ECOSYSTEM-BASED ADAPTATION OF URBAN HYDROLOGY TO CLIMATE CHANGE IN THREE SOUTH AFRICAN CITIES

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Declaration

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

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Acronyms

CBD	Convention on Biological Diversity
CoCT	City of Cape Town
CoD	City of Durban
CoJ	City of Johannesburg
CoP	Conference of Parties
DEA	Department of Environmental Affairs
EbA	Ecosystem-based Adaptation
FEBA	Friends of Ecosystem-based Adaptation
ICZM	Integrated Coastal Zone Management
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resource Management
MEA	Millennium Ecosystem Assessment
NCP	Nature’s Contribution to People
SANBI	South African National Biodiversity Institute
TDR	Transdisciplinarity research
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change

Abstract

There can be no doubt that the world is experiencing climate change. Urban areas suffer intensified impacts thereof, including floods, severe storms, droughts and heat waves. Urban populations are increasing exponentially, forcing local governments to investigate functional, alternate ways to adapt cities to the negative risks of climate change, thereby becoming more resilient and ultimately suffering less catastrophe. Conventional hard infrastructure methods have proven to be insufficient against the impact of climate change. A method which has been considered positively is Ecosystem-based Adaptation (EbA), which makes use of natural processes, including biodiversity and ecosystem services (the benefits people derive from nature), to assist people in adapting to the adverse effects of climate change. EbA actions identified in literature range from maintaining rivers and wetlands to promoting natural vegetation. This dissertation aimed to critically explore the practice and presence of EbA within the climate change adaptation plans of three cities in South Africa (also referred to as metropolitan municipalities), namely: Cape Town, Durban and Johannesburg. The assessment of the adaptation plans was further supported by semi-structured interviews conducted with city officials and experts in the field. High-level water balances were calculated for these cities, so that the potential of EbA to contribute to reducing the vulnerability of urban water systems to the negative effects of climate change could be critically examined. The water balances were also used to identify the different types of water related infrastructure, either 'soft' (also called 'green' - e.g. wetlands, parks, rivers) or 'hard' (also called 'grey' - e.g. storm water drains, sewers, roads). I found that the inclusion of EbA related solutions within the adaptation plans was sparse, often only vaguely making reference to EbA through ecosystem services or soft infrastructure. There is uncertainty as to whether the implemented EbA actions, were in fact implemented with EbA as the driver, or if they were merely projects undertaken for other reasons, rebranded as EbA. Determining the proportion of the water balance managed by soft infrastructure, proved difficult, due to the challenges in defining and categorising the different components of the water balance as either hard or soft. It was noted however, that rainfall was the main quantitative contributor to the all three of the cities' water balance. EbA methods to manage a future reduction in rainfall include maintaining green spaces by growing drought resistant plants, and managed aquifer recharge. EbA methods to manage too much rainfall (for instance, floods resulting from increased rainfall intensity) include maintaining rivers and wetlands through river clean-up programmes to remove litter and alien vegetation. The suggestion that the resilience of urban water management can be supported by soft infrastructure using EbA approaches receives quantitative support from this study, since the natural water flows are of similar magnitude to the manages 'hard' infrastructure flows, but are currently only partially considered in the urban adaptation plans.

However, the uncritical championing of EbA as a sole or dominant solution is premature. Further research is required into the efficacy of EbA actions in managing urban water.

1. Introduction

Proof of the existence and occurrence of climate change is copious (IPCC, 2018). The challenge that currently faces humanity, most of whom, live in cities, is how to adapt to it. A recent suggestion by Depietri and McPhearson (2017) is that more preferable outcomes can be achieved, at lower cost, with greater reliability, by combining soft infrastructure (green - e.g. wetlands, parks, rivers), as provided by the remnants of naturally occurring ecosystems within urban areas, with the hard infrastructure (grey - e.g. storm water drains, sewers, roads) provided by city engineers, than would be achieved by either alone. This dissertation sets out to explore that idea.

The National Development Plan approximates that 80% of South Africa's population will stay in cities by 2050 (National Planning Commission, 2011). Considering the large percentage of the population living in cities, it then becomes increasingly important to ensure cities are 'resilient' and adaptable to a range of threats and challenges, including climate stresses. Cities, hubs of economic activity and development, are dependent on natural and farmed areas, for the supply of essential services such as water and food. Climate change directly affects natural and farmed areas and in turn, the cities. The IPCC Fifth Assessment Report found, with medium confidence[1], that worldwide, climate risks will be intensified in urban areas. Expeditious urbanisation has resulted in the development of severely vulnerable communities, especially those in informal settlements, on land that is most at risk of acute weather (Revi *et al.*, 2014). Cities are made up of multifaceted inter-connected systems, some natural, some built and some social or economic, which effective local governments can use to support climate change adaptation (Revi *et al.*, 2014). The IPCC further states that "Ecosystem-based adaptation is a key contributor to urban resilience" (Revi *et al.*, 2014).

There is unequivocal evidence that climate change is taking place (IPCC, 2013). Projections of observed trends and processes suggest that South Africa will be exposed to increasing occurrence and severity of both drought and rainfall events during the 21st century and these events will occur well within the planning horizon of most cities (DEA, 2013a). Average near-surface air temperatures in South Africa are projected to increase by as much as 5 to 8 degrees centigrade, over central parts by the end of 2100, under forcing scenarios which assume no successful emission mitigation efforts. Rainfall projections under climate change are less certain than temperature predictions, but are constrained to be in the order of approximately 15%, with most models suggesting drying in the west, and slight wetting in the east (DEA, 2018). Changes in runoff amplify changes in rainfall, and are therefore

[1] The IPCC uses levels of confidence to indicate the amount of evidence and level of agreement for a specific finding.

expected to range from a 20% decline to a 60% rise by the middle of the 21st century, with unmitigated global emissions pathway (DEA, 2018). Much of the Western Cape will experience decreases in runoff, while KwaZulu-Natal has a high risk of extreme runoff related events due to flooding. Climate change[2] has the potential to exacerbate existing constraints, such as aging infrastructure and informal settlements in South Africa while also creating unforeseen issues due to rainfall variability and extreme weather events, such as droughts and flooding.

EbA is a method that utilises "biodiversity and ecosystem services to assist people to adapt to the negative effects of climate change" (CBD, 2008, p. 10). EbA inspired interventions, such as maintaining or restoring natural vegetation in place of impermeable concrete or tarmac surfaces, could reduce stormwater runoff and increase groundwater recharge. In addition to these direct benefits, EbA also has the potential to contribute significantly to social, cultural and economic co-benefits (The World Bank, 2010). It promotes biodiversity conservation and makes use of traditional local knowledge (UNFCCC, 2017).

In this study the aim is to critically explore the use and potential of EbA in the climate change adaptation plans of three major South African cities. The lens of the city water balance is used in each case to understand the potential for EbA to contribute to reducing the vulnerability of urban water systems to climate change, both in terms of coping with drought, heatwaves, and reducing hazards from extreme rainfall events such as flash flooding. The study is summarised in Figure 1, indicating the interdependent relationship between urban water management within a city and the municipal climate change adaptation plans.

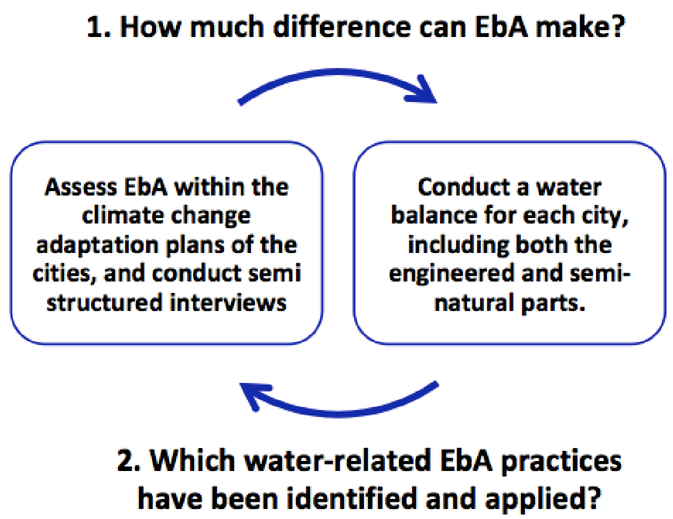

Figure 1: The relationship between EbA and urban water management systems within cities.

[2] Climate change includes both climate variability and especially change in variability.

The two, interacting aspects of the study lead naturally to two objectives and two work streams, under one overarching hypothesis (Figure 2).

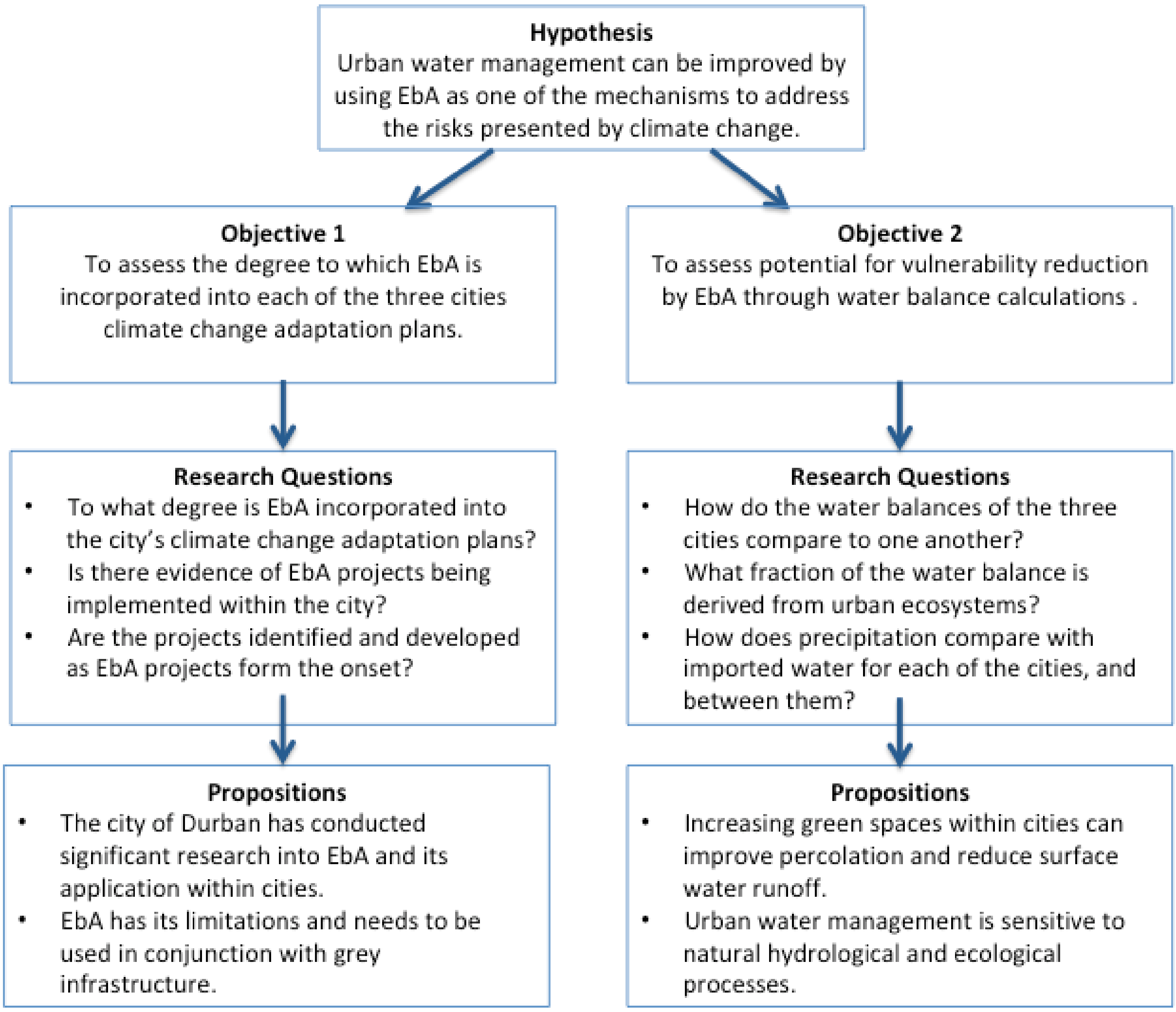

Figure 2: Hypothesis, objectives, research questions and propositions of the study.

1.1 Literature Review

EbA is emerging as a new option for cities, endeavouring to successfully manage ecosystems and urban populations, exposed to climate change. The Friends of Ecosystem-based Adaptation Network (FEBA) note that "*Few concepts have acquired as much prominence in such a short time span in the conservation and development sectors as Ecosystem-based Adaptation (EbA*)" (Bertram *et al.*, 2017, p. 3). Global and local case studies on EbA are prolific. In South Africa, for example, several policy efforts are emerging in this field (DEA and SANBI, 2016), and EbA forms the centre of the Department of Environment climate adaptation strategy. The research reported here was stimulated by the relative lack of literature on the linkages between semi-natural hydrological systems in urban areas, and the largely engineered systems of pipelines, pumps and reservoirs that supply water to urban populations, remove the resultant wastewater, and manage storm water. This study seeks to fuse concepts based in the natural water cycle (including rainfall and evapotranspiration) with the more conventional engineering view of water infrastructure (including storage and wastewater treatment works) in the hope that the hybrid combination will provide an affordable and resilient response to climate change.

1.1.1 Ecosystem-based Adaptation

Adaptation to climate change has garnered much attention in the global agenda over recent years (Barkdull and Harris, 2018). It emerged as an imperative policy response to climate change, when it became obvious that the world is committed to a certain degree of climate change, regardless of whether or not attempts to limit climate change by mitigation will be successful (Rogelj *et al.*, 2018). In the urban context adaptation can include both hard and soft measures. Hard measures include infrastructure investments designed to cope with floods, such as stormwater handling drains; or to bridge over shortages of water supply, such as increased importation of water from distant sources, larger storage capacity and new recycling facilities (Walsh, Dawson and Sayers, 2015). Soft measures cover non-structural options such as the use of services offered by urban ecosystems and the broader environment, to reduce the occurrence of extreme events and provide alternate sources of water purification and subsequent supply (Walsh, Dawson and Sayers, 2015).

The concept of ecosystem services, the benefits people derive from nature, first came to policy prominence in 2005 when the Millennium Ecosystem Assessment (MEA) was issued. The MEA most likely formed the basis from which the idea of EbA was formed. The MEA assessed the impacts of ecosystem change in relation to human wellbeing as well as the preservation and maintainable use of ecosystems (Millennium Ecosystem Assessment, 2005b). Ecosystem services were defined in four categories by the MEA: "supporting services, provisioning services, regulating services and cultural services" (Millennium Ecosystem Assessment, 2005b). In 2016, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), an institutionalised successor to the MEA, conducted a review of ecosystem services. The revision renamed ecosystem services as nature's benefits to people, to remove the association with the utilitarian economic concept of goods and services (Díaz *et al.*, 2015). This phrase later became "nature's contributions to people" (NCPs) in order to embrace both benefits and hazards (Díaz *et al.*, 2015). The classification of NCPs differs from that of the MEA. Supporting services Including hydrological processes are no longer considered NCPs, but are now considered ecosystem functions which under NCPs. Provisioning services such as the supply of freshwater are now included under "material contributions", while cultural services are "non-material contributions." Regulating services, for example the lessening of floods or the purification of water through wetlands, are now called regulating contributions.

