



**DESIGNING A STORMWATER HARVEST SYSTEM IN NEW SMART CITIES
IN KWAZULU-NATAL, SOUTH AFRICA**

By

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DECLARATION

I hereby declare that the work reported in this dissertation, title '**Designing a Stormwater Harvest System in New Smart Cities in KwaZulu-Natal, South Africa**', is my original research work. All sources cited herein are indicated and acknowledged through a comprehensive list of references. I hereby certify that the work contained in this thesis has not previously been submitted either in its entirety or part for a degree at this or any other university.

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ABSTRACT

The nexus between climate change and water management represents one of the contemporary challenges confronting economic development and sustainable livelihoods in many cities the world over. Thus, assessing the impacts of climate change for evolving smart-city water management, especially for a country like South Africa that is classified as a “water-stressed” country, constitutes an innovative way to water management. This study aimed at proposing an alternative water supply augmentation source that is sustainable for new smart cities under different climatic scenarios within the KwaZulu-Natal Province of South Africa. The specific objectives of the study were to assess the impacts of climate change and the imperativeness of a sustainable and efficient stormwaterharvesting (SWH) system in the new smart city; determine the social, economic and technical barriers to an efficient SWH system; evaluate the technical and financial feasibility of stormwaterharvesting system integration in smart cities; and design a prototype sustainable and efficient pilot-scale engineering SWH system.

To address these objectives, the aggregated views of stakeholders within the Water/ Climate change sector were solicited through questionnaires and interviews—collected data were analysed using a statistical package and thematic classification. The triangulation method was used to justify acceptable opinions where both the qualitative and quantitative responses were in opposing positions. The standardised rainfall anomaly index (SRAI), simple precipitation ratio (SR), coefficient of variation in rainfall distribution (CV), precipitation concentration index (PCI), and the seasonal precipitation index (SPI) were used to evaluate the impacts of climate change on rainfall variability; whilst different inferential statistics techniques like Mann Kendal, Sen slope, regression, correlations, multifactor analysis (MFA), and chi-square test values- interpreted using the p-values- were used to identify the abrupt changes, trend patterns and significant impacts of climate change on the hydrological water balance for the study area, which in turn influenced decision-making in designing a new smart city.

Based on a monthly water balance evaluation, the technical and financial feasibility of stormwater harvest system integration in smart cities was thematically deduced from survey interviews conducted and validated with simple component costing for SWH design and operation. The design of a sustainable and efficient pilot-scale engineering SWH system was synthesised through an extensive literature review for future adaptation.

The various analyses and results in ranking the socio-economic and technical barriers to SWH system integration into smart cities connotes ageing infrastructure; the lack of proactive maintenance; and a lack of finance as the biggest challenges to efficient stormwaterharvesting system implementation. The study concludes that SWH presents a viable alternate source for water that might improve urban water self-sufficiency sustainability under different climatic smart city assessments, whilst recommending capacity development where climate change experts transfer knowledge, skills and expertise to upcoming researchers.

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LIST OF ABBREVIATIONS

AWS - Alternate water supply sources
CCS- Climate Change Scenarios
CV- Coefficient of Variation
DWS- Department of Water and Sanitation
DEM- Digital Elevation Model
GIS - Geographic Information System
IA- Integrated assessment
IPCC - Intergovernmental Panel on Climate Change
ICT- Information and Communication Technology
IWA- International Water Association
MCDA- Multi-criteria Decision Analysis
NDP- National Development Programme -2030
NMC- New Smart Cities
NUP- National Urban Policy
NWA- National Water Act (Act 36 of 1998)
PCI - Precipitation Concentration Index
PET - Potential Evapo-transpiration
PR - Precipitation Ratio
PPPs- Public-Private Partnerships
SAWs- South Africa Weather Service
SRAI- Standardized Rainfall Anomaly Index
SSC - Smart Sustainable City
SWH - StormwaterHarvest System
WCM - Water Conservation Mechanisms
WDM- Water Demand Management
WWC- Water-wise Cities
WWT- Wastewater Treatment Discharge

CHAPTER 1: GENERAL INTRODUCTION

1.0 Introduction

This chapter provides background information on a climatic smart city water vulnerability assessment. The need exists to assess stormwater harvesting and the storage of stormwater for human-related activities using a range of technologies. It relates to the consideration of expanding urban populations and uncertainty surrounding climate change to consider the integration of knowledge across a range of systems in order to determine an appropriate mitigation and adaptation strategy to any of the climate change water-related challenges. After placing the work in a broader context, the chapter outlines the study's aim and objectives, and poses specific questions to be answered by the study. The chapter concludes with basic technical terms and component outlines for the subsequent chapters' discussions.

1.1 Background to the study

The estimation of water resources and their future availability under the effects of global warming and population growth represents the modern challenges of the 21st century (Markolf et al., 2021; Garrote, 2017). Water use and its re-use management represents an intrinsic means of livelihood in modern civilisation urban planning and smart city configuration (Kumar, 2020). The dynamic nature of climate change and its variabilities have had many adverse impacts on water resources, not only in South Africa but also all over the world (Garrote, 2017). This study examines the potential impacts of climate change at a local scale in terms of evolving smart city water management. The study explores how the System of System (SoS) approach can be used in designing and exploring alternate water sources for storage facilities based on rainfall variability, catchment type and subsequent run-off coefficient conversion into stormwater harvest systems for future use using a selected study area (Jozini) as a case study.

The water demands of many major urban centres globally exceed the water availability in their immediate vicinity. This necessitated the implementation of complex bulk, integrated storage and water supply systems. South Africa is classified as a “water-stressed” country and the 30th driest in the world (Malunda, 2019) with a threshold of 1000-1666 m³ /person/year (du Plessis, 2019a). Thus, there is a need for a research study proposing a sustainable resilient water regeneration solution for an evolving smart city under different prognostic climatic conditions for a country like South Africa.

Climate-friendly urban planning allows for the sustainable development of living conditions for both the near and future generations (Tiboni et al., 2021). Hence, this makes sustainable development and its multi-variate attendants in the urban water supply a topical issue for discussion. Although water scarcity problems are more pronounced in recent decades due to increased competition for available water resources (Nyam et al., 2020), the combined effect of climatic change, population growth, man's anthropogenic activities and managerial policy have caused ineffable variability in water security in an increasingly unpredictable world. These have affected the economic development and sustainable livelihoods of many cities in the world (Condon, 2020; Coletta et al., 2021)

The water-wise city is a concept outlined by the International Water Association (IWA) to conserve and preserve water resources. “It is all about diversifying and integrating the urban water cycle into the design of robust waterways, stormwater, groundwater, wastewater management, and water supply systems,” (Talat, 2021). The concept denotes livable, resilient, sustainable and productive cities, which requires multi-disciplinary research, especially when considering the climate change and global water resources nexus (Talat, 2021; Singh et al., 2017). Figure 1.1 below summarises the water-wise city concept as a requirement for urban planning and architecture configuration.

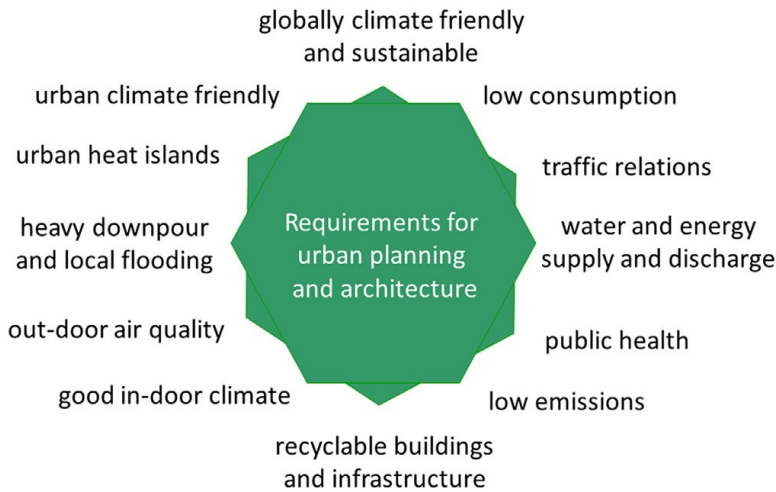


Figure 1.1: Major issues in urban planning and architecture governance
(Talat, 2021)

It is obvious from Figure 1.1 that climate matter cycle knowledge forms an essential component of urban planning and architecture in water and energy conservation. The energy point of view was required for atmospheric air quality and public health adaptation issues. In addition, Figure 1.2 below summarises the modern urban planning issues and the sustainability in life-cycle point of view as expressed by Angrill et al. (2017).

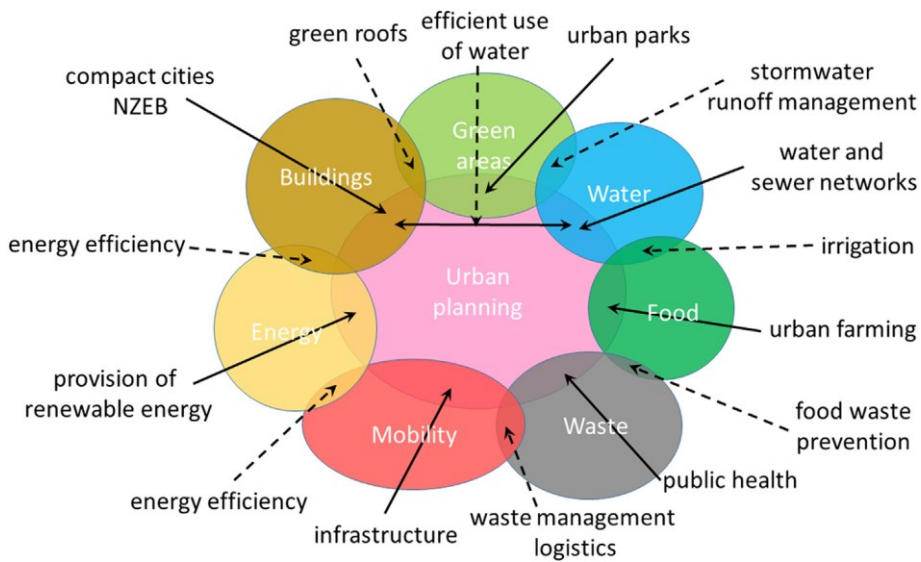


Figure 1.2: Urban planning issues and sustainability in life-cycle studies
Source: Angrill et al. (2017)

Figure 1.2 depicts the requirement for a compact city as a nexus between atmospheric energy and climatic issues as listed on the left-hand side, while technical and water management aspects are listed on the right. Moreover, Figure 1.3 below presents an example of a possible graph that can emerge from interrelations amongst urban issues and the sustainability of life cycle when both Figures 1.1 and 1.2 are combined, as expressed by Petit-Boix et al. (2017).



Figure 1.3: Interrelations amongst urban issues towards sustainability (Petit-Boix et al., 2017).

Figure 1.3 essentially illustrates a new graph with three overlapping bubbles: ‘Urban Climate’, ‘Global Climate’ and ‘Air’ as new climatic issues that had been added. A closer look depicts the overlap bubbles amongst two or more urban issues, namely Climate-sensitive and urban planning. These, amongst other measures, are cost-benefit factors required for socio-economic equality in meeting the needs of a rapidly growing and urbanised population, with changing lifestyles and economic growth (Mishra et al., 2020; du Plessis, 2019b). In summary, the ‘Smart city concept in recent years implies requirements for urban planning and architecture with better information and enhanced information technology (IT) applications for improved infrastructure development which lead to better governance and communication feedback’ (Satterthwaite, 2017).

In addition to addressing the adverse impacts of extreme climate events on water supply systems, sourcing alternate water sources in meeting projected water usage and minimising future water scarcity represent core value aims in a smart city. Therefore, water resource planners and relevant authorities take necessary inventory for drawing inferences on water re-use strategies such as stormwater harvest systems as alternate sources of water for a sustainable new smart city under different climatic scenarios. Thus, the use of water conservation mechanisms and water demand management (WCM/WDM) presents a fundamental step in promoting the efficient, effective and sustainable use of water resources within the KwaZulu-Natal Province of South Africa and provides a vital part of water resources management. An inventory of water conservation design and operation of the SWH system is of high expected benefit both in the mitigation, adaptation and risk reduction potential to society (O'Connell, 2017).

1.2 Smart city and urban infrastructure development

Peng et al. (2017) defined a “smart city” as a city using a set of advanced technologies, such as wireless sensors, smart meters, intelligent vehicles, smartphones, mobile networks, or data storage technologies. In turn, Crnčević et al. (2017) claimed that a “smart city” is an urban development based on the integration of many information and communication technology (ICT) solutions to manage the city’s resources. These definitions of a “smart city” emphasise the role of technology. However, a city can hardly become smart because of technology alone (Dhakal, 2021). Öberg et al. (2017) included citizens as part of the smart city's definition. The authors described a “smart city” in the context of its intelligent inhabitants, the quality of social interactions, and integration with public life.

Tang et al. (2019) also emphasised aspects of Smart city management to include its intelligent management, efficiency and sustainability. Based on Caputo and Wallezký's (2017) assumption, a “smart city” is a city where public issues are

solved using ICT, along with the involvement of various types of stakeholders working in partnership with the city authorities. However, as noted by Fernandez-Anez et al. (2018), complexity, diversity and uncertainty are the three key attributes of modern cities that have hindered the conceptualisation and technical progress implementation of the “smart city concept”. These three attributes (complexity, diversity and uncertainty) entail patterns that can help attain productivity, competitiveness and prosperity in cities. Kinyanjui (2020) also relates that the three main pillars of smart cities are participation, capacity development and acupuncture in nature. Any smart environment entails that they are feasible in diagnosis, formulated, implemented, monitored and re-evaluated, more especially in this era of climate change where increasing water demands are leading to many water-related conflicts (Kabisch, 2019; Nhemachena et al., 2020).

Stormwater harvesting refers to the collection and storage of rainwater using a range of technologies, from simple jars and pots to more complex engineered systems. The popularity of rainwater and run-off harvesting is apparent as the only source of water, especially for developing countries where cost, technology and skilled manpower requirements for sea desalination and other sources are still inadequate (Danti, 2018, Oyeniya, 2020). Stormwater harvesting (SWH) has been used as an alternate source of water for man, animals and irrigation purposes in dry and water-stressed environments (Qi et al., 2019, Al-Komaim, 2018). It is as relevant for urban areas as it is for rural areas since water is a precious natural resource, vital for sustaining all life on earth. It has also proven to be more beneficial because of its decentralised nature, located in proximity to the end-user’s utilisation with coordination and planning responsibilities given to the district and managed by local authorities, together with the participation of the user community (Rossman, 2010).

Although it is more pronounced where permanent rivers are few and far apart, groundwater exploration, abstraction and development are expensive and beyond the reach of most farmers. When surface run-off is collected in reservoirs, it can be used for recharging groundwater, which will positively impact springs and

shallow wells (Abdullah and Rahman, 2015). The stormwater harvest system has yielded numerous social and economic benefits in aiding poverty alleviation and ensuring sustainable development (Kabo-Bah et al., 2021).

The systems implementation also varied from one region or locality to another, based on the hydro-ecological characteristics of the particular region (Oweis, 2017, Yadava, 2018). SWH systems have formed the foundation of many development projects that promote agriculture and land management (Oweis, 2017, Nyam et al., 2020). The SWH system has also offered “support” to environmentally sustainable, social and economically viable land management practices, which helped in improving the production and utilisation of food and other commodities”, especially in semi-arid and dry sub-humid zones (Xu et al., 2019). Amongst the advantages in SWH are the minimisation of crop failure risk during droughts, intra-seasonal droughts and floods (Kiggundu et al., 2018); reduction of women's burden of collecting water for domestic use; and allowing time for other productive activities. SWH allows the girl child to attend school and provides a relatively safe and clean source of drinking water when applied at the watershed level (Kattel, 2019).

Present engineers are now challenged on how to find ways and means of designing a system that uses local technology for sustainable water development which can simultaneously satisfy basic human needs (Abubakr et al., 2020). Hence, the use of water conservation technology and water demand management mechanisms presents a fundamental step in promoting efficient, effective and sustainable urban water use which is consistent with the National Water Act 36 of 1998 (Viljoen, 2019). As noted by Ndeketeya and Dundu (2019), the South African Water Act of 1998 was promulgated to support sustainable and efficient water resources allocation and uses within the framework of/in enhancing the social-economic growth and development of the nation, but this has only been its wish as the reality is still far from realisation. Lack of access to a safe water supply is not limited to the arid climate regions only but is becoming a critical

problem, either because of low water storage capacity, low infiltration, larger monthly and annual fluctuations of precipitation, or with high evaporation hindrance (Malmir et al., 2021; Xue et al., 2021).

1.3 Statement of the problem

Expanding urban populations and uncertainty surrounding climate change represent a significant challenge for the water sector. For this reason, there is a need to consider a range of possible future scenarios in climate adaptation and the smart city wise water use concept in meeting the increasing demand for water resources for domestic, agricultural and industrial activities. Amongst the plethora of challenges, the (study area) and the country at large is facing a water crisis, not limited to recurrent droughts and inequities in access to the water supply, but sustainable adaptation to the climate change impact on the natural ecosystems, infrastructure and livelihood which requires an adequate and timely solution to better citizens' living condition. It is therefore critical to explore an alternative water source for smart city usage in this era of climate change that can effectively address the inadequate water resource supply for usage.

Although nature could reclaim some of its natural position and maintain sustainability in the built environment through its self-reclaim cleansing mechanism, this takes a longer time, thereby jeopardising the immediate use that projects climate-human induced effects on the hydrological cycle. These induced changes affected the amount and pattern of precipitation, as well as the residual residence time of water movement together with its quality and quantity in any of the catchments. Thus the need to understand the dynamic nature of the climatic-smart city water vulnerability assessment concept. SWH is now considered a necessary supplementary and alternative water source, especially during the dry periods since it has proved to be cost-effective and environmentally sustainable. It has become one of the alternate sources of water for irrigation and industrial purposes, as well as for water boards, municipalities

and other water supply institutions producing water for potable use. This study intends to provide answers to some of the following questions:

- How can water demand and its utilisation be managed in a smart city?
- Which factors hindered the smart-city water conservation mechanism in this era of climate change?
- What are the issues affecting the socio-technical and financial feasibility of SWH integration in smart cities?
- How can one develop a water resources utilisation model with regional best-practices that enhance the stormwater harvest (SWH) system for urban planning?

1.4 Study aim and objectives

This study aims to explore an alternative water source for smart city usage under different prognostic climate change scenarios.

1.4.1 Specific objectives:

The specific objectives entail to: -

- Evaluate the impact of climate change on sustainable stormwater harvesting (SWH) systems;
- Determine the social, economic and technical barriers to an efficient SWH system;
- Evaluate the technical and financial feasibility of stormwater harvesting system integration in smart cities; and
- Contributes in designing a sustainable and efficient pilot-scale engineering SWH system.

1.5 Rationale and justification for the study

Although there have been feasibility studies as part of the master plan of the Department of Water and Sanitation to integrate efficient stormwater harvesting

systems into smart cities such as Durban. To date, there has not been a pilot study to demonstrate this. This study is the first in this climate to study and design a sustainable and efficient pilot-scale engineering SWH system with the inclusive adaptation mechanisms needed in coping with extreme weather conditions, both at present and in the near future. The study proposed a resilient water regeneration solution for an evolving smart city that imbibes sustainable and efficient mechanisms in meeting future needs.

Urban planning and environmentally sustainable policies have evolved from different scales, from short-term to long-term livable, hygienic and friendly environments into climate-smart cities to develop strategies to cope with foreseeable challenges in extreme events happening. Therefore, this study explores how the most preferred decisions in Engineering design and environmental hazard consideration can be integrated into stormwaterharvest utilisation schemes in evolving sustainable smart cities under different climatic scenarios. It considered the socio-economic and technical barriers facing its operations management in smart cities and provides alternate adaptation mechanisms towards achieving an efficient climate target city. Thus, the study aims at proposing alternative water supply augmentation that is sustainable for new smart cities under different climatic scenarios within the KwaZulu-Natal Province of South Africa. The study examines ways of harvesting stormwater and subsequent run-off in and around the study area, which can be replicable in other major cities for non-beneficial purposes, considering the current enormous wastage of these water resources that can be used but which are currently being washed away to the sea.

1.6 Research methods

Adopting a mixed design research method, the triangulation method was used to justify the acceptable opinion where both the qualitative and quantitative responses are in opposing positions. Primary and secondary sources of data were

used for answering the research objectives. This includes questionnaires, interview records, documentation reports and past hydro-climatic data (rainfall, temperature and streamflow) collected from the South African Weather service (SAWs)-(1990 – 2020) for Durban metropolitan cities. This was supported with online data repository support from the World Bank (<http://data.worldbank.org>) for future projected climate change impacts (2020 – 2075) assessment on water resources in Durban/KZN. Other information was sought from water stakeholders and climate experts from the Department of Water and Sanitation's (DWS) officials towards providing an adaptive and mitigative measure in ensuring water security.

Thematic classification of recorded documentation reports with different statistical analyses not limited to the standardized rainfall anomaly index (SRAI), precipitation concentration index (PCI) and coefficient of variation (CV) were used to evaluate the impacts of climate change on rainfall variation in the area; while regression, correlations, multifactor analysis (MFA) and factor analysis as part of the principal component analysis (PCA) were used to identify the trend, change pattern and preferred criteria selection in identifying the socio-economic, technical and financial barriers considerations towards proposing an alternate water source that is viable and sustainable under different prognostic climate change scenarios within the KwaZulu-Natal Province of South Africa.

1.7 Scope of the study

The scope of the study was limited to:

- i) Only surface water configuration;
- ii) The analysis of demand-side information on water supply services was obtained from stakeholders and expertise from DWS for domestic purposes only;
- iii) The snowball sample size was limited to 42 stakeholders and experts within the Durban cities in KwaZulu-Natal Province;

- iv) The proposed different adaptation mechanism under changing climatic scenarios as it affects water supply was limited to analysing varied rainfall frequency;
- v) Stormwater harvesting system barriers were only limited to the socio-economic, technical and financial barriers; and
- vi) The technical and financial feasibility in designing a smart city considered only pipe diameters as a decision variable with the initial capital expenditure.

1.8 Concluding summary

This chapter has provided a background for the re-use of existing water structures, regenerative strategies for environmental flow, and water conservation measures in building a resilient urban smart city. The chapter explained how and why the wise-city water re-use concept invigorated stormwater harvesting systems as an alternate water source. The chapter provided background knowledge of SWH, the smart city concept, and the needs for a climate change integrated assessment for urban planning and smart city evolution. The proceeding Chapter Two provides the reader with theoretical background information on the stormwater harvest system and regional best practices, and elucidates the emerging methodologies for climate change impacts assessment and adaptation modelling.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter presents a literature review of research relevant to the aim and objectives of the study. The chapter explores the theoretical background and related work on climate change, smart cities and stormwater harvest integration systems. This was captured by recent progress, key constraints and critical opportunities that are yet to be a tap in leveraging technology for stormwater harvest usage and conservation measures. The chapter concludes with different mathematical and built-in software models useful for assessing climate impacts, alternate water supply sources within the context of smart city development, stormwater harvest system, usage and configuration.

2.1 State-of-the-art literature review

Over 500 million people across the planet live in highly populated areas along river basins where severe weather conditions have threatened their everyday lives (Nel et al., 2017; Vörösmarty et al., 2018). Climate-smart cities need to examine the effects of short-term and long-term strategies to cope with these extreme events happening more often than one can imagine in the future. The process of developing and revising a city's strategic plan is a complex combination of politics, technical inputs and engagements with communities of residents and other key city stakeholder groups, with varied concerns and priority given to climate risks (Schlosberg et al., 2017).

Furthermore, there have been growing efforts to ensure that urban planning processes integrate the best available scientific climate information in order to align them with international and national agendas on low carbon and effluent emission targets (Mo et al., 2021; Campisano et al., 2017). For this reason, there is a need to consider a range of possible future climate conditions in a region of increasing population, coupled with an increasing demand for

water resources for domestic, agricultural and industrial activities, and how these will affect urban water availability in a climate- smart city.

The concept of the climate-resilient smart city strives toward high-quality resource management and service delivery (Cowley et al., 2018). It involves the use of digital and communications technologies that support the reduction of cost and energy consumption, integrate public service functions, and include cooperation with citizens. In comparison with other terms, such as “digital city” and “city of the future”, the term “smart city” primarily means “smart” data management (Cowley et al., 2018). “A smart sustainable city (SSC) is an innovative city that uses information and communication technologies (ICTs) and other means to improve the quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations to economic, social and environmental aspects” (Elgazzar and El-Gazzar, 2017).

A city is made up of different infrastructure verticals forming a system of systems (SoS). However, such city infrastructure elements typically operate in silos. Smart cities need an integrated approach to harness the full potential of smart infrastructure. Amongst its important features is project implementation from the “bottom-up” through the involvement of local communities (Antonić and Djukić, 2018). Included in the key criteria for achieving a smart city are a smart economy, smart citizens, a smart city administration, smart mobility, a smart living environment, and a smart way of life (Fernandez-Anez et al., 2018).

