the need for a trans-disciplinary approach that leverages expertise across fields to address Johannesburg's water challenges. This mirrors South African calls for collaboration between academia, industry, and government to co-develop solutions that address the complex social, economic, and environmental factors involved (Moyo, 2019). Establishing communities of practice could foster knowledge-sharing and practical implementation, addressing water security at a more systemic level.

Conclusion

This discussion demonstrates the multifaceted nature of water resilience in Johannesburg, emphasizing the importance of addressing technical, governance, socioeconomic, and behavioural aspects in tandem. A water-sensitive Johannesburg requires overcoming infrastructural and political barriers, fostering stakeholder accountability, promoting behavioural shifts, and leveraging innovative technologies—all within an equitable framework. Future policies and initiatives should prioritize equitable access and adaptive strategies, aligning with South Africa's broader commitment to sustainable and inclusive urban development.

5.1. Limitations to study

- The study is limited to the Gauteng Province and specifically the city of Johannesburg this study area may not be big enough to get the full picture and make conclusions on the research topic.

- Also setting up appointments and getting the authorities to respond in time is a challenge since they have busy schedules and some of them are unwilling to participate due to different reasons including company policy.
- The time frame of the study is limited to 2 years and this is limited time to gather completely conclusive data on the subject matter since the research is on a real-life problem the conclusions drawn vary over time as more research is done.

6. Recommendations

Drawing on the study's results and discussion, this section provides targeted recommendations aimed at advancing Johannesburg's transition toward a water-sensitive and resilient urban framework. These recommendations are structured to address the research objectives, aligning them with challenges identified in the study and supported by findings from South African literature.

1. Enhance Infrastructure Maintenance and Address Non-Revenue Water

To tackle Johannesburg's high rate of non-revenue water (NRW), attributed to leaks, theft, and aging infrastructure, a robust maintenance and upgrade program is essential. Non-revenue water is a significant issue nationwide, contributing to unsustainable water losses in urban areas (Mguni et al., 2022; Carden & Fell, 2021). Therefore, the Department of Water and Sanitation (DWS) should prioritize NRW reduction through regular infrastructure assessments and prompt leak repairs, particularly in lower-income areas where infrastructure degradation is more severe. Implementing digital monitoring tools to detect and address leakage in real-time can also enhance efficiency, aligning with Rogers (2020) recommendations for smart technologies in urban water management.

2. Foster Collaborative Governance and Strengthen Stakeholder Accountability

Given the identified lack of coordination among Johannesburg's water management stakeholders, a structured, collaborative governance framework is critical. As South African literature indicates, successful water-sensitive initiatives are often hindered by bureaucratic delays, political interference, and fragmented accountability structures (Warner & Jones, 2019). Johannesburg can benefit from establishing a centralized water governance body that facilitates transparent decision-making, ensuring that key stakeholders—including provincial and local governments, community representatives, and industry actors—are held accountable. A regular forum for stakeholder engagement, involving the voices of vulnerable communities, could also ensure a more inclusive and representative water policy (Hellberg, 2018).

3. Address Socioeconomic Disparities in Water Access

The findings of this study emphasize significant socioeconomic disparities in water access, often exacerbated by the legacy of apartheid and spatial inequality, where marginalized communities face more frequent water shortages and lower-quality infrastructure (Carden & Fell, 2021). To address this, water policies in Johannesburg should include specific provisions for equitable water distribution and prioritize infrastructure investment in historically underserved areas. Additionally, the introduction of subsidized water tariffs and social support programs for lower-income households could improve equitable access to water resources. As noted in South African literature, addressing these disparities is crucial to creating a more just and resilient urban environment (Mguni et al., 2022).

4. Promote Behavioral Change and Water Conservation Education

A shift toward water-sensitive behaviors among Johannesburg residents is essential for long-term water resilience. Public awareness campaigns focused on water conservation can foster a city-wide

culture of responsible water use. Educating communities on rainwater harvesting, greywater recycling, and other conservation techniques could directly support Johannesburg's water-saving initiatives (Carden & Fell, 2021). The literature emphasizes that behavioral change is most effective when coupled with incentives and penalties for water usage, such as rebates for households and businesses that implement conservation measures (Moyo, 2019). Municipal authorities should therefore launch community-driven workshops and educational programs to foster a shared sense of responsibility for water resources.

5. Invest in Alternative Water Sources and Technological Innovation

This study recommends a diversified approach to water sourcing, including rainwater harvesting, storm water capture, and groundwater utilization, to reduce dependence on centralized water supply systems. Rand Water's exploration of non-potable reuse of acid mine drainage is a step in the right direction; however, the city should consider further decentralizing water systems to ensure resilience against climate variability (Carden & Fell, 2021). The literature supports this approach, suggesting that water resilience is best achieved through a mix of sustainable practices and innovative technology (Mguni et al., 2022). Local governments should partner with private sector entities to develop green infrastructure solutions, such as permeable pavements and bioswales, which can enhance rainwater capture while providing environmental benefits.