The Rio Conventions: Convention on Biological Diversity (CBD); the United Nations Convention to Combat Desertification (UNCCD); and the United Nations Framework Convention on Climate Change (UNFCCC); all address climate change adaptation in their activities. In reports and processes over recent years, all the Rio Conventions implicitly or explicitly address the concept of EbA.

The term "ecosystem based approaches for adaptation" was recognised at the tenth conference of parties for the Convention on Biological Diversity (CBD) in October 2010. Prior to this the Secretariat of the Convention on Biological Diversity (2009, p. 41) had defined EbA as, "the use of biodiversity and ecosystem services as part of an overall strategy to help people to adapt to the adverse impacts of climate change." The convention stresses that the use of biodiversity and ecosystem services needs to be sustainable. EbA is based on the sustainable management, conservation and restoration of ecosystems which in turn enables the ecosystems to provide services that reduce the impacts of climate change (Secretariat of the Convention on Biological Diversity, 2009).

The United Nations Convention to Combat Desertification (UNCCD) has "focused on the adaptive capacities of dryland populations to highly variable environmental conditions" specifically addressing desertification and drought (CBD, UNCCD and UNFCCC, 2012, p. 2). The UNCCD 10 year strategic plan outlines three objectives, one of which includes improving the condition of affected ecosystems. More specifically the plan indirectly mentions EbA through the following expected impact: "Land productivity and other ecosystem goods and services in affected areas are enhanced in a sustainable manner contributing to improved livelihoods" (UNCCD, 2007, p. 10).

The United Nations Framework Convention on Climate Change first addressed EbA using it's Nairobi Work Programme. This programme was established at COP 11, in December 2005 with the aim of assisting all countries, specifically least developed countries and small island developing states, to advance adaptation understanding through distribution of knowledge in support of policies and practices (UNFCCC, 2011). A database on EbA was established under the Nairobi Work Programme, which includes examples from a variety of countries, including South Africa.

More recently the Paris Agreement developed a global aim on adaptation: "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" (UNFCCC, 2015). Even though EbA is not explicitly mentioned, the goal does include exposed people, places and ecosystems. In the supporting science conference prior to the Paris CoP, EbA concepts were prominent, including a special session devoted to them.

Some useful tools and methods, that couple to other key themes in reducing risks to climate stresses, have been designed. Ecosystem management, which enables EbA, for example, is a useful tool for climate change adaptation and disaster risk reduction as it increases the resilience of natural systems (Lackey, 1998; Tompkins, Adger and Adger, 2004; Munang, Thiaw, Alverson, Liu, *et al.*, 2013). Examples of EbA in cities include maintaining natural vegetation and increasing permeable surfaces. Approaches have also been developed to consider climate change adaptation and risk reduction incorporating ecosystem management. Such methods include Integrated Water Resource Management (IWRM) and Integrated Coastal Zone Management (ICZM) (Turton *et al.*, 2007; Munang, Thiaw, Alverson, Mumba, *et al.*, 2013). In the case of cities these are combined into a range of EbA measures (Table 1).

Table 1 Identifying and classifying EbA measures in cities. Adapted from the European Environment Agency (2012) and Geneletti & Zardo (2016).

EbA measure	Climate change impact	Justification	References
Promoting coastal zone protection.	Increased risk of sea level rise, intense and more frequent storm surges and associated flooding along coastlines.	Many cities are coastal. Natural vegetation and dune systems buffer the coastline from storm surges and erosion along coastlines.	(Barbier *et al.*, 2011; O'Farrell *et al.*, 2012)
Maintaining natural vegetation in the urban fabric and reducing the extent of impermeable surfaces.	Increased extreme rainfall events causing flooding.	Natural vegetation increases surface permeability and capacity to absorb runoff, thus attenuating storm peaks. It further promotes ground water replenishment.	(Tyrvainen *et al.*, 2005; Foster, Lowe and Winkelman, 2011; O'Farrell *et al.*, 2012)

EbA measure	Climate change impact	Justification	References
Maintaining and managing rivers and wetlands.	Increased extreme rainfall events causing flooding. Higher temperatures and decreasing rainfall can reduce freshwater quality.	One of the ecological functions of wetlands and rivers is flood moderation. Rivers and wetlands allow for attenuation of flood peaks and reduced risks to people and infrastructure. Keeping people and structures out of these habitats reduces risk. Wetlands and rivers also improve water quality through filtration and detoxification.	(Mitsch and Gossilink, 2000; Zedler and Kercher, 2005; Lewis and Kalidas, 2009; TEEB, 2011; O'Farrell *et al.*, 2012)
Maintaining natural green spaces such as parks, gardens or ecological corridors.	Increased heat waves	Green spaces have a cooling effect on cities, as the vegetation increases evapotranspiration and shaded area. The energy load is diverted into latent energy, reducing the urban heat island effect. Gardens and parks within urban areas improve connectivity, acting as corridors which assist in wildlife movement in response to climate change.	(Givoni, 1991; Gill *et al.*, 2007; Goddard, Dougill and Benton, 2010; Ignatieva, Stewart and Meurk, 2011; Kleerekoper, Van Esch and Salcedo, 2012)

EbA measure	Climate change impact	Justification	References
Promoting indigenous drought and high temperature resistant plant species.	Increased frequency and intensity of drought periods and heat waves.	Green spaces in cities are often water intensive, contributing to water scarcity. The use of indigenous, drought and heat resistant plants can reduce water scarcity. The xerophytic species can survive periods of water scarcity without irrigation.	(European Environment Agency, 2012)
Buffering food insecurity through urban agriculture.	Reduced yields of crops due to increasing temperatures and decreasing rainfall.	Urban agriculture allows vulnerable communities to produce their own food and become self-reliant, thus reducing food insecurity.	(Armar-Klemesu, 2000)
Reducing local air pollution through absorptive surfaces such as vegetation.	Higher temperature may increase local pollution levels.	Vegetation within urban areas improves urban air quality by absorbing pollutants on and in their leaves.	(Akbari, Pomerantz and Taha, 2001)

EbA has its limitations, which are often poorly acknowledged by its advocates (Barkdull and Harris, 2018). EbA is favoured by national governments, NGOs and research institutes, partly because it is seen as an incremental adaptation approach, not requiring large redirection of effort and capital expenditure. As the concept of EbA gathers traction opposing arguments can be expected, due to preference by some stakeholders for more transformational adaptation approaches (Barkdull and Harris, 2018). Transformational adaptation is considered a paradigm shift from incremental adaptation. Incremental adaptation refers to "*extensions of actions that already reduce the impacts of natural variations in climate and extreme events*" (Kates, Travis and Wilbanks, 2012, p. 7156). Whereas transformational adaptation refers to adaptation actions that go beyond current actions, alter and modify locations, and are implemented at a greater scale and intensity (Kates, Travis and Wilbanks, 2012). Transformational adaptation is used when the existing limits of incremental adaptation have been reached.

There are many uncertainties in the EbA approach, since it's implementation is still relatively new. There are likely to be thresholds regarding how much an ecosystem can reduce vulnerabilities to climate change (Perez, Fernandez and Gatti, 2010; D. Roberts *et al.*, 2012; Barkdull and Harris, 2018). Climate change is expected to have a negative impact on many ecosystems by directly affecting the ecosystems services that they provide. A point may be reached, for example, where temperatures will have increased beyond what current ecosystems are able to manage, which will lead to the appearance of novel ecosystems, that may have a reduced capacity to deliver key ecosystem services (TEEB, 2010).

Maintaining delivery of ecosystem services depends on ecosystem health. Ecosystem health is the fundamental foundation, upon which EbA is based, although defining a healthy ecosystem can be challenging. The core idea is that if the ecosystem remains healthy, it will continue to supply services and adapt to changes. There are two problems with this apparently "reasonable" idea: firstly, it is a statement of faith rather than evidence; secondly, it is a tautology, since what the proponents define to be "healthy", means "able to deliver the selected services". Barkdull and Harris (2018) suggest that a healthy ecosystem as it relates to EbA, is an ecosystem which preserves, maintains and enhances social systems for the benefits of humans, noting that "pristine" ecosystems "untouched" by human interference, no longer exist. This is thought provoking as it would seem that EbA was developed on the premise that "pristine" ecosystems are still in existence.

At a broader level even successful adaptation to climate change can be challenging to define, making it difficult to assess EbA interventions. A broad definition of climate change adaptation could include: "*any adjustment that reduces the risks associated with climate change, or vulnerability to climate change impacts, to a pre-determined level, without compromising economic, social and environmental sustainability*"(Doria *et al.*, 2009, p. 810). It is also worth noting that typically the "front runners" of climate change adaptation are developed countries. Comparatively, developing countries are most often forced to apply reactive adaptation in response to specific extreme climate events, mainly due to capacity and finance constraints (Doswald *et al.*, 2014). The finding by (Doswald *et al.*, 2014) is interesting because it is generally understood that developed countries focus on mitigation while developing countries focus on adaptation.

There is often a notion that EbA is an easier or cheaper alternative to "hard" engineering solutions (referred to as "grey infrastructure" in reference to the widespread use of cement). This may be a misconception, as Roberts et al. (2012) found in the City of Durban, EbA is as intensive in terms of data, technology and skills as hard infrastructure. The benefit of choosing EbA is that it brings co-benefits such as poverty alleviation, amenity value and biodiversity conservation and it may be more cost effective in the long run due to it's self-sustaining (and self-adaptive) attributes (Perez, Fernandez and Gatti, 2010; D. Roberts *et al.*, 2012).

Developing and implementing successful EbA requires cogeneration of solutions and participation from multiple actors. Transdisciplinarity, explained below, is an approach that encompasses both aspects.

1.1.2 Transdisciplinarity

The term ‘transdisciplinarity’ was first introduced in 1970. Transdisciplinarity operates beyond disciplinary boundaries, and aims to solve problems independently of a specific discipline (Mittelstrass, 2011). Transdisciplinarity is characterised by it’s focus on “wicked problems” that need creative solutions, it’s reliance on stakeholder involvement and engaged, socially responsible science” (Bernstein, 2015, p. 1). More specifically, transdisciplinarity research (TDR) is about conducting science *with* society (rather than *for* society) (Gibbons *et al.*, 1994; Becker, 2012; Bergmann, Jahn and Knobloch, 2012). Solutions to current global concerns like climate change are increasingly addressed through transdisciplinary research.

Transdisciplinarity works to address the limitations of disciplinary specialisation and compartmentalisation of knowledge (Bernstein, 2015). It is used to solve real world problems that require unique understanding and practical solutions. Conducting transdisciplinary research involves increasing the social relevance of research questions so that stakeholders are intimately involved in setting research goals and the research process (Woiwode, 2013).

TDR goes further than interdisciplinary or multidisciplinary research, by engaging stakeholders to co-develop, jointly analyse and transform the problem statement (van Breda and Swilling, 2018). Transdisciplinarity builds on interdisciplinarity. Interdisciplinary research speaks to the social grounding of knowledge generation (Rip, 2011). A crucial characteristic to successful TDR is to develop solution based TDR that explains and understands broader societal challenges and is capable of transforming these challenges. Implementing successful transformative TDR in the developing world differs to the developed world because of the differing and complex social conditions (Scholz *et al.*, 2006; Miller *et al.*, 2014).

Successful use of TDR is more than just involving a variety of disciplines, it is about co-creation and dual problem solving. The nature of climate change particularly in complex contests such as cities requires approaches that are broad and yet also deep enough to tackle the wicked problems we are being faced with. Utilisation of EbA to address climate change using a transdisciplinary approach can bring us closer to possible workable, practical solutions to climate change in urban contexts. Addressing climate change impacts through the implementation of EbA will, therefore require more than a generic implementation plan (e.g. EbA) that is replicated and transferred between different contexts. It will require all stakeholders and actors, ranging from local government to local citizens, to be involved with defining the problem state and jointly solving the problem using EbA.

Historically urban water management has been conducted in disciplinary silos. However, in order to withstand complex climate change impacts and create cities that are adaptable, cogenerated problem solving between a variety of different technical, social and political professionals is required. Ideally a transdisciplinary process should be encouraged between "*people who value different aspects*" of city spaces (Fratini *et al.*, 2012, p. 319). (Fratini *et al.*, 2012, p. 319) reference Wiek and Walter's (2009) definition of transdisciplinarity "*as an approach to team work that implies a mutual and joint learning process between the stakeholders and the experts involved*". This specific approach contributes to addressing complex societal challenges through cooperation and knowledge exchange between society and academia. Transdisciplinarity is specifically useful when addressing the transition towards a more sustainable economy.

Complex social conditions include communities that have informal social networks with limited formal leadership engagement (van Breda and Swilling, 2018). Implementing projects within such conditions can be challenging but failing to recognise the informality of some communities can lead to unsuccessful implementation projects. Recognising and functioning with informality is therefore crucial to implementing transformative TDR approaches in developing countries like South Africa.

Further to complex social conditions, the gap between scientific research and implementation is critical when considering the complexity of climate change and the wide range of stakeholders involved (Hirsch Hadorn *et al.*, 2007; Shackleton, Cundill and Knight, 2009). This gap can be narrowed by using TDR to collaboratively build partnerships between science researchers, implementers and communities to provide more effective and useful adaptation solutions (Cockburn *et al.*, 2016). TDR includes approaches such as multi stakeholder engagement, as well as university and government partnerships.

In the context of this study, TDR is important in urban water management, as it brings together multi stakeholders, like, hydrological engineers, environmental managers and affected communities to co-create solutions. While a much more engaged and detailed co-creation EbA agenda is clearly required this research, as detailed in the various sections that follow, begins to highlight some areas where a co-created, transdisciplinary engagement space can begin to be considered.

1.1.3 Water in the urban system

Given the plethora of EbA measures listed in the Table 1 above, attention can be drawn to the measures that relate directly to water resources. Climate change will substantially impact water resources (Jiménez Cisneros *et al.*, 2014). This study uses a high-level water balance to understand the potential for EbA to contribute to reducing the vulnerability of urban water systems to climate change. To conduct this type of a water balance, both the natural and engineered hydrological cycles need to be understood.

The generalised hydrological cycle, as shown (Figure 3), is the process that redistributes water across the Earth's surface (Pagano and Sorooshian, 2002; Oki and Kanae, 2006). Water evaporates from the ocean and land into the atmosphere, where it is transported as water vapour and aerosols (cloud droplets and ice crystals). The aerosols precipitate in the form of rain, snow, sleet or hail. The precipitation may be intercepted before it reaches the soil surface and evaporates off those wetted surfaces. The water puddled on the surface can either filter into the soil or run off. Most of what infiltrates into the soil is taken up by plant roots and transpired by the vegetation, back into the atmosphere. A small amount drains below the reach of plant roots, into the aquifer, which supplies springs feeding the drainage system in the form of a steady flow called baseflow. The local runoff often infiltrates in a different place, but that which is not directly absorbed recharges freshwater bodies such as rivers, often in a sharp peak known as stormflow. Finally the ocean is recharged through precipitation or river discharge, completing the hydrological cycle (Pagano and Sorooshian, 2002).

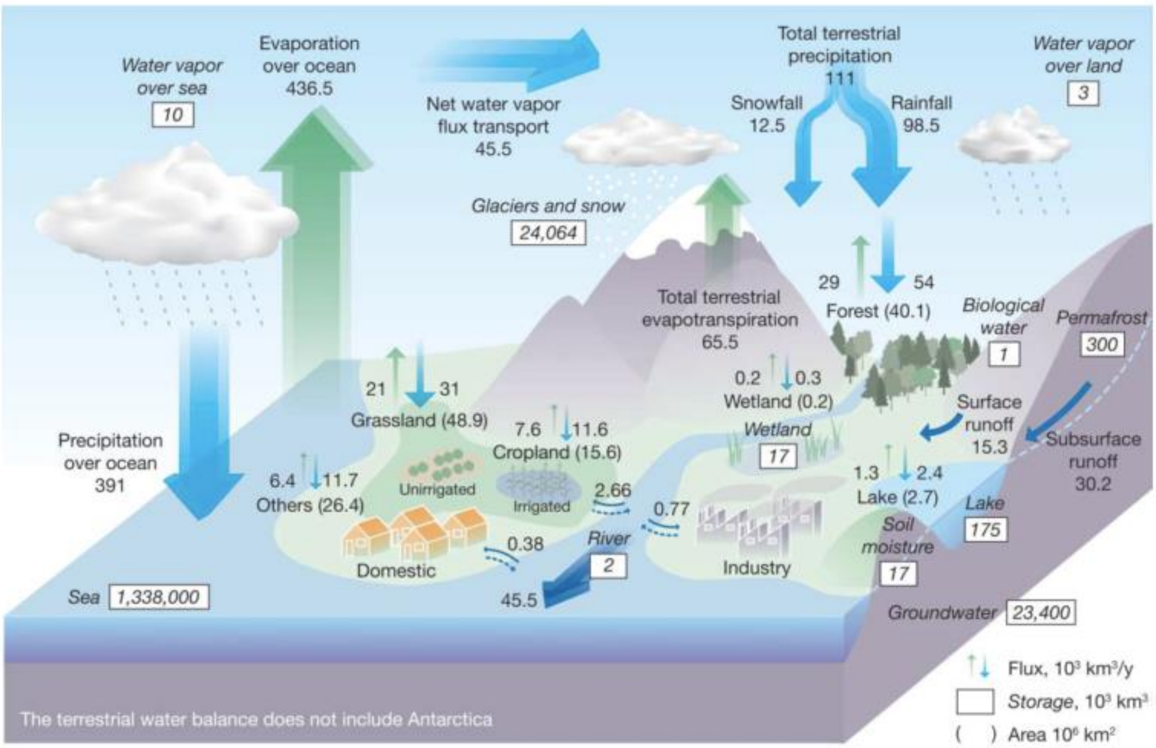

Figure 3: The global hydrological cycle (Oki, 2005).

The natural hydrological cycle is often overlooked or bypassed by water engineers within the city, who replace it with an engineered water system. Typically water engineers consider the following three main water systems within cities (Mitchell, Mein and McMahon, 2001; Wong, 2007):

- Potable water supply comprised of a piped water system, which transports water from catchments and storage dams outside of the city area, treats the water and uses a pump-and gravity-fed reticulation system, including temporary storage reservoirs, to distribute it to users.
- Sewage system also comprised of a piped system which collects wastewater and transports it to treatment plants.
- Stormwater drainage system which transports runoff through a variety of conduits such as drains and pipes, often including natural waterways, in their original or channelled form to a place where it can safely dissipate.

Through the use of EbA, and specifically by integrating the natural water cycle with the engineered systems, urban water systems can be improved and made more adaptable to climate change impacts (Zalewski, 2000). Over-engineered water systems within cities do not consider the role of ecological processes in moderating the urban water cycle. This oversight can result in extreme hydrological events, like flash flooding.

Urban water systems are often managed entirely from an engineering and technocratic perspective and not much consideration is given to local, natural water cycles. In both arid and wet urban ecosystems, ecology and hydrology form an interconnected relationship in which surface cover and water flows interact (Pataki *et al.*, 2011). Surface cover within the urban context is often highly transformed relative to the cover in the pre-urban ecosystem, with strong influences on the hydrology of the area.

Incorporating water sensitive urban design and permeable surfaces within future city plans can slow water surface flow and allow for percolation (Colvin *et al.*, 2016). Increased percolation assists in recharging groundwater and reduces pollution in rivers. Water sensitive urban design can be broadly defined as: "*the integration of urban planning with the management, protection and conservation of the urban water cycle, that ensures that urban water management is sensitive to natural hydrological and ecological processes*" (Wong, 2007, pp. 1–2). Initially water sensitive urban design focused primarily on stormwater management but it has since evolved to include the complete urban water cycle and its assimilation into urban design (Mouritz, Evangelisti and McAlister, 2006; Wong, 2007; Fletcher *et al.*, 2014).

Calculating an urban water balance is the first step to understanding water sensitive urban design. By calculating the urban water cycle, including all its major pools and flows, in both the engineered and natural parts, one is able to see the impact that urbanisation has on catchment hydrology (Mitchell, McMahon and Mein, 2003). An urban water balance also assists in identifying alternative methods for managing urban water resources.

A water balance focuses on the inflows and outflows of water from basins (Shiklomanov, 2005). The first step to conducting a water balance is to specify the spatial and temporal boundaries (Molden, 1997). A water balance is often manipulated by humans to accommodate their own needs. The simplest form of the water balance equation (Grimmond, Oke and Steyn, 1986; Shiklomanov, 2005; Kokkonen, Grimmond, Christen, *et al.*, 2018; Li *et al.*, 2018; Wakode *et al.*, 2018) at a basin level is the following:

$$p + I = r + E + \Delta S$$

Where:

p = precipitation

I = piped in water supply

r = net runoff

E = evapotranspiration

ΔS = net water storage change

An urban water balances considers two key aspects that are not relevant to rural water balances, these are namely piped water supply and organised water disposal (wastewater). Piped water supply for residential domestic use can account for more than half of the total water use in cities (Grimmond, Oke and Steyn, 1986). Piped water supply is typically brought in from outside urban areas and wastewater is usually treated and discharged outside of the urban area.

Both precipitation and piped in water volumes are high in urban contexts, while evapotranspiration and change in storage is low due to the impervious surfaces (Grimmond, Oke and Steyn, 1986). This often results in high runoff volumes, which need to be managed efficiently and effectively during heavy rainfall events to move the water away from flood prone areas. In many cases the different flows of the water balance can be difficult to estimate or the data is not readily available. An example of one such flow which can be difficult to estimate is groundwater because it does not stick to the specified temporal boundaries (Molden, 1997). Given these difficulties, rudimentary water balances can still be considered useful to managers, water engineers and researchers. The water balance equation in an urban context is useful as it can be used to understand and predict hydrological events such as extreme flooding within cities (Kokkonen, Grimmond, Raty, *et al.*, 2018).

2. Methods

The aim of this study was to investigate the use of EbA within the adaptation plans of three cities namely: the City of Johannesburg, the City of Cape Town and the City of Durban (the larger metropolitan area known as eThekwini)[3]. EbA was critically examined through two distinct work streams. The first work stream was an analysis of how EbA is being addressed by each city, which was achieved through semi-structured interviews and a review of climate change adaptation plans. The second involved estimating a high-level water balance for each city. The water balance was used as a tool to assess how EbA can be used to reduce the vulnerabilities of cities and the urban water system to climate change impacts like drought and flooding.

The two distinct work streams were set up to directly relate and complement each other. Considering the climate change adaptation plans of the cities as well as the semi structured interviews, the following question was raised: *How much difference can EbA make?* During the interviews critical questions were raised around the efficacy and success of EbA actions implemented in the cities.

Relating the urban water balance back to the climate change adaptation plans, the following question was raised: *Which water-related EbA practices have been identified and applied?* The climate change adaptation plans of the cities were reviewed to determine if there were any EbA actions that related to urban water management. If so, were these actions supported by the findings in the urban water balance conducted.

Answering these two questions through the methods presented in the sections below, contributes towards addressing the hypothesis of this study: Urban water management can be improved by using EbA as one of the mechanisms to address the risks presented by climate change.

2.1 City Descriptions

The subsections below broadly describe the biophysical characteristics of each of the cities.

City of Johannesburg

The City of Johannesburg is situated on the north eastern plateau of South Africa, referred to as the Highveld grassland (CoJ, 2009). The city is 1 740 metres above sea level and is located within the land

[3] South Africa is in the process of replacing colonial-era place names, such as Durban, with indigenous names, such as eThekwini. In this interim period, both are used, often one applying to the municipality and the other to the metropole.

locked province of Gauteng (Fatti and Vogel, 2011). The area of the city spans 1 841 km^2 and has a population estimated at 5.05 million people (CoJ, 2018).

Johannesburg has a dry and sunny climate, with mild temperatures and summer rainfall. During summer, thunderstorms normally occur during the late afternoon. Mean annual precipitation reaches roughly 600 mm. The city is strongly reliant on the Vaal River which is supplemented by water from Lesotho (Abrahams *et al.*, 2018). Due to this challenge the city commonly experiences water scarcity and increased costs of accessing water.

There are four broad aquifer types that have been identified in Johannesburg (Abiye, Mengistu and Demlie, 2011): Intergranular aquifer in alluvial covered areas; Fractured aquifer in the Witwatersrand Supergroup; Karstic aquifer in dolomites and Intergranular and fractured aquifer in crystalline rocks. Dolomitic aquifers produce low levels of surface runoff leading to relatively high levels of recharge and prevalence of underground water flow (Abiye, Mengistu and Demlie, 2011).

City of Durban

The City of Durban has an area of 2 650 km^2 with a population of 3.6 million people in 2016 and is located within the greater KwaZulu-Natal province (eThekwini Municipality, 2019). Durban is situated within the Maputo-Pondoland-Albany global biodiversity hotspot.

Durban has a subtropical climate with warm wet summers and mild dry winters. Mean annual precipitation is more than 1000 mm. The Agulhas Current that flows along the city's coastline, which is 100 km long, influences this climate (Roberts and O'Donoghue, 2013). Durban is described as hilly with some areas reaching up to 850 m in altitude.

Durban's primary aquifer is the Durban Harbour Beds, which are comprised of alluvial and estuarine deposits (Bell and Maud, 2000). These deposits sit on top of the St Lucia Formation. The secondary aquifer – the Dwyka Formation is considered to be the poorest groundwater aquifer within the city (Bell and Maud, 2000).

City of Cape Town

The City of Cape Town has an area of 2 953 km^2 with a population of 4 million people (CoCT, 2017b) and is located within the greater Western Cape province. Cape Town has a Mediterranean style climate with cold wet winters and hot dry summers (Midgley *et al.*, 2005). Mean annual precipitation is less than 800 mm. The city is situated within the broader mountains of the Cape Fold Belt. Cape Town has a coastline of 294 km (Abrahams *et al.*, 2018). The city is surrounded by the Atlantic Ocean to the west and the south and falls within the Cape Floristic Region.

A prominent aquifer in Cape Town is the Cape Flats aquifer. Most of the land above this aquifer is built up and hosts industrial sites. The Cape Flats aquifer is a shallow aquifer with the average thickness of the deposits about 30 m; a secondary aquifer exists below the primary aquifer, which comprises of shale and granite (Saayman and Adam, 2002).

2.2 Assessment of Adaptation Plans

In line with the first objective of this study, 13 interviews (Table 2) were conducted over a two-year period with departmental officials in each of the municipalities as well as experts from universities and the private sector. The individuals interviewed were selected based on the following criteria:

- The individual worked for one of the municipalities; and/or
- The individual conducted research on EbA, climate change adaptation, or urban water systems.

This selection criteria was used to identify individuals with extensive knowledge on EbA specifically relating to the municipalities of Johannesburg, Cape Town and Durban.

The following themes were explored during the interviews:

- Participant's perception of links between EbA and urban water management;
- Water related EbA practices that have been identified and applied within the municipalities;
- Limitations of EbA specifically within the municipalities;
- Municipality's management of stormwater runoff;
- Municipality's response during drought periods.

Semi structured interviews were conducted so that participants would not be limited by questions, but rather given space to explore the themes described above, allowing for an emergent set of responses and a narrative to be developed.

Table 2: Individuals interviewed, their designation and institution.

Designation and Department	Municipality or University
Head: Climate Change **Environmental Management Department**	City of Cape Town
Head: Environmental Policy & Planning **Environmental Management Department**	City of Cape Town
Head: Catchment, Stormwater and River Management Branch	City of Cape Town
Climate Change Adaptation/Resilience	Western Cape Government
Secretary **Director**	PACE (NPO) Credible Carbon
Climate Adaptation Branch **Environmental Planning and Climate Protection Department**	City of Durban
Manager: Catchment Management **Coastal, Stormwater and Catchment Management Department**	City of Durban
Lecturer **School of Built Environment & Development Studies**	University of KwaZulu-Natal
Umgeni Water Chair of Water Resources Management **Director: Centre for Water Resources Research**	University of KwaZulu-Natal
Post-Doctoral researcher **Durban Research-Action Partnership (D'RAP)**	University of KwaZulu-Natal City of Durban
Deputy Director: Open Space Planning, Water and Biodiversity Directorate	City of Johannesburg
Programme Manager: Climate Change Adaptation	City of Johannesburg
Managing Director **Surface water studies and environmental management**	Fourth Element Consulting

The following documents were obtained during the interview process:

Table 3: Documents and plans reviewed as part of the assessment of adaptation within each of the cities.

Municipality	Documents obtained
City of Durban	• Durban Climate Change Strategy (eThekwini Municipality, 2014) • Climate Change Municipal Adaptation Plan: Health and Water (Constable and Cartwright, 2009) • Sihlanzimvelo Stream Cleaning Project Progress Report (Tooley, 2014) • Catchment Coordinated Interventions (Tooley, 2010)

City of Cape Town	• Framework for Adaptation to Climate Change in the City of Cape Town (Mukheibir and Ziervogel, 2006) • Water and Sanitation Sector-Based Climate Adaptation Plan of Action (CoCT, 2015a) • Catchment, River and Stormwater Sector Climate Adaptation Plan of Action (CoCT, 2015b) • City of Cape Town Climate Change Policy (CoCT, 2017a) • Maintenance Management Plan: Dunes and Beaches (CoCT, 2017c) • Management and Rehabilitation Plan for the Hout Bay Dunes (Low and van Eeden, 2013)
City of Johannesburg	• Climate Change Adaptation Plan (CoJ, 2009)

2.3 Water Balance

In this study the key focus was on conducting a high-level water balance for three cities as mentioned above. The water balance included the inputs, outputs and changes in storage of water for a defined time period (2000 - 2015) for a bounded system (the city jurisdiction). The following generalised equation applies (Grimmond, Oke and Steyn, 1986):

$$\Delta S = (P + I) - (E_p + R_s + R_w + R_b)$$

Where:

$\Delta S =$ Change in storage, which can be in aquifers (including the soil) or surface water, such as dams.

$P =$ Precipitation (in the three cities assessed almost entirely in the form of rainfall).

$I =$ Imported water, in these cities from water supply schemes outside the city boundary, often in distant locations. For instance, a substantial part of the Johannesburg water is supplied by the Lesotho Highlands Water Scheme, 300 km to the southeast. Some of this imported water comes in via pipelines, and some is supplied by rivers which rise outside of the city bounds, and flow into it. The rivers themselves are often fed by pipelines from other catchments.

$E_p =$ Evapotranspiration from vegetated and non-vegetated surfaces.

$R_s =$ Stormwater runoff, the peak immediately after rainfall events, in cities mostly shed by hard surfaces and channelled through the engineered drainage system.

$R_w =$ Wastewater discharge, in principle a series of point sources from wastewater treatment plants. In practice there is leakage from the wastewater system to the aquifers and surface water, that ends up mixing with the runoff, and some of which evaporates.

R_b = Baseflow runoff, which is sustained after the rainfall event (throughout the year, for perennial rivers), and is largely fed from aquifers and the soil, and this is ultimately derived from permeable surfaces. In practice it is difficult to distinguish wastewater from stormwater as sewage leakage enters the stormwater system when high flows resulting from extreme rainfall events exceed the capacity of the stormwater system, causing the stormwater to penetrate the wastewater system.

Sankey diagrams were used to clearly illustrate the water balance results for each of the cities. Sankey diagrams are flow diagrams where the width of the arrow matches the flow quantity. In the case of this study, Sankey diagrams were used to represent the volume (in million m^3) associated with the inputs, outputs and flows of water. Version 4.5 of e!Sankey was used to generate the Sankey diagrams for this study (ifu Hamburg GmbH, 2018).

2.3.1 Storage

Two types of storage were considered as part of this study namely: dam storage and aquifer storage. A list of registered dams was downloaded from the Department of Water and Sanitation's website (DWAS, 2016). The capacity (in million m^3) of each of the dams within each of the city jurisdictions was extracted from the download.

Aquifer storage was obtained from the second Groundwater Resource Assessment, which was supplied by the Department of Water and Sanitation (DWAS, 2003). Volume of water stored within the aquifers was listed in m^3 per catchment. It should be noted that aquifer storage could not be accurately calculated for each of the cities as the aquifers span across the municipal jurisdiction.

2.3.2 Precipitation

Precipitation data for this study was obtained from the Climate Hazard Group Infrared Precipitation with stations (CHIRPS) record, which is derived from a fusion of satellite derived estimates based on cold cloud temperature and passive radar, calibrated against reported point records. CHIRPS is a quasi-global (50°S-50°N), high resolution (0.05°) dataset. It has been available daily, five-daily and monthly since 1995 (Funk *et al.*, 2015). This study used the monthly precipitation dataset for Africa. The data is provided as .tif files, which were visualised using the open source geospatial programme, QGIS (QGIS Development Team, 2018). The data for each city was extracted as follows:

1. Municipal demarcations (South African Municipal Demarcation Board, 2016) were loaded into QGIS.
2. Monthly CHIRPS data (raster files) were clipped to the municipal boundary for each of the respective cities using the GDAL extraction tool *clip raster by mask layer*.
3. GRASS GIS 7 command *v.rast.stats* was used to convert the clipped raster files to shape files. The command also generated the average monthly rainfall for each city, and this information was then exported to Microsoft excel.

Monthly CHIRPS data was also clipped according to the quaternary drainage regions that overlapped fully or partially with municipal boundaries.

2.3.3 Imported Water

The volume of imported water, also referred to as bulk water, was sourced from the water departments at the City of Cape Town (Halwiindi, 2018) and City of Durban (Govender, 2017) and from Joburg Water (Nthutang, 2017) for the City of Johannesburg. Imported water volume for the City of Cape Town and the City of Durban was only available from July 2002. The imported water for the missing period was estimated from the average of the monthly data for each of the cities for the period which was available.

2.3.4 Evapotranspiration

Evapotranspiration data was sourced from the ARC-ISCW Agrometeorology Programme's climate databank (ARC, 2014). The programme has roughly 500 weather stations within agricultural lands, mostly in rural areas around the cities, rather than in the urban area itself. The raw evapotranspiration estimates used for calculating the water balance were therefore larger than would be expected from cities themselves given the prevalence of impervious, non-vegetated surfaces in urban areas. The evapotranspiration data provided was for potential evapotranspiration (Ep). Actual evapotranspiration (Ea) was calculated by reversing evapotranspiration out of the water balance equation for the 16-year period and deriving the Ea:Ep ratio. The ratio was applied to the monthly Ep data to derive the Ea monthly data.

2.3.5 Runoff

Stormwater runoff channelled through the engineered drainage system is difficult to measure and data for this is not readily available. To work around this lack of data, flow within rivers was assumed to roughly represent stormwater runoff, since the stormwater system ultimately discharges into the rivers, either directly or via the soil and aquifer storage. Monthly river flow volumes (million m^3) for gauged catchments within the city bounds were downloaded from the Department of Water and Sanitation's Verified Data website (DWAS, 2011) by searching the river station numbers.

Rivers within the boundary of each city jurisdiction were identified using the Department of Water and Sanitation's Water quality data exploration tool. The tool provided KML files for the rivers and quaternary drainage regions of South Africa (DWAS, 2017). From this the rivers and drainage regions were clipped to the municipal boundaries of each city using QGIS. A list of rivers and drainage regions within each city was generated from the clipped files.

It should be noted that not all the river stations that fell within each city boundary, had available data. For this reason, a 10 km buffer was placed around the city boundary to include more river stations representative of similar geohydrological conditions. Furthermore, some of the river stations had flow data available that fell outside of the time period (2000 – 2015). To address this challenge the Budyko formula (Budyko, 1974) was used to estimate flow data for the period of interest, based on records from an earlier period, as per the following equation:

$$P = ET + Q$$

where P is precipitation, ET is evapotranspiration and Q is runoff.

The Budyko formula relates the runoff in a non-linear way to the aridity index, which is the ratio of potential evaporation to precipitation. The relation, in the form used, has a single parameter, which was fitted using the data for the available period. Runoff was then calculated for the unavailable period by using the available potential evaporation and rainfall for the target period, assuming the same catchment specific parameter value. The Budyko formula was used to characterise the different catchments taking note of the non-linearity of the runoff function.

2.3.6 Wastewater discharge

The wastewater departments within each of the cities provided the wastewater data used in this study (Viljoen, 2017; Brassell, 2018; Govender, 2018). All three wastewater departments noted that only inflow of wastewater was measured. It was generally assumed that inflow of wastewater matched the outflow of wastewater, given that treatment of the wastewater mainly removes sludge and not a large volume of water. In practice there is some leakage to groundwater, and some evaporation.

The City of Durban was only able to provide wastewater data for the time period 2005 – 2015. To address this challenge, the wastewater flow for the time period 2000 – 2004 was estimated based on the average for the time period 2005 – 2015.

2.3.7 Statistical Methods

The gathered data for the water balance was analysed using the following statistics:

- Mean: to indicate the average of the data and forms the base of the other statistics.
- Standard deviation: to indicate the variation from the mean and to assess if there are any major outliers in the water balance data.
- Trend %/y: to draw a trend from the data and to determine the robustness of the data. This statistic was not used to infer the presence of climate change but rather to assess the stationarity of the water balance data.

- Coefficient of variance: to determine relative variability in the data to understand the inter annual variability of the different water balance components.
- Regression Analysis: to examine the relationship and determine significance of trends highlighted in the different water balance components.

All statistics were calculated in Microsoft Excel © 2010 Microsoft Corporation.

3. Results

In this chapter a comprehensive climate adaptation policy review for each of the cities: Durban, Cape Town and Johannesburg is presented. The research is undertaken in the light of the high-level hydrological analysis for each location, which reveals the opportunities for Ecosystem-based adaptation, and their limits.

3.1 Overview of South African Policy regarding climate adaptation

There are a number of plans, policies, programmes and frameworks that include EbA in South Africa, either explicitly or implicitly. The National Development Plan (NDP) is a key policy document that outlines South Africa's vision for 2030. It sets out South Africa's transition to an environmentally sustainable, climate change resilient, low carbon economy (National Planning Commission, 2011). The transition includes "programmes to conserve and rehabilitate ecosystems and biodiversity assets" (National Planning Commission, 2011, p. 199). The NDP acknowledges that human welfare is reliant on a healthy planet and that sustaining South Africa's ecosystems and their services is essential for the country's social and economic development.

The National Climate Change Response White Paper takes its directive from the National Development Plan. The White Paper introduces the South African Government's climate change response in the transition to a climate resilient and low carbon society (DEA, 2011). Ecosystem services and EbA are specifically mentioned in the White Paper. These services are maintained through the management and protection of biodiversity and ecosystems and are fundamental to an effective climate change response (DEA, 2011). The White Paper stresses that climate change resilience can be improved by conserving, rehabilitating and restoring natural ecosystems. (DEA, 2011). The first policy directive for EbA in the country was essentially from the White Paper, even though the term, EbA, did not have much currency at the time it was written and the assertions around EbA were statements of faith rather than fact.

The Long Term Adaptation Scenarios (LTAS) Flagship Research Programme was developed in response to the White Paper. The LTAS was led by the Department of Environmental Affairs (DEA) in collaboration with the South African National Biodiversity Institute (SANBI). The aim of the programme was to develop national and subnational adaptation scenarios for primary sectors including water; agriculture and forestry; human health; marine fisheries; and biodiversity. Given that the LTAS was coordinated by the SANBI it is not surprising that the programme included climate change implications for the biodiversity sector in South Africa. EbA and expansion of protected areas were highlighted as adaptation response options for the biodiversity sector (DEA, 2013a). The EbA approach was also implicitly advocated as a measure for disaster risk reduction (coastal and inland flooding), the agriculture sector (protecting the livestock industry), and the human settlement sector (reducing the effects of heat waves in cities (DEA, 2013b).

The Strategic Framework and Overarching Implementation Plan for EbA was published by DEA together with SANBI in 2016 (DEA and SANBI, 2016). The strategy aims to develop a significant role for EbA in South Africa's work on biodiversity and climate change. Four priorities are identified by the strategy:

1. Mobilise capacity and resources for EbA through effective coordination, learning and communication.
2. Provide evidence for EbA through research, monitoring and evaluation.
3. Integrate EbA in policies and plans to support the overarching climate change strategy.
4. Implement EbA projects and realise the range of co-benefits.

The national policy context for EbA in South Africa is evident, but the question remains, who should implement EbA?

The City of Durban has taken positive steps towards implementation of EbA through a transdisciplinary approach. The case study that follows presents a good example of local government working with a university. The following problem was identified by the city: a deficit in human capacity and expertise within local government departments focusing on biodiversity and environmental projects (Roberts *et al.*, 2012). The solution brought together postgraduate students from the University of Kwa Zulu-Natal and the municipality's Environmental Planning and Climate Protection Department. The research partnership was termed the Durban Research Action Partnership (D'RAP) and was formalised in 2011, although, an informal relationship had been present from the early 2000s (Cockburn *et al.*, 2016). The long period of informal engagement between the municipality and the university, contributes towards D'RAP's success.

D'RAP works towards bridging the gap between scientific research and implementation. As part of D'RAP, postgraduate students are directly embedded within the municipality to promote transdisciplinary research. This has contributed towards developing a practical, well-structured and collaborative research team. Primary and secondary leaders were identified for the university and municipality respectively. In addition, a steering committee was developed to ensure finance control and project implementation.

A challenge faced by D'RAP is in integrating and applying the knowledge generated into decision making and management (Cockburn *et al.*, 2016). To address this challenge, a framework was developed to highlight the relationships between the main research themes and the human drivers of ecosystem change. The framework also linked the research themes with decision making processes, to improve reintegration of knowledge.

Durban's case study highlights the challenges local government faces when working with multiple partners to research and implement EbA. Noting this challenge, Brink *et al.* (2016) conducted a review of EbA research in urban environments. They analysed 110 articles and found that 31 % of the articles referenced local government as the EbA implementing partner. The plethora of current research on EbA struggles to include it within a broader socio-economic and bio geophysical context. 79% of the articles exclude participation of broader society in the research process (Brink *et al.*, 2016). Moreover, the articles that did include societal participation, used consultation rather than collaboration.

Considering local government, the next chapter examines EbA within the context of the City of Johannesburg, City of Cape Town and the City of Durban. Climate change adaptation related plans, policies and strategies were reviewed for each of the cities to ascertain the degree to which EbA was included or implemented within the city.

3.2 EbA in three South African cities

Possibly one of South Africa's best examples of incorporating EbA into city planning, using a variety of approaches including transdisciplinarity, comes from the City of Durban .

City of Durban

Durban's Environmental Management Department has been conscious of climate change challenges since its establishment in 1994. It took some years before climate change became a substantial part of the city's agenda due to the urgent need to address post-apartheid legacies and the restructuring of local government (Satterthwaite *et al.*, 2007). The citywide Municipal Climate Protection Programme (MCPP) was implemented in 2004 to manage the multifaceted challenges of climate change (Roberts, 2008). One of the main reasons behind the success of the MCPP at the time, was the participation of the Head of the Environmental Management Department, Dr Debra Roberts, in the global arena of environmental management (Roberts and O'Donoghue, 2013). This participation allowed for thorough engagement on climate change and was crucial for developing the MCPP as a "local level activist for change" (Roberts and O'Donoghue, 2013, p. 306). The MCPP example highlights the importance of capacity building in imbedding climate change within local government.

Durban is considered a front runner globally in terms of climate change adaptation, due to the fact that their MCPP was published as early as 2004 (Roberts, 2008; Carmin, Roberts and Anguelovski, 2009). The MCPP is comprised of four main elements: municipal adaptation (local government); community-based adaptation (adaptive capacity of local communities); ecosystem based adaptation (through municipal and community interventions) and a group of urban management interventions that address specific climate change impacts (urban heat island effect, storm water runoff) (D. Roberts *et al.*, 2012; Roberts and O'Donoghue, 2013). EbA has been incorporated well within the three adaptation constituents. The EbA projects were implemented through an iterative process that relied on experimentation, flexibility and innovation (D. Roberts *et al.*, 2012). In addition to the three main elements mentioned above, the MCPP also comprised numerous actions initiated to promote and facilitate the uptake of climate preservation (Roberts and O'Donoghue, 2013). An Environmental Planning and Climate Protection Department was developed to support the MCPP, with an inherent focus on biodiversity planning and in turn EbA (D. Roberts *et al.*, 2012).

EbA in Durban is strongly influenced by the fact that the city is located within the Maputaland−Pondoland−Albany global biodiversity hotspot. The structure and function of Durban's ecosystems are expected to change as the climate warms. These changes could negatively impact critical ecosystem services, such as water storage and purification, coastal protection and urban cooling (EPCPD and EO, 2014). Durban's urbanised area straddles this coastal hotspot, and potentially blocks climate-induced movement of species. Roberts *et al.* (2012) proposes that the adaptive capacity of the city can increase through the protection of biodiversity and associated ecosystem services. The EbA Roadmap for Durban was developed from this understanding. The roadmap (Table 5) consists of 10 steps that explain the building blocks of EbA, and how they can be incorporated into local government.

Table 2 EbA roadmap for Durban (D. Roberts *et al.*, 2012).

Step 1: Asking the climate question	An effective EbA programme should consider local climate. Local Government generally doesn't focus on long term biodiversity research, bioclimatic envelope models or general circulation models. For this reason, partnerships between local government and research institutions are critical.
Step 2: Filling the gaps	Due to the uncertainty of broad scale climate change projections, local governments are required to develop fine scale climate change projections. Cooperation between tertiary institutions and local government can be beneficial for knowledge generation surround EbA.
Step 3: Reducing the impact of non-climate stressors	To enable effective EbA, cooperation and knowledge sharing is required between government departments as ecosystems are often not limited to municipal boundaries.
Step 4: Securing the conservation estate	EbA is often seen as a cost-effective adaptation approach, however some degree of capital investment is required for land acquisition for

	example. This may be a limiting factor however for local municipalities that lack resources. Town planning and urban management tools can be used to protect biodiversity assets.
Step 5: Expanding the conservation estate	Expanding the conservation estate through community reforestation projects improves biodiversity, allows for carbon sequestration and creates ecosystem services. The long term timeframe of tree planting and carbon sequestration pose limitations for local government.
Step 6: Expanding green infrastructure	Green roofs are a common form of green infrastructure. Durban implemented the Green Roof Pilot Project in 2008 on an existing municipal building. Although there was initial resistance to the project, it has revealed the value of pilot project's ability to change perceptions. Rolling out pilot projects remains a challenge for EbA initiatives.
Step 7: Reducing the threat of invasive alien species and woody encroachment	Invasive alien species are expected to become more prevalent as the climate warms. In order to improve the adaptive capacity of ecosystems, invasive alien species need to be removed which is often a costly and complex process.
Step 8: Building the green economy	Development and climate change adaptation go hand in hand particularly for countries within the Global South. Developing a green economy together with improving socio-economic conditions is critical. Of particular interest is the Expanded Public Works Programme which includes Working for Fire and Working for Ecosystems. These programmes both have EbA benefits as well as providing employment for local community members.
Step 9: Institutional change	Local government departments will need to be restructured in terms of roles, responsibilities, skills and functions, to effectively implement large scale EbA projects.
Step 10: Exploring new directions	There is the need to effectively communicate to the general public the important link between biodiversity, ecosystem services and successful climate change adaptation and the severe consequences that would result from taking no action. This can be achieved through well-known environmental phenomenon such as the sardine run which generates substantial ecotourism each year.

Following the EbA roadmap, a Climate Change Adaptation Strategy was developed, with the aim of pinpointing municipal sectors that would be most at risk in terms of climate change (Roberts, 2010). Furthermore the strategy aimed to emphasise relevant and reasonable adaptation options to address the risks identified. The process of developing the strategy was beneficial in bringing together municipal sectors to discuss climate change risk management and adaptation options, but it did not generate any new adaptation options except for those within the biodiversity sector (Roberts and O'Donoghue, 2013). The reasons given for the unsuccessful process included the broad nature of the strategy; large existing workloads; lack of skills and funding and a lack of urgency in response to climate change.

In an effort to rectify the initial strategy process, the Environmental Planning and Climate Protection Department and the Energy Office of eThekwini Municipality developed the Durban Climate Change Strategy (DCCS) in September 2014 (eThekwini Municipality, 2014). The strategy included sector specific adaptation plans and addressed both mitigation, reducing the municipality's contribution to climate change and adaptation, in response to negative climate change impacts. Dividing the strategy into sectors was far more effective than the initial integrated approach as it generated climate change adaptation champions who were able to communicate the adaptation message back to the specific sectors and departments who were not directly involved in the strategy development. The strategy was developed through an initial phase of consultation and theme reports (water, biodiversity, food security, health, waste and pollution, energy and transport). Ten interdependent climate change response themes were recognised: Water; Sea level rise; Biodiversity; Food security; Health; Energy; Waste and pollution; Transport; Economic development; and Knowledge generation and understanding. The goals of each theme are described in the table below.

Table 4: Goals set in Durban's Climate Change Strategy.

Theme	**Goal**	**Relation to EbA**
Water	Effectively manage water resources and infrastructure to ensure maximum protection from climate change impacts.	Infrastructure can refer to both hard and soft infrastructure. Promoting soft infrastructure like rivers, wetlands and natural vegetation can regulate water runoff, mitigate floods and improve water purification (Mitsch and Gossilink, 2000; Zedler and Kercher, 2005; Lewis and Kalidas, 2009; TEEB, 2010; O'Farrell *et al.*, 2012).
Sea level rise	Protect coastal ecological infrastructure[4] by maintaining and restoring it where possible to provide a buffer against sea level rise and coastal storms. Further commercial development along Durban's coastline is discouraged in high-risk areas.	Promoting natural vegetation and dune systems along Durban's coastline will assist with buffering the coastline against storm surges and coastal erosion (Barbier *et al.*, 2011; O'Farrell *et al.*, 2012).
Biodiversity	Protect and enhance Durban's biodiversity and associated natural capital to deliver ecosystem services that provide long-term management opportunities and protection from the impacts of climate change.	This goal speaks directly to EbA, without actually mentioning the term, as an adaptation approach that makes use of biodiversity and ecosystem services to assist people in adapting to the adverse effects of climate change (CBD, 2008).
Food security	Maintain a robust and resilient food security system that ensures availability, equitable access to and	Buffering food insecurity through urban agriculture, will contribute towards maintaining

[4] Ecological infrastructure is defined as vital constituents including rivers, wetlands, soils, aquifers which assist with the supply of ecosystem services (Bristow *et al.*, 2010).

	efficient utilisation of food in the context of both climate variability and climate change**.**	robust and resilient food systems (Armar-Klemesu, 2000).
Health	Promote public health and safety and the prevention of diseases in the face of a changing climate. Maintain a public health system that is resource efficient and climate smart.	Absorptive surfaces such as vegetation reduce local air pollution, by reducing smog levels, which in turn improves public health (Akbari, Pomerantz and Taha, 2001).
Energy	Maintain Durban's sustainable energy sector, by supplying a significant portion of Durban's energy needs with safe, affordable, and appropriate renewable energy supply, while promoting energy efficiency across all sectors.	Maintaining natural green spaces such as parks, gardens or ecological corridor has a cooling effect on cities, because the vegetation increases evapotranspiration and amount of shaded areas. In turn this reduces the urban heat island effect through increasing latent energy (Givoni, 1991; Gill *et al.*, 2007; Goddard, Dougill and Benton, 2010; Ignatieva, Stewart and Meurk, 2011; Kleerekoper, Van Esch and Salcedo, 2012).
Waste and pollution	Maintain effective air, water, solid waste and waste water management systems on which resources are focused on reduction, re-use and recycling strategies that effectively reduce greenhouse gas emissions in all economic sectors, divert waste from landfill, and create employment opportunities. Design waste infrastructure appropriately so as to adapt to the impacts of climate change.	Green spaces such as parks, gardens or ecological corridors, improve local air quality by reduce smog levels (Akbari, Pomerantz and Taha, 2001). In addition, maintaining and preserving wetlands can assist with water purification (Mitsch and Gossilink, 2000; Zedler and Kercher, 2005; Lewis and Kalidas, 2009; TEEB, 2010; O'Farrell *et al.*, 2012).
Transport	Provide integrated, climate smart, low carbon transport systems for passengers and freight.	This goal does not have a direct link with EbA.
Economic development	Transition to a low-carbon economy that is socially responsible and environmentally sustainable, providing diverse economic opportunities, and increasing the capacity to adapt to the impacts of climate change.	Increasing the capacity to adapt to the impacts of climate change not only requires effective hard infrastructure but also soft infrastructure through the promotion of EbA (Wesener *et al.*, 2017).
Knowledge generation and understanding	Promote an engaged climate change research sector that generates regionally and locally relevant knowledge that is widely disseminated to all sectors in Durban for informed decision making and action.	An engaged climate change research sector should not only involve climatologists or ecologists, but it should also include engineers, planners, policy makers and the general public (Gibbons and Nowotny, 2001; Tress, Tress and Fry, 2005). Similarly a variety of disciplines need to be included during the research and implementation phases of EbA.

While Durban's climate change strategy does not specifically mention EbA, nine out of the ten goals mentioned above can either be:

- Directly related to the concept of EbA; or
- EbA can be used to achieve the goal.

The strategy is coming up for a 5 year review. Part of the review will include developing a fully integrated adaptation plan that incorporates the various line function adaptation plans.

City of Cape Town

The City of Cape Town published it's Framework for Adaptation to Climate Change in 2006, commissioned by the Environmental Planning Department (Mukheibir and Ziervogel, 2006). The framework aims to reduce climate change vulnerabilities in the city and provide an overarching plan for developing a City Adaptation Plan of Action. Adaptation to climate change in the biodiversity sector is addressed, detailing the importance of maintaining healthy ecosystems and ecological corridors for climate change adaptation (Driver, Smith and Maze, 2005). This is a more vague definition of EbA.

Following on from the framework, a Municipal Adaptation Plan was researched in 2007 for the City of Cape Town (Mukheibir and Ziervogel, 2007). At the time adaptation planning was focused at a national level, with little work focused on local scale. The research outlined current and future climate change impacts for the city and presented the process for developing a Municipal Adaptation Plan but no details were actually provided on adaptation planning.

Cape Town's Action Plan for Energy and Climate was published in 2010 (City of Cape Town, 2010). This Climate Adaptation Plan of Action is mentioned as a component of the Energy and Climate Action Plan. Significant attention is given to the protection, management and rehabilitation of functioning ecosystems as an adaptation strategy. The Ecosystem Mapping Programme aimed to identify the ecosystems that the city should protect and manage.

The City of Cape Town approved a Climate Change Policy in 2017. The policy promotes EbA for healthy lifestyles and social interactions, but it neglectfully overlooks EbA's benefits in terms of climate risks such as flooding and drought (CoCT, 2017a).

With the intention of working towards transdisciplinary methods, the City of Cape Town's Transport and Urban Development Authority (TDA) was formed in 2017. The TDA links key urban functions including transport, urban planning, public housing and environmental sustainability to promote synergy and investment partnerships within the city (TDA, 2017).

City of Johannesburg

The City of Johannesburg published the first climate change adaptation plan in 2009 (CoJ, 2009). The report included climate modelling and risk assessment. It covered, in detail, the vulnerabilities of key sectors within the city and also identified adaptation actions for the city.

Ecosystems are addressed in the adaptation plan, however, they are viewed in terms of degradation and the impact of urbanisation. No attention is given to the use of ecosystem services as a resource for adaptation. Interestingly, the city has initiated projects to protect the aquatic ecosystems of the Jukskei and Klipriver catchment areas (CoJ, 2009). A number of other projects are also beginning to emerge that may be useful in ensuring a comprehensive EbA approach in the City including the review of the adaptation plan by the City and the Global Change Institute of the University of the Witwatersrand, the work undertaken by GCRO (Khanyile and Maree, no date) and the emerging documents on green infrastructure.

It is worth noting, for example, that the city is in the process of developing a Green Infrastructure Plan, a Climate Change Strategic Framework and updating the 2009 Adaptation Plan, which may provide more insight into the City's EbA actions. The revised Adaptation Plan specifically focuses on priority areas including flooding and water security in times of drought and extreme heat. The plan avoids the use of specific terms such as EbA. An interview with a city official from Johannesburg revealed the following with respect to the recently updated Adaptation Plan:

"*The report itself only mentions EbA once. This update experiment didn't prescribe adaptation approaches to the city; rather it was city officials themselves who suggested adaptation options that will be important for Joburg. We consulted extensively with colleagues from our biodiversity unit and City Parks so that we could get their ideas and insights into the plan.*" (Respondent, City of Johannesburg).

The City of Johannesburg has also been working on a draft Spatial Development Framework (SDF) Review (CoJ, 2016). The review is encouraging as it has a greater focus on biodiversity and ecosystem services. One of the five major issues that SDF plans to address is the increasing pressure on the natural environment and soft infrastructure. The polycentric spatial vision for the City of Johannesburg aims to embed the city within a protected and integrated natural environment. The SDF outlines the plan to develop a resilient city with a metropolitan open space system as a protection buffer. Protecting valuable soft infrastructure, areas of high agricultural potential and biodiversity resources is endorsed. An integrated natural structure which provides valuable ecosystem services is a key focus area for the SDF.

Shortcomings of the current city structure include increasing pressure on the natural environment. The monetary value of providing ecosystem services (provisioning, regulating, cultural and supporting) by open space in Johannesburg was estimated at between R38 million and R77 million per annum (Schäffler *et al.*, 2013). The current asset value of Johannesburg's open space was between R966 million and R1.9 billion (Schäffler *et al.*, 2013). The total area of the Johannesburg municipality is 164 500 ha, of which only 54 082 ha (32.9%) remains in a semi natural state (SANBI). There are only 10 nature reserves in the city, covering a combined area of 993.7 ha (0.6%). This means that only a small percentage of the city's ecosystems are formally protected.

The table below lists the suggestions made by the SDF for the City of Johannesburg (CoJ, 2016):

Table 5 Suggestions from the City of Johannesburg's SDF and the relation to EbA.

SDF suggestion	Relation to EbA
Invest in and support the agricultural industry and agricultural projects.	Reduces the impact of climate change on food security within urban areas.
Invest in and support tourism, social, and spiritual projects in critical biodiversity areas to protect the areas, grow the economy and create jobs.	Creates awareness around the importance of ecosystem services and may provide corridors for biodiversity movement.
Make use of wetlands and swamps as natural buffers, serving as a natural urban development boundary and protection from flooding and climate related impacts.	Improves water quality and reduces flood peaks.
Plan green corridors and green patches as buffers between incompatible land use areas, such as between residential areas and industry.	Allows for biodiversity movement and increases suitable habitat for species.
Ensure that each street is planned with a tree line, a pedestrian and bicycle pathway using neighbourhood guidelines.	Reduces heat island effect and increases evapotranspiration.
Support and invest in community parks, gardens and urban agriculture and incentivise development on a neighbourhood scale.	Reduces the food security impact of climate change. Increases shaded areas and evapotranspiration. Regulates water runoff, reducing flood peaks and replenishing ground water flow.

Cities of the Global South face unique challenges as they often lack adaptive capacity to respond to climate variability and climate change (Satterthwaite *et al.*, 2007; Roberts *et al.*, 2012). Compounding the limited adaptive capacity is, the lack of hard infrastructure (e.g. storm water drains, sewers, roads) and the destruction of soft infrastructure (e.g. wetlands, parks, rivers) (Roberts *et al.*, 2012). Poverty, under development, poor government and lack of skills are also contributing factors. The poorer communities of urban areas are often regarded as limiting, maladaptive factors for the success of the city (Satterthwaite *et al.*, 2007).

Cities provide a range of ecosystem services to urban populations (Zalewski and Wagner, 2007; McDonald and Marcotullio, 2011). The ecosystem services are provided from a variety of habitats including domestic gardens, which are often overlooked (Cameron *et al.*, 2012; Cilliers *et al.*, 2013; Standish, Hobbs and Miller, 2013). Colding (2011) emphasises the importance of incorporating ecosystem services into urban planning. Integrating ecosystem services into urban sustainability planning will require new knowledge in planning and engineering (Calkins, 2005; Steiner, 2011). Given the scope and range of issues, a transdisciplinary approach is usually suggested to ensure effective engagement of various knowledge holders and the inclusion of “hard” and “soft” issues (Gibbons and Nowotny, 2001). This new knowledge should ideally incorporate co-design and co-production processes involving environmental scientists, planning professionals, engineers and representatives of various other interested groups (e.g. civic society) (Tress, Tress and Fry, 2005).

3.2.1 Examples of EbA Actions within each city

The ecosystem based and non-ecosystem based adaptation actions taken by each city with respect to water supply, sanitation and stormwater infrastructure; based on the Adaptation Plans that were accessible at the time of this study are summarised in Table 6. The City of Durban appeared to be the most advanced with respect to EbA actions, because, two of the actions relate directly to EbA and three could be considered as both EbA and non-EbA related actions. Including EbA related actions in a city adaptation plan can be challenging but this was not the case with the City of Durban as one interviewee noted:

“EbA is mainstream enough certainly in our municipality but probably in other places as well, to not run up against those walls” (respondent, eThekwini Municipality).

Another challenge encountered when identifying EbA related actions within the adaptation plans is that the actions identified may not have been developed with EbA in mind. In other words, EbA may merely be a consequence of broader more general adaptation actions. The City of Cape Town and Johannesburg are similar in that they both have one action which relates directly to EbA and one action which could be considered as both. Water sensitive urban design and sustainable urban drainage systems are two examples of adaptation actions that could be considered as both EbA related and non-EbA related actions.

The City of Durban specifically references protection and restoration of riparian vegetation as well as stormwater runoff reduction mechanisms such as green roofs (Constable and Cartwright, 2009). Similarly to Durban, the City of Johannesburg lists maintenance of wetlands, rivers and other waterways as an adaptation action (CoJ, 2009). The City of Cape Town broadly references maintenance and use of natural infrastructure, one example being the management and rehabilitation of the Hout Bay Dunes (Low and van Eeden, 2013).

EbA example in the City of Durban

An example of one of Durban's EbA actions is the Sihlanzimvelo Stream Cleaning Project (Tooley, 2010, 2014). The project is located within the umHlangane River Catchment and was developed to help the city manage increased rainfall intensity and flooding caused by climate change. During the first two pilot phases, 285 km of river courses were cleared of flow-obstructing material and flood defence measures were installed. The project also provided for an ongoing river clearing programme, to maintain the rivers in a flood-resilient state. The clearing involved removal of waste which had been illegally dumped or had accumulated in the rivers, as well as the removal of alien invasive species. Clearing in this way reduces the risk of blockages at bridges and roads. Removing blockages in turn reduces the risk of damage to water and sewer pipes, infrastructure, and roads. Furthermore, removing blockages assists in preventing and reducing the flooding of informal settlements that are often clustered along the riverbanks below the flood line, because, in some areas, this land is not privately owned. The high-level water balance includes stormwater flow and highlights focus areas for urban water management.

EbA example in the City of Cape Town

The City of Cape Town's Stormwater and Sustainability Branch are partners in the Source to Sea project within the Zandvlei catchment (WESSA, 2016). The project involves the city, South African National Parks and civil society organisations in managing and improving riverine habitats in an effort to rehabilitate and maintain the Zandvlei catchment. As part of the Zandvlei Catchment Management Plan, interventions were listed to reduce flood risk and improve water quality. The interventions included, for example, widening rivers, constructing litter traps and formal retarding basins to store water and protect against flooding.

EbA example in the City of Johannesburg

The City of Johannesburg lists a general category of "Maintain wetlands, rivers and other natural waterways" in it's adaptation plan. Examples of these adaptation actions include the rehabilitation of Klipspruit Kliprivier (KK) project. The KK project includes 36 interconnected parks along the river corridors (CoJ, 2010). Actions including river and wetland rehabilitation were implemented as part of the project. More specifically the rehabilitation measures included hard infrastructure measures such as river bank stabilisation, weirs and pollution reduction. There is little evidence to support the theory that the KK project is an EbA related adaptation action. It may provide similar benefits to EbA actions but in essence the project was not developed with EbA as the objective.

From these examples, one challenge was primarily identified as an inhibitor to EbA projects. This challenge related to the local governance of EbA projects, as they typically require the involvement of a number of different municipal departments. It was generally understood that while integration between departments is required, realistically, it can be challenging to implement due to silo line functions, in other words having multiple departments headed up by different individuals with no cross communication on common issues or challenges. This point is strengthened by the following quote:

"The silo nature is something that we are all aware of and that we all try to fight against, but it's so easy to fall into that pattern, because it's just the way people work… it's very easy to fall into that habit, so the idea for integrated adaptation plans is to try to be constantly aware of it [silo nature] *and to make sure that we are thinking in an integrated way"* (Respondent, City of Cape Town).

Roberts and O'Donoghue (2013) from the City of Durban agree that silo line functions are a challenge but instead of creating an integrated plan, the municipality promotes working with sectors individually to increase climate change awareness within the different sectors. An interview with a hydrological engineer at the City of Durban highlighted the success that the municipality has had with sectoral climate champions:

[We have] *"Various people in the various line functions that have an environmental consciousness about them, and EbA is a part of that."* (Respondent, City of Durban)

The champions within the City of Durban have contributed to the positive implementation of EbA within the municipality. Sectoral climate champions are successful because they have detailed knowledge of specific sector requirements and they understand the areas in which collaboration can be successful to fulfil climate change adaptation actions.

An opportunity that was highlighted by all the individuals interviewed at the City of Durban was the link between EbA and community based adaptation. It was generally acknowledged that community based ecosystem adaptation provides an opportunity to harness local knowledge and capacity in driving EbA on the ground. Roberts *et al.* (2012) reiterates the necessity to prioritise community based adaptation for the benefit of social cohesion and to improve knowledge about the socioeconomic advantages of current adaptation projects. Successful community based adaptation is evident in the Sihlanzimvelo Stream Cleaning Project, as discussed previously.

Table 6: A summary of EbA and non-EbA related actions for each city, with specific focus on water.

City	EbA actions	Non-EbA actions	Both
Durban	Protect and restore riparian vegetation to protect integrity of river banks and retain biological buffers against flooding.	Analysis of latest rainfall/run-off projections and system modelling.	Develop an overarching water use strategy.
	Raise awareness on the benefits of retrofitting storm water run-off reduction techniques e.g. green roofs.	Develop Master Drainage Plans for all river catchments within eThekwini municipal boundary	Prepare Coastal Management Plans
		Revise coastal set back lines	Develop co-ordinated procedure for inspection, clearance and maintenance of all storm water channels, attenuation infrastructure and water courses.
		Relocate informal settlements that are highly vulnerable to flooding and sea level rise.	
		Protection of municipal infrastructure (e.g. transport, storm water, sewerage, electricity).	
Cape Town	Maintenance and use of natural infrastructure	Model future water supply in the face of projected climate changes.	Promote and encourage the implementation of water sensitive urban designs through effective communication and education programmes.
		Consider the use of alternative water resources to surface water supply	
		Monitor rainfall data.	
		Ensure a continued drought response plan taking into account climate change projections.	
		Monitor groundwater recharge rates	

City	EbA actions	Non-EbA actions	Both
		Consider predicted climate changes and ensure that all new bulk water infrastructure is located out of high-risk areas.	
		Check adequacy of existing stormwater infrastructure under predicted climate change impacts and assess various adaptation options for implementation.	
Johannesburg	Maintain wetlands, rivers and other natural waterways.	Update flood line assessments	Implement a sustainable urban drainage system trial project.
		Urban floods early warning systems	
		Increase minimum pipe size for storm water infrastructure.	
		Retrofit Integrated Stormwater Management designs in existing infrastructure.	
		Conduct a stormwater infrastructure vulnerability assessment.	
		Consult Rand Water as well as other trans and intra boundary basin transfer management regarding security of water supply under climate change projections.	

3.3 The scope for EbA as revealed by hydrological analysis

The results of the high level water balance are presented below.

The water balance for each of the cities, in the year 2000 is graphically represented in a Sankey diagram (explained previously) in Figure 4, Figure 5 and Figure 6. The inflows of water include rainfall and imported water. The outflows of water include stormwater runoff, evapotranspiration and wastewater. Together the inflows and outflows of water make up the water balance. The light green arrows in the Sankey diagram represent water managed by soft infrastructure. The grey arrows are representative of water managed by hard infrastructure. Stormwater is depicted by the orange arrow because it can be managed by both soft and hard infrastructure. Stormwater and wastewater generally intersect at some point within the water cycle even when they are intended to be kept apart. Sewage leakage enters the stormwater system when high flows resulting from extreme rainfall events exceed the capacity of the stormwater system, causing the stormwater to penetrate the wastewater system. Dam, soil and aquifer storage are represented by the dark green blocks within the boundary of the municipality.

A comparison of water flows between each of the cities is presented in Table 8. The flows represent the average flow between the 2000 to 2015 time period. Rainfall volume, calculated over the total area of the city limits, is highest in Durban and lowest in Johannesburg. This indicates that Durban may require additional mechanisms to manage rainwater when compared with Johannesburg. Excessively high levels of rainfall can lead to flooding which is managed by stormwater drains (hard infrastructure). Maintaining rivers and wetlands can assist with flood mitigation by attenuating flood peaks (EbA related action). Durban's stormwater runoff is the least out of the three cities, and is likely due to differences in topography, soils, vegetation and intensity and frequency of rainfall event a contributing factor could also potentially be an increased presence of permeable surfaces, such as natural vegetation.

Evapotranspiration is greatest for the City of Durban, and smallest in magnitude for Cape Town. Usually, expectations would be that evapotranspiration is higher in an arid climate like Johannesburg and lower in a humid climate such a Durban. However, this was not what the results indicated. Durban showed higher evapotranspiration when compared with Johannesburg and this result could be attributed to the fact that Durban has greater vegetated areas than Johannesburg, which allows for higher evapotranspiration. Another reason for Durban's high evapotranspiration could be due to seasonality as depicted in Table 7. Durban's actual evapotranspiration is in excess of 80% of potential evapotranspiration, which means that unlike Johannesburg and Cape Town, there is not a strong seasonal water deficit, which explains the overall high evapotranspiration year round. Durban's high evapotranspiration is accompanied by low actual evapotranspiration seasonality, meaning that evapotranspiration remains roughly the same throughout the year. However Cape Town and Johannesburg have much lower evapotranspiration and much higher seasonality in actual evapotranspiration, meaning that the evapotranspiration is much higher during summer than in winter for Cape Town and higher in winter than summer for Johannesburg.

The potential evapotranspiration data for all three cities was sourced from the ARC-ISCW Agrometeorology Programme's climate databank (ARC, 2014). The potential evapotranspiration data was sourced from weather stations within agricultural lands, mostly in rural areas around the cities, rather than in the urban area itself. The raw evapotranspiration estimates used for calculating the water balance were therefore larger than would be expected from cities themselves given the prevalence of impervious, non-vegetated surfaces in urban areas.

Table 7: A comparison of average evapotranspiration over a 16 year period, rainfall variability and variability in actual evapotranspiration for the cities' of Johannesburg, Cape Town and Durban.

	Johannesburg	**Cape Town**	**Durban**
Evapotranspiration (Mm3.y-1)	1 000	592	2 011
Rainfall seasonality (%)	110	170	58
Ea seasonality (%)	24	43	16

The results showed that Cape Town had the largest stormwater runoff. This could indicate one, or all, three of the following problems: The stormwater drainage system is inadequate; Cape Town has a greater extent of impermeable surfaces or the rivers and wetlands in Cape Town are not adequately maintained.

The results show that imported water is relatively similar across the three cities (it works out at about 74 to 112 m^{-3} per capita per year) and is substantially lower than rainfall (42%, 19% and 14% of rainfall for Johannesburg, Cape Town and Durban respectively). Admittedly, a large fraction of the rainfall returns to the atmosphere as evapotranspiration, but in all cases there is a substantial surplus which can be used; and the size of this surplus can be increased either by rainfall harvesting (for instance by promoting the use of domestic rainwater tanks connected to roof gutters) or by promoting infiltration of rainwater and stormwater into the aquifer, where the water is largely insulated from the atmosphere, and can be extracted when needed by borehole pumps). This result suggests that adaptive water management efforts should have rainfall capture and runoff management as a high priority.

The results showed that wastewater volumes were also similar across the three cities, equivalent to 47 to 68 m^3 $capita^{-1}$ $year^{-1}$. Note that in all cases, the stormwater stream exceeds the wastewater stream. Thus there is quantitatively a bigger opportunity in capturing some of this flow, rather than in, for instance, efforts to recycle wastewater. Captured runoff (which is what stormwater is) may be socially more acceptable than the idea of recycled wastewater. In practice, in Johannesburg, substantial fraction of wastewater is effectively recycled, because it is released into rivers draining from the jurisdiction (for example the Klip river), but then captured outside the jurisdiction (for example at Vaal Barrage) and pumped back into the Johannesburg jurisdiction (McCarthy *et al.*, 2007). This does not happen in the coastal cities, since both stormwater and treated or untreated wastewater is discharged into the ocean from where it cannot easily be recovered. As a result, the public in those locations is more averse to the idea of recycling wastewater, despite the fact that it would be energetically more efficient than desalination, since the mole fraction of impurities is orders of magnitude lower.

Dam storage is largest in Johannesburg and similar in volume between Cape Town and Durban. Dam storage represents less than 1% of the rainfall flow for all of the cities, and less than 1% of the stormwater flow. This indicates that the current dam capacity it would not be able to capture and store the stormwater excesses. The opportunities for dam construction in urban areas are quite constrained – land is expensive, moving people from the flooded areas is problematic, and there may be few suitable dam sites. Furthermore, shallow dams are a relatively inefficient way of storing water, since they are subject to evaporation. On the other hand, in a dry country like South Africa, dams provide an aesthetic and recreation resource, which enhances the nearby property values if the dam is attractive and not polluted. Emmarentia Dam in Johannesburg is a good example, as are the dams on Table Mountain. The capacity of soil and aquifer storage is in all cases much larger than existing dam capacity, and therefore offer greater opportunities for adaptation. Water generally passes through the soil on its way to the aquifer, but the soil itself is not the best place to store water against drought periods, because it is within the root zone and thus subject to evapotranspiration (Bouwer Herman, 2000). Widespread waterlogged soils would also constitute a damp and subsidence problem from a building point of view. The benefit of storing water in the soil is short-term – it helps to even out horticultural water demand, and the resultant evaporation-driven cooling helps to make the city more liveable and attractive. But a better strategy may be to encourage rainfall and runoff to pass more efficiently into the aquifer storage, which is quantitatively larger, and is protected from evaporation (Bouwer Herman, 2000). This could be done by pumping excess water down boreholes, for later recovery; or more passively, by designing infiltration areas such as flood diversion areas in the lowlands, especially in places where the aquifer is permeable and within reach.

The difference between imported water and wastewater for Johannesburg, Cape Town and Durban differs by 39%, 25% and 43% respectively. This means that there is a portion of water which is being diverted into the evapotranspiration stream, either inadvertently, through leaks or deliberately through irrigation of gardens. This modifies the natural cycle by about 20% in Johannesburg, 10% in Cape Town and 5% in Durban, permitting for example the 'urban forest' of Johannesburg.

Interestingly, the City of Johannesburg's aquifer storage is substantially higher than that of Cape Town and Durban. This could be due to the fact that one of the aquifer types found in Johannesburg is the karstic aquifer in dolomites (Abiye, Mengistu and Demlie, 2011). Dolomites have low surface run-off with reasonably high recharge and prevalence of underground water flow (Witthuser and Holland, 2008) which may explain why Johannesburg's aquifer storage is noticeably higher than that of the other two cities.

Table 8: A comparison of the average annual flows, and maximum stocks within the Cities of Johannesburg, Cape Town and Durban, with the flows expressed as millions of cubic metres per year (Mm^3 y^{-1}) and the stocks as Mm^3.

	Johannesburg	**Cape Town**	**Durban**
	Mm^3.y^{-1}		
Rainfall	1 284	1 538	2 186
Evapotranspiration	1 000	592	2 011
Stormwater	498	1 020	416
Imported water	552	296	308
Wastewater	337	221	175
	Mm^3		
Dam storage[5]	35	313	315
Soil storage	368	591	530
Aquifer storage	3 865	837	314
	km^2		
Jurisdiction Area	1 841	2 953	2 650

[5] Dam storage was obtained from the Department of Water and Sanitation's registered dams list in terms of Dam Safety Legislation in terms of Chapter 12 of the National Water Act (Act 36 of 1998).

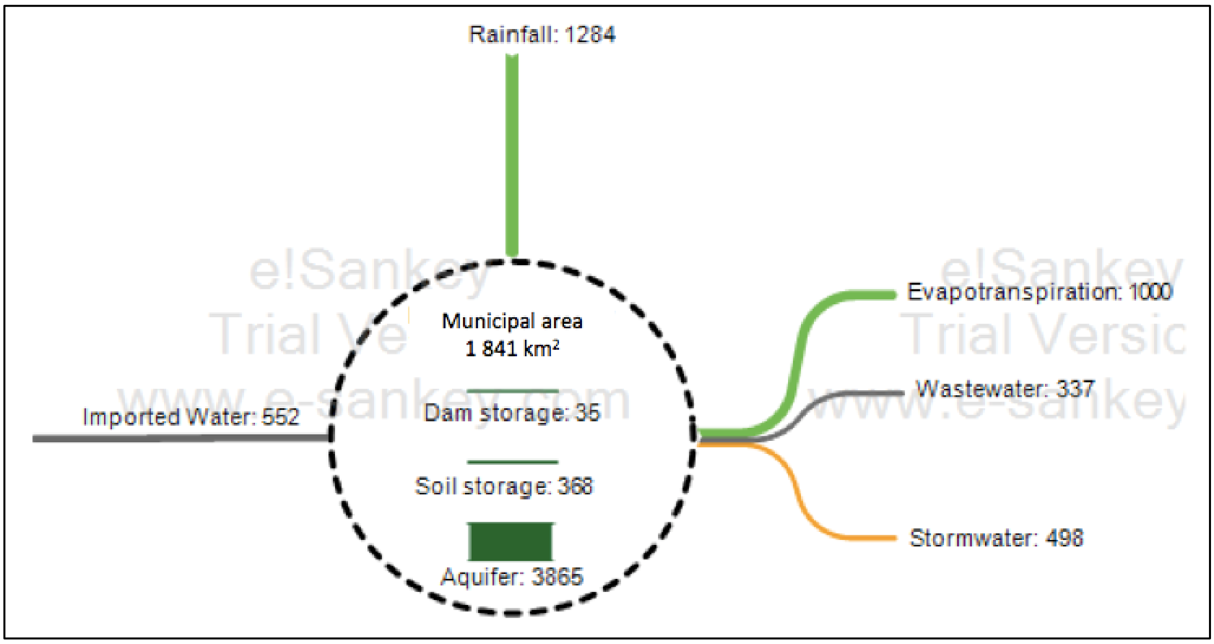

Figure 4: A high level water balance for the City of Johannesburg based on an average for the time period 2000 - 2015.

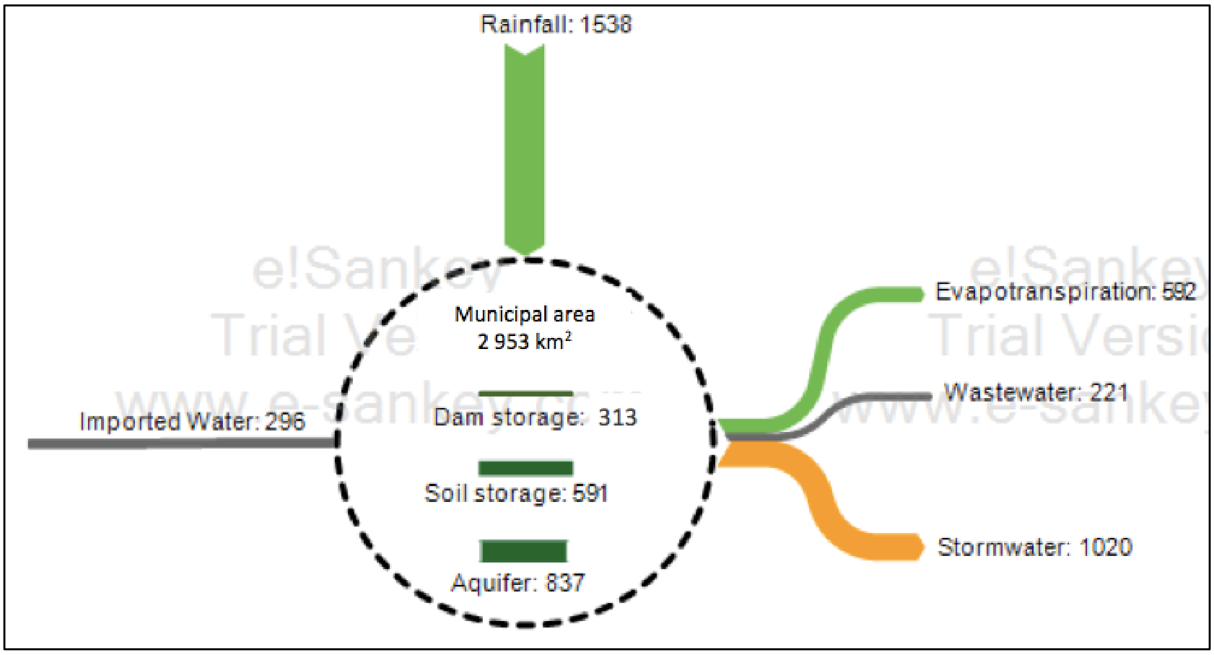

Figure 5: A high level water balance for the City of Cape Town based on an average for the time period 2000 - 2015.

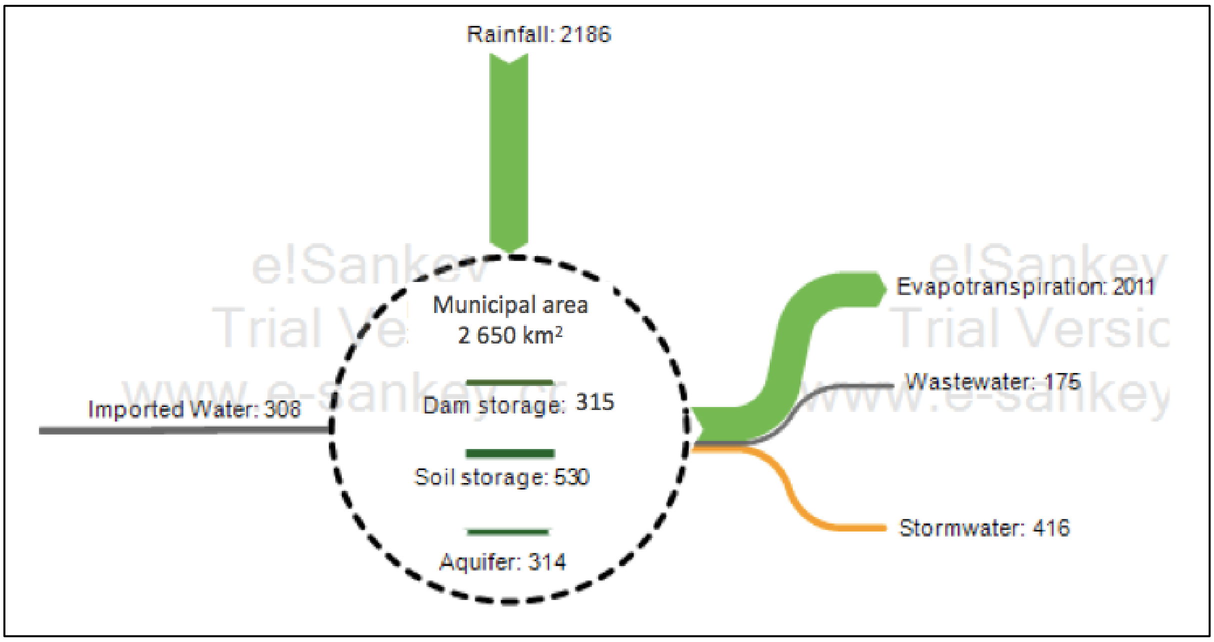

Figure 6: A high level water balance for the City of Durban on an average for the time period 2000 - 2015.

Interestingly, and contrary to the general perception of the city managers, in all three cities the majority of the total water budget within the metropolitan area passes through the 'soft' (or 'green', natural) infrastructure, rather than through the 'hard' ('grey', or engineered) infrastructure[6]. It follows from this, and from the fact that the water in the 'soft' infrastructure is hardly managed at all as a water resource, but only as a nuisance to be routed off the terrain as fast as possible, that many of the key opportunities for adaptation of the metropolitan water system lie in the ecosystem domain, rather than in the engineered infrastructure domain. A more detailed analysis, city by city, follows.

City of Johannesburg

The year-to-year data for the City of Johannesburg is presented in Table 9.

The three largest contributors to the City of Johannesburg's water balance are rainfall, evapotranspiration and stormwater runoff. Rainfall and stormwater runoff intercept both hard and soft infrastructure. City engineers typically build structures such as stormwater drains to account for large amounts of rainfall. Given its predominance in the water balance it may be pertinent for city officials to start looking at new avenues to manage large amounts of rainfall and stormwater runoff. Actions such as ensuring rivers and riparian zones are clear of litter or alien vegetation, which can

[6] Classification of the different components of the water balance as being managed by soft or hard infrastructure is subjective, noting that for example rainfall is managed by both soft and hard infrastructure.

cause blockages, should be prioritised. In addition there is the potential for stormwater runoff to be diverted onto school fields or golf courses. Furthermore, parking lots could be reconstructed to ensure the use of more green surfaces to allow for infiltration. High inter annual variance in imported water is most likely due to population demands.

Imported water and wastewater are the smallest contributors to the City of Johannesburg's water balance, representing roughly 17 – 20% of rainfall. This result is based predominantly on the size of Johannesburg's population. Given the small percentage contribution to rainfall, it would make sense that additional management efforts should focus rather on rainfall and stormwater runoff than imported water and wastewater.

The coefficient variance for wastewater and evapotranspiration is low which may make it easier to predict and manage. The coefficient of variance for stormwater runoff, imported water and rainfall is high and thus indicates high inter annual climate variation. Such variation and severe fluctuation, year to year, in rainfall and stormwater runoff could make it difficult for Johannesburg city officials to manage these water flows.

Results for rainfall and evapotranspiration show a downward trend, indicating climate variability. In comparison, imported water shows a significantly positive trend. This could indicate that Johannesburg experienced increased water consumption over a consistently drier period thus exacerbating droughts and heatwaves. The EbA implications of this finding would indicate that Johannesburg should focus on maintaining natural green spaces such as parks, gardens or ecological corridors to reduce the impact of heatwaves. Furthermore, the green spaces should include indigenous xerophytic species to ensure that the areas don't contribute to water scarcity.

Stormwater runoff and wastewater show an upward trend. The wastewater substantial upward trend can be attributed to the increasing upward trend in imported water. The increasing positive trend in stormwater runoff in relation to the downward trend in rainfall could be indicative of an increase in the intensity of rainfall events over Johannesburg. Essentially, reduced volume of rain was experienced, due to a drier period, however when rainfall did occur, it was severe and lead to sudden and vast volumes of stormwater. This problem should be addressed through increasing permeable surfaces and frequent maintenance of rivers and wetlands. During storm events, rivers rapidly become blocked with debris, litter and encroaching alien invasive plants that inhibit streamflow. Regular clearing of the rivers would improve the capacity of the river to handle sudden storm events.

Table 9: A high level water balance for the City of Johannesburg, indicating the inflows and outflows of water in million m³, for the period 2000 - 2015.

Year	Rainfall	Imported water	Stormwater runoff	Evapo-transpiration	Wastewater
	Mm³				
2000	1 693	338	790	977	302
2001	1 226	385	302	979	298
2002	1 177	422	261	1 025	308
2003	933	484	197	1 030	306
2004	1 389	497	255	947	336
2005	1 312	507	295	1 013	333
2006	1 478	523	513	953	341
2007	1 128	567	374	982	331
2008	1 308	572	549	962	353
2009	1 583	589	529	903	354
2010	1 535	579	791	1 006	384
2011	1 165	646	771	1 033	363
2012	1 315	660	614	1 056	344
2013	1 102	707	533	1 058	364
2014	1 239	666	719	972	357
2015	957	689	482	1 107	318
Mean	1 284	552	498	1 000	337
Standard Deviation	214	110	202	51	25
Trend %/y	-0.94%	4.07%	4.10%	0.42%	1.08%
Coefficient of Variation	17%	20%	41%	5%	8%
R^2	0.07	0.95	0.23	0.16	0.47

City of Durban

The data behind the Sankey diagrams for the City of Durban is presented in Table 10. Similar to Johannesburg, Durban's three largest contributors to the water balance are rainfall, evapotranspiration and stormwater runoff. This result indicates that city officials should focus their management efforts on rainfall and stormwater runoff. In coastal areas, stormwater typically drains into the ocean. There may however be an opportunity for the City of Durban to capture the stormwater runoff, recycle and reuse it.

The coefficient of variance for stormwater is high, indicating that the mean is not a good representation of the data. Stormwater in Durban can vary drastically year on year. This result could indicate that some years may be extremely wet while other years may be very dry. It would be beneficial to capture stormwater runoff and rainfall in water tanks and potentially pump it into the aquifers through bore holes, so that it can be stored until it is required during a drought period.

Rainfall shows a significant downward trend, which indicates climate variability as Durban's climate became drier over the 16 time year period. Similarly, stormwater and evapotranspiration decrease were most likely attributed to the declining rainfall. Imported water shows a substantial upward trend, which would mean that the city is consuming more water than is available. This could be contributed to increased demand along with drought conditions. Durban could increase the number of natural green spaces such as parks, gardens or ecological corridors to reduce the impact of heat waves. Making sure that the green spaces use drought and heat resistant plants, so as to avoid water scarcity implications. Capturing stormwater runoff could also assist during drought periods.

Table 10: A high level water balance for the City of Durban, indicating the inflows and outflows of water in million m3, for the period 2000 - 2015.

Year	**Rainfall**	**Imported water**	**Stormwater runoff**	**Evapo-transpiration**	**Wastewater**
	Mm^3				
2000	2 261	286	675	2 011	175
2001	2 531	286	511	2 322	175
2002	2 506	275	449	2 390	175
2003	1 763	279	226	1 872	175
2004	2 082	287	304	2 097	175
2005	1 900	292	298	1 903	169
2006	2 661	297	561	1 797	181
2007	2 404	311	366	1 996	137
2008	2 104	330	323	1 969	184
2009	2 174	330	567	1 907	189
2010	1 914	327	283	1 862	171
2011	2 474	315	502	1 901	202
2012	2 328	318	642	2 015	207
2013	2 420	326	535	2 240	168
2014	1 577	338	165	2 196	158
2015	1 874	336	253	1 692	160
Mean	2 186	308	416	2 011	175
Standard Deviation	314	22	158	193	17
Trend %/y	-0.88%	1.35%	-1.72%	-0.59%	0.02%
Coefficient of Variation	14%	7%	38%	10%	9%
R^2	0.0843	0.8158	0.0464	0.0849	0.0001

City of Cape Town

The data behind the Sankey diagrams for the City of Cape Town is presented in Table 11. As found for the previous two cities, rainfall, evapotranspiration and stormwater runoff account for the largest portion of Cape Town's water balance. The coefficient of variance for stormwater is high. This indicates that Cape Town experiences high variability in its stormwater runoff on an inter annual basis, meaning that there will be very wet and very dry years. Cape Town has been investigating desalination as a process for obtaining more potable water to assist during times of drought. However it may be more cost effective to capture stormwater runoff during the very wet years recycle it and store in the aquifers.

A prominent aquifer in Cape Town is the Cape Flats aquifer. Most of the land above this aquifer is built up and hosts industrial sites. The Cape Flats aquifer is a shallow aquifer with the average thickness of the deposits about 30 m; a secondary aquifer exists below the primary aquifer, which comprises of shale and granite (Saayman and Adam, 2002). This aquifer has high yields and positive borehole success rates (Colvin and Saayman, 2007) which may lend themselves to being used for pumping water into the aquifer.

Rainfall, imported water, stormwater runoff and wastewater show a positive trend for the 16 year time period. This indicates that Cape Town had excess water during the period, which may have resulted in flooding. There is scope for EbA to manage excess stormwater through maintaining rivers and wetlands. Litter and alien invasive vegetation can block rivers channels, causing the rivers banks to burst and result in flooding. Evapotranspiration shows a downward trend possibly due to the wetter environment over the period.

Table 11: A high level water balance for the City of Cape Town, indicating the inflows and outflows of water in million m3, for the period 2000 - 2015.

Year	**Rainfall**	**Imported water**	**Stormwater runoff**	**Evapo-transpiration**	**Wastewater**
	Mm^3				
2000	1 124	296	698	592	190
2001	1 806	296	1 287	592	207
2002	1 634	296	1 032	592	197
2003	1 224	277	608	519	189
2004	1 693	274	574	582	203
2005	1 570	245	1 280	603	205
2006	1 586	285	989	610	207
2007	1 935	293	1 350	610	238
2008	1 702	300	1 597	540	239
2009	1 515	302	1 206	621	247
2010	1 166	311	608	657	237
2011	1 239	316	530	680	219
2012	1 555	315	1 152	689	234
2013	1 955	294	1 805	563	249
2014	1 582	305	1 144	493	250
2015	1 314	327	467	522	232
Mean	1 538	296	1 020	592	221
Standard Deviation	260	19	404	56	22
Trend %/y	0.08%	0.79%	0.76%	-0.05%	1.69%

Coefficient of Variation	17%	7%	40%	9%	10%
R^2	0.0005	0.3288	0.0084	0.0006	0.6874

4. Discussion

The first objective of this study was to assess the degree to which EbA is already incorporated into each of the three cities climate change adaptation plans. The second was to calculate a water balance for each of these cities, to reveal the potential for ecosystem-based adaptation (EbA) to increase resilience to climate change.

To what degree is EbA already incorporated into city's climate change adaptation plans?

At the start of this project, the assumption was made that each of the cities have adaptation plans developed and published. Upon further investigation through interviews with city officials, it became clear that most climate adaptation plans are out-dated and are still in the process of development. In general, the cities first develop a climate change strategy, and only once this is complete are adaptation plans developed. Cape Town and Durban are leading in this area, as both have fairly recently published climate change strategies or policies. Johannesburg is still in the process of developing a climate change strategy but is close to finalising their Adaptation Action Plan review.

One of the reasons for outdated adaptation plans could be due to the fact that to use a transdisciplinary approach is a lengthy process. It was confirmed that the City of Johannesburg encountered this particular challenge, as one respondent noted:

"*From the onset we insisted on co-design/co-creation approach, where knowledge is shared from both the expert and also the practitioner's side with the view to creating one vision. The update of this plan took much longer than expected precisely because we engaged stakeholders a lot. But it was an opportunity of shared learning.*" (Respondent, City of Johannesburg)

The inclusion of EbA within the strategies, policies and previous adaptation plans is still minimal. EbA related activities are alluded to in some ways but the actual term "EbA" is rarely used. Typically, reference is made towards ecosystem services or the conservation of ecosystems, but the link with adaptation is missing. Zölch et al. (2018) also found that there appears to be no widespread adoption of EbA in the adaptation plans of, for example, German municipalities. The adaptation plans in Germany implicitly reference EbA by mentioning ecosystem services, biodiversity and soft infrastructure (Zölch, Wamsler and Pauleit, 2018).

The single EbA related action identified by the three cities, in South Africa, pertinent to this study was the clearing of alien vegetation and solid waste from rivers and other waterways. The intent in removing alien vegetation is to clear rivers of excess biomass that inhibit streamflow and lead to flooding. The critical question however, is how does alien vegetation differ from indigenous vegetation? Alien vegetation is a challenge in river ecosystems as it consumes more resources and water than indigenous vegetation. Removing alien vegetation improves streamflow (Dye *et al.*, 2011). Improving streamflow is positive for maintaining river ecosystems but can also exacerbate flooding instances. Alien vegetation grows faster and more easily when compared to indigenous vegetation (Holmes *et al.*, 2000). This means that removal of invasive, alien vegetation from rivers must be frequent, especially during warm seasons when growth is greater. Also, there are few natural ecosystem controls to maintain the carrying capacity of the land. Therefore, there may be more alien vegetation within in rivers that has the potential to cause blockages and aggravate flooding.

It is also apparent from the three cities adaptation plans that EbA related actions are currently only being used to address flooding and severe storms. This appears to make sense as the results in the previous section indicate that rainfall and stormwater runoff are two components that dominate the urban water balance, and would therefore require stronger focus by city officials.

While EbA related actions are important and should be addressed within the adaptation plans of the cities, one should not negate the contributions towards climate change resilience made by hard infrastructure. An effective strategy to reduce climate change related risks in the urban context should include a combination of hard and soft infrastructure (Depietri and McPhearson, 2017).

It was apparent from the interviews conducted that city officials are well aware of EbA and the role it can play in addressing climate change adaptation. It is therefore assumed that the adaptation plans currently under development and review will include stronger and more prominent links to EbA than the material currently available. A reassessment of the updated climate change adaptation plans for each of the cities could be an opportunity for future research.

Are the projects identified and developed as EbA projects from the onset?

Given the plethora of EbA actions mentioned in Table 1 above, maintaining rivers and wetlands is the most rudimentary and easily achievable action. It is difficult to ascertain whether maintaining rivers and wetlands is an action driven by EbA or if it is purely an action that can be rebranded as EbA. This theory is supported by the fact that the policies, strategies and plans do not directly reference EbA as a method to adjust to climate change risks such as flooding or drought. Furthermore the current actions such as maintaining rivers and wetlands, may in actual fact be in response to perceived vulnerabilities to current climate variability, as opposed to vulnerabilities to risk added by expected future climate change. Doswald *et al.*, (2014) makes a similar distinction between EbA and EbA related actions. Noting that EbA refers to actions that are explicitly developed and outlined in terms of EbA objectives. While EbA related actions refers to a wider array of actions with the possibility to achieve

EbA objectives but not intended or applied with the specified goal of achieving EbA. Maintaining rivers and wetlands is an action originally intended to preserve biodiversity and the natural environment, reduce litter content and improve aesthetic appeal (Millennium Ecosystem Assessment, 2005a). The intent to mitigate flooding would have been only one of the purposes of maintaining rivers and wetlands. For this reason it would appear that this action taken up by all of the cities, achieves EbA objectives but was not intended or applied with the specified goal of achieving EbA.

Rebranding actions may be more prominent than originally thought. EbA is often a favoured adaptation approach, as it is perceived to require little redirection of effort and capital expenditure. However this is not the case as (Debra Roberts *et al.*, 2012) found that EbA actions can be just as costly and time intensive as grey infrastructure actions. It is also suggested that for EbA actions to be successfully implemented in cities, it requires transformational adaptation, going beyond current actions (Kates, Travis and Wilbanks, 2012).

How does precipitation compare with imported water for each of the cities, and between them?

Rainfall across the three cities is almost an order of magnitude larger than imported water (bulk water supply). Purely based on the volume of water, it would make sense that cities should invest in managing rainwater. The declining rainfall and drier conditions in Durban and Johannesburg would suggest that these cities need in future to manage the risk of having too little rainfall, as well. Little to no EbA action is included thus far in metropolitan climate plans with respect to drought or heat waves. This is peculiar, given that South Africa is a drought prone country (Gibberd *et al.*, 1996) and that the country recently experienced the worst drought in 23 years (DAFF, 2016; Vogel and van Zyl, 2016). More emphasis should therefore be placed on EbA actions that reduce the impact of drought or heatwaves. Cape Town was possibly the worst hit in terms of the drought. Difficulties that arose in the municipality were related to too few rainwater tanks and grey water systems (Ziervogel, 2019). Rainwater harvesting is beneficial as it allows for water to be captured and stored across the city rather than in dams alone.

Natural drought responses include introducing additional and maintaining current green spaces within cities. The green spaces should include xerophytic plant species which are capable of growing in drought conditions and which will not contribute to water stress (Benvenuti and Bacci, 2010). Increasing green spaces within cities could go further than parks to include private gardens of the city residents. The cities of Durban and Johannesburg could look at investing in planting programmes that promote the use of xerophytic plants. Trees may be more favourable to use in achieving increased infiltration as they modulate the below ground ecosystem through root growth, senescence and stabilization of soil structure (Denman, May and Moore, 2011). The trees should ideally be positioned at the bottom of the slope as this is where the stormwater will collect.

In addition to direct drought responses, the City of Durban and Johannesburg could also consider additional storage facilities for water during heavy rainfall periods. Cities typically use hard infrastructure storage facilities. The potential to use existing dams as storage facilities has proven inadequate, as the volume of water that can be stored is far less than the volume of water from rainfall. Soft infrastructure related storage facilities investigated in this study included soil and aquifer. Soil provides short term storage, and is not appropriate for long term storage of rainfall. Managed aquifer recharge could provide a potential solution to develop deliberate reserves for drought. Managed aquifer recharge has multiple benefits one of which is securing and enhancing water supplies during drought periods (Dillon *et al.*, 2009). The Australian Governments National Water Commission is investigating this method as a feasible drought response.

Interestingly, Cape Town experienced increasing volumes of rainfall over the 16 year period, which could be linked to increasing stormwater. It is generally accepted that in urban areas, impermeable surfaces are the primary contributors to stormwater runoff (Boyd, Bufill and Knee, 1993). Cape Town faces challenges associated with urban stormwater runoff and flooding, particularly in informal settlements and wide low-lying areas (Madonsela *et al.*, 2019). To manage this the City's Disaster Risk Management Centre runs a programme in preparation for the winter rainfall season. The programme includes clearing stormwater infrastructure, drainage systems and banks of channels from solid waste, litter and sand to ensure functionality (Madonsela *et al.*, 2019). This programme appears to be missing an EbA component such as maintaining rivers and wetlands that would contribute to flood risk reduction. For example, how would managing the riparian vegetation alter the ability of the river to handle large volumes of stormwater? EbA remains an overlooked factor within plans and strategies (Renaud, Sudmeier-Rieux and Estrella, 2013; Matthews, Lo and Byrne, 2015).

Across all three cities, the general consensus was that stormwater and wastewater are difficult to separate, even though the initial intention was to keep them separate. During extreme rainfall events, stormwater drains overflow and intercept the wastewater system. This can primarily be attributed to a post-development state of high peak flows of water and short duration (Rizzo *et al.*, 2018). Pre-development state would typically refer to green permeable unpaved surfaces, which promote low peak flows and longer duration. Natural vegetation increases surface permeability and capacity to absorb runoff, thus attenuating storm peaks. It also further promotes aquifer recharge.

What fraction of the water balance is derived from hard infrastructure?

The water balances of the three cities reveal that the volumes of water provided by soft infrastructure are orders of magnitude larger than the volumes of water processed by the hard infrastructure. At the beginning of this study I proposed that urban water management is sensitive to natural hydrological and ecological processes. The results indicated that the fraction of the water balance derived from hard infrastructure was approximately 20% and the fraction from soft infrastructure was approximately 80%. Noting however that rainfall can also partially be classified as being managed by hard infrastructure, specifically the stormwater and sewage systems. Therefore drawing a hard conclusion around the dominance of soft and hard infrastructure on the water balance is difficult to achieve, but it is nevertheless clear that the current emphasis pays too little attention to the potential and risks associated with the soft infrastructure.

Study Limitations

A primary limitation to this study is the definition of water managed by hard and soft infrastructure. In most cases water flows are managed by both hard and soft infrastructure. This makes it difficult to draw a clear distinction between the volumes of water managed by either hard or soft infrastructure. This study suggests that urban water is primarily routed through soft infrastructure and for that reason urban water management should focus on more EbA related actions. The primary contributor to the urban water balance, as found by this study, is rainfall. Rainfall is an element of the soft infrastructure, but once it becomes urban runoff, it is in actual fact it routed through both soft (rivers) and hard (drains) infrastructure. This limitation does not alter the conclusion that the soft infrastructure is insufficiently