Mourtzios et al. (2019) believe that the majority of the water crises witnessed in cities is because of deep complexity in water demand in response to its availability, without a systematic approach that tries to foresee them in a sectoral management process. Cities must become “smarter” to respond to the numerous challenges in the 21st century, which include environmental degradation, limited resources, urban migration and climate change. Amongst

the emerging methods in analysing the impacts of climate change on water resources and cities, the response is the approach that links socio-economic variables with climatic variables in developing modelled relationships (Jato-Espino et al., 2018).

Hence, the system of systems (SoS) framework enables interdependencies analyses between various systems (environment, human, physical and information systems) in order to have a better understanding of the complex nature of the climate-smart city problem (Herslund and Mguni, 2019). The SoS presents the integration of knowledge across a range of systems to determine an appropriate mitigation and adaptation strategy for any of the climate change-related challenges (Ardabili et al., 2019; Bibri, 2018). These factors (environment, human, physical and information systems) can be linked with sensor-based big data for applications at evolving a climate-smart city and stormwater harvest storage integration. The most commonly used approach in the integrated development of a city is to aggregate the different data streams of a city under a single roof in the form of an operations centre (Taji et al., 2021). Such centres may act as nerve centres that help break down administrative silos. Co-locating different infrastructure components is another way to achieve the integrated development of a smart city. Findings such as smarter integrated approaches to infrastructure development may establish the foundation for conceptualising infrastructure systems for smart cities under the SoS approach (Sapkota et al., 2018; Chen et al., 2017).

Du et al. (2019) developed a multiple regression-based analysis to determine flood risk in urban catchments. A geographic information system and regression analysis model were used to analyse the influence of climate change on the hydrological cycle in the Yangtze River Basin (Keliang, 2019). Hassan and Jalut (2018b) use a logit regression model to regress demography parameters (age, educational level, marital status, etc.,) to water service delivery principles. Tikkanen (2013) applied a stormwater management model (SWMM) for Hydrological modelling of a large urban catchment,

while clustering analysis and different statistical analyses were used for assessing rainwater harvesting potential from roof catchments in Thailand by Villar-Navascués et al. (2020). The Factor analysis as part of the principal component analysis was used for parameter selection for the development of a novel water quality index at Ganga River, India; while non-linear regression (NLR) had proven to be a useful model in analysing multiple evidence-based equations like climate-smart city-water adaptation (Roberts and O’Donoghue, 2013).

The multiple non-linear regression, multiple logistics regression and multiple binary regression methods permeate a better solution to the challenge of balance over- and under-fit problems in linking socio-economic variables with climatic variables through the development of predictive models. Equations 2.1 to 2.3 below present the various logit models that have found technical consideration in stormwater harvesting:

$$P/(1-p) = \text{Exp}(a+bx) \quad \text{Eqn 2.1}$$

$$Y = \frac{e^{\beta_0 + \beta_1 x_1 + \beta_2 x_n}}{1 - e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n}} \quad \text{Eqn 2.2}$$

$$\ln D = b_0 + b_1 \ln x_1 + \dots \dots b_n \ln x_n + E \quad \text{Eqn 2.3}$$

where the probability (p) of an event occurring (y=1) rather than not occurring (y=0); is the exponential function of (xi); x_n can be any socio-economic and rainfall variability drivers or household variables. E is a random error variable describing the joint effect on D (water demand) of all the factors not explicitly considered by the predictor variables.

Many water researchers think that effective city development and management must be supported by the carrying capacity of the conveyance networks and storage facility for water uses in promoting socio-economic growth, reducing

poverty, and offering valued added advantages towards the depleted environment (Tiboni et al., 2021; Twigg, 2004). Denault et al., (2006) in their work title “*Assessment of possible impacts of climate change in an urban catchment*” first used a linear regression model to analyse non-stationarities in rainfall records, and detected trends are extrapolated to build potential future rainfall scenarios before the Storm Water Management Model (SWMM) was used to analyse the effects of increased rainfall intensity on design peak flows in assessing future drainage infrastructure capacity sustainability according to the derived scenarios. Thus, thereby make use of different hydrological models, in-built climatic-urban software, and developed mathematical models as viable tools for managing catchment on a local scale, with a socio-economic, event-based process of cause-and-effect.

2.2 Effective urban planning models

Effective urban planning models must address the two distinct systems that shape the water management landscape, namely bio-physical and socio-economic (Reed, 2004). Factors related to the bio-physical system include climate, topography, land cover, surface water hydrology, groundwater hydrology, soils, water quality and ecosystems, which shape the availability of water and its movement through a watershed. Factors related to the socio-economic management system are driven largely by human demand for water, which shapes how available water is stored, allocated and delivered within or across catchment boundaries, together with the management policies.

Amongst the most effective common urban planning and design models related to urban climate change assessment and hydrologic catchment management are the Hydrologic Engineering Center-Geographic River Analysis System (HEC-GeoRAS) (Mawasha and Britz, 2021), InfoWorks River Simulation, (infowork RS) (Papanikolaou et al., 2019), Hydrologic Simulation Program-Fortran (HSPF) model (Yazdi et al., 2019), The Distributed Routing Rainfall-Runoff Model (DR3M) (Al-Suhili et al., 2019), Stormwater Management Model

(SWMM) and MIKE-SWMM (Arumsari and Setyandito, 2018), The Quantity-Quality Simulation(QQS) (Ma et al., 2018), Hydrologic Engineering Center’s Hydrologic Modeling System (HEC-HMS) (Yan et al., 2020), as well as STORM, DRAINS, MOUSE and Manual Saliran Mesra Alam (MSMA) Design aid and Database (Fernandez-Anez et al., 2018). These urban models are not limited to the above enumerated emerging model but include other numerous couple and offline couple models, depending on their location and purpose of the problem. To this end, Tables 2.1, 2.2, and 2.3 summarise the various stormwater management software availability, functionality and accessibility, characteristics and components in the quantity analysis in their representative models.

Table 2.1: Functional and accessibility of the representative models

Urban Models	Functionality			Accessibility	
	Plannin g	Operationa l	Desig n	Public Domai n	Commercia l
DRAINS	x	x	x		X
MOUSE		x	x	x	
Infowork RS		x	x		X
HSPR	x		x	x	
DR3M	x		x	x	
SWMM	x		x	x	
MIKE-SWMM	x	x	x		X
QQS	x		x		
STORM	x			x	
HEC-HMS		x			X
MSMA Design aid and Database	x	x	x		X

Table 2.2: Characteristics of representative models

Urban Models	Model Characteristics				
	Routing Level			Time modelling scale	
	Simple storage	Hydrologic	hydraulic	Continuous	Event
DRAINS	x	x	x	x	x
MOUSE	x	x	x	x	x
Infowork RS		x	x	x	x

HSPR	x	x		x	x
DR3M	x	x	x		x
SWMM	1	x	2		x
MIKE-SWMM	x	x	x		x
QQS	x	x	x	x	x
STORM	x	x	x	x	x
HEC-HMS		x		x	x
MSMA Design aid and Database	x	x	x	x	x
1-flow balance only, 2-with EXTRAN module					

Table 2.3: Components in the quantity analysis in representative models

Urban Models	Model quantity component					
	Pipes	Open channel	Retarding basins	Others	Natural Streams	Rainfall-runoff
DRAINS	x	x			x	x
MOUSE	x	x			x	x
infowork RS		x			x	x
HSPR	x	x	1		x	x
DR3M	x	x	x		x	x
SWMM	x	x	x	4		x
XP-SWMM	x	x			x	
MIKE-SWMM	x	x	x	2		x
QQS	x	x	x		x	x
STORM						
HEC-HMS		x			x	x
MSMA Design aid and Database	x	x	x	x	x	x

1-reservoir module; 2-weirs and pumps; 3-pressurised pipes; 4-gutter and pumps; 5-surcharges; 6-bridges; 7- overland flow

The SWMM software is a computer program that can assess the impacts of runoff; simulate the quality and quantity of rainfall over urban catchments; and

evaluate the effectiveness of its mitigation strategies. SWMM is mainly used on urban catchments (Limitation), but not for the river basin model. The INFOWORK RS model plays an important role in flood management in lowland catchment areas. The QQS model defines the impact of urban runoff on receiving waters and is good for urban runoff control; while the HEC-HMS model has been quite apt to estimate the basin's hydrological response due to precipitation. Depending on location and study purpose, the MSMA Design aid and Database had proven usefulness for Urban Stormwater Management for Malaysia. The DR3M model has been a very effective tool for simulating runoff from small urban watersheds when compared to the HPRS model, which is good to estimate the impacts of land cover change on runoff behavior. The DRAINS and mouse urban models are usually affected by such factors as conduit storage, backwater and pipe surcharging. Furthermore, a good understanding of the future rainfall distribution and variation will be of vital importance if any meaningful development is to take place in the city environment-water resource management (Dey and Mishra, 2017).

However, most of these urban models' objectives are meant to evaluate gray infrastructure through their hydraulic processes. Hydraulic routing is the process of combining all inflows that enter the upstream end of each conduit in a conveyance network and transporting these flows to the downstream end over each instance of time (Bell et al., 2020), as characterized in Table 2.2. Table 2.4 depicts some of the available hydrological models that have found large usage in South Africa, their objectives, applied methodology, research years, advantages and disadvantages. This can be used as a guide in extracting an appropriate hydrological model that can be combined with the urban stormwater model.

Table 2.4: Hydrological and climate assessment models

Hydrological model	Objectives	Application	Advantages	Disadvantages	Remarks
MIKE SHE	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Water quality - Surface and groundwater movement - Irrigation management - Water use management 	<ul style="list-style-type: none"> - Large spatial scale range (Butts et al., 2005) - 	<ul style="list-style-type: none"> -Model use requires technical expertise -Requires huge amounts of input data, -Takes long computational time -Baseflow overestimation -Real complexity of hydrological systems (Unbearable below the ground scale of representatives and Approximation of processes involved and numerical solutions) 	The model accuracy in an ungauged and gauged catchment is not guaranteed
ACRU	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Land use - Crop yield - Irrigation - Sediment yield - Water resources assessment 	<ul style="list-style-type: none"> - Confidence in assessing climate and land-use change - Good structure for hydrological responses and 	<ul style="list-style-type: none"> -Model availability and support are difficult -Requires a huge amount of input data - Data pre-processing, and GIS analysis are 	Default values are based on the South African dataset

		<ul style="list-style-type: none"> - Design hydrology - Climate change - Impact analysis - Environmental flows estimation - Risk analysis 	sediment mechanism	<p>difficult. (Beckers et al., 2009)</p> <ul style="list-style-type: none"> - Not robust in semi-arid regions (Magombeyi, 2010) 	
SWAT	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Agricultural purposes - Subsurface drainage - Irrigation and reservoir operation - Water quality - Hydrological studies - Land use - Climate change - Sediment yield - Pollution loading 	<ul style="list-style-type: none"> - Automatic calibration - Well adopted using remotely sensed data. - Flexible and robust 	<ul style="list-style-type: none"> -Does not simulate single-event storms adequately -Non-spatial aspects of the Hydrologic Response Unit (HRU), which does not provide an explicit spatial representation of riparian buffer zones, wetlands. -Limited ability to account for targeted placement of grassland or other land use and ignores flow and pollutant routing within a given sub-watershed. <p>(Daniel et al., 2011)</p>	Very robust, versatile and easy to access

HSPF	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Hydrological studies - Water quality - Pollutant analyses - Sediment transport - Agricultural practices 	<ul style="list-style-type: none"> - Gives a detailed representation of land and watershed land, stream processes and watershed pollutant sources - Flexibility and adaptability to most watershed conditions - Well-designed code modularity and structure 	<ul style="list-style-type: none"> - Huge amount of data input for setup -Not fully physically based - Not user-friendly -Difficult to calibrate 	Very difficult to set up in gauge and ungauged watershed
TOPKAPI	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Catchment hydrology - Water resources management - Reservoir management - Flood forecasting - Land-use change - Climate change - Irrigation and drought 	<ul style="list-style-type: none"> - Easy to calibrate - Run segment and continuous event simulation - Low computational time 	<ul style="list-style-type: none"> -Expensive -The model fails to account for infiltration into the soil layer 	It has limitations to the infiltration process

HEC-HMS	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Water balance - Water resources management - Flood hydrology - Urban drainage - Stream restoration - Urbanization impact - Reservoir operation 	<ul style="list-style-type: none"> - User-friendly - Auto calibration - Low computational time - Can be applied in a lake 	<ul style="list-style-type: none"> -High complexity due to broad functionality in representing both watershed and river processes -Requires a high number of parameters -Cannot simulate on a large watershed scale 	It requires many parameters to be available before it can be run
PyTOPKAPI	Hydrological routing of a catchment	<ul style="list-style-type: none"> - Catchment hydrology - Water resources management - Reservoir management - Flood forecasting - Land-use change - Climate change - Soil moisture estimate 	<ul style="list-style-type: none"> - Well adopted using remotely sensed data - Ease of use - Robust in an ungauged catchment - Simulate at an hourly time scale - Less computational time 	<ul style="list-style-type: none"> -Requires large data input 	Also, this model requires a large input of data

In summary, it is not gainsaying that the global climate and the hydrologic cycle are tightly related. Depending on the problem statement and site-specific challenges and dataset requirement availability, any of the abovementioned models in Table 2.1 to Table 2.4 can be applied to urban catchment modelling for runoff routing and estimation of available water in a catchment, aside from the use of historical trend analysis or hypothetical assumptions in projecting climate change impacts on water resources assessment (Dong et al., 2020).

Urban runoff harvesting techniques ensure healthy river maintenance, as well as the cultural and socio-economic development of urban communities. They require a storage tank design for future use. Modern design criteria for storage structures have changed over time due to an improved understanding that facilities must control not only the extreme runoff events to prevent flooding, but also the more common smaller events that produce a “first flush” pollution phenomenon, which negatively impacts the quality of receiving water bodies. The capacity of the storage size is by far the major largest consideration in determining the total overall cost for its installation (Chilton et al., 2000). Hence, its optimisation in determining the system financial back-roll and its possibility for implementation is amongst the technical and financial reliability analysis of urban rainwater harvesting that has been carried out by Santos and Taveira-Pinto (2013). Therefore, the design and analysis of the prototype model system before implementation helps to maximise the benefits and the need to further add value to the system's effectiveness (Bashar et al., 2018; Rahman et al., 2012).

2.3 Development of an integrated smart city

Integrated approaches effectively capture the dynamic relations between people, policies and environments (Fernandez-Anez et al., 2018). It must capture the planning of water systems that must function for long periods under potentially large future uncertainty. Many researchers have used various rainfall-runoff models to assess the impact of climatic change on city

hydrology (Xiang and Demir, 2020; Hu et al., 2018; Adnan et al., 2021). The future impact of climatic change on city hydrology indicates that both the quality and the quantity of the availability of the water will be considerably impaired (Chrispim et al., 2020).

Thus, what matters most in the nexus between climate change and available water resources is the ability to anticipate change and provide a solution. Therefore, a stormwater harvest system is now considered a necessary supplementary and alternative water source during dry periods as it is cost-effective and environmentally sustainable (Fisher-Jeffes et al., 2017). It requires a storage capacity as an alternate water supply source, which could be based on monthly, annual and seasonal variability patterns.

2.4 Investment planning and improvement to water supply systems

It is most likely that approval will be given to investments in water improvement systems that indicate positive economic impact, as well as a technical advantage when the development of the process proves to be successful. The economic analysis indicators such as return on investment, net present value, discounted cash flow rate of return, payback time, break-even point and sensitivity analysis have proven useful for measuring the viability of the process. Hence, an economic evaluation or analysis usually comprises an estimate of the capital and operating costs as an indication of financial visibility (Smith, 2005; Sinnott and Towler, 2012; Peters et al., 2013). This can be further narrowed down to profitability standards and economic potential. **Error! Reference source not found.** detailed the effects and the relationship between costs, revenue and demand volume as factors responsible for profit. In order words, Economic potential = Revenue – fixed cost - variable costs – taxes **Eqn. 2.4**

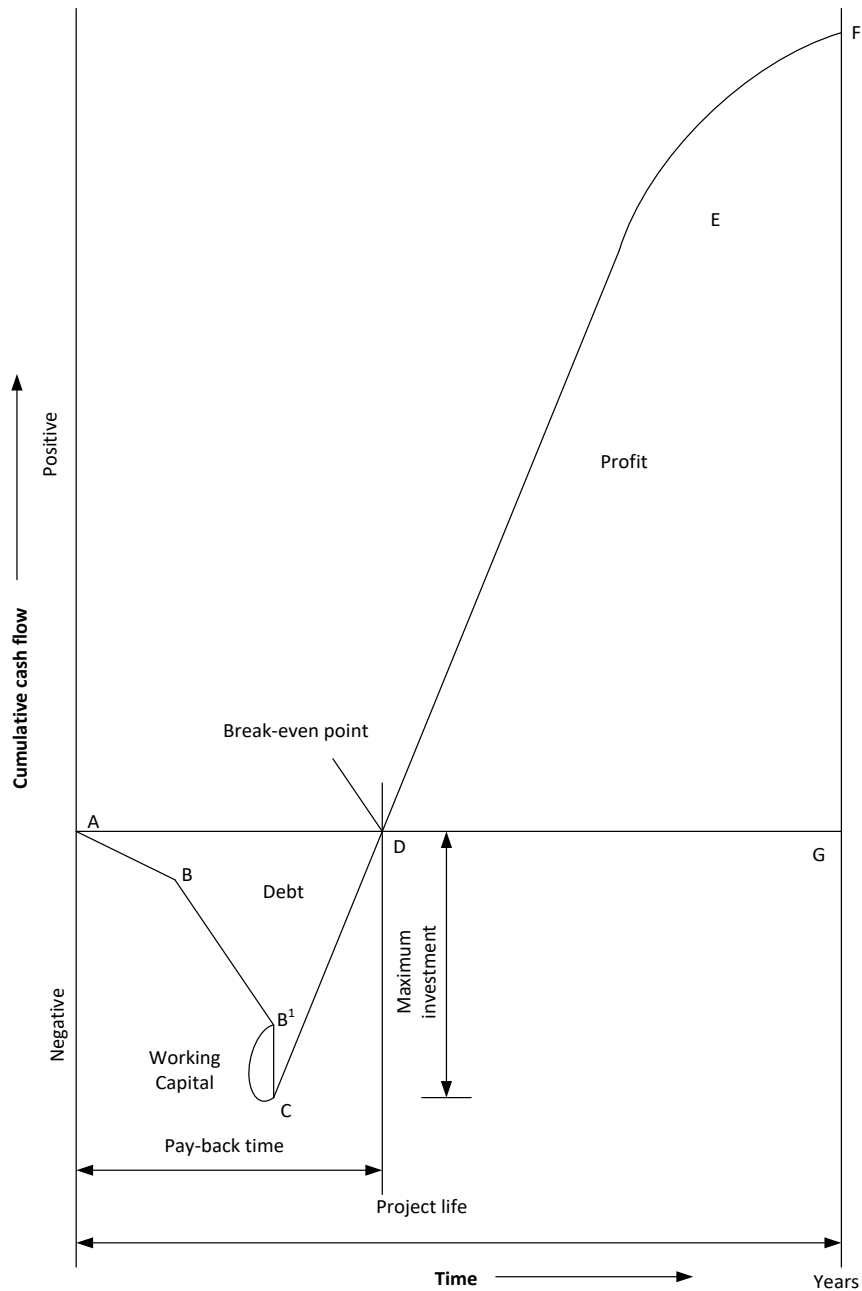


Figure 0 Project Cash-flow Diagram
 (Sinnott and Towler, 2012)

This is useful for developing robust, technical and financially viable alternatives for future water distribution network arrangements and the development of smart cities (Afifi et al., 2018).

2.5 Water harvest technology for sustainable cities

Water harvesting technology, though initially devised for arid and semi-arid regions, has now become imperative for sub-humid and humid regions (Conejos Fuertes et al., 2020). Moreover, the water resources in the dry area can be utilised sustainably amongst various stakeholders by building an integrated urban service delivery with a water supply system. The water harvest systems can either be concentrated into a storage reservoir or apply water directly to the soil in the cropped area (Van Opstal et al., 2021). These are fundamental in building a base for a sustainable urban smart city with risk reduction and that is people-centred. Stormwater harvesting technologies are highly location-specific (Snelder et al., 2018). The SWH practices have evolved in each agro-ecological region, with limited applicability in other regions. The physiographic information for SWH application and its assessment impact on different regions of the country proffer suitable techniques for water supply augmentation, which could be a good potential for alternate water use and an assessment impact on the water balance (Ejegu and Yegizaw, 2020).

Stormwater harvesting has been receiving much attention over the past two decades and shares a total water supply of 10–15% (Snelder et al., 2018). It is the most unconventional water source applicable in many regions. The various SWH techniques that have been proposed, tested and adopted by users can be grouped roughly into five broad types, namely:

- (i) Roof-top SWH and storage in either surface or underground tanks;
- (ii) runoff harvesting from open surfaces and paths, roads, rocks and its storage in ponds, underground tanks, or other structures;
- (iii) flood flow harvesting from valleys, gullies, temporary streams and its storage in ponds, weirs and small dams;
- (iv) flood flow harvesting from ephemeral watercourses and its storage within sand formations as sub-surface or sand dams; and
- (v) runoff harvesting and its diversion from any other sources when stored within the soil profile.

Amongst the several authors that have postulated the use of rainwater harvest systems for domestic and irrigation water supply use, especially in the dry period, are Swilling (2006); Villarreal and Dixon (2005); Dinar et al. (2012); Abdullah and Rahman (2015); Tolossa et al. (2020) and Zabidi et al. (2020). The SWH system presents many benefits for urban sustainability and is quickly emerging as a key strategy to cope with water scarcity in urban and rural settlements (Qi et al., 2019; Nabwire, 2020).

2.5.1 Water conservation methods

The various types (aspects) of water harvesting technology can be broadly categorized into two: *In-situ and ex-situ*, namely agronomic and engineering measures. The *ex-situ* type of water harvesting system has a larger opportunity to combat the frequent and diverse dry spells occurring in the monsoon period or post-monsoon period, while the *in-situ* water conservation includes practices like contour cultivation, mulching, deep tillage, contour farming and ridging. The engineering measures include practices such as contour bunding, graded bunding, conservation bench terrace (CBT) systems, bench terracing, contour trenches, conservation ditches, and broad bed and furrow systems. Agronomic measures are preferred as they involve the least disturbance of the land and are farmer-friendly. However, in situations where agronomic measures are insufficient due to topographic or climatic constraints, mechanical measures are recommended to improve soil moisture regimes and conserve runoff water.

2.5.2 Micro-catchment stormwater harvesting

The micro-catchment water harvesting system consists of a distinct catchment area and cultivated area that are adjacent to each other. The distinct advantages of micro-catchments are the high specific runoff yield (runoff per unit area) compared to large catchments in terms of simplicity, inexpensiveness and easy reproducibility. A decentralized network of water harvesting structures in a watershed is more beneficial than a single large structure at the remote outlet. Decentralized the harvesting of stormwater in micro catchments can yield 95 m³

of water per ha per year as compared to collection efforts from a single large unit at the outlet of a 345ha watershed which yielded only 24 m³ of water per ha per year. Various forms of bunding, circular and V-shaped micro-catchments have been used successfully for horticultural crops in arid and semi-arid regions (Ali et al., 2010).

2.6 Imperativeness of stormwater harvest systems

Water harvesting refers to the small-scale concentration, collection, storage and use of stormwater for both domestic and agricultural purposes (Terêncio et al., 2018). Human activities have the potential to lead to changes in the water balance. However, in-detail modelling of large urban areas is time-consuming as it typically involves model calibration based on highly detailed input data (Tikkanen, 2013). The types of SWH systems can vary in scale and uses, ranging from a few hectares benefiting a single farmer to a few hundred hectares (watershed) serving a larger group of people. SWH has served a major role in preventing issues such as flash floods and urban water-quality problems. Since future climate remains uncertain, seeking its understanding will continue to emerge in improving both life above and below water (Liang, 2018).

2.7 Regenerated water harvest and environmental impact

The success of any water harvesting practice depends upon the amount of harvested water, its temporal availability, and the way it is used or recycled for economic use. The regenerated upstream re-use and the direct use of harvested water in household and crop production can be realized at a small scale, benefiting a few persons or a limited farm area. However, the important point is the benefits that are accrued, and its sustainability in the long run. The essential components of the stormwater harvesting system include the catchment area, channel/overland flow, the water harvest storage, and the conveyance system (gutter and downpipe), either by gravity or lift/pressure flow. The collection system can also be classified according to the type of

catchment surface being used, which can be the roof, underground or rock catchments system (Tiboni et al., 2021).

Roof catchment systems are the most common type used in the world and are usually the roof of houses or buildings. The roof type material influences the efficiency of collection and the water quality. The groundwater system is suitable where roof surfaces are not available or hindered. It can collect water from a larger area and is more useful in low rainfall regions. However, the contamination of runoff and inaccessibility for maintenance and cleaning of the underground tank make it unsuitable for drinking water collection. Rock catchment systems are generally constructed for communal supplies in areas where massive rock outcrops provide suitable catchment surfaces. The runoff is channelled by stone and cement drains to reservoirs or storage tanks. Figure 2.2 illustrate the essential components of water harvesting systems.

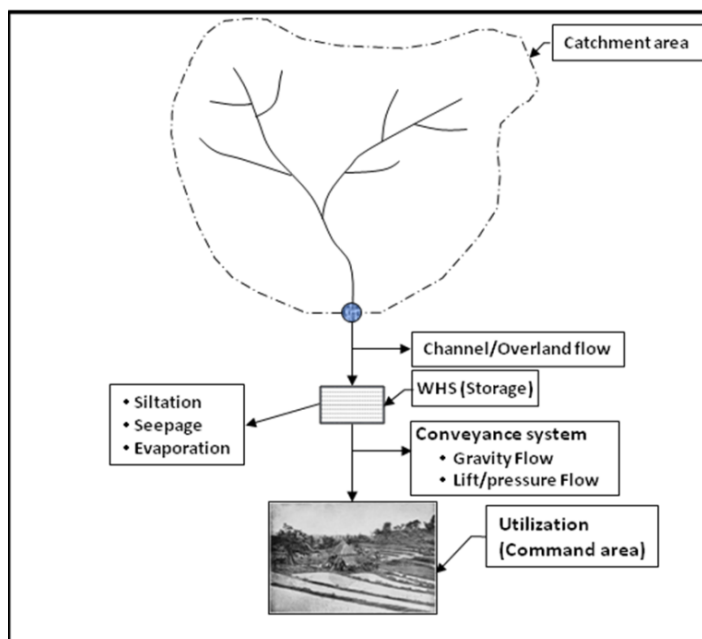


Figure 2.2: Essential components of water harvesting systems,
Adopted from Reed (2004)

The benefits of water harvesting and its recycling in improving crop yields are not confined to farm level only. More recently, studies have shown that the

impacts of small water harvesting structures are realised on a bigger watershed scale for improving the overall environment of the area (Ejegu and Yegizaw, 2020). Some of these intangible benefits include a reduction in soil and nutrient loss, groundwater recharge, improvements in livelihood systems, perennial flow, and the regeneration of natural vegetation (Fisher-Jeffes et al., 2017). A direct effect of the water harvesting structures is to impound stormwater for a considerable time, which results in reduced surface runoff and thereby soil and nutrient losses from the watershed area. Additionally, a positive off-site effect of impoundment is increased percolation. If the watershed area contains a suitable aquifer, it is substantially recharged by the percolated stormwater. This has been demonstrated in different watershed development projects implemented in various agro-ecological regions in China (Jing et al., 2017). The structures having a proven effect on watershed runoff yield and groundwater recharge including percolation ponds, gully plugs, check dams, diversion and graded bunds, farm ponds and contour trenches.

2.8 Best-practices review in designing a water harvest system

Water harvesting has been practiced successfully for millennia in parts of the world – and some recent interventions have also had a significant local impact (Kahinda et al., 2007). Yet, water harvesting’s potential remains largely unknown, unacknowledged and unappreciated. Water harvesting offers under-exploited opportunities for the predominantly rain-fed farming systems of the drylands in the developing world. It works best in precisely those areas where rural poverty is worst. When practiced well, its impact is to simultaneously reduce hunger and alleviate poverty, as well as to improve the resilience of the environment. Improving the efficiency of stormwater use is therefore extremely critical in these water-scarce areas, with rapidly expanding populations living in a fragile environment and facing food insecurity and depleted natural resource bases (Kiggundu et al., 2018).

As water shortages in dry areas are a recurrent crisis, people have a great need for information on how to capture and use every available drop of water efficiently. Water harvesting is an effective and economical means of achieving this objective, and information on its various systems and techniques is in great demand.

2.9 Computing dependable catchment yield

The dependable yield is usually determined from past available data of the last 35 years or so. The rainfall data of the past years is generally used to work out the dependable rainfall value corresponding to the given dependability percentage (p). This dependable rainfall value is then converted into the dependable runoff value by using the available empirical formulae connecting the yearly rainfall with the yearly runoff (Srinivasulu and Jain, 2009). The catchment yield is the total yearly runoff, expressed as the volume of water passing through the outlet point of the catchment in Mm^3 or $M.ha^{-m}$. Generally, a period of one year is considered for determining the catchment yield. In achieving a reasonable agreement, an intermediate dependability percentage value, such as 50 to 75%, may be used to compute the dependable yield or the design yield. The yield, which corresponds to the worst or the most critical year on record, is called the firm yield or the safe yield. Water available over the firm yield during years of higher inflows is designated as the secondary yield. Hydro-power may be developed from such secondary water. The arithmetic average of the firm yield and the secondary yield is called the average yield (Holden, 2019).

2.10 Mean annual runoff for designing an SWH system

Considering the important elements of the basin to be modeled and the problem identification, the conceptualisation and the mathematical description of the problem are appropriate computational techniques in obtaining a reliable model. Thereafter, the model results are compared with measured outputs. If they are found to agree, the model is verified and ready for use. The estimation of the

amount of water that can be harvested or supply of rainwater per month or yield can be estimated from the following equation, as suggested by Vigneswaran et al. (2009) and Visvanathan et al. (2015).

$$\text{Monthly yield (m}^3\text{)} = \text{monthly rainfall (mm)} \times \text{catchment area (m}^2\text{)} \times \text{runoff coefficient}$$

Eqn. 2.5

The runoff coefficient for different types of catchment surfaces varied in a wide range from 0.05 for sandy soil to 0.95 for metal or concrete roofs.

Since rainfall is unpredictable, a storage system is required to supply steady water use and to store rainwater through other periods. The volume of the storage tank did not only depend on the catchment area and surface type. A balance statement of each month of a calendar year is prepared and the cumulative excess (supply minus demand) available at the end of each month is calculated. The highest cumulative excess water is the required capacity of the storage requirement. Thus, a rough estimate of the storage requirement can be obtained from:

$$\text{Storage} = \text{consumption per capita} \times \text{number of people in household} \times \text{longest average dry spell days}$$

Eqn. 2.6

In this way, the modeler can see the change in model output values resulting from modest changes in input values and determine the importance of imprecision or uncertainty in model inputs in the modeling process (Loucks and Van Beek, 2017).

2.10.1 Ombro-Thermic Diagram in designing an SWH system

Rainfall and temperature are the two important climatic parameters that determine the climatic situation of any place (Mehan et al., 2017). The ombro-thermic diagram helps to identify the dry and wet months in a region. It uses a simple line graph of monthly average rainfall and means temperature or

evapotranspiration plotted on both the Y-axis of the graph scale with months on the X-axis respectively. It has enjoyed wide usage in a Mediterranean climate to establish the temperature-rainfall relationship (El Houssaine Ouharba and Triqui, 2021).

2.10.2 Empirical methods used for estimating the SWH system

The basic component of SWH is the catchment area, pond (water harvesting structure), water conveyance system, and command area.

- i) The Catchment area - the land area producing the surface (overland flow) and sub-surface water for capturing into the SWH.
- ii) The pond/tank/reservoir) - is used for collecting or holding the water.
- iii) Conveyance system - the system of pipes or channels for conveying water from SWH to the command area.
- iv) Command area (water management) –the harvested water area for the irrigation or the crops command area.

The SWH structure determinants like siltation, seepage and evaporation are immensely important to consider while designing a WHS to ensure its functional efficiency.

A detailed estimation of stormwater harvest potential includes the use of Probability analysis of rainfall data using Kimball's method (Sunusi, 2019), as in Equation 2.7

$$F (\%) = \frac{1}{T} * 100 \quad \text{Eqn. 2.7}$$

where $T = (n + 1) / m$

Amongst the developed empirical methods that could be used to estimate the volume of stormwater harvested per household per month is (Kalita et al., 2017; Aladenola and Adeboye, 2010; Ghisi, 2006):

$$V_r = \frac{R.HRA.RC}{1000} \quad \text{Eqn. 2.8}$$

Where, V_r = monthly volume of stormwater per household (m^3), R = monthly rainfall depth (mm), HRA = household roof area (m^2), and RC = runoff coefficient.

The basic monthly balance could be estimated by subtracting monthly water demand from collected monthly stormwater, which can be expressed as in Equation 2.9:

$$W_a = I_v + V_c - V_u \quad \text{Eqn. 2.9}$$

Where, W_a = water available, I_v =initial volume in storage, V_c =volume collected and V_u = volume used.

In addition, the estimation of stormwater harvesting potential varies in methods and operational performance. This has been documented amongst other studies in Inamdar et al. (2013), Brodie (2008) and Inamdar et al. (2018). The water harvesting practices, such as in-situ water conservation, micro- catchments and ex-situ water harvesting and storage systems, exist in operation (Inamdar et al., 2018; Inamdar et al., 2013).

To deal with water augmentation and management issues, the knowledge of water yield and water balance in a river catchment is an indispensable prerequisite in the sustainable management of water resources at watershed and basin-wide levels. Components of water balance are influenced by climate and the physical characteristics of the catchment such as morphology, land use and soil. Therefore, understanding the relationship between these physical

parameters and the hydrological component is necessary to assess the hydrologic response to climate and land cover variability in determining water availability.

The impact of land use and change on the water resources of an area is a serious challenge. The conversion of natural landscapes for agricultural and urban uses often impacts soil integrity, nutrient fluxes and native species assemblages. Such changes can affect watershed hydrology by altering the rates of interception, infiltration, evapotranspiration and groundwater recharge that result in changes to the timing and amounts of surface and river runoff. However, there is conflicting evidence regarding how forest conversion or afforestation in tropical regions impacts watershed hydrology.

2.11 Stormwater harvest system: The South African Experience

Although SWH is a well-recognised source of water, its nationwide adoption and implementation (particularly in urban settlements) have been at a much slower pace. This has been largely due to the lack of specific user and programme implementation guidelines. To this end, the DWS (formerly the Department of Water Affairs and Forestry (DWAF)) released a document concerning the criteria guidelines required for the design of the SWH system and a Rural Development Programme (RDP) water supply (DWAF, 1997). The South African Department of Water and Sanitation supports a national SWH programme, which has a narrow but important focus on the construction of above- and below-ground rainwater storage tanks by rural households for food gardens and other productive water uses (Campisano et al., 2017). The intention was well highlighted in Chapter 4 of the National Water Resource Strategy 2 (NWRS 2) (Maphela and Cloete, 2020).

The national guidance for SWH system design gives several factors that must be considered or need to be undertaken to ensure that a constant quality of rainwater exists in South Africa. On SWH, the following were suggested:

- Animals and people should be prevented from contaminating rainwater collection surfaces. House roofs are generally the preferred collection surface;
- Rainwater collection surfaces should be constructed from inert materials and should be well maintained and cleaned (particularly at the end of the dry season) to prevent contamination; and
- A ‘first flush’ system should be incorporated into the rainwater collection system in order to remove as much contamination as possible before the storage tank starts to fill.

Furthermore, the scope and purpose of the manual were to guide the design, installation and management of domestic rainwater harvesting systems. The document contains vital information and decision support for all stakeholders' consideration, not neglecting other available information guidelines in international literature. The ultimate purpose of the guidelines was to enhance water security by mainstreaming domestic rainwater harvesting into the development and management of water resources in South Africa. It was divided into the following information sets:

- An overall introduction and discussion on domestic rainwater harvesting within the South African context;
- The current existing enabling environment: legal framework and institutional arrangements, or the lack thereof;
- The factors that can affect rainwater quality and suggestions on how these risk factors can be mitigated through the appropriate design, installation of rainwater harvesting systems, and use of appropriate household water treatment;
- The first point of contact for rainfall, the catchment area and conveyance systems required to transfer the rainwater collected on the rooftops to the storage tanks;

- The issues that must be considered when selecting, sizing and installing a storage tank. It therefore guides how to optimise the tank size and maximise system collection efficiency;
- A synopsis of the various components that comprise a dual system: guidance on how to assess and then mitigate the risks associated with cross-connection and backflow;
- Guidance on the selection, installation and management of the appropriate type of overflow-handling system;
- Financial assessment; and
- While water-related legislation that provides a proper enabling environment for the integrated management of water resources is in place, its implementation still proves to be a challenge.

The South African water experience is unique since access to water by most of the population was restricted by the apartheid regime up until 1994. To convolute the situation further, acid mine drainage from defunct and flooded underground mines severely threatens South Africa's scarce water resources (Naicker et al., 2003; Oelofse et al., 2007; Hobbs et al., 2008).

Stormwater management in South Africa has been well-researched into both in principle and implantation (Pollard and Du Toit, 2008; Mukheibir and Sparks, 2003; Beck et al., 2016; Kativhu et al., 2020). Rooftop SWH systems are the readiest source of drinking water in rural areas, especially in the Eastern Cape and KwaZulu-Natal (Ndeketeya and Dundu, 2019; Yosef and Asmamaw, 2015). It promotes improved management practices in the cultivation of corn, cotton, sorghum and many other crops in addition to a water supply for livestock consumption (Macauley and Ramadjita, 2015; Kusangaya et al., 2014).

However, the impacts of different prognostic climate changes on smart city water requirements under South African weather conditions have only been studied in scattered and few studies (Olabanji et al., 2021; Dube et al., 2020; Zubaidi et al., 2020; Elum et al., 2017). Thus, this study is the first attempt to

address the impacts of projected climate change on smart city water development and assess alternate water augmentation systems that can complement the water demand.

2.12 Methods for rainfall variability measure

The possibility of temporal changes in rainfall patterns can be analysed using two locations that have longer daily records, while the Spatial distribution could also be investigated from correlations between distances and rain catch (Cristiano et al., 2017). The temporal and spatial distribution of rainfall patterns are indicated by the most common statistical method of Measures of Central Tendency, Dispersion and Symmetry (Cheung et al., 2008). The central tendency of a random variable (x) such as rainfall is its mean or average value (μ_x). The most common measure of dispersion on the mean is the variance or standard deviation, while the coefficient of skewness depicts their relative measure of skewness. They may tail off to the right or the left and, as such, are said to be skewed. A relative measure of skewness can be obtained by dividing the difference in the mean and the mode by the standard deviation.

The gamma probability function is given in Equation 2.10:

$$\Gamma(y) = \int_{\beta}^{\alpha} y^{(x-1)} e^{-y} dy \quad \text{Eqn. 2.10}$$

Where:

α = Shape parameters

β = Scale parameters

x =precipitation amount in a particular month (mm)

$\Gamma(y)$ = Gamma function

Integrating the probability function, the cumulative probability function is yielded, which is given in Equation 2.11:

$$G(y) = \int_0^y G(y) dy = \frac{1}{\beta^n \Gamma(\alpha)} \int_0^x y^{(n-1)} e^{-\frac{y}{\beta}} \quad \text{Eqn. 2.11}$$

Gamma distribution is undefined when $y=0$, thus this accounts for a zero-precipitation value.

2.12.1 Standardized precipitation anomaly index

The Standardized Precipitation Anomaly Index (SPAI) is a statistical tool used to depict the fluctuation exhibited by the hydro-meteorological parameters (Mlenga and Jordaan, 2020, Monish and Rehana, 2020). Similarly, the Standardized Rainfall Anomaly Index (SRAI) can be used to determine dry and wet years using Equation 2.12.

$$Z = \frac{x-\mu}{\delta} \qquad \text{Eqn.2.12}$$

Where z = standardized rainfall anomaly Index (SRAI); x =annual rainfall total observation each year; μ = Mean annual rainfall of a period considered; and δ = Standard deviation of a period considered. Table 2.5 depicts the SPAI value which was categorised based on Gitima et al. (2021). This category was modified after McKee et al. (1993).

Table 2.5: Standardized Precipitation Anomaly Index

SPAI	Category
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

Source: McKee (1993)

There are different indices to describe the rainfall variability based on monthly and annual rainfall, maximum and minimum rainfall (Rapolaki, 2020). SAI was used to provide a synthesis of the average area behavior of precipitation at a specified time. The index was found to be effective for rainfall variability and

trend detection (Shahid, 2010; Alemu and Bawoke, 2020). Equation 2.13 and Table 2.6 depict the SPAI calculation procedure and RAI value classification.

$$X_{ij} = \frac{1}{N_j} \sum_{i=1}^{N_j} (R_{ij} - R_i) / \sigma \quad \text{Eqn. 2.13}$$

Where: X_{ij} = precipitation departure for j^{th} year.

R_{ij} = the year precipitation total at station i

R_i = the mean of station i 's total for the base period

σ = the standard deviation for the period

N_j = number of years with complete records in the year j

Table 2.6: SPAI and its value category

Precipitation anomaly index value	SPAI value classification
> 2.0	Extreme wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.84 to 0.99	Near normal
0.84 to -1.28	Moderate drought
-1.28 to -1.65	Severe drought

2.12.2 Simple Ratio of Precipitation

Moreover, the use of the Precipitation Ratio (PR) may give the stability of rainfall with a special relationship (Safeeq et al., 2016). The higher the ratio, the higher is the abnormality in rainfall and vice-versa. The abnormalities of rainfall at any location are worked out by a simple ratio of precipitation, which can be expressed as in Equation. 2.14:

$$PR = \frac{(P_{max} - P_{min})}{P_{mar}} \times 100 \quad \text{Eqn. 2.14}$$

Where PR = Precipitation ratio; Pmax= Maximum mean annual rainfall; Pmin = Minimum mean annual rainfall; Pmar = Mean annual rainfall.

2.12.3 Coefficient of Variation (CV) of rainfall

The coefficient of variability (CV) is expressed as the percentage ratio of the standard deviation to the mean rainfall for a given period as expressed by Wong et al. (2009). It measures the dispersion of a probability distribution (Martinez-Pons, 2013). CV can be calculated by Equation 2.15:

$$CV = \left(\frac{S}{X} \right) \times 100 \quad \text{Eqn. 2.15}$$

where CV is the coefficient of variation, S is the standard deviation, and X is the mean.

2.12.4 Precipitation Concentration Index (PCI)

The PCI allows for quantifying the relative distribution of precipitation patterns. It also provides a good presentation to the spatial variability of monthly precipitation (Coscarelli and Caloiero, 2012; Raziei et al., 2008) and information on long-term total variability in the precipitation amount record (Luis et al., 2011; Martins et al., 2012). The Precipitation Concentration Index (PCI) allows quantifying the relative distribution of Precipitation patterns into uniform, moderately seasonal, seasonal and irregular categories (Ezenwaji et al., 2017). PCI and its category are shown in Table 2.7 and PCI can be calculated using Equation 2.16, as given by Gocic et al. (2016).

$$PCI = 100 \cdot \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i \right)^2} \quad \text{Eqn. 2.16}$$

where P_i is the precipitation amount in the month i . The classification of PCI values is shown in Table 2.7.

Table 2.7: PCI and its Rainfall category

PCI	Category
8.3- 10	Uniform
10-15	Moderately seasonal
15-20	Seasonal
50-100	Irregular

2.12.5 Precipitation Seasonality Index

The Precipitation Seasonality Index (PSI) was used to detect the seasonality of rainfall. Although it affords a simple arithmetic description of precipitation in season, it is an ideal tool for the study of temporal and spatial variation in seasonality (Sumner et al., 2001). The seasonality index classification, after Lawler and Walsh (1981), depicts that the higher the index values, the more the overall departure from an equal distribution of precipitation through the year, as depicted in Table 2.8.

Table 2.8: Seasonality index classes

Sii	Precipitation regime
< 0.19	Precipitation spread throughout the year
0.20 - 0.39	Precipitation spread throughout the year, but with a define wetter season
0.40- 0.59	Rather seasonal with a short drier season
0.60 -0.79	Seasonal
0.80 -0.99	Largely seasonal with a long dry season
1.00 -1.19	Most precipitation in < 3months
> 1.20	Extreme seasonality with almost all precipitation in 1- 2 months

Aadapted after Lawler and Walsh, (1981)

The seasonality index is given as follows:

$$SI = \frac{1}{R} \sum_{n=1}^{12} \left| \bar{X}_n - \frac{\bar{R}}{12} \right|$$

Eqn. 2.17

where X_n is the mean rainfall of month n , and R is the mean annual rainfall.

Due to noise in averaging the monthly value, the long-term mean Sli for each catchment can be used to overcome this shortcoming. The long-term mean Sli for each site can be calculated using the summation of the individual seasonality index (Sli) over a longer period, and j can be found as follows in Equation 2.18:

$$SI = \frac{1}{j} * \left(\sum_{j=1}^{j=n} SI_{ij} ; j = \text{number of years} \right) \quad \text{Eqn. 2.18}$$

2.13 Water balance assessment in a city

The estimation of catchment water balance is needed to give an overview of periodic water availability for water resources planning and management. The quantification of individual components of the hydrological cycle, especially at the catchment scale, is a crucial step in determining the water balance configuration for a proposed city. In a city system with no external inflows from neighbouring catchments and territories, the water is entering the system via precipitation (P), converted into evaporation (E) and/or runoff (R) (surface, sub-surface, or groundwater) and associated storage (S) or change in storage ΔS during the time investigated. This can be expressed as in Equation 2.19.

$$\Delta S = \text{input} - \text{Output} \quad \text{Eqn 2.19}$$

A further breakdown of Equation 2.19 can be as presented in Equation 2.20 as:

$$\Delta S = I_s + I_u + P_i - Q_s - Q_u - E_i \quad \text{Eqn 2.20}$$

where:

ΔS = Change of water storage; I_s = surface inflow; I_u =underground inflow; P_i =River precipitation; Q_s = surface outflow; Q_u =underground outflow and E_i =River evaporation.

The water budget for a short time-scale like the monthly time-scale can be represented as in Equation 2.21 to Equation 2.23, as suggested by Ferencz and Dawidek (2014).

$$P = R + E \pm \Delta S \quad \text{Eqn. 2.21}$$

$$P - (ET + RO) = 0 \qquad \text{Eqn. 2.22}$$

$$P - (ET + RO) = \pm\Delta S \qquad \text{Eqn. 2.23}$$

where P = precipitation, ET = evapotranspiration, RO = surface runoff, ΔS =change in storage.

Equation 2.21 is applicable for a case in which there was no significant change in total water storage in the basin (i.e. no significant change in groundwater, wither lake, or river levels) over the period for which the balance is set up. This assumes that there is no persistent climatic change in the basin that would cause amounts of water storage to change. Given these conditions, water entering the basin in the form of precipitation would simply equal the amount of water leaving the basin in the form of evaporation or runoff.

Evaporation from free water surfaces can be estimated by several methods such as Blaney Criddle, Modified Penman, Thornthwaite, and others (Sankarasubramanian and Vogel, 2002). The Thornthwaite method was used because it provides an estimate of potential evapotranspiration based on average monthly temperature and climatologic indices. This method is approximate but provides a reasonable estimate where sophisticated measurement equipment is not available. The Thornthwaite equation for Potential Evapotranspiration evaluation is shown in Equation 2.24 (Ferencz and Dawidek, 2014).

$$PE_{\text{month}} = 16 * (10T/I)^a * CF \qquad \text{Eqn. 2.24}$$

$$PE_{\text{annual}} = \sum PE_{\text{month}}$$

Where:

PE = Potential Evapotranspiration

T = Average monthly temperature °C; a = (T/5)^{1.514} unitless;

I = Sum of twelve monthly is unitless; and CF = Latitude correction factor unitless

Note: For any given month, if $T < 0$ then $i = 0$; that is, there is no PE for a month with average temperatures below 0.

The evaluation of the reservoir evaporation can be taken as the product of annual evaporation and reservoir surface area at $\frac{3}{4}$ maximum capacity. Likewise, the estimation of the watershed runoff depth/ the Reservoir Inflow can be done by multiplying precipitation by the runoff coefficient, i.e. runoff depth = $(P * C_w)$ (Fowe et al., 2015; Tian et al., 2021). From the above discussion and facts, it is clear that rainfall is the main source of water on earth, but it is not uniformly distributed in time and space. It provides the basis for the water resources utilisation model for a smart city development (Akuraju et al., 2020; Herslund and Mguni, 2019).

2.14 Development of a water utilisation model for a smart city

Water use refers to the amount of water applied to achieve various ends and can be divided into the following categories: Consumptive use and non-consumptive use (Parandvash and Chang, 2016). Consumptive use is mainly used in municipal, agriculture, industry and mining, in which water is the end in itself; whilst non-consumptive use includes in-stream uses such as hydropower, transportation and recreation, in which water is a means to an end.

The water utilisation model can be expressed as a multiple regression equation based on demand models which are typical of the linear, logarithmic or semi-logarithmic forms (Ghimire et al., 2016; Gargano et al., 2017; Villar-Navascués et al., 2020). Hassan and Jalut (2018a) use a logit regression model to regress demography parameters (age, educational level, marital status, etc.) to water service delivery principles, as illustrated in Equations 2.25 and 2.26:

$$D = a_0 + a_1x_1 + \dots + a_nx_n + E \quad \text{Eqn 2.25}$$

$$\ln D = b_0 + b_1 \ln x_1 + \dots + b_n \ln x_n + E \quad \text{Eqn.2.26}$$

Where D denotes demand and f is the function of demography explanatory variables x_1, x_2, \dots, x_n .

$$Z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \dots \dots \beta_n x_n \quad \text{Eqn 2.27}$$

Where:

x_1 =Age (years)

x_2 =Educational level (No. of years spent in school)

x_3 =Marital status. Dummy variable (married=1, unmarried=0)

x_n = can be any Household variables and E is a random error variable describing the joint effect on D of all the factors not explicitly considered by the explanatory variables.

2.15 The research gaps identified in the literature works

Due to the escalating economic costs of supplying water via centralised supply systems, there is a renewed interest in decentralised water supply infrastructures where necessary on-site availability and public service delivery will be at the minimum. This has made the need for a SWH system to constitute a significant portion for residential and commercial water augmentation and alternate use demand (Kahinda et al., 2007).

Also worthy to note amongst the notable factors affecting the possibility of adopting stormwaterharvesting in a particular area are the highly dependent rainfall frequency and the intensity of rainfall (Bell et al., 2020). The uneven distribution of rainfall is a major contribution in sizing a storage tank for SWH in any given year. It varies both in temporal and spatial distribution, which can sometimes be erratic. Thus, water harvesting practices in various countries have therefore been described based on agro-ecological regions which have homogeneity in biophysical attributes of soil, weather, topography and land-uses (Garg, 1991; Djukić and Antonić, 2016; Chanza, 2018).

In addition to other important factors identified in the literature review that can affect the choice and adoption of the SWH system are the catchment area, type of surface and cultural background, which can be adjusted to suit individual needs (Holden, 2019; Van Opstal et al., 2021). Thus, the adaptability and viability of stormwater harvesting systems is a function of cultural acceptability; the quality and quantity of water available from other sources; household size; and per capita water requirements, which make it serve only as a supplementary source of freshwater for the household (Christian Amos et al., 2016; Deng et al., 2019; Fisher-Jeffes et al., 2017).

Furthermore, records of serious illness associated or linked to stormwater supplies are few, indicating that stormwater harvesting technologies are effective sources of water supply for various purposes, depending on the collection methods (Campisano et al., 2017). Contrary to popular beliefs, stormwater quality often improves as bacteria and pathogens gradually die off (Gould and McPherson, 1987).

2.16 Research gaps addressed by the study

Having identified advanced research efforts on SWH by capturing recent progress, key constraints and critical opportunities that are yet to be tapped for sustainable city water supply and water conservation technology, this study integrates regenerated water uses as an alternate to the limited water sources and retrofits the use of SWH in smart city integration under different climatic conditions for sizing the storage capacity requirement.

In addition, this study addresses the various alternatives sources of water for smart city usage and provides a solution in alleviating the impact of climate change on water sources. This will enable the public and private sectors to understand the potential risks, as well as what general adaptation and mitigation measures can be implemented to reduce the study area's risk.

This study adopts a combined detailed qualitative and quantitative approach to address the imbalance of water demand using various analytical and data-driven regression in selecting the most suitable engineering and environmental hazard consideration for healthy living conditions. Finally, the study proposes an alternative water supply augmentation source that is sustainable for new smart cities under different climatic scenarios within the KwaZulu-Natal Province of South Africa considering the socio-economic, technical and financial barriers hindering its applications.

2.17 Concluding summary of the chapter

From the above discussion and facts, the chapter provided the reader with a review of state-of-the-art literature works related to the study objectives, existing urban models, applied methodology, advantages and disadvantages of different hydrological models' applications. In addition, the chapter assists the reader(s) to understand what climate change is; its impact on water resources; and how to minimize the impact of climate change on water resources. The chapter enunciated various methods of measuring rainfall variability; the role of hydro-meteorological variables in assessing water balance; and highlighted the problems and opportunities in the use of stormwater harvesting systems. The chapter concluded with theoretical information on regional SWH best-practices for climate-smart city adaptation assessment. Chapter Three, which follows, details the study area description and research methods employed in achieving the research aim and objectives.

CHAPTER 3: THE STUDY AREA AND RESEARCH METHODOLOGY

3.0 Introduction

This chapter details the study area description and research methods employed in achieving the overall aim and the research-specific objectives. The chapter starts with the study area's climate, geology and hydrogeology characteristic description, with the proposed sustainable new smart city development under different climatic scenarios within the KwaZulu-Natal Province of South Africa, using the Jozini area as a case study. The normality and probability tests were conducted on the dataset to study the data distribution as part of the preliminary data analysis. Furthermore, the chapter explains the employed methods used to address each of the research objectives, thus laying a strong framework based on the theoretical background and information from the literature review in achieving the study aim and objectives.

3.1 Research study area

The selected study area (Jozini) was in the semi-arid region of KwaZulu-Natal Province. Jozini (29.86°S, 31.01°E) is one of the urban centres in the province. The area, amongst other major cities, is challenged with immense water problems due to the growing demand for water services because of population growth. The choice of the selected study area was based on life patterns/ social classification and geographical densification, and historically recorded on variant weather patterns due to observed rainfall variability and the evolving township water supply scheme. Jozini is located in the catchment area of the Pongola River, which is a major river in the Usutu to Mhlathuze Water Management Area (WMA) in the north. The study area (Jozini) is a settlement in the uMkhanyakude District Municipality in the KwaZulu-Natal province of South Africa. Figure 3.1 depicts the study area in relation to South Africa. It is a small town on the main route to Mozambique, and it is close to the Pongolapoort Dam, also known as Lake Jozini. It has an area of 3442 km², with an estimated population of 186 502 people (SSA, 2011).

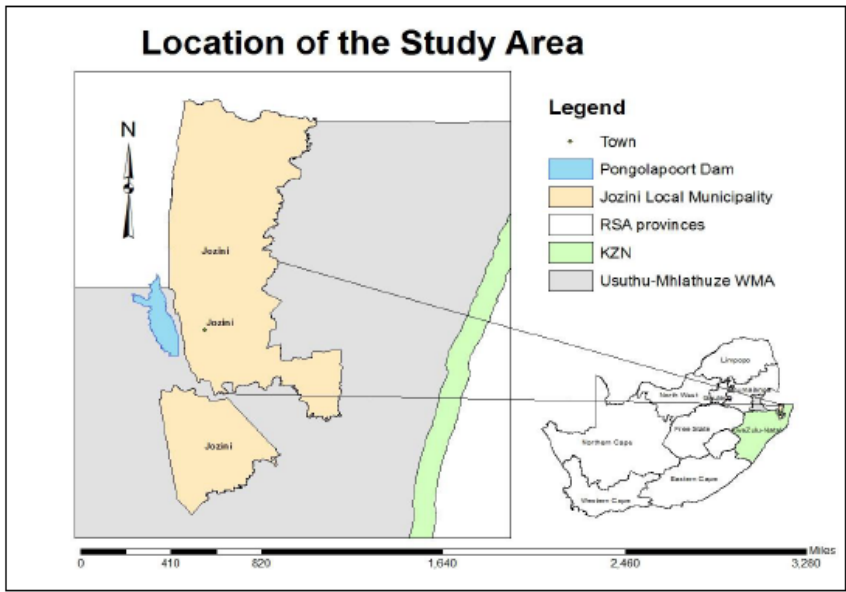


Figure 3.1: The locality of the study area
(Mofokeng, 2017)

The WMA borders on Mozambique and Swaziland and shares two of the major rivers (Usutu and Pongola) with these countries. The area receives an annual average rainfall of 414 mm. (DWAf, 2004a) (Figure 3.2).



Figure 3.2: The Usutu to Mhlathuze WMA's sub-catchments
(DWAf, 2004a)

The study area aligned itself the country's four seasons, namely autumn (March-May), winter (June-August), spring (September-November) and summer (December-February). Most parts are characterized by summer rainfall, while rainfall occurs during winter in others. Raw water is sourced from the Pongolapoort Dam situated on the Pongola River, where it is thereafter treated at Jozini-Malobeni Water Treatment Works (WTW). The study area is rural and is characterised by commercial and subsistence dry-land agriculture. The main forms of commercial agriculture are sugarcane and timber, with cotton, sisal and pineapples as well (DWA, 2010). Recent socio-economic development in the area has escalated the discharge rate of disturbances and disasters in ecosystems. Thus, consideration of the ecosystems and sustainability in smart cities development are two prime targets. The following section describes the climate, geology, hydrogeology and soil maps of the area as a precondition to evaluate the surface runoff potential of the catchment and the suitability of the area for new smart city development or retrofitting.

3.2 The major climatic conditions of the area

Understanding the climatic conditions of the study area is very important because this influences the catchment hydrology, which in turn aids evolving a smart city. Some of the meteorological factors that greatly influence the design of water storage structures, reservoirs, crop production and water management systems are rainfall, evaporation, spatial radiation, temperature, sunshine, wind, etc. Table 3.1 presents the study area weather averages from 1999 till 2018 as collated by the South African weather agency (SAWs) from [Climate-Data.org/South Africa/KwaZulu-Natal /Jozini](https://climate-data.org/South-Africa/KwaZulu-Natal/Jozini). Table 3.1 depicts the meteorological variation of the area.

Table 3.1: Jozini weather by monthly average (1999-2018)

	Avg. Temperature °C	Min. Temperature °C	Max. Temperature °C	Precipitation (mm)	Humidity (%)	Rainy days (d)	avg. Sun hours (hours)
January	24.9 °C	21 °C	29.9 °C	97	71%	9	6.6
February	25 °C	21.1 °C	30 °C	77	72%	8	7.1
March	24.3 °C	20.4 °C	29.5 °C	78	72%	8	7.3
April	22.1 °C	17.9 °C	27.3 °C	38	71%	5	7.1
May	20 °C	14.8 °C	26.2 °C	22	67%	2	7.9
June	17.8 °C	12 °C	24.4 °C	11	63%	2	8.0
July	17.3 °C	11.5 °C	24.1 °C	12	62%	2	7.8
August	19.1 °C	13.4 °C	25.9 °C	19	60%	2	7.8
September	20.8 °C	15.4 °C	27.5 °C	30	61%	3	7.2
October	21.6 °C	17 °C	27.5 °C	64	66%	7	6.2
November	22.9 °C	18.5 °C	28.2 °C	84	69%	8	6.2
December	24.4 °C	20.2 °C	29.7 °C	89	69%	8	6.6

Source: Climate-Data.org /South Africa/KwaZulu-Natal /Jozini

There is a difference of 86 mm of precipitation between the driest (June) and wettest (January) months. During the year, the average temperatures vary by 7.7 °C. The mean annual temperature in the study area for the period (1999-2018) was 18.8°C, and the mean maximum and mean minimum temperatures were 25.2°C and 12.4°C respectively. The average monthly temperature is 21.7°C while the precipitation is about 621 mm per year. The driest month is June, with 11 mm of rain and 4°C in temperature, while the most precipitation falls in January with an average value of 97 mm.

3.2.1 Rainfall

The study area lies in the semi-arid region of the country. The main rainfall period for the location is characterized by either summer (December-February) or winter (June-August) months. However, both seasons as well as rainfall patterns often overlap with neighboring months, that is, the summer rainfall period sometimes ranges from October-March and winter from April-September. This option is based on an analysis of rainfall stability over the study period and

estimated water balance (not shown) and is supported by Fisher-Jeffes et al. (2017) and Mofokeng (2017). Figure 3.3 shows the average rainfall (mm) by year as a line chart. There are 56 number of distinct rainfall (mm) that was found.

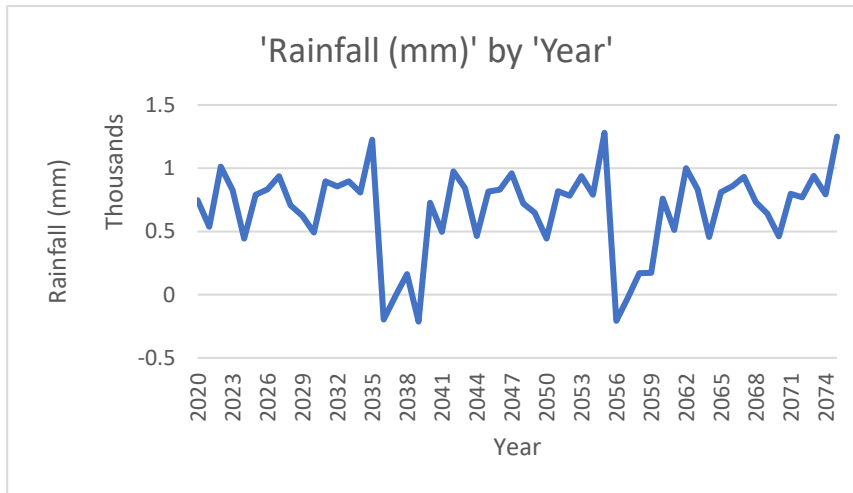


Figure 3.3: Shows the future projected average rainfall (mm) by year

3.2.2 Geology and hydrogeology

The geology and hydrogeology understanding of the area assists in identifying anomalous areas associated with significant sub-surface features. It gives insight into the lithological sections and fractures beneath the surface in determining the potential water availability and water quality. Usually, these are investigated by geophysical boring of trial pits and holes. The hydrogeology investigation is very effective in evaluating the sub-surface geological structures; potential pathways of leakage; resistive bedrock discontinuities; and the detection of local anomalies in the site, especially as part of the engineering sites criteria (Nabwire, 2020). Jozini area is underlain mostly by the rocks of the Lebombo and Drakensburg Group, which are the uppermost rocks of the Karoo Super-group (Botha & Singh, 2012). Boreholes drilled in this area generally have low yields in the range of 0.15 to 0.65 l/s. Figure 3.4 illustrates the geological map of the Karoo Super-group.

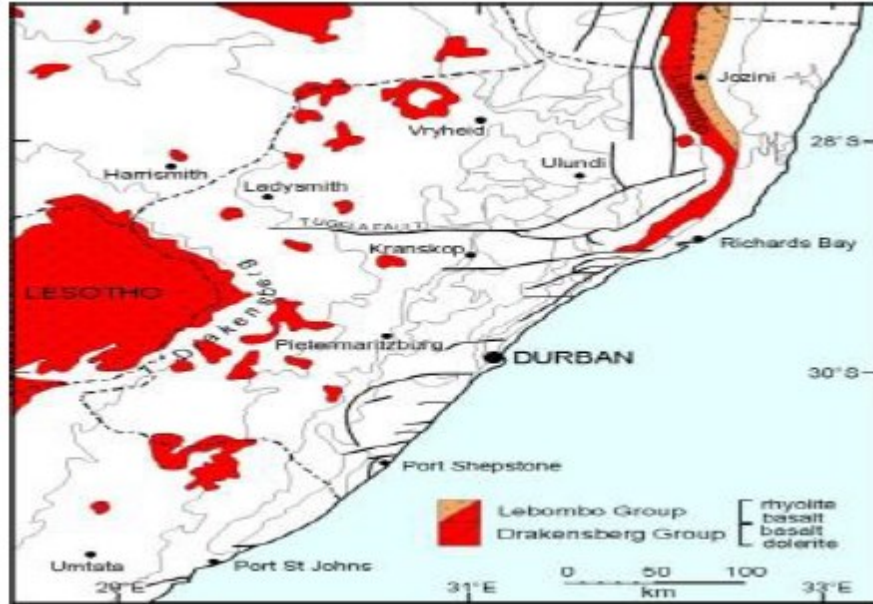


Figure 3.4: The geological map of the Karoo Super-group
Adapted from DWAF (2004b)

3.2.3 Urbanisation

Urbanisation does not only provide opportunities for jobs, but also serves as an engine for Urbana's economic growth, compact urban land use with increased vulnerability and exposures of the cities. Moreover, the continuous advancement of urbanisation is associated with the problem of urban domestic wastewater. Furthermore, the big worry is urban growth disasters with population, and the number of people killed will increase if the city's government fails to intervene. The bulk and retail water supply in the town of Jozini (and the entire Jozini Local Municipality) is serviced by the Umkhanyakude District Municipality (UDM), which acts as the Water Service Provider (WSP). Water is then supplied to the town of Jozini and the surrounding communities by the Jozini-Malobeni Water Supply Scheme (Mofokeng, 2017).

3.3 Research Design

The research design was based on primary and secondary sources of data, such as questionnaires, interview records and reports, which were used in designing a

stormwaterharvest system in new smart cities under different climatic scenarios in KwaZulu-Natal, South Africa. The research design was based on collected survey information which was verified from records to establish the facts that defend the research question hypothesis. This approach was well suited for trend analysis and abrupt trend detection in the collection of the online dataset while the interview sample assists in selecting the best engineering and environment hazard factors to consider in answering the research objectives.

3.4 Research Approach

The research was approached using the triangulation method in order to justify acceptable opinions where both the qualitative and quantitative responses are in opposing positions. The triangular technique uses multiple methods of data collection, intending to increase the reliability of the observation. It was used due to some findings that require the personal assessment of the provincial information collected from respondents. The administered questionnaire was used to obtain relevant data about the subject matters. It consists of numerical data which can be quantified, while the quantitative data help to affirm and to bring clarity to the quantitative collected data. It consists of the reports and records of the conducted interview with stakeholders in water and climate change which gives the expertise side to the comments and collected documents for verification.

3.5 Sampling Strategy

Rahi (2017) describes a sample as a sub-group of a population selected to participate in research or an inquiry. In so doing, a precise process or procedure is followed by the investigator or researcher to extract the required sample from the whole population. This process of extraction is termed a ‘sampling strategy’ (Alvi, 2016). In quantitative studies, only a sample, commonly referred to as a sub-set of a population, is chosen for a particular study; whilst in qualitative studies, a selected few who possess some traits or qualities may be chosen (Creswell and Poth, 2016). Cognizance and priority are given to the research aim and objectives as these are amongst the determinants of who the study

participants should be. A further determining factor is the nature of the research. A study such as the current one requires participants who have some level of expertise on themes such as stormwater, climate change and water management in general. Having discussed the sampling strategy herein, the sections below provide discussion on the sampling technique, target population, and size, as well as the rationale for choosing a non-probability sampling technique as part of the employed research methods.

3.4.1 Sampling technique

The sampling technique, as explained by Johnson (2014), is a sampling process that involves selecting units or elements from a relevant population, otherwise referred to as the “population of interest”. Through the sample, a researcher can obtain generalisable results that are representative of the population from which the sample was chosen. As mentioned by Sharma (2017), there are two main types of sampling techniques, namely probability sampling technique and non-probability sampling.

In the probability sampling technique, each element from the study population has an equal chance of being selected; whereas in non-probability sampling, elements do not have an equal chance of being selected (Etikan and Bala, 2017). According to Mitchell and Education (2018), the major types of probability sampling techniques are inclusive of simple random sampling, stratified sampling, cluster sampling and systematic sampling. Etikan and Bala (2017) also outline convenience sampling, quota sampling, purposive sampling as well as snowballing as the main types of non-probability sampling techniques/ methods. In selecting the participants, the non-probability sampling technique was used. Attributes of purposive sampling and snowballing were collectively used while selecting research participants for the study.

As earlier mentioned, the snowball sampling method was adopted. Snowballing is often relevant when participants of a study are difficult to locate. These may

include participants such as undocumented immigrants, individuals with specific skill sets and homeless people, amongst other populations that may be difficult to find. In snowballing, a researcher collects data from a few people (participants) whom he or she can find, then ask the same people (participants) to recommend where potential participants may be found or people whom such participants relate with. Hence, the researcher continuously solicits referrals for other potential participants till all the contacts have been exhausted (Mitchell and Education, 2018; Sharma, 2017).

These later sections further specify the target population, size and rationale for selecting the non-probability sampling technique, namely purposive and snowballing non-probability sampling methods.

3.4.2 Target population and size

A population, when defined from a research perspective, is said to be the universe of attributes, subjects or elements from which an investigator or researcher draws inferences or deduces a sample (Rahi, 2017). Similarly, Tewari and Surbhi (2016) define a “*population as the overall membership of a distinct set of individuals, events or objects*”. The sample size is defined as the act of selecting the number of replicates or observations to include in a statistical sample (Bartlett et al., 2001). A population is the entire set of cases in which a study is interested. It is the full set of individuals or objects having some common characteristics. The sample is a part of the population where the study takes place- it is a fraction of the whole, selected to participate in the research study. In this study, snowball sampling techniques were used.

Due to the nature of this research, which requires the insights of experts, scientists who are well-grounded in storm-water-related issues, climate change and water management were consulted both from fellow researchers and experts from the Department of Water and Sanitation (DWS), Durban. Thus, structured interviews were conducted with senior personnel from the DWS, while other

personnel were administered the questionnaires. A total of 11 senior personnel were interviewed, while questionnaires were administered to 39 employees at the DWS. Amongst these 39 employees, the researcher was able to retrieve 32 completed questionnaires. The remaining questionnaires were either not filled (which makes them void) or were not completed at all.

3.4.3 Rationale for choosing a non-probability sampling technique

This section justifies why a non-probability sampling technique was used in this study. It further explains why the participants were suitable, as well as reasons for using the purposive and snowballing methods.

While some experts in qualitative research avoid the topic of “*how many*” interviews are enough, there is indeed variability in what is suggested as a minimum. An extremely large number of articles, book chapters and books recommend guidance and suggest anywhere from 5 to 50 participants as adequate (Dworkin, 2012). In practice, the sample size used in a study is usually determined based on the cost, time or convenience of collecting the data, and the need for it to offer sufficient statistical power.

Non-probability sampling techniques, such as purposive sampling, can provide researchers with strong theoretical reasons for their choice of units (or cases) to be included in their sample (Etikan et al., 2016). Rather than using probabilistic methods (i.e., random selection) to generate a sample, non-probability sampling requires researchers to use their subjective judgments, drawing on theory (i.e., the academic literature) and practice such as the experience of the researcher and the evolutionary nature of the research process. Unlike probability sampling, the goal is not to achieve objectivity in the selection of samples or necessarily attempt to generalize, such as statistical inferences from the sample being studied being applied to the wider population of interest. Instead, researchers following a qualitative research design tend to be interested in the intricacies of the sample being studied. Whilst making generalisations from the sample to the population under study may be desirable, it is more often a secondary consideration.

In respect to the fact that the general populace may not have deep insights on stormwater, climate change or water management-related issues, the researcher believed that consulting experts or stakeholders was a meaningful and justifiable approach to answering questions posed in the interview schedule, as well as those found in the questionnaire. In line with the above justifications and relevance, the snowballing and purposive non-probability sampling techniques were used in this research.

3.5 Data Collection

Aside from the qualitative data collected from the interviews, the researcher distributed questionnaires to the DWS staff and customers residing in Durban and the study area to get information for the analytical part of the study. The primary data (online interview surveys and questionnaires) and secondary data used for this study include collected historical data from the South African Weather Agency (SAWs) for rainfall, temperature and streamflow (1980-2020), as well as future projected data from the World Bank (1980-2060). These datasets were supported with the study area geological map and hydrogeological information from works of literature to give a better understanding of the area.

It is important to evaluate how climate has varied and changed in the past. Past historical and future monthly mean rainfall and temperature data are obtained from the Climate Change Knowledge Portal of the World Bank as secondary data to complement the primary data. It is a Couple Model Intercomparison Project 5 (CMIP5) model consisting of change anomaly mean data for four (4) different scenarios for, namely low, medium-low, medium-high, and high emission scenarios that are available for download. The CMIP5 promotes a standard set of model simulations to evaluate how realistic the models are in simulating the recent past, providing projections of future climate change on two-time scales, near-term (out to about 2035) and long-term (to 2100 and beyond). The projected future rainfall emission scenarios in medium-high were employed for the prognostic annotated design of the smart-city, while other secondary data from

documented works of literature and the repository of SAWs was used to assess monthly mean historical rainfall and temperature baseline in seasonality for the duration of the study.

3.5.1 Validity of Data

Validity is defined as a measure of truth or falsity of the data obtained by using the research instrument. It could be classified as the internal and external validity of the measuring instrument. In this study, an expert was consulted to check the questionnaires before distributing them to the relevant participants. Modifications, where necessary, were made before actual data collection to measure the theoretical meaning, concepts and consistency of the language used to represent concepts. Moreover, a validity pre-test of the questionnaire was done for detecting irrelevant, ambiguous and redundant questions.

3.5.2 Sampling Design and Procedure

The design of the interview and the questionnaire was done in such a way that it elucidates worthwhile information from respondents. It has six basic information headings, namely:

- A) Demographic information;
- B) Water sources for domestic consumption. This includes the nature and type of municipal water supply system;
- C) Relationship between water sources and climate change;
- D) Barriers to efficient stormwater(rainwater) systems;
- E) Adaptation to climate change; and
- F) Recommended measures that may be used to sustain a viable stormwaterharvesting system in the study area/ Durban/ KZN.

The content of the questionnaire instrument was structured in the modified Likert fashion on a 5-point scale ranging from Strongly Agree (SA) to Agree (A), Neutral (N), Disagree (D) and Strongly Disagree (SD). Participants were then instructed to respond to their degree of agreement with the statements contained in the instrument. These questions were sufficient in designing the new city under different climatic conditions.

3.6 Pre data analysis

A descriptive statistical summary consisting of the mean, standard deviation, skewness and kurtosis of all the collections was presented. Before this, the preliminary analysis on normality and probability tests was conducted to study the data distribution and to test the data's reliability, consistency and accuracy. Reliability can be computed by taking several average measurements on the same subjects. A reliability coefficient of 0.60 or higher is considered acceptable for a newly developed concept (Raubenheimer, 2004). Likewise, by using Cronbach's alpha coefficient thumb rule, which lies between 0 and 1, a *value* of 0.70 and above is good; 0.80 and above is better; while 0.90 and above is best. A negative number indicates that something is wrong with the data.

The Kolmogorov-Smirnov normality test was used to show if the data is uniformly distributed, while the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test was used to test for stationarity in the dataset. It has the null hypothesis H_0 : that the variable from which the sample was extracted follows a normal distribution and vice versa. It is accepted if the null hypothesis P-value is lower than the 0.05 alpha significance level. Detailed results and the usefulness of these various pre-data analyses are discussed in Chapter Four under section 4.1.

Amongst the assumptions made/developed to guide each of the objectives are those enumerated below:

H₀₁: there is no significant relationship between climate change impacts on water yield and water balance.

H0₂: there is no significant relationship between the demographic data of an area and water consumption/ water usage quantification.

H0₃: there is no significant relationship between smart city development and catchment water resources configuration management.

H0₄: there is no significant relationship between meteorological data and predicting water availability either on a monthly or yearly basis.

3.6.1 Multivariate analysis of variance

The multivariate analysis of variance was used to test if there were statistically significant differences amongst the determinant variables. It entails the traditional cross-tabulations approach to report a statistical statement of significance. A p-value is generated from a test statistic. A significant result is indicated with $p < 0.05$, while a second Chi-square test was performed to determine whether there was a statistically significant relationship between the variables (rows vs columns). The null hypothesis states that there is no association between the two. However, the alternate hypothesis indicates that there is an association. Chi-square tests are interpreted using the p-values.

3.6.2 The Multifactor Analysis

Multifactor Analysis (MFA) is useful to uncover the latent structure (dimensions) of an asset of variables. It reduces attribute space from a larger number of variables to a smaller number of factors through its principal component analysis. The PCA as a choice of FA explains the contribution of the unobserved common features in a target event from observed ones. It reduces the variety of collected data matrices to form a few selected derived component variables, which form a true representation of the original sets. This was used in selecting the most influential parameter regarding the choice of the technical, financial, socio-economic and environmental factors that influence the smart city design.

3.6.3 Factor Analysis

Factor Analysis was used to represent several questions with a small number of hypothetical factors that can be combined to create a new variable, and a factor score variable contains a score for each respondent. In this study, Kaiser Meyer Olkin (KMO) and Bartlett tests were used to abstract the factor analysis for the primary data collected. These tests measure the strength of the relationship amongst the variables. The KMO determines if the responses given with the sample are adequate or not, and the result from this test should be 0.5 or more for satisfactory factor analysis to proceed. Bartlett's Test is another indication of the strength of the relationship amongst the subject variables. This tests the null hypothesis that the correlation matrix is an identity matrix. The result from this test should be 0.05 or less for satisfactory factor analysis to proceed.

3.7 Research methods breakdown

As mentioned in Chapter One and expatiated in Chapter Three under Section 3.4, a mixed design research approach was adopted, whereby both the qualitative and quantitative collected data were analysed in answering the research objectives. The triangulation method was used to justify the acceptable opinion where both the qualitative and quantitative responses are in opposing positions in selecting the best factors that influence the design. Details of the data analysis carried out include tables and figures for the chi-square test, regression, correlation and demography analyses. Factor analysis (FA) as part of the principal component analysis (PCA) was used in selecting the best consideration for the SWH system design for the augmentation of water sources for the smart city. The multivariate analysis of variance (MANOVA) was used to test the developed water utilisation regression model for the smart city demographic water consumption. All the study's statistical analyses were done in the XLStart statistical software package and Excel. The subsequent section details how each of the objectives was achieved.

3.7.1 Research methods for Specific Objective 1

- To assess the impacts of climate change and the imperativeness of sustainable and efficient stormwater harvest systems in new smart cities

Since rainfall is an important parameter of weather and climatology, the above-mentioned research objective was achieved through the efficacy of different time series models not limited to the standardized rainfall anomaly index, simple precipitation ratio, coefficient of variation in rainfall distribution, precipitation concentration index and the seasonal precipitation index, which were used to evaluate the impacts of climate change on the rainfall variability of the study area. Other inferential statistics techniques like Mann Kendal, Sen slope, correlations and multifactor analysis (MFA) were used to identify the abrupt change, trend pattern and preferred best factor consideration in retrofitting planning and designing a new smart city. The study looked at changes in the mean annual runoff and the associated impacts on the average water supply to the town in designing efficient stormwaterharvest systems as alternate water supply in new smart cities.

3.7.2 Research methods for Specific Objective 2

- To determine the social, economic and technical barriers to an efficient SWH system

Sections C and D of the survey interview and questionnaire were used to identify the barriers hindering an efficient stormwater system. Thereafter, multi-factor analysis as an integral part of the principal component analysis (PCA) was used in managing the trade-offs amongst the different barriers (social, economic and technical hindrances) towards an efficient stormwater system using two indices-engineering factor and environmental hazard factor consideration- in selecting the most influential factors to consider when designing a new smart city driver under different climatic conditions; while the interview response was used in this decision-making for adaptation in designing a smart city amongst future climate events.

3.7.3 Research methods for Specific Objective 3

- To evaluate the technical and financial feasibility of SWH integration in smart cities

Sections E and F of the survey questionnaire were used to evaluate the feasibility of the technical and financial viability of stormwater harvest system integration in smart cities. The ranked reduced factors of PCA were used in assessing the technical and financial feasibility of SWH integration in smart cities. This was also assessed through the qualitative interview responses using a stratified random sampling technique in which a simple random sub-sample was taken from different respondent strata in the same or equal characteristics (Sharma, 2017). This technique is less in error and enhanced the precision of the sample selection. In this case, the population of this study is stakeholder players at DWS, and the strata consist of Cooperative Governance and Traditional Affairs (CoGTA) participants at the conference. The analysis of the responses was summarised in a thematic heading.

3.7.4 Research methods for Specific Objective 4

- To design a sustainable and efficient pilot-scale engineering SWH system

Towards achieving this objective, the implication of the various hydro-meteorological trend analyses on temporal and spatial rainfall were carried out. Thereafter, the impacts on the water balance were examined. This helps in determining the reservoir storage capacity and expected total available water to be stored. Subsequent controlling variables and factors not limited to the structural stability of the building, road network and embankment designed within a certain factor of safety in designing for the worse condition were all considered. Figure 3.1 depicts the procedural block diagram.

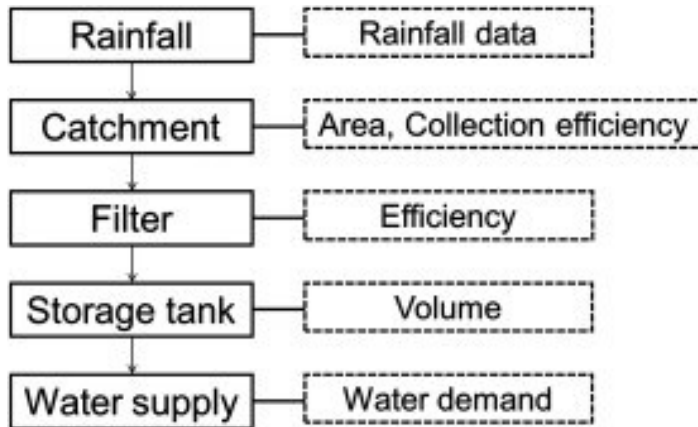


Figure 3.1: Components of SWH and their design parameters

Source: (Villar-Navascués et al., 2020)

In designing a sustainable and efficient SWH system for the area, a Geographic Information System (GIS) was used. This allows for merging vector-based soil map units with the raster-based land use and land cover (LULC) for the area. The resultant product is a raster image of each soil map unit and LULC classification, commonly referred to as a hydrologic response unit (HRU). The specific area of each HRU can be used to calculate a spatially weighted composite CN (CN_{comp}) for the catchment according to the following Equation (3.1)

$$CN_{comp} = \frac{\sum A_i CN_i}{\sum A_i} \quad \text{Eqn.3.1}$$

with A_i and CN_i being the area and CN for each HRU within the catchment, respectively.

The raster-based drainage network for the area was derived from the Digital Elevation Model (DEM) by the steepest decent method “lateral flow procedure” where the digital runoff routing was from the external upstream node to the internal downstream junction node. The discharge was then routed to the next downstream junction after the discharge routed from upstream tributaries was added together. The above routing algorithm continues until runoff flow is routed

to the outlet of a catchment. This routing phenomenon was modelled after the Muskingum method (Loucks and Van Beek, 2017), which is given as:

$$S = K\{XI + (1 - X)Q\} \quad \text{Eqn 3.2}$$

where S= storage (cumulative channel storage);

I = inflow (volume/time);

Q = Outflow (volume/time); and

K = Proportionality coefficient indicative of residence time, while

X = weighting factor

$$Q^{J+1} = C_1 * I^{J+1} + C_2 * I^J + C_3 * Q^J \quad \text{Eqn. 3.3}$$

Where

$$C_1 = \frac{\Delta t - 2 * K * X}{2 * K * (1 - X) + \Delta t}, \quad C_2 = \frac{\Delta t + 2 * K * X}{2 * K * (1 - X) + \Delta t}, \quad C_3 = \frac{2 * K * (1 - X) - \Delta t}{2 * K * (1 - X) + \Delta t} \quad \text{Eqn. 3.4}$$

The routing coefficients C_1, C_2, C_3 are required in the Muskingum routing techniques to generate the outflow (Q) hydrographs.

Where: Δt = routing period, days

Q^{J+1} = outflow of the first day

I^{J+1} = inflow of the first day

I^J = Inflow of the previous day

Q^J = Outflow of the previous day

J and J + 1 denote the times separated by the interval Δt^J

The dimensional weighting factor X and the corresponding channel constant K were obtained from Equation 3.1 through Grid base analysis. C_1, C_2 , and C_3 are computed from Equation 3.4.

Table 3.2 guides the curve number adjustment based on cumulative precipitation for the preceding 5 days, with adjustments for dormant and growing season conditions.

Table 3.2: Antecedent moisture condition assessment

AMC	Soil Wetness	Dormant Season	Growing Season
Total rain previous 5 days (mm)			
I	Dry but above wilting point	<12	>35
II	Average	12 - 28	35-53
III	Near Saturation	> 28	>53

(Modified for metric units from the National Engineering Handbook (NEH-4) US Department of Agriculture 1985)

Also considered were the environmental hazard factors, which include, but are not limited to, waste collection and disposal (solid and liquid); ventilation and lightening; recreation; and modern ICT infrastructure implantation in the area. All these factors were considered in designing the SWH augmentation system, which was made to topography terrain to allow water to find its natural course, while variation in expected climate was designed to 50%, 75% and 95% reliability monthly rainfall magnitude dependability frequency. This has proven useful in determining the storage capacity required for the different climatic conditions. Furthermore, the storage capacity was validated by the attested degree in the qualitative interview conducted. Amongst the highlighted criteria and factors considered in designing a sustainable smart city were those documented by Yan et al. (2020).

3.8 The Chapter summary

The chapter presented the study area description and research methods employed in achieving the aims and objectives. It provided the preliminary basis on data collection, sampling design and the procedural method employed in achieving each of the research objectives. The chapter further enumerated the procedural steps and factor consideration needed in designing a stormwater harvesting system; examined how much water is needed; and how essential cultural background in water usage, rainfall frequency and intensity is quite difficult to calculate because it required various factors, some of which are completely independent and time-varying to determine. Chapter Four presents the results and discussion for future impacts of climatic assessment on the catchment hydrology and runoff for stormwater harvesting.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents the results under the study's four specific objectives and signposts the reader to the applied methodology used accordingly in achieving the research objectives. This is concluded by providing an in-depth results discussion and implications for designing a sustainable smart city SWH configuration for the area.

4.1 Pre-data analysis results

The collection of reliable data is important for accurate study analysis and meaning/deduction making. Thus, for the quantitative analysis, normality and probability tests were applied to test the data distribution. Among the formal methods of testing the goodness of fit of time series data is the normal distribution assumption. These include the use of Chi-squared test, the Kolmogorov-Smirnov test, the Probability Plot Correlation Coefficient (PPCC) test, Coefficient of determination (R^2), mean absolute percentage error (MAPE), and mean squared error (MSE). Apart from these formal tests, it is also possible to informally infer the form of the probability distribution by plotting the histogram of the data as done in this study. The histogram may either be symmetrical, indicating that the use of the normal distribution may be plausible, or it may be asymmetrical, indicating a non-zero skew, which cannot be modeled with the normal distribution.

The qualitative datasets were designed to ensure that the questions were relevant and allowed for any changes that needed to take place to ensure that content validity was maintained. Furthermore, the meteorological data (precipitation and temperature) required for assessing the impact of the climate change of the area before the design and operation of the SWH under varies climatic scenarios were subjected to a rigorous scientific test for their reliability, consistency and accuracy. Both the historical monthly temperature and rainfall for the watershed (1991-2018) and downscale projected future data span (2020-2075) for

precipitation sums (mm) and mean air temperature (°C) was sought from the World Bank online database for usage. The results of the various preliminary data analyses are presented below.

4.1.1 Abrupt change detection

Table 4.1 depicts the Kolmogorov-Smirnov normality test to show whether the collected data is uniformly distributed. Thereafter, a homogeneity test was performed to check whether the data are from the same sample stations, as well as whether there is a date at which there is a change in the data sample. The result of the Kolmogorov-Smirnov normality test is shown in Table 4.1 below.

Table 4.1: The Kolmogorov-Smirnov normality test

Variable\Test	Shapiro-Wilk	Anderson-Darling	Lilliefors	Jarque-Bera
Ave.Rainfall (mm)(yearly)	0.000	<0.0001	<0.0001	0.005

Test interpretation: since the null hypothesis (H0) assumed that the variable from which the sample was extracted follows a normal distribution, the result of the Kolmogorov-Smirnov normality test shows that the computed p-value in Table 4.1 is lower than the significance level $\alpha=0.05$. Thus, one may conclude that the variable from which the sample was extracted does not follow a normal distribution. Pettit's homogeneity test (SNHT) is presented in Table 4.2.

Table 4.2: Pettit's and SNHT Test

	Pettitt	SNHT test
Ave.Rainfall (mm)(yearly)	0,537	0,707

In conclusion, as the computed p-value is greater than the significance level $\alpha=0.05$, the data are homogeneous and there was no date at which the data exhibited anomaly. Figure 4.1 captures Pettit's homogenous test graph.

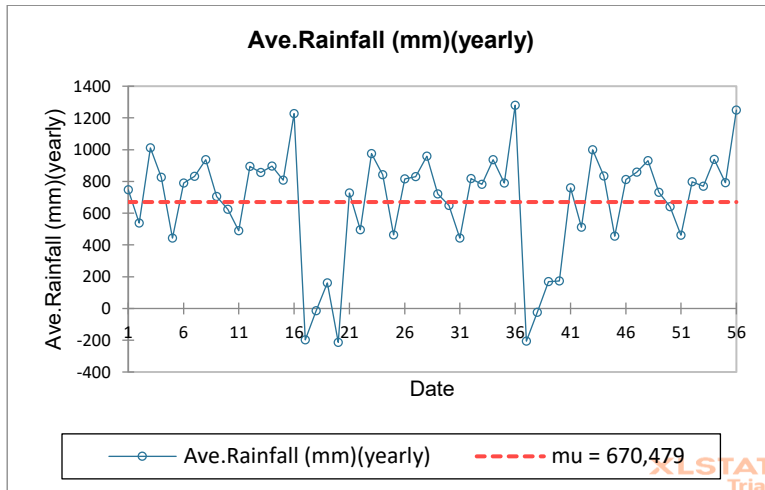


Figure 4.1: Homogeneous test graph

4.1.2 Data Reliability Test

Table 4.3 depicts the results of Cronbach's alpha and Standardized Cronbach's Alpha reliability tests for the precipitation and average temperature for the area.

Table 4.3: Cronbach's alpha reliability tests

Cronbach's alpha	Standardized Cronbach's Alpha
Precipitation 0.65000	Temperature 0.765000

Since the average alpha coefficient obtained is 0.732, this indicates a good ability of the dataset's internal consistency.

4.1.3 Stationarity detection test

The test for stationarity on the series following differing performance was carried out using the Kwiatkowski–Phillips–Schmidt–Shin (KPSS test) for a fair representation of the catchment area. The trend and lag short average on rainfall (mm) and temperature for a period (2020-2075) is depicted in Table 4.4 below.

Table 4.4: Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test

	Precipitation	Temperature
Eta (Observed value)	0,095	0,079
Eta (Critical value)	0,144	0,154
p-value (one-tailed)	0,202	0,302
alpha	0,05	0,05

Test interpretation: H_0 states that the series is stationary. H_a states that the series is not stationary. Conclusion: Accept H_0 since $p > 0.05$ and conclude that the data series is stationary.

4.2 Results and discussions for Specific Objective 1

In assessing the impacts of climatic change on the catchment hydrology, the abrupt change detection in time-series statistical analysis was used for change detection in rainfall and temperature patterns, which subsequently affect the streamflow. Thereafter, a standardized rainfall anomaly index (SRAI), precipitation concentration index (PCI) and coefficient of variation were computed based on monthly, annual and seasonal rainfall and temperature data sets from 2020 – 2075 for the study area; while the imperativeness of sustainable and efficient stormwaterharvest systems in new smart cities was assessed through the respondents' interviews, which was supported with work from the literature review.

4.2.1 Statistical summary for historical and projected future dataset

Table 4.5 summarises the projected statistical time distribution for the study area. The skewness from the table depicts a range between -1.05 to -0.5 negative skewness value (i.e. the degree of asymmetry measures), which violated the assumption of the normality test. The Kurtosis measures the level of sharpness or flatness of the normal curve, (Martins et al., 2012) and the obtained values of -0.42 and 0.91 depict the extreme flatness at the two ends.

Table 4.5: Monthly statistical summary of average rainfall from 2020-2075

Parameter	Mean	Median	Standard	Kurtosis	Skewness	Range	Minimum	Maximum
Jan	100,238	111,1399	54,12	0,37773	-0,4819	237,63	-22,541	215,089
Feb	86,7396	102,3684	49,2161	0,24947	-0,6413	212,66	-29,32	183,343
Mar	78,9262	90,21137	44,3059	-0,3593	-0,541	180,43	-19,808	160,626
April	53,4068	58,3385	30,7043	-0,4272	-0,5059	118,69	-16,24	102,452
May	35,0128	40,91854	21,1735	-0,1596	-0,6863	88,906	-15,474	73,4328
June	22,6334	27,55068	14,3168	0,42124	-0,909	58,054	-14,592	43,4617
July	23,0075	24,28841	14,3609	0,83997	0,04504	70,22	-9,8018	60,4186
Aug	23,849	27,66227	14,9528	0,56842	-0,7623	68,538	-15,638	52,9003
Sept	29,714	32,50324	18,6657	0,15102	-0,4791	80,396	-16,027	64,3693
Oct	49,3415	53,86449	28,1132	0,53891	-0,8557	125,57	-22,365	103,208
Nov	74,7936	82,52392	36,9716	0,91781	-1,0579	154,5	-19,358	135,138
Dec	92,8165	98,00979	47,36	0,5573	-0,7555	202,49	-22,716	179,779

Overall, the mean months' rainfall ranges from 22.63-100.24. This shows that the rainfall value is highly variable in space and time.

4.2.2 Catchment hydrological water budget

Precipitation and evaporation are the primary drivers of the hydrological cycle, with temperature being an important factor in the evaporation process. Therefore, with changes in various temperature parameters having been identified over the year, the likelihood of the water budget is affected. Using an arithmetic average to estimate the mean monthly and mean annual rainfall of the study area, Figure 4.2 below illustrates the mean monthly Ombro-thermic diagram (average rainfall depth and temperature) for Jozini showing annual water deficit or water surplus for the study area.

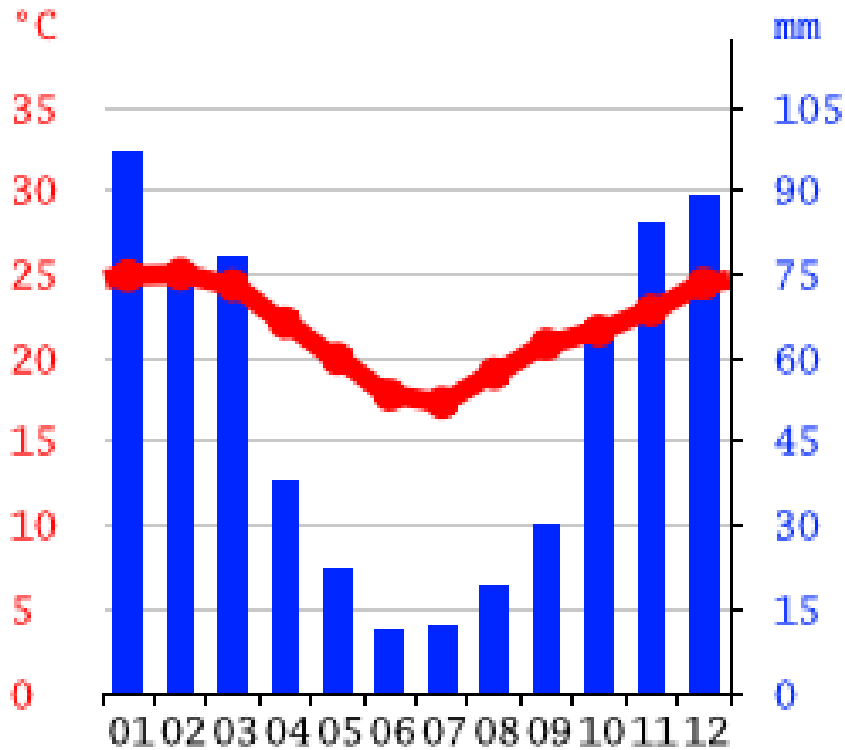


Figure 4.2: The mean monthly Ombro-thermic diagram for Jozini

Figure 4.2 depicts that the spatial distribution of rainfall is a major factor controlling the streamflow patterns of the river study. It is evident from the figure that the months April to September are considered ‘dry months’ as they fall below the mean temperature, while the other months are wet as they fall above the mean temperature. The temporal trend changes and patterns characterized the observed monthly distribution of temperature and rainfall over the study area from 1999 to 2018. The average rainfall depth and temperature show a mixture of low and high values in monthly measure parameters.

4.2.3 Mann-Kendall and Sen’s slope test results

Thereafter, the study used the Mann-Kendall and Sen’s slope test across the months (Jan- Dec) and annual basis to buttress the catchment characteristic trend of either an increasing or decreasing rate variables. Table 4.6 and Figure 4.3 illustrate the monthly and annual Mann–Kendall and Sen’s Slope estimation.

The Mann Kendall test, with a very high positive value, is an indication of an increasing trend; whereas a very low negative value indicates a decreasing trend, while the closer the Sen's slope value was to 0, the less its trend signifies. The sign of the Sen's Slope buttress trend is characteristic of either an increasing or decreasing rate.

Table 4.6: The monthly Mann-Kendall and Sen's slope test

Series\Test	Kendall's tau	p-value	Sen's slope	Trend
Jan	0,056	0,769	6,376	Increasing
Feb	0,111	0,492	2,535	Increasing
Mar	0,028	0,922	4,886	Increasing
April	-0,083	0,624	-0,171	Decreasing
May	-0,028	0,922	-1,009	Decreasing
June	-0,194	0,202	-0,765	Decreasing
July	-0,167	0,281	-0,616	Decreasing
Aug	-0,139	0,377	-0,883	Decreasing
Sept	-0,167	0,281	-2,629	Decreasing
Oct	-0,25	0,096	-3,048	Decreasing
Nov	-0,139	0,377	1,761	Increasing
Dec	-0,056	0,769	-0,925	Decreasing

The MK trend test statistics show a significant increase in mean annual rainfall of p-value 0.714, with a Sen's slope of 0.541. Figure 4.3 shows an increasing trend and variability changes that were observed in the Sen's slope estimator for the study duration (2020-2075).

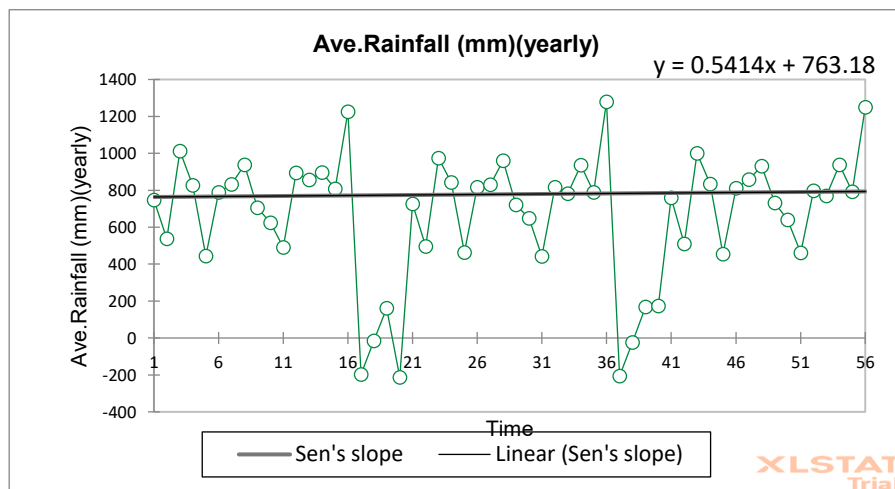


Figure 4.3: Annual Sen's estimate for 55 years of rainfall data

4.2.4 Result discussion for best-fit projected rainfall behaviour

The regression analysis is carried out on the data collected to predict the behavior and dependence of the rainfall variable. The models can be in many forms ranging from simple linear equations to complex equations, and more tedious algebra like quadratic, exponential trigonometry equations. The result of the exponential, moving average and Holt-winters best-fitted model for the projected rainfall data is depicted in Figures 4.4, 4.5 and 4.6.

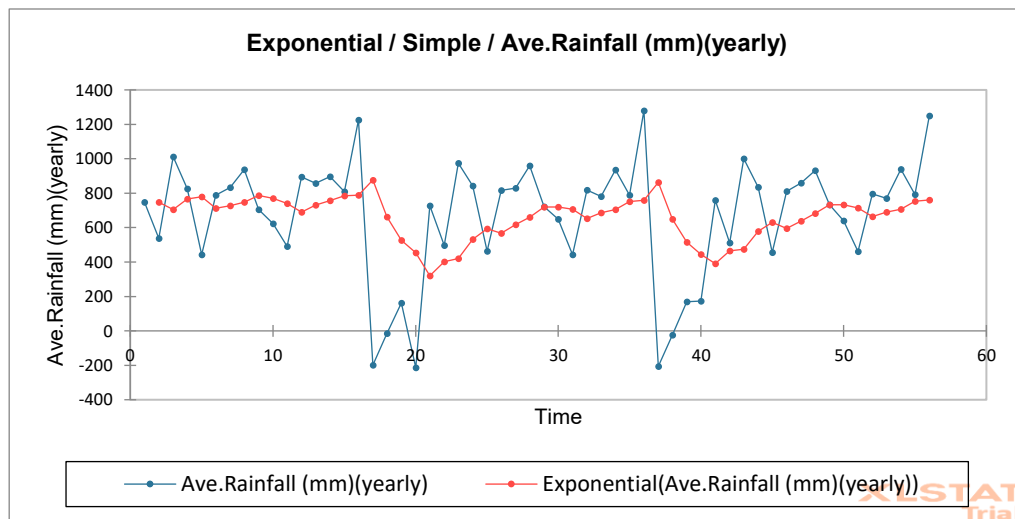


Figure 4.4: Exponential average annual predicted precipitation graph

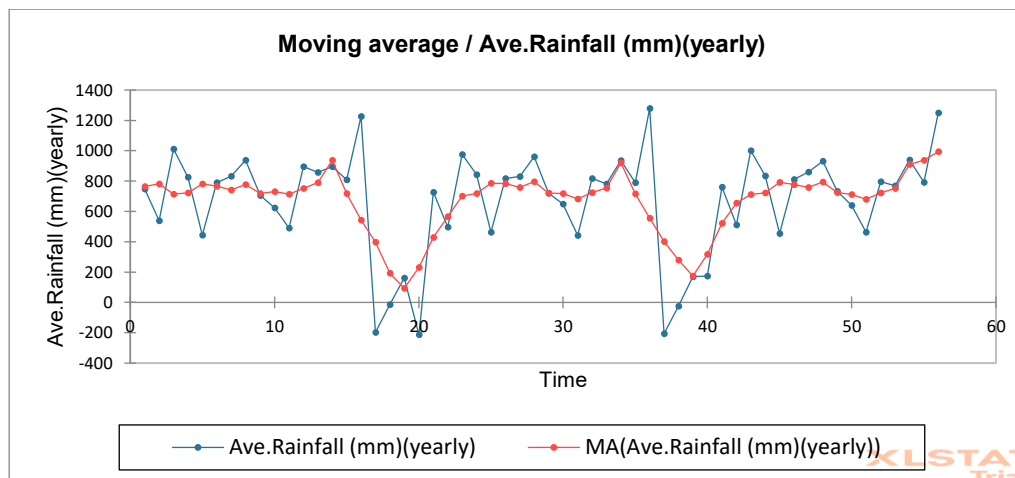


Figure 4.5: Annual moving average predicted precipitation graph

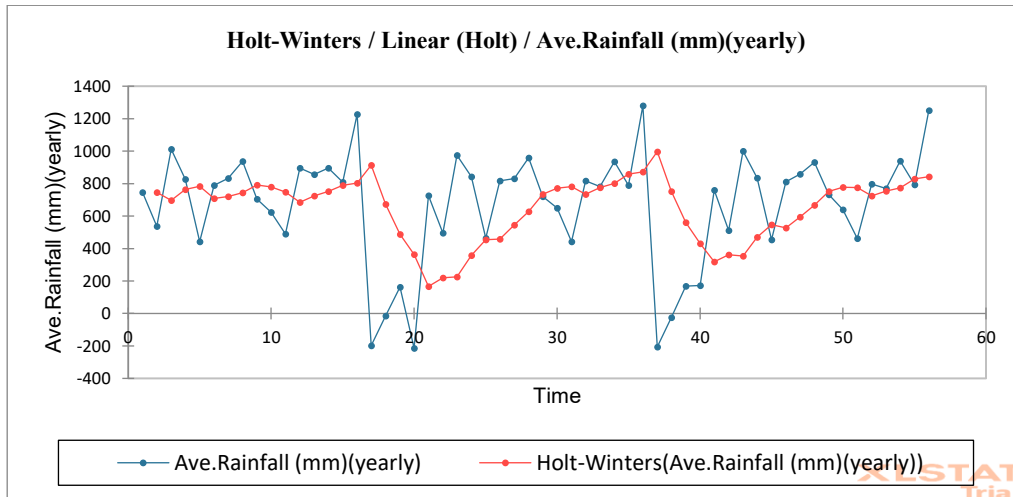


Figure 4.6: Holt winter annual predicted precipitation graph

The abnormalities of rainfall at any location may not only be explained in the best-fit graph, but reasonable consideration must also be given to residue errors distribution. The results of various compared goodness-of-fit statistics indices are as shown in Table 4.7:

Table 4.7: Goodness of fit statistics [Ave.Rainfall (mm)(yearly)]

Statistic	Exponential value	Moving average	Holt-Winters
Observations	56	56	56
MSE	126076.831	59589.115	157675.081
MAPE	191.470	81.921	206.598

Using the goodness-of-fit performance, the comparison with lower values between the mean square error (MSE) and mean average percentage error (MAPE) indicates a better fit (Jou et al., 2009). As shown in Table 4.7, the moving average model with corresponding MSE and MAPE values of 59589,115 and 81.921 had the smallest value, which shows it to be a better forecasting time series for future rainfall trends.

4.2.5 Result discussion on the rainfall variability assessment

Using a simple PR and CV measure, the abnormalities of rainfall at any location have been worked out. The simple Precipitation Ratio (PR) may give the stability

of rainfall with a special relationship (Safeeq et al., 2016). The higher the ratio, the higher is the abnormality in rainfall and vice versa; while the CV measures the dispersion of a probability distribution. It is defined as the ratio of the standard deviation (S) to the mean (X) (Martinez-Pons, 2013). Figure 4.7 summarises the annual and seasonal mean (mm) coefficient of variability (CV - %), precipitation ratio (PR), and precipitation concentration index (PCI). The PR depicts the maximum abnormality observed for annual rainfall ranged, while the PCI gives the possibility of knowing the existing high seasonality, which means greater differences between the dry seasons and the rainy seasons, and vice versa.

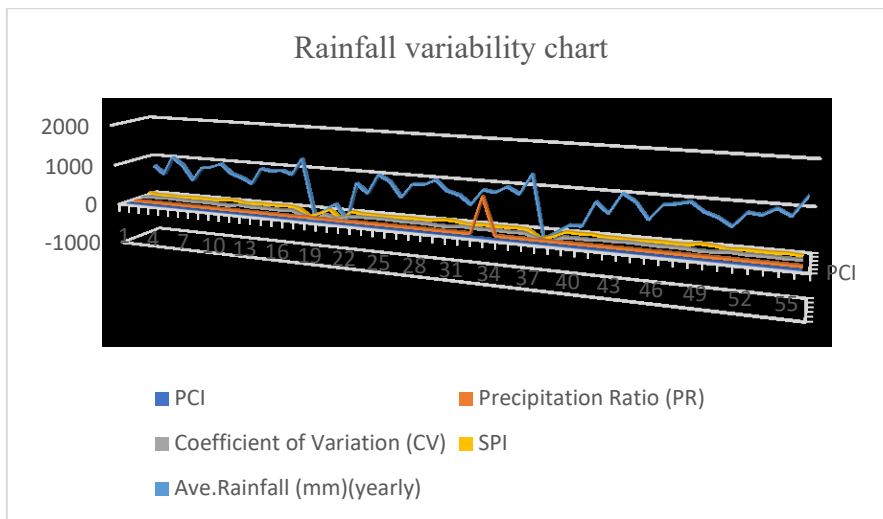


Figure 4.7: The different years of PCI seasonal classification

The PCI was useful in estimating the physical upper limit to a storm rainfall over a basin and in quantifying the basin hydrological responses to runoff relation. The successful construction of PCI, PR, CV and SPI demonstrates the use of the rain seasonality index, where the highest values of the PCI indicate great variance observed in the Spatio-temporal distribution and concentration of rainfall patterns over the years; while the SPI result highlights that climate change variation can be associated with the calculation of the indicators through the mean annual ombrothermic (precipitation–temperature diagram) to corroborate SPI yearly classification as a relative uniform dry year. This may be because the

northern part of KwaZulu-Natal varies greatly from the Southern region. The northern region receives less rainfall.

4.2.6 Seasonal annual results for projected rainfall

The annual season's result (Table 4.8) shows an intermittent decrease from summer to winter with 93.264, 55.782 and 23.163 mm in average rainfall depth witnessed.

Table 4.8: Linear regression result of seasonal precipitation (2020-2075)

<i>Regression Statistics</i>	<i>Summer</i>	<i>Autum</i>	<i>Winter</i>	<i>Spring</i>
Multiple R	0,066921	0,099382	0,042298	0,00805
R Square	0,004478	0,009877	0,001789	6,48E-05
Ave. mean(mm)	93,26469	55,78194	23,16331	51,28306
Std	49,20019	30,90019	13,99315	26,81167
CV (%)	52,75329	55,39462	60,41082	52,28173

Figure 4.8 illustrates the seasonal index behaviour of precipitation in the area. Autumn decreased between the highest 200mm to 70mm, which varies per decade. In addition, the highest impact of the basin meteorological variables was felt during the winter period, followed by autumn and spring respectively with a decline in the streamflow generation.

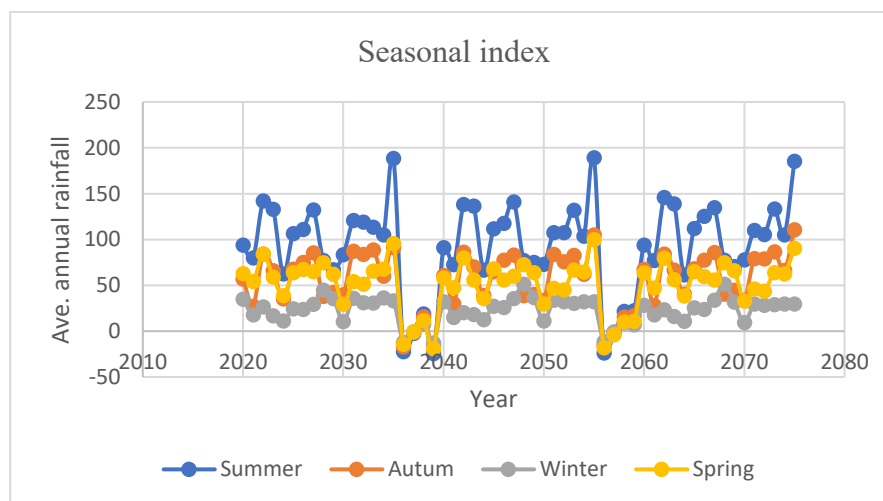


Figure 4.8: The different years' seasonal index classification

As depicted in Figure 4.8, the average rainfall is relatively uniform across the seasons, except that an accelerated sharp decrease is witnessed in the years 2035-2038, which also repeated in the years 2056-2058. Thereafter an upward projection was witnessed.

4.2.7 Result discussion on the coefficient of rainfall variation

Figure 4.9 depicts the relationship between the coefficient of variation ratio and the annual average of rainfall in Jozini and its environs. The figure shows that the coefficient of variation of rainfall varies most in degree between 40% and 80%. These rates are not too high, and the difference between them is significant (greater than 40%). This indicates that the coefficient of variation increases with decreasing rainfall rates under such climatic conditions. This may further support the assertion that the region is of the semi-arid region (Cheung et al., 2008). Furthermore, a positive coefficient variation in rainfall concentration signifies a positive increasing trend between the mean annual rainfall and time (year). This suggests that the mean annual rainfall within the catchment will increase with time, but at a very low rate.

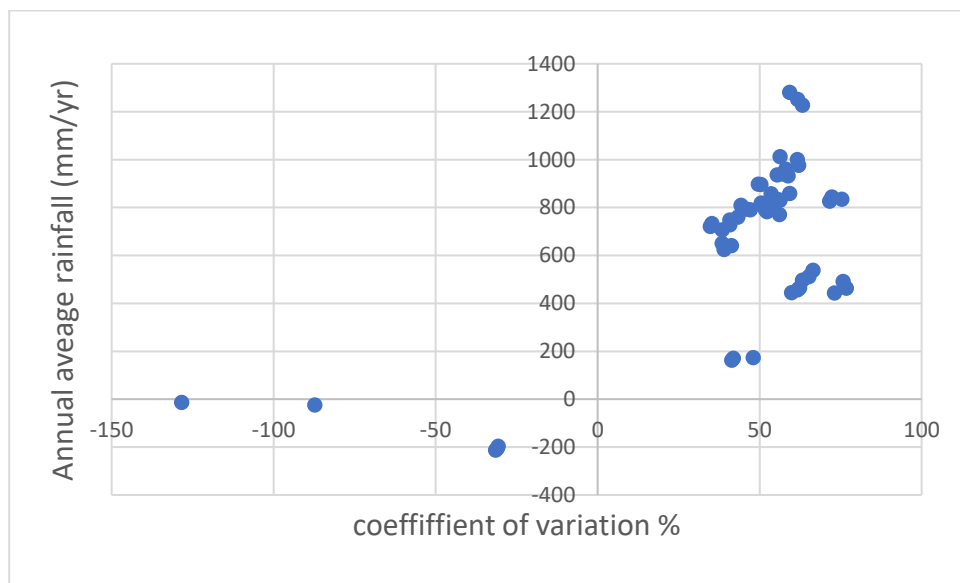


Figure 4.9: The CV and the annual average of rainfall in Durban

4.2.8 Analysis of drought in the watershed

The Standard Anomaly Index (SAI) and results of the PCI values were used to determine the variability and anomalies of rainfall fluctuations in the study region. Figure 4.10 presents the annual standardized rainfall anomalies calculated for the years 2020-2075.

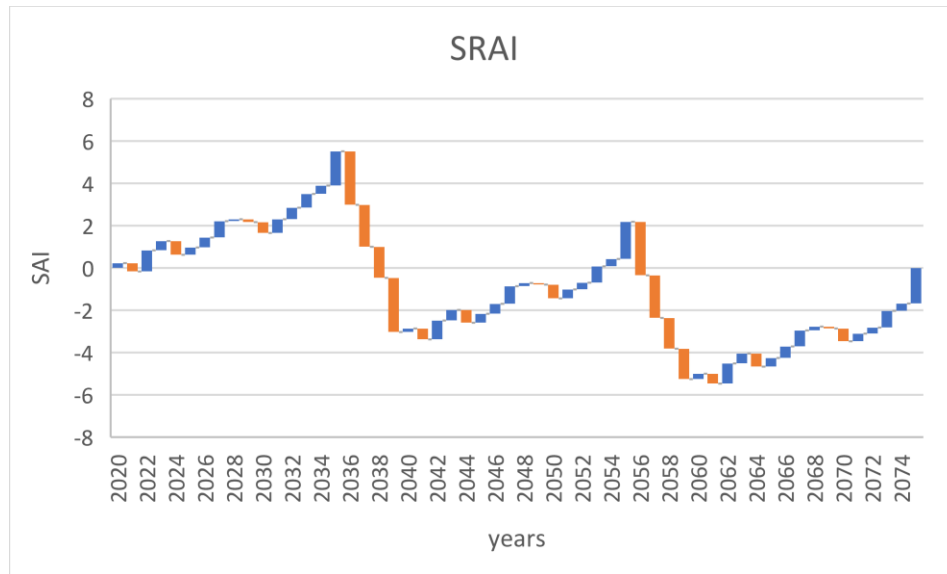


Figure 4.10: Mean yearly rainfall fluctuation for the study area

The anomaly index for fluctuation analysis with a line bar above the reference zero line means that the year has a positive (or surplus) anomaly, while those with line bars below the reference zero line means negative (or deficit) anomaly (Valt et al., 2005). Figure 4.10 depicts the SAI yearly classification exhibited by the rainfall distribution. The years 2020-2028 show moderately wet (1.0 to 1.49) while the years 2026, 2027, 2028, 2029 and 2030 experienced wet. On the other hand, moderate dry (>1.0 to <1.49) years will be observed from 2031 till 2034. The extremely dry (>2.0) years will be recorded in 2036 and 2056. The rest of the years in the watershed exhibited below normal rainfall distribution. The result agrees with recent studies that the frequency of the drought cycle has been changing over time in South Africa (Wolski et al., 2021, Thomas et al., 2007).

4.3 Designing SWH under different climatic scenarios results

The proposed smart city was conceived to regenerate the upstream water utilisation by various users and recycle it for sustainability and backup. The proposed SWH system to be designed under different climatic scenarios was based on various dependable monthly rainfall magnitude frequencies, which will serve as inflows into the services reservoir dam together with the regenerated water re-use as alternate water argumentation sources. Using the dependable rainfall frequency percentage that was arrived at through Kimball’s method (Wolski et al., 2021), the Weibul approach arranged the collected monthly rainfall series in descending order, which was later ranked for the probability of exceedance using **Error! Reference source not found.4.1**. The value of one represents the highest rank value, while the lowest value is the amount of data in the series.

$$P_i = \frac{m}{n+1} \quad \text{Eqn 4.1}$$

Where M is the rank, n is the number of data points in the series, and Pi is the dependable rainfall at different frequencies in the monthly statistics. Table 4.9 is the monthly statistics and the Weibul ranking for the dependable flow.

Table 4.9: Monthly statistics and dependable rainfall at a different frequency

Year/ Month	n	Min	max	Mean	F=50%	F=75%	F=95%
June	480	209.098	1422.011	112.248	466.476	552.573	352.006
July	480	164.208	317.930	100.261	287.104	327.056	189.573
August	480	268.170	2.897	707.359	3534.308	1383.116	224.744
September	480	1590.366	73.383	411.408	116.395	911.351	672.261
October	480	213.782	147.835	1187.455	951.530	1285.462	187.183
November	480	775.928	698.551	901.356	572.173	1294.327	925.168
December	480	577.683	724.110	93.304	697.405	2754.340	2252.905
January	480	3838.547	521.758	66.374	800.982	4384.080	40.683
February	480	4128.536	500.917	1653.272	1854.475	3059.669	751.579
March	480	1617.623	1852.063	3.701	1691.778	3113.075	884.982
April	480	2255.383	4429.006	1024.100	3899.427	4284.967	433.814
May	480	1826.235	7555.745	112.509	4156.812	1553.320	1153.144
Probability of					19.02	24.90	8.06

exceedance
flow (pp)

The water supply augmentation estimation was made based on the dependable rainfall monthly frequency which drives the storage tank size design in meeting the different users' needs. Table 4.10 depicts the stormwater availability at different dependability monthly frequencies.

Table 4.10: Stormwater availability at different dependability

Rainwater availability (MCM)			
Month	Rainfall (mm) at		
	F=50%	75%	95%
January	14.6	1.5	0.2
February	37.2	3.8	0.5
March	10.8	1.1	0.2
April	5.4	0.5	0.1
May	32.0	3.2	0.5
June	66.9	6.8	1
July	27.7	28	3.9
August	30.1	30	4.3
September	12.9	13	1.8
October	0.10	0	0
November	0.16	0	0
December	3.40	0.3	0
Total	66.3	88	12

The tables help in determining the monthly and annual rainfall variation for the study area, while probability analysis of rainfall using Weibull ranking depicts the rainfall dependability at different frequencies of 50%, 75% and 95% for the chosen (Jozini-Mubulanga) area. This helps in determining the storage capacity for the reservoir needed, which in turn can be supplemented by the regular municipal water treatment supply for the area.

4.3.1 Calculation of uniform depth of stormwater harvesting

For a given precipitation event, the CN method partitions a given uniform depth of precipitation into a runoff component and an infiltration/initial abstraction

component through the following two equations (US Department of Agriculture 1986):

$$S = \frac{1000}{CN} - 10 \quad \text{Eqn 4.2}$$

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad \text{Eqn. 4.3}$$

Where Q= runoff (m³/s);

P = rainfall (mm);

S= potential maximum retention after runoff begins; I_a = Initial abstraction represents that portion of retention associated with interception, ponding and wetting of soil and vegetation surfaces.

$$I_a = 0.2S \quad \text{Eqn 4.4}$$

Substituting Equation 4.4 in 4.3 gives

$$Q_{m^3 s^{-1}} = \frac{(P - 0.2SI_a)^2}{(P + 0.8I_a) + S} \quad \text{Eqn. 4.5}$$

For a given uniform depth precipitation event (P), Q, the uniform depth of runoff (in mm) is then determined.

The subsequent section summarises the quantitative and qualitative results that constitute each section of the research objectives. The aggregated results were first presented. Thereafter, further discussion analyses were done on the implication of the various results obtained to aid the stormwater harvesting system design as a means to augment available water in a new smart city under different climatic scenarios within the KwaZulu-Natal Province of South Africa.

4.4 Qualitative and quantitative results analysis and discussion

A thematic analysis of the participants' responses was used in presenting the qualitative results (interview), while the visualised description in the form of graphs, figures and cross-tabulations was used for each section of the

questionnaire analysis. The triangulation method with supported literature review works was adopted where both the quantitative result and conducted interview results are in opposing view to juxtapose the chosen view in support of the argument.

4.4.1 Respondent demographic profile results and discussion

One of the key inputs for the stormwaterharvest system design is the study area demographic profile. These include the study area’s age distribution, gender, race, level of their education distribution, occupation years of experience, and water demand; while the correspondent expert interviews, and survey questionnaires give more clarity for the study area consideration during the city design and pilot scale for new smart cities development under different climatic scenarios within the KwaZulu-Natal Province of South Africa. Table 4.11 presents the respondents' expert demographic data employed for the study.

Table 4.11: Respondents’ years of experience and respondents’ field

Year of experience/Expert field	1-5yrs	6-10yrs	11-15yrs	16-20yrs	Over 20yrs	Total	Mean	S. D
Soil expert	0	0	5	2	2	9	1.8	2.05
Climate change	0	0	1	3	2	6	1.2	1.30
SWH expert	0	5	7	4	1	17	3.4	2.88
Agriculture/irrigation)	0	4	8	3	0	15	3.0	3.32
Total	0	9	16	12	5	42		

The respondents’ experience ranged from 3 to 20 years, which the researcher considered as fit for the study. Most of the respondents had more than three years of work experience. Amongst these 42 interviewees, seven were deputy directors; 13 were senior researchers; and the remaining 21 were internship fellows. The gender composition comprises 28 males, while the remaining 18 participants were female. Table 4.12 summarises the gender distribution.

Table 4.12: Gender distribution

Sex	Frequency	Valid Percent
Male	28	66.667
Female	14	33.333
TOTAL	42	100

4.4.2 Gender and Age Bracket interaction

The overall ratio of males to females is 2:1. More respondents were within the age category of 36 to 40 years, with 10.5% female and 8.1% e male. Within the category of 46 to 50 years, more males were cooperative at 38.5% (age) and 11.8% for the female (gender) sample.

4.4.3 Highest educational qualification

Figure 4.11 below indicates the education levels of the respondents.

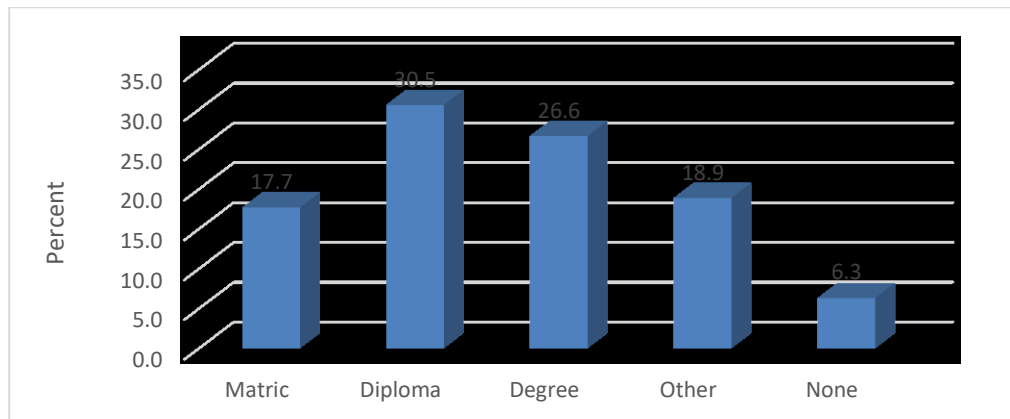


Figure 4.11: Education Level of Respondents

The above analysis shows that about 61 % of the total respondents were university graduates, while a little less than 30.5% had a diploma, with approximately 26.6% having a degree level of education. This is a useful statistic as it indicates that a fair proportion of the respondents have higher qualifications and that the responses gathered were from informed sources who understand the research subject. On average, it was found that the majority were learned fellows.

Although women are the most affected in the advent of water shortages as they are the custodians for home management in terms of cooking, washing bathing, etc). The sex representation shows a fair distribution for the respondents.

Figure 4.12 summarises the racial groups of the participants. The race composition shows a fair racial composition of the sample with Africans occupying 87% of the population and other races occupying 12%, 11.7 and 10.8% respectively from the overall population of 42 people sampled.

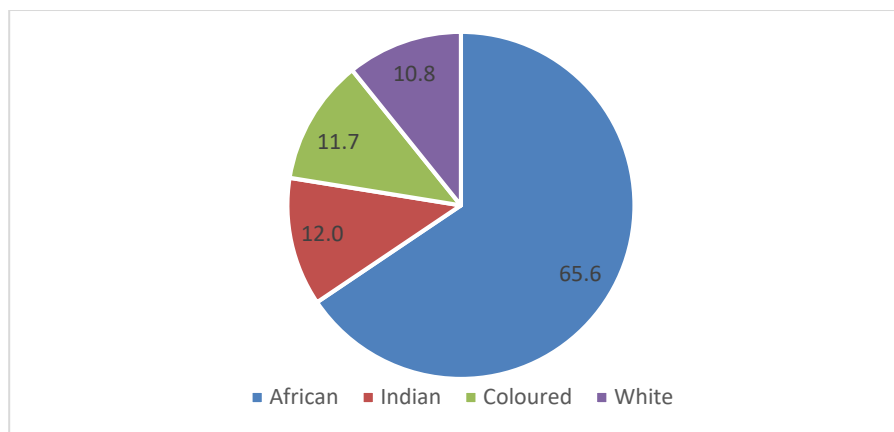


Figure 4.12: Racial Composition of Sample

In developing a water resources utilisation model for the smart city, this section of the study explores the demographic factor to model water utilisation for the smart city.

4.4.4 Development of water utilisation model for the smart city

Multiple regression analysis was used to model the water demand for the study area. The multiple regression model (predictors -demographic) was modeled as a function of the city water demand. Predictive correlations amongst the variables were cumulated and then their relationship with the demographic data was analysed using the Pearson r product moment formula. Table 4.13 shows the statistical summary for the demographic data analysis, while Table 4.14 shows the values of the model predictor parameters to depict the relationship between

the demographic data and the explanatory variables which greatly influence water usage in the city.

Table 4.13: The mean and standard deviation of the demographic variables

<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
45.81	10.00	269.07	26.91	1228.34
A	5.00	59.58	11.92	47.84
G	5.00	261.98	52.40	172.11
Etn	5.00	165.00	33.00	868.81
Edu	5.00	100.00	20.00	87.51
OPS	5.00	100.00	20.00	21.71

Where A- Age; G- Gender; EG- Ethnic Group; Edu- Educational Level; OPS- Occupation period of service

From Table 4.14, the probability value for the F-test statistic (0.48) is less than 2.63 F critical (5% level of significance), which indicates that the model is adequate. This means that the contribution of the predictors significantly contributes together to predict the sustainable water demand required for future usage.

Table 4.14: Summary of the model predictor parameters ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	1146.68	4.00	286.67	0.48	0.75	2.63
Columns	11296.00	5.00	1255.11	2.11	0.05	2.15
Error	21432.37	36.00	595.34			
Total	33875.04	49.00				

As a further measure of the strength of the model fit, **Error! Reference source not found.** depicts the demographic-factors variables correlation matrix for smart city water demand. The multiple correlation coefficient, R, between the observed and the model predicted values of the dependent variable are mostly below 0.5, except for the occupation period of service, which implies that it is

the only variable that contributes significantly to the explanation of the dependent variable.

Table 4.15: Statistical summary of the correlation matrix

	Age	Gender	Ethnic Group	Educational Level	Period of service
Age	1	-0.784	-0.278	-0.365	0.460
Gender	-0.784	1	0.290	0.541	-0.248
Ethnic Group	-0.278	0.290	1	-0.472	-0.464
Educational Level	-0.365	0.541	-0.472	1	0.212
Period of service	0.460	-0.248	-0.464	0.212	1

Table 4.16 shows the summary of the model predictor performance determination statistics. Given R^2 , 100% of the variability of the dependent variable water demand is explained by the 5 explanatory variables. The t-values can be used in comparing the contribution of each predictor (independent variables). The largest δ -value coefficient is 1.242 for gender. A multiple linear regression model can be formulated from Table 4.16 as follows:

$$Y = -39.9818 - 0.3525*Age + 1.242*Gender + 0.752*Ethnic\ group - 0.352*Educational\ Level + 1.24223*Period\ of\ service$$

Table 4.16: Regression Model parameters

Source	Value	Standard error	T	Pr > t	Lower bound (95%)	Upper bound (95%)
Intercept	-39.982	0.000			-39.982	-39.982
Age	-0.352	0.000	0.300	0.003	0.000	0.000
Gender	1.242	0.000	0.002		0.000	0.000
Ethnic Group	0.752	0.000	0.267		0.000	0.000
Educational Level	-0.352	0.000	0.003		-0.352	-0.352
Period of service	1.242	0.000	0.001		1.242	1.242

For each of these variables, the value in the column marked sig. ($p > |t|$ -value) was checked, which showed whether this predictor made a statistically significant contribution to water demand. This depends on which variables are

included in the equation. In general, if p-values are less than 0.05, the variables made a significant contribution to the prediction of water demand. In this case, Respondents' period of service made statistically significant contributions to the prediction of the water demand, while other variables contribute negatively to the explanation of the dependent variable. Although social class, ethnicity and gender are significantly associated with water demand, there is substantial individual variability that cannot be explained by social class, ethnicity or gender, which one might expect to reflect individual choice and requirements for water service delivery, like pipe-pressure, water quality, etc.

4.4.5 Cross-sectional result for domestic consumption water sources

This section analyses the scoring patterns of the respondents per domestic consumption subject variable in design analysis. Thereafter, whether the scoring patterns per statement were significantly different per option was ascertained using a chi-square test. Table 4.17 depicts the cross-sectional analysis of alternate water sources for domestic consumption.

Table 4.17: Water sources for domestic consumption

Statement Description		Strongly Disagree		Disagree		Neutral		Agree		Strongly Agree		Chi-Square
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	p-value
There are a variety of water sources in Durban/ KZN for domestic consumption	B1	2	0.6 %	15	4.6 %	92	28.1 %	136	41.6 %	82	25.1 %	0.000
The depleting water resources necessitates an alternate water source in Durban/KZN	B2	3	0.9 %	17	5.2 %	11	3.4 %	130	39.8 %	16	50.8 %	0.000
The water sources in Durban/ KZN are reliable	B3	5	1.5 %	24	7.3 %	59	18.0 %	171	52.3 %	68	20.8 %	0.000
The water sources in Durban/KZN are sustainable	B4	7	2.1 %	31	9.5 %	79	24.2 %	147	45.0 %	63	19.3 %	0.000

The water sources in Durban/KZN suffice for the Durban populace/ region	B5	3	0.9 %	17	5.2 %	11	3.4 %	130	39.8 %	166	50.8 %	0.000
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Using the chi-square cross-tabulation, the column marked sig. (p-value) was checked, which helps to know which variables are statistically significant to the city water usage/consumption. P-value less than 0.05 signify strong contributions and vice-versa. The results show that some statements are significantly at higher levels of agreement, whilst other levels of agreement are lower but still greater than levels of disagreement.

4.4.6 Results and discussion on alternate sources of water

A systematic analytical response for the different alternate sources is shown in Figure 4.13.

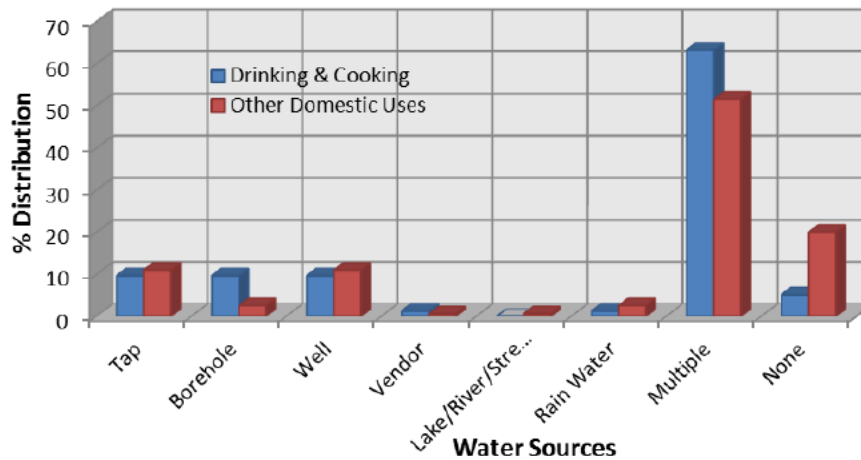


Figure 4.13: Scoring Patterns for the various water sources

Using responses to the question: What are the available water sources for domestic purposes in Durban/ Jozini in KZN? from both interviews and quantitative data, most respondents affirm that water sources are from lakes, rivers and streams, which constitutes 65% of the respondents. However, Participant label No. 4 states that some industries may be authorized to abstract

water from various rivers through the DWS licensing process. Most of the responses to the sources of water available for domestic, farming and industrial purposes in Durban/ KZN are from the tap water supply from the local municipal, which is sometimes supplemented with borehole water, streamflow and stormwaterharvest. Deduced response from the expert claimed that:

- a. KZN is serviced by 22 state dams. Domestic supply is augmented from several boreholes and springs;
- b. Groundwater, springs, potable water from local municipality via taps from Dams. Rainwater harvesting;
- c. Surface and groundwater resources;
- d. Depending on where one is located, the sources include groundwater (boreholes), taps (as distributed by Municipalities), rivers (indigent communities amongst the rural poor), etc;
- e. there are 22 dams, springs, boreholes and rivers in disadvantaged rural communities; and
- f. Water is available to residents of KZN through springs, boreholes and dams.

Some said: “Direct abstract from Dams and river and boreholes”, while others affirmed that surface and groundwater resources constituted agriculture sources with support from Dams and piped water sources.

Other sources include direct abstraction from rivers/ dams/ boreholes, according to Participant No 7. Farm irrigation is mostly from groundwater and dams, according to Participant No 8. Likewise, the DWS does issue licensing to some industries and farmers to extract water from nearby water sources, states Participant 11.

Furthermore, to the question: Are these sources viable and reliable? the majority response was “*Yes, at present but not sustainable in the long run due to main source stream being over-extracted especially in deprived communities*”. Participant 9 says: “*A significant amount of them is viable but due to the ever-increasing demand and the effects of drought most will not be viable in the long*”

run”. Participants No 3 and 10 stated: “Most will be viable except where the water source is far or over-extracted, hence because of this, the DWS has developed a national water and sanitation master plan to deal with such demands, especially for industries and agricultural purposes”.

4.4.7 The relationship between water sources and climate change

Table 4.18 depicts the respondents’ relationship between the various water resources sources and climate change in Section C of the questionnaire.

Table 4.18: Relationship between water sources and climate change

Statement Description		Strongly Disagree		Disagree		Neutral		Agree		Strongly Agree		Chi-Square p-value
		Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	
The effects of Climate change have significantly impacted the water sources in Durban/ KZN	C1	2	0.6 %	15	4.6 %	92	28.1 %	136	41.6 %	82	25.1 %	0.000
There is an urgent need to find an alternative water source for the Durban/KZN region	C2	3	0.9 %	17	5.2 %	11	3.4 %	130	39.8 %	166	50.8 %	0.000
Exploring alternative water sources in Durban/KZN is very important	C3	5	1.5 %	24	7.3 %	59	18.0 %	171	52.3 %	68	20.8 %	0.000
Exploring alternative water sources in Durban/KZN is important as a means to ensuring water security	C4	7	2.1 %	31	9.5 %	79	24.2 %	147	45.0 %	63	19.3 %	0.000
It is important to promote efficient stormwater (rainwater harvest) system as a means to ensuring water security	C5	3	0.9 %	17	5.2 %	11	3.4 %	130	39.8 %	166	50.8 %	0.000

Using the p-value in analysing Section C of the questionnaire, Table 4.18 depicts the respondents’ patterns to the relationship between water sources and climate

change effect. The respondents' results viewed the imperativeness for water harvest systems to be improved to benefit the smart city for efficient and sustainable water consumption augmentation.

4.4.8 Foreseeable challenge to the water sources: Respondents' Results

A vast 80% of respondents affirmed climate change as the most foreseeable challenge to the water sources in Durban. This was also collaborated by Woodford et al. (2005). The country is a relatively dry country that is prone to droughts, receiving on average about 500mm/year of precipitation. Some of the excerpts from the interview responses to how climate change has affected water sources are presented below:

***Participant (4):** Yes, I do agree with the adverse impacts of climate change on water resources in Durban. This has been felt through: air and water temperature increases; changes in Dam levels and redistribution of rainfall; increases in storm intensity; with little or no difference in sea level rises, which has caused devastating changes in coastal and the ocean characteristic.*

***Participant (12)** said he understood how the impact of climate has negatively imparted the aquatic species distribution, caused a shift in population; incessant pond-drying condition and misalignment which together has resulted in the alteration of the catchment hydrological cycle through unimaginable differences in the amount of precipitation, frequency, intensity, duration, and type.*

***Participant 18** claims how a rise in temperatures, has resulted in the rivers, streams, and lakes reduction. He says climate change will cause the rivers, str, and lakes to retreat and become scarce. As a result, less melted water will feed into the rivers reducing the water level and eventually leading to them becoming merely seasonal rivers, flowing during the wet months and dry during the other months.''*

***Participant 2** claims: “Changes in rainfall patterns affected the umgeni systems dam that supplies the EThekweni metro. In drier years, the dam experience pressure due to increasing demand”.*

***Participants 3** claims that the water situation in KZN more especially in areas such as Jozini, Ubombo, Mkhuze, Mbazwana, etc in the Northern KZN, will in the near future experience water problems (Mofokeng, 2017)*

***Respondent No 6** said: “For average water users, viability and sustainability are subject to not only the climate outlook but also to availability and rate of use”. The foreseeable challenges to the water sources in Durban/KZN include Frequent drought, climate change, water quality impacts, alien vegetation, and overuse says Participant 11 while participants 12 highlights: leakage of water, Poor maintenance, Population growth, Urbanization, and Climate change.*

Furthermore, ***Participants No 5, 6 and 7** attributed increases in population particularly in the main cities, lack of infrastructural damage/ vandalism, invasive plants, water leakages, inadequate maintenance, and climate change, as most foreseeable challenges to the water sources in Durban.*

***Participant 2** affirms SWH to be very important, it reduced pressure to demand the water resource and it can allow tapping into additional water sources such as rainwater, recycling of wastewater, etc.*

In summary, climate change has resulted in a significant and devastating reduction in surface water resources in the country. The effect of extreme weather variations such as floods and droughts has caused an increase in sea levels, which has also resulted in the salination of many coastal surface and groundwater resources. This means that both the water quality and quantity have been impacted. Furthermore, the erratic weather patterns have impacted negatively on the freshwater suitable for human use, which sometimes has caused it to be mixed with saltwater. The apparent effects of climate change are more pronounced on

agricultural farmland, with an induced effect on the hydrological cycle of the area. These have generally resulted in a decline in water availability.

Amongst the challenges to alleviating the impact of climate change on water sources in Durban/KZN are: unsustainable water usage, resource constraints, issues of non-compliance, poor maintenance of facilities/ infrastructure, according to *Participants No 11 and 7*.

Furthermore, the resultant effect includes a wide reduction in the groundwater recharge available caused by increased evaporation. Participant No 15 mentioned that it impacts most on low-lying areas and coastal plain areas, which are the areas more vulnerable to witness a shift in sea level.

As deduced from the findings, the participants affirmed more impacts of climate change on low-lying areas and coastal plain areas. It is these areas that are more vulnerable and should be discouraged in building settlement areas. The socio-economic and technical barriers to having an efficient stormwaterharvesting system are narrated in the theme below.

4.4.9 The social, economic and technical barriers to an efficient SWH

What are some of the socio-economic and technical barriers to having an efficient stormwater harvesting system?

Putting it in a simple form, the response from **Participant 10** was:

- *Social barriers include a lack of awareness amongst communities and poor buy-in into the idea of a SWH culture. Most people prefer surface water sources from running rivers for their domestic usage.*
- *Also, the Economic barriers may be high initial start-up costs of developing the system.*
- *Technical barriers may include lack of requisite climate data (such as rainfall) for determining effective rainfall and runoff.*

Participant No 2 summarised the constraints to be: *Poor maintenance of the stormwater drains as well as rainwater harvesting systems at the household level.* However, some are skeptical or not sure about the cost and sustainability of the setup of the system and how it can be installed in a big city like Durban. The participants were further asked if they could enumerate some of the social, economic and technical barriers to an efficient SWH system architecture. A variety of mixed responses were given. **Participant 11** enumerated the barriers to be:

- a. *Contamination by the waste in stormwater drainage;*
- b. *Deliberate vandalism and criminality; and*
- c. *Poor maintenance.*

Participant 8 said *Poor knowledge and awareness.* **Respondent No 2** also identified the barrier to be: *“poor capacity building in water management”* and proffered suggested measures to a sustainable and viable stormwater harvest system in Jozini and Durban/ KZN to include a *“training the trainer programme”*.

Within the same question, the respondents were asked which factors are the most tedious barriers for SWH design and operation consideration. The responses to these questions are summarised by **Participant 6** as follows:

- a. *– damage to storm water infrastructure*
- b. *– pollution*
- c. *– deficiency of well-trained staff*
- d. *– budget constraint*
- e. *-Lack of political will, poor investment in climate change*

In summary, inadequately trained personnel and poor allocation of budget are the main barriers to socio-economic consideration for adequate SWH infrastructure operation.

4.4.10 Technical and financial feasibility results of a SWH system

The technical and financial barriers are the most difficult in implementation.

Some of the excerpts from the interviews are presented below:

“The technical barrier and the challenges to alleviating the impact of climate change on water sources in Durban include non-compliance to prescripts of the water use licenses and water restrictions during drought, unsustainable water use, limited resources to meet water requirements, and failure to intervene in a timely and effective way and water leaks.”

Some participants did attest that climate change affects water and it was not too difficult to understand or realise its negative impacts. Most respondents attested to the significance of stormwaterharvest and why it is important because it is relatively inexpensive and not technically complicated in construction. When further asked how feasible it is to integrate efficient stormwaterharvesting into smart cities such as Durban or Jozini the study area, Responses were:

- *It's feasible since the integration requires the will to do it, the reconfiguration, and adapting of the current climate condition and future projection will require inclusive terms of providing opportunities for all and ensuring that certain groups are neither left out of positive impacts nor disproportionately affected by any societal costs that may be imposed. (Participant 10)*

From the above, it could be said that most of the participants share the view on the imperativeness of the SWH system integration into smart city configuration. However, their frequency and the need for increases in storage reservoirs in events of greater rainfall variability should be considered, with the shifts in timing, duration and depth of water level as major requirements in saving river discharges and augmenting the shallow nearshore marine environment.

Additionally, the information on how to capture and use every available drop of water efficiently calls for better curbing in water wastage for expanding populations, and behavioral change for people living in a fragile environment needs to be ably aligned to the SWH pond storage towards ensuring food security.

4.4.11 Adaptation techniques in designing a SWH system results

As deduced from the quantitative and qualitative analyses, most of the key findings were generic amongst the participants. For instance, some suggest the integration of best practices around the world and good mitigation against Alien invasive plants (i.e. its removal). Others state that the existing variety of approaches thus suggests that SWH best-practice can be achieved, although these methods do have their advantages and shortcomings.

The generic findings further revealed strong reliance on SWH past studies and implementation in other areas with similar settings like Durban/the study area in order to help share strategic information that is useful for planners and other decision-makers.

A few excerpts from the participants are: *“Around 2015/16 the Department of Water and Sanitation (DWS) has drilled boreholes to assist and mitigate against the effects of drought, but I don’t think those boreholes will be sustainable, most of them are low yielding. (Participants 2 and 3)*

The response to mitigation measures in place to alleviate the effect of climate change on water sources and the challenges to alleviate its impact is at varying degrees. Most affirmed that government should look into treating and re-using wastewater, as well as looking into stormwater harvesting to supplement the current water resources. However, inadequate understanding and a lack of awareness constitute most communities’ mitigation to climate change and water use.

Some respondents also suggested the use of the latest instrumentation technologies for hydraulic water supply to assist clients with strategic decision-making and long-term planning. Moreover, the need for smart infrastructure in the water sector for evolving cutting-edge digital capabilities that embrace the Internet of Things and Industry 4.0. are some of the proffered solutions for industrial automation of the cities.

Based on the different participants' recommendations and past literature review, good planning, evaluation and re-monitoring serve as a common base and a pre-requisite to building climate resilience and adaptation cities. Other considerations should include high investments in infrastructure design planning, with an inculcated maintenance culture to be put in place.

4.5 Operation of stormwater harvest systems

Climatic findings: Since the climate of the area is a tropical climate, the region has distinct wet and dry seasons. The rainy season starts in March and ends around October, with a mean annual rainfall of between 750- 1400mm. The dry season starts in November and lasts till February (Mofokeng, 2017). Temperatures are high throughout the year but highest around April and May. The mean temperature range is between 32 °C to 33 °C, while relative humidity is dependent on seasons but lowest in the dry season period and highest during the rainy season.

The geophysical study shows that the river channel is underlain by fine sandy topsoil, sandy shale and fresh shale. This implies that the safe yield that would be available at the reservoir site should be sufficient for the optimal operation of the catchment hydrologic budget.

In the face of engineering hazards and environmental hazard factors selection for retrofitting the urban city, the design to worst conditions was based on its suitability to the terrain and a water body for effluent discharge using precise demand estimation and reliability-based optimisation in the Geographical Information System (GIS) where the road network, population distribution and topography of the area are known as a priori in sizing the storage requirement.

$$\text{Recall, Monthly yield (m}^3\text{) = monthly rainfall (mm) x catchment area (m}^2\text{) x runoff coefficient}$$

Eqn. 4.6

$$\text{Storage = consumption per capita x number of people in household x longest average dry spell days}$$

Eqn. 4.7

$$V_r = \frac{R.HRA.RC}{1000} \quad \text{Eqn. 4.8}$$

Where, V_r = monthly volume of storm- water per household (m^3), R = monthly rainfall depth (mm), HRA = household roof area (m^2), and RC = runoff coefficient.

Substituting average monthly rainfall (30 mm)- R ; runoff coefficient- $CN = 0.64$; consumption per capita- 150 l/c/p; N - number of people in household=4 people longest average dry spell days (DD)= 15 days; water saving efficiency (WSE) = 60%; Stormwater use efficiency (SUE) = 0.3; A_i - the study area = 3442 km^2 ; value in Equations 4.6, 4.7 and 4.8. The resultant simulated design was carefully analysed and assessed in a frequency analysis-based spreadsheet. A detailed description of the adopted procedural step can be found in Han and Mun (2008) and Mun and Han (2012). Figure 4.14 depicts the plan sketch of the proposed SWH augmentation system.

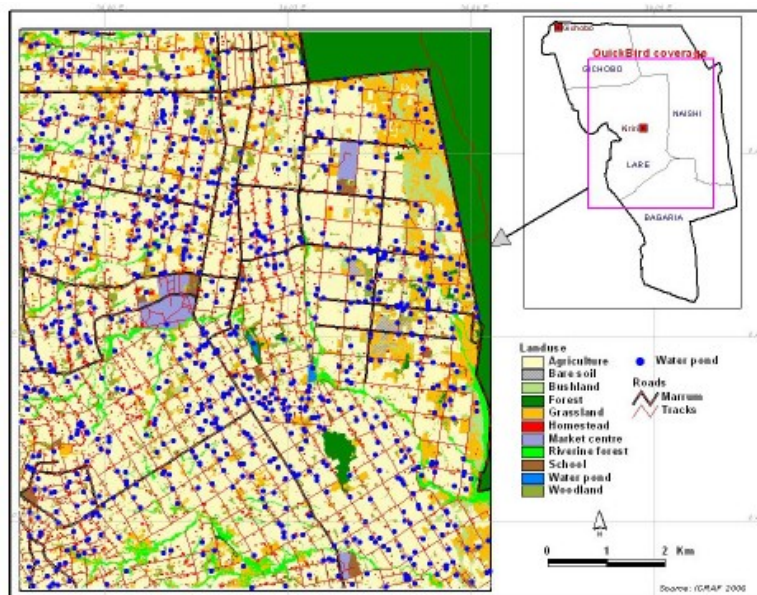


Figure 4.14: Evolving smart cities distribution in Jozini, KwaZulu-Natal

In summary, the operational procedure and data employed in this study were obtained from various literary works review documents and South African statistical data (SSA, 2020). The designing and evaluation of the operational

parameters were manually calculated and considered in the GIS layout of the catchment as illustrated in Figure 4.14. All these steps are necessary to improve the system performance and the stability of the water supply in the area.

The cost estimate and the financial feasibility of implementing SWH for the chosen area was carried out in a phased manner. The area was divided into 7 sectional districts to help develop the system in a phased manner. The design city was meant to use average water of 150 m³/day for an initial population of 186 502 people (SSA, 2011) up to a projected population growth estimated at a 1.5% growth rate.

The financial feasibility and the economic potential of SWH system integration consideration were further broken into engineering and environmental safety considerations for cost-benefit analysis. The annual benefit is the annual revenue generated through the sale of water. When the annual benefit is divided by the annual cost of electricity consumed, it is termed the benefit-cost ratio. The benefit-cost ratio represents the financial attractiveness of SWH system integration in a smart city. It consists of provisional costs for equipment connection with fitting and excavation work to and from the site. The total cost includes workmanship and tank storage required. Table 4.19 presents the financial feasibility and the economic potential of SWH system integration.

Table 4.19: The SWH system economic potential and financial consideration

Source	Minimum	Maximum
Revenue	5000	>40,000
Fixed cost (the cost of installation)	2000	2000
Variable costs (pipe drain component/additional cost)	500	3000
Taxes	100	1500
Grand Total for SWH reliability	2,400	33,500

Table 4.19 depicts the minimum and maximum costs of installation to be R2 400 and R33 500 respectively, per household. This is a veritable option for

stormwaterstorage operation irrespective of the period and season. This amount will be required to build an SWH and a storage tank.

Factor analysis as a choice of PCA was explored to identify the underlying latent factor in the socio-economic, technical and financial attractiveness responsible for designing an efficient and sustainable stormwater system. The study used a rank reduced analysis for aggregating the engineering and environmental factors selection (ageing infrastructure; a lack of proactive maintenance; a lack of finance; the lack of capacity development to handle the bulk conveyance, collection and distribution for stormwater; and the lack of commitment from politicians and industry in reducing climate change impacts with vigorous funding on research towards climate change adaptation strategy).

The FA segregates the different factors into two: high and low factors. These construct variables were based on the respondent cumulative frequency on barriers to the efficient stormwater system from the questionnaire. Thereafter, Spearman’s rank correlation coefficient was used to evaluate the degree of relationship between the two contributing variables for hazard comparison response consideration. The result of factor loading is shown in Table 4.20.

Table 4.20: Factor loadings results with correlation estimates constructs

Constructs	Factor loadings		Spearman’s rank correlation coefficient							
	F1	F2	1	2	3	4	5	6	7	
A	0.628	0.040	1.000							
B	0.740	0.006	0.936	1.000						
C	0.711	0.297	0.546	0.678	1.000					
D	0.368	0.006	-	-	-	1.000				
E	0.587	0.381	0.409	0.525	0.581		1.000			
F	0.687	0.014	0.486	0.579	0.263	-	0.565	1.000		
G	0.067	0.015	-	-	-	-	-	-	1.000	
			0.046	0.189	-	-	0.452	-	0.232	1.000
<i>Bold values match each variable to the factor for which the squared cosine is the largest and are significantly correlated at the 0.05 level or better.</i>										

Where a-ageing infrastructure, b-lack of proactive maintenance, c-lack of finance, d- lack of expert capacity development, e-General populace awareness, f-lack of commitment from politicians and g-industry willingness in reducing poisonous gas emission.

Using FA as part of the PCA for the initial screening of the data, the data were grouped into two main parts, including PC1 and PC2. PC1 is a more significant component than PC2. The corresponding factors loading for the PC1 score can be ranked using Equation 4.9, while the PC2 scores can also be ranked hierarchically using Equation 4.10.

$$PC1 = 0.628 \times A + 0.740 \times B + 0.711 \times C + 0.368 \times D + 0.587 \times F + 0.687 \times G$$

Eqn. 4.9

$$PC2 = 0.040 \times A + 0.006 \times B + 0.297 \times C + 0.008 \times E + 0.381 \times F + 0.014 \times G$$

Eqn.4.10

The estimated PC1 shows the most considered factors to be selected in designing a sustainable smart city under technical and financial feasibility considerations as: 1-ageing infrastructure, 2-lack of proactive maintenance, 3-lack of finance, 4-lack of expert capacity development, 5-General populace awareness, 6-lack of commitment from politicians and 7-industry wiliness in reducing water and gas emission. These will enhance the system to be efficient and sustainable, while Spearman's correlation results depict a strong positive relationship between engineering factors and environmental elements consideration ($p < 0.05$).

Furthermore, using the pair-wise factor analysis, the responses from the interview and quantitative analyses were ranked to select the most considerate factors as major hindrances/ barriers responsible for designing an efficient and sustainable stormwater system for the study area. Some of the statements are at significantly higher levels of agreement when compared to other levels of agreement. There are no statements that negated climate change and sustainability solutions as a key focus for the water sector, not only to the Jozini area but also the Durban area in comparison. The result analysis implies that the

two indices are indispensable decision tools to be considered both in the design and operation of the smart city. These will be useful in predicting the likelihood of the system's sustainability and responsiveness to a friendly climate change.

Other mentioned barriers include capabilities and expertise in human development to handle the bulk conveyance, collection and distribution for water waste and stormwater. Other alternative finance models for refurbishing and upgrading essential infrastructure include Public-Private Partnerships (PPPs) or blended finance initiatives for fund assistance. The detailed socio-economic factors consideration that influences the household need and their characteristics have been reflected in regression equations 2.24 to 2.26 in Chapter Two.

4.6 Chapter concluding summary

This chapter has illustrated how climate variability and trends analysis have proffered a feasible solution in dispersing a reliable water supply for an evolving smart city. Using a mixed-method research design that is driven by participatory action research philosophies, it has used the System of Systems (SoS) approach in the analytics dataset to evolve a climate-smart city storage requirement at the Josini area within KwaZulu-Natal Province, South Africa. Various regression models (multiple non-linear) were tested to show the level of relationship between the predictors to urban storage capacity required under varied climatic conditions, while conjunctive standardized rainfall anomaly index (SRAI), Standard Precipitation Index (SPI), precipitation concentration index (PCI) and coefficient of variation (CV) were tested for the downloaded World Bank dataset (2020-2075), which was used to evaluate the impacts of climate change on rainfall variability based on monthly, annual and seasonal variation as a precondition to determining stormwater harvest system (SWH) potential as an alternate water supply. Dependable rainfall at different ranked Weibull frequencies of 50%, 75% and 85% help in determining the safe-yield and the storage capacity requirement for proposed smart urban water supply adaptation. Detailed findings and conclusions are presented in Chapter Five.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study has illustrated the importance of sustainable stormwater harvest in a smart city, highlighting its socio-economic, technical and financial barriers in ensuring efficient SWH integration towards an alternate regenerated water augmentation plan. In assessing the impacts of climate change for evolving smart-city water management the study employed the Mann–Kendall and Sen’s Slope analyses to show the trend and variability changes amongst the climatic variables, while the observed patterns in meteorological data analysis were considered in determining the available runoff and discharge storage size requirement during the design stages. The use of the precipitation concentration index (PCI) was useful in estimating the physical upper limit to stormwater harvesting over a catchment and in quantifying the catchment runoff relations. In general, most of the findings were meticulously tied with the study's aim and objectives.

5.2 Summary of findings

5.2.1 Designing a stormwater harvest system.

The proposed SWH system designing under different climatic scenarios was based on 50%, 75% and 95% reliability monthly rainfall magnitude dependability frequency which serve as inflows into the services reservoir dam together with the regenerated water re-use that was used as alternate water argumentation sources. Likewise, the implication of the various hydro-meteorological trend analyses on temporal and spatial rainfall were carried out. Thereafter, the impacts on the water balance were examined. This helps in determining the reservoir storage capacity and expected total available water to be stored. Subsequent controlling variables and factors not limited to the structural stability of the building, road network and embankment designing were within a certain factor of safety in designing for the worse condition.

The curve number (CN) partitions method in GIS environment was used in routing uniform depth of precipitation and an infiltration abstraction component into a runoff component for the routing of the stormwater for collection. The resultant simulated smart-city design was carefully analysed using necessary value for average monthly rainfall (30 mm)-R; runoff coefficient-CN = 0.64; consumption per capita- 150 l/c/p; N- number of people in household=4 people longest average dry spell days (DD)= 15 days; water saving efficiency (WSE) = 60%; Stormwater use efficiency (SUE) = 0.3; and A_i - the study area = 3442 km²; and assessed in a frequency analysis-based spreadsheet where necessary value were substituted in relevant Equations 4.6, 4.7 and 4.8 in designing the storage capacity reservoir.

5.2.2 Amongst the identified challenges in implementing SWH

Amongst the identified hindrances to efficient SWH implementation are:

- Disinterest from government officials;
- Budget constraints /Inadequate funding;
- Poor knowledge and awareness;
- Lack of trained personnel/ technical skilled staff;
- Poor stormwatermanagement of infrastructure by municipalities;
- Stormwaterpollution caused by waste in drains, etc.;
- Vandalism of infrastructure;
- Lack of budgets for operations and maintenance; and
- Damage of stormwaterinfrastructure.

Also included are: poor stormwater management of infrastructure by municipalities; pollution caused by waste in drains, etc.; vandalism of infrastructure; a lack of technically skilled staff; and the lack of budgets for operations and maintenance. This is not also limited to urban migration, population growth, water losses, illegal water connections, illegal use of water by certain sectors, and industrial development as part of the foreseeable challenges to implementation of SWH system.

5.2.3 Derivable benefits of a SWH system in KZN

The efficient SWH integration into smart city designing when practiced well, its impact simultaneously in reduce hunger and alleviate poverty by provided an alternate reservoir of water available for crop farming and animal husbandry. Furthermore, among other multiple potentials benefits of a SWH system used in KZN and other area, include a reduction in soil and nutrient loss, improved groundwater recharge, aid livelihood systems improvements, and the regeneration of natural flow for vegetation uses (Fisher-Jeffes et al., 2017). Also, it has been noted to offer some of the intangible benefits that has been well documented in Ejegu and Yegizaw, (2020). Amongst other intangible benefits include its positive off-site effect of impoundment perennial flow; as well as improve the resilience of the environment through substantial recharged of the aquifer through the percolated stormwater.

Other multiple potentials benefit of a SWH system usage entail its adaptation to serve as a mean for short, medium and long terms plan to fight the impact of climate change. Moreso, that most decision-maker and stakeholder engagement in climate change adaptation still lack coherent in formulating, implementing, monitoring and evaluating its uses to compact negative effect of climate change.

5.3 Key Research findings

This research had shown that using historical and projected data analyses to assess the impacts of climate on the area's water resource shows an increase in temperature and high levels of evaporation, which is an indication of erratic weather conditions. The annual and seasonal MK trend test and Sen's slope analysis results showed a mixed trend, with an increasing trend at a rate of incremental interval 0.15°C to 0.35°C per decade for temperature, which invariably impacts negatively on the rainfall, based on this assertion, it is evident that available water resources is on the decline which further emphasises the need

for creating an alternative water source (SWH), such as proposed in the body of this dissertation.

Furthermore, the questionnaire survey performance shows a good correlation index performance of $R^2 > 0.75$ with $ENS > 0.68$ between changes in dependable rainfall frequency and smart cities storage capacity requirement while some respondents viewed the relationship between socio-economic, technical and financial barriers in the quantification of water availability either on a monthly or yearly basis to be of insignificant.

Also, the study has identified the effect of varied rainfall concentrations both in the temporal and spatial distribution as a major factor affecting stormwater distribution in the area. This assertion has also been corroborated by the study conducted interviewed results that these two indices (temporal and spatial rainfall distribution) should be considered in the design and operation of the smart city.

Also, the results of the analysed standardized rainfall anomaly index, precipitation concentration index and coefficient of variation using monthly rainfall data revealed that this rainfall characteristic are influenced greatly by climate change. The visual trend observed from historical rainfall records shows an onward declining trend buttressing the need for the proposed SWH adaptation to suite the smart city demographic data.

Furthermore, the study has argued the assumption that cities cannot simply copy good practices but must develop approaches that fit their situation (contingency) and concord with their organisation in terms of broader strategies, human resource policies, information policies, and configuration to the reality that is susceptible to constant change. Greater emphasis on stakeholders' involvement right from the planning stage and provision for appropriate extension support could help in expanding the benefits of water harvesting to large areas.

5.4 Contribution of the study to the body of knowledge

No doubt, the study has contributed to assess the impacts of climate change on water availability and provides practical adaptation and mitigation measures in ensuring water security in the area. The combined employed mixed method (adopted detailed qualitative and quantitative data) to address the imbalance of water demand using various considerations in selecting the most engineering and environmental hazard factor for consideration can serve as a prerequisite in designing a sustainable SWH system for the envisioned smart city development.

The responses from qualitative and quantitative surveys affirmed the feasibility of integrating efficient stormwater harvesting systems into smart cities such as Durban. The study has also highlighted other solutions to erratic water supply in the smart city evolving to include the use of groundwater exploration; the use of storage facilities within the house by pumping to elevated tanks; and allowing water to flow for usage in the house by gravity.

The research findings show that the total mean annual water yield for the area (Jozini) at various dependability frequency of $F= 50\%$, 75% and 95% depict available water for collection to be 88, 66.3 and 12 MCM per year. Likewise, the result for the projected annual seasonal variability shows an intermittent decrease from summer to winter with 93.264, 55.782, and 23.163 mm in average rainfall depth witnessed while the annual mean variability of rainfall coefficient of variation (CV) indicates that a moderately variable exists for Summer (CV = 52.7%) and Spring (CV = 52.37%), while Winter and Autumn were of fewer variables with CV=55.3% and CV=60.4% respectively. This implies the fitted a non-linear logistic regression between each season's precipitation and runoff over the area, tends to be highly variable in space and time to further suggest that available water resources are on the decline which further emphasised the need for creating an alternative water source (SWH), such as proposed in the body of this dissertation.

5.5 Limitation of the study

This study was limited to the nexus between climate change and water sustainability in the smart city only by assuming that all other smart city parameters and factors consideration remain constant. Amongst the many key drivers in promoting the smart city development.

The understanding of the hydro-climatic relationship in the catchment was also limited to the available data in deriving the water balance and water supply augmentation system. Also not considered in this study is the smart city pipe sizes and network performance under hydraulic demand and mechanical uncertainties.

Amongst other limitation is the confusion in cities classification as urban, semi-urban and rural areas was jettisoned in selecting the most preferred barriers that hindered the evolution of a smart city. This was too risky due to complex informal settlements, instability in political will, and an increasing population.

The barriers ranking factors and regression model developed were based on presumptions of constant socio-economic, technical and financial stability in the area's demography and water consumption pattern.

5.6 Areas for further research

Since the assessment of climate change variability and trend impact was limited to the use of PCI, CV, PR and SPI on the first trial, the additional use of analytical and sophisticated hydrological climate models should be tested with practical simulation approaches for further evaluation in order to ascertain their uncertainty.

Further research on how to quantify and evaluate the uncertainty associated with changing climate's effect on urban adaptation and resilience should be investigated.

The uncertainty and accumulative effects on the catchment streamflow and discharge records at the gauging station should be evaluated using a projected varying length of dataset as a mean to combat future challenges such as a climate-unstable future.

Further research is also needed on bias correction for potential evapotranspiration (PET) evaluation and its cumulative effect on topography, soil, water and vegetation. Overall, the result of this study is indicative of the likely future events to happen rather than accurate predictions. Hence, caution should be exercised in using quote figures and tables values.

5.7 Recommendations

Amongst the suggested mitigation measures that must be in place to alleviate the effect of climate change on the area's water sources are the development of operating rules for dams and stand-alone groundwater schemes, as well as adequate funding commitment from government and industry in reducing the impact of climate change through the adoption of climate change vulnerability assessments.

Although the DWS has a good monitoring system, this system should be used to forecast potential extreme events backed by a predictable, regular and sustained budget within the municipal plans (i.e., financial certainty is essential beyond project life). Moreover, the development of bulk water schemes by the DWS; the implementation of water conservation and demand management measures should be adopted as part of the best practices to be inculcated/adapted from other municipalities within and beyond South Africa.

Furthermore, the SWH system storage capacity should be designed to be resilient to projected climatic change while the integrated management of facility, process and cost requires significant consideration of more awareness campaigns, more investments in infrastructure, and better training of staff as necessary ingredients for its sustainability.

5.8 Conclusions

This study has analysed SWH integration under regenerated water uses as an alternate water use for sustainable city water supply and water conservation technology. The imperativeness of the SWH system provides a greater assurance of water supply, particularly during extreme drought events. However, despite localised successes, the broader acceptance of stormwater harvesting techniques has been limited, mainly due to the high cost of design implementation and adaptation to end-users. SWH is a decentralized water supply system that encourages community participation and self-reliance for local communities that have an enormous capacity to invest labour and time in doing it. Hence, proactive measures in SWH retrofitting are reasonably safe and a worthwhile investment in water transfer rights, with low risks.

This study concludes that government departments and other agencies should be striving to save people's lives through the provision of sustainable stormwater harvest infrastructure as an alternative water source in a smart city system configuration using the system of systems application of numerous data technology. Moreover, the design for the worst prognostic climate change scenarios should be further pursued with more historical data and projected future climate information.

The study recommends intuitive suggestions on policies and capacity development approaches through the institutionalization of proactive and capacity developmental platforms whereby climate change experts transfer knowledge, skills, and expertise to upcoming researchers. Likewise, future studies should consider the land use and land cover change effect in a smart city. Further research development in water utilities to not only optimise their energy consumption but also evaluate the feasibility of wastewater reconversion into an energy potential (biogas) is recommended.

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LIST OF PUBLICATIONS

Four research articles were written, three have been submitted for publication in reputable academic journals while two conferences papers were presented as at the time of compiling this thesis. The details are listed below:

Published Chapter in a TextBook

- B. Mukome., M. Seyam and O.T. Amoo 2022: Retrofitting Stormwater Harvest System in Dispersing Reliable Water Supply in a Climate-Smart City; ISDA 978-3-030-96307-1, 2022, Lecture Notes in Networks and Systems (LNNS 418), Springer, Chapter 81, Intelligent Systems Design and Applications

Peer-Reviewed Journal Articles (Submitted, and in-preparation)

- Operational design of Stormwater harvest storage capacity in a climate - smart city: (submitted) International Journal of Computer Information Systems and Industrial Management (Scopus indexed)
- Development of water resources utilisation model: case study of Jozini City (Manuscript ready for submission- Water SA Journal)
- Analysis of climate variability and trends at augmenting water demand in a smart city (in-preparation)

CONFERENCE PRESENTATION

- Multi-criteria comparison of engineering and environmental hazard factors in evolving a sustainable new smart city: presented at SAICE Environmental Engineering Division - Stormwater Management Conference 18 August 2021
- Retrofitting Stormwater Harvest System in Dispersing Reliable Water Supply in a Climate-Smart City (presented at 21st Intelligent Systems Design and Application (ISDA 21)- Auburn Washington, USA offline presentation on world wide web 13-15 December 2021

- Assessing alternate water supply sources under futuristic climate change scenarios (CCS) – a case study of Durban cities metropolis (Accepted) to the Future of Information and Communication Conference (FICC) 2023-3-4 March 2023 | San Francisco, United States.

APPENDIX A: ETHICAL CLEARANCE

APPENDIX B: INTERVIEW AND QUESTIONNAIRE SURVEY SAMPLE

DURBAN UNIVERSITY OF TECHNOLOGY

RESEARCH TITLE: DESIGNING A STORMWATER HARVEST SYSTEM IN NEW SMART CITIES UNDER DIFFERENT CLIMATIC SCENARIOS IN KWAZULU-NATAL, SOUTH AFRICA

This Interview schedule has been specifically designed to solicit experts' opinions on stormwater harvesting systems as a means to proposing sustainable and new smart cities under different climatic scenarios within the KwaZulu-Natal Province of South Africa. Your input may equally facilitate an adaptive and mitigative measure towards ensuring water security. Your participation and co-operation are voluntary. You may decide to withdraw from participating in this research at any stage without stating any reasons. Should you be willing to participate in this research, you may decide to stay anonymous or include your name and designation.

Thank you!

Virtual Interview – Qualitative

Date of Interview - _____

Name of Interviewee (Optional) - _____

Position/ Designation of Interviewee (Optional) - _____

INTERVIEW QUESTIONS

1. What are available water sources for domestic purposes in Durban/ KZN?
2. What are the available water sources for farming and industrial purposes in Durban/ KZN?
3. Are the identified water sources viable and sustainable?
4. What are the foreseeable challenges to the water sources in Durban/KZN?
5. How has climate change affected water sources in Durban/ KZN?
6. What mitigations have been put in place to alleviate the effect of climate change on water sources in Durban/ KZN?
7. What are the challenges to alleviating the impact of climate change on water sources in Durban/ KZN?
8. How significant is stormwater (rainwater) harvesting and why is it important?

9. What are some of the social, economic, and technical barriers to having an efficient stormwater (rainwater) harvesting system?
10. How feasible is it to integrate efficient stormwater (rainwater) harvesting into smart cities such as Durban?
11. Please recommend measures that may proffer a sustainable and viable stormwater (rainwater) harvesting system in Durban/ KZN.

QUESTIONNAIRE

Dear Respondent

This Questionnaire has been specifically designed to solicit (aggregated) views of experts/ stakeholders within the Water/ Climate change sector. It is presumed that the aggregated responses may be used to draw inferences on stormwater harvesting systems as a means to propose sustainable and new smart cities under different climatic scenarios within the KwaZulu-Natal Province of South Africa. Your input may equally facilitate an adaptative and mitigative measure toward ensuring water security. Your participation and co-operation are voluntary. You may decide to withdraw from participating in this research at any stage without stating any reasons. Should you be willing to participate in this research, you may decide to stay anonymous or include your name and designation.

Thank you!

Online survey – Quantitative

Date Questionnaire was completed - _____

Name of Respondent (Optional) - _____

Position/ Designation of Respondent (Optional) - _____

Responded instructions:

- Please insert an “X” in the appropriate box.

Please note: (Applicable to Sections B, C, D, and E)

Strongly Agree	SA
Agree	A

Indifferent	I
Disagree	D
Strongly Disagree	SD

SECTION A: DEMOGRAPHIC INFORMATION

A1: Gender

Male		Female	
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A2: Age Bracket

18-25 years	
26-35 years	
36-49 years	
Above 50 years	

A3: Highest Educational Qualification

Matric	
Diploma	
Degree	
Honours Degree	
Postgraduate	

A4: Closest Profession or Industry related to

Water	
Climate change	
Stormwater	
Rainwater	
Agriculture	

A5: Work experience within the chosen sector

0 - 2 years	
2 - 5 years	
6 - 10 years	
10 -15 years	
Above 15 years	

A6: Race group

Black (African)	
Indian	

Coloured	
White	

SECTION B: WATER SOURCES FOR DOMESTIC CONSUMPTION

		SA	A	I	D	SD
B1	There are a variety of water sources in Durban/ KZN for domestic consumption					
B2	The depleting water resources necessitate an alternate water source in Durban/KZN					
B3	The water sources in Durban/ KZN are reliable					
B4	The water sources in Durban/KZN are sustainable					
B5	The water sources in Durban/KZN suffice for the Durban populace/ region					

SECTION C: RELATIONSHIP BETWEEN WATER SOURCES AND CLIMATE CHANGE

		SA	A	I	D	SD
C1	The effects of Climate change have significantly impacted the water sources in Durban/ KZN					
C2	There is an urgent need to find an alternative water source for the Durban/KZN region					
C3	Exploring alternative water sources in Durban/KZN is very important					
C4	Exploring alternative water sources in Durban/KZN is important as a means to ensure water security					
C5	It is important to promote efficient stormwater (rainwater harvest) system as a means to ensure water security					

SECTION D: BARRIERS TO EFFICIENT STORMWATER (RAINWATER) SYSTEM

		SA	A	I	D	SD
D1	There are technical barriers to having an efficient stormwater (rainwater) system in Durban/KZN					
D2	There are social and economic barriers to having an efficient stormwater (rainwater) system in Durban/KZN					
D3	There are financial barriers to having an efficient stormwater (rainwater) system in Durban/KZN					
D4	There are cultural barriers to having an efficient stormwater (rainwater) system in Durban/ KZN					
D5	Lack of political will is an attributing factor to having efficient stormwater (rainwater) system in Durban/ KZN					

SECTION E: ADAPTATION TO CLIMATE CHANGE

		SA	A	I	D	SD
E1	The Department of Water and Sanitation has adaptive strategies to mitigate the effect of climate change					
E2	The effect of climate change is fast outwitting the adaptative strategies by the Department of Water and Sanitation					
E3	The Department of Water and Sanitation has a contingency plan in the short, medium, and long term to fight the impact of climate change					
E4	More investment and resources are needed to adapt to the impact of climate change					
E5	The Department of Water and Sanitation has the technical competence to offer an effective stormwater (rainwater) harvest system					
E6	The Department of Water and Sanitation has the financial competence to offer an effective stormwater (rainwater) harvest system					

SECTION F: RECOMMENDATION AND FURTHER REMARKS

F 1. Please recommend measures that may be used to sustain a viable stormwater (rainwater) harvesting system in Durban/ KZN.

F.2 Further remarks/ comments?