6. Strengthen Policy and Regulatory Frameworks for Water-Sensitive Urban Planning

Current water policies and regulatory frameworks need updating to enable effective implementation of water-sensitive practices. South African research emphasizes the importance of by-laws and regulatory mechanisms to support water-saving initiatives and ensure compliance (Carden & Fell, 2021). The city of Johannesburg should revise its water policies to incorporate

enforceable measures for water-sensitive urban design (WSUD) and mandate sustainable water use practices in new developments. Creating incentives for developers to adopt water-saving technologies and integrating spatial planning with water resource management are essential steps toward fostering a resilient urban environment (Bettini et al., 2015).

7. Establish Transdisciplinary Research and Community of Practice Initiatives

The complexity of water security challenges necessitates a trans-disciplinary approach that draws on expertise across academia, industry, and government. The formation of community practice groups that bridge the gap between research and practical solutions is critical, as demonstrated by the positive outcomes of similar initiatives in other South African cities (Carden & Fell, 2021). Johannesburg can lead in establishing knowledge-sharing platforms that facilitate continuous learning, policy updates, and the scaling of best practices. These groups should include local communities, thus ensuring that water management strategies are culturally relevant and community-supported (Ferguson et al., 2013).

8. Develop Long-Term Strategies for Climate Adaptation

Climate change continues to threaten Johannesburg's water security, with an increasing frequency of droughts and extreme weather events that affect the water supply. Implementing climate adaptation strategies that account for future climate scenarios is essential, as highlighted in recent South African studies (Mguni et al., 2022). Long-term planning should focus on building climate-resilient infrastructure, investing in water-efficient technologies, and incorporating adaptive management strategies that allow for flexibility in response to changing conditions. Developing policies that embed climate resilience into water management practices will be crucial for sustaining Johannesburg's water security.

As a researcher it is very difficult to access some departments to conduct research they tell you about policies and paperwork and board meetings that sit once in two months. All of this can be overwhelming and seems overboard as some departments that are higher up the pyramid are more accessible than the departments that are closer to the grassroots (communities). I recommend that they stop being hostile and be more open and willing to cooperate with researchers as this will allow for the better flow of information between academia and professionals.

These recommendations are grounded in South African literature and address the core findings of this study, offering practical steps toward achieving a water-sensitive, resilient Johannesburg. Implementing these strategies requires dedicated commitment from local authorities, community stakeholders, and policymakers, creating a foundation for a sustainable urban water future.

7. Conclusion

This research aimed to explore the dynamics of water security and sustainability in Johannesburg, with a focus on understanding the perceptions and insights of key stakeholders involved in water management. Through the examination of various objectives and research questions, this study sought to uncover critical issues surrounding water availability, challenges to water security, and potential solutions to enhance water security in Johannesburg.

The responses from the research participants provided valuable insights into the multifaceted nature of water management in Johannesburg. One key theme that emerged was the disconnect between water availability and consumer behavior. Participants highlighted the prevalent perception of water abundance among residents, leading to wasteful water use practices and a lack of appreciation for the value of water. This sentiment was echoed by the Gauteng government

research participant, who emphasized the need for a shift in water use behavior and greater awareness of water scarcity.

Infrastructure challenges also emerged as a significant barrier to achieving water security. Participants, including representatives from the Johannesburg Roads Agency and Johannesburg Water, pointed out issues such as outdated infrastructure, non-revenue water losses, and inadequate stormwater management. These challenges underscored the importance of investing in infrastructure upgrades and implementing innovative solutions to mitigate water losses and improve resilience to climate change.

The discussions highlighted systemic challenges, including political interference, and economic constraints. A research participant from the Johannesburg Roads Agency emphasized the historical neglect of water catchment planning, leading to inefficient water management practices.

The literature provided additional context and support for the findings of this study. Studies by Hoekstra & Mekonnen (2012) underscored the global significance of water scarcity and the urgent need for sustainable water management practices. Similarly, research by Khan et al. (2015) highlighted the role of governance and institutional arrangements in water security, echoing the sentiments of the research participants regarding the importance of collaboration and effective governance structures. Studies by Moyo (2019) emphasize the urgent need for integrated water resource management and stakeholder collaboration to address water challenges effectively. Findings from De Oliveira and Taljaard (2018) underscore the impact of political dynamics and historical legacies on water governance in South Africa.

Furthermore, the role of governance and collaboration was highlighted as crucial in addressing water security challenges. Participants emphasized the need for coordination among various

stakeholders, including government agencies, water utilities, and communities, to develop and implement effective water management strategies. The DWS participant emphasized the importance of collaboration between public and private sectors, while the WRC participant stressed the need for polycentric governance and stakeholder engagement.

In conclusion, this research has shed light on the complex challenges facing Johannesburg in terms of water security and sustainability. Achieving water security in Johannesburg requires multifaceted interventions that address behavioral, institutional, and systemic challenges. By fostering stakeholder collaboration, leveraging innovative technologies, and prioritizing community engagement, the region can move towards a more sustainable water future.

Annexure 1: Ethical clearance certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Shoba

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H18/09/28**
PROJECT TITLE	Transitioning towards water-sensitive resilient cities in urban South Africa: A study of Gauteng
INVESTIGATOR(S)	Miss N Shoba
SCHOOL/DEPARTMENT	Geography, Archeology and Environmental Studies/
DATE CONSIDERED	14 September 2018
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	01 November 2021

DATE 02 November 2018 **CHAIRPERSON** J. Knight
(Professor J Knight)

cc: Supervisor : Professor M Simatele

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

NAP
Signature

01 / 12 / 2018
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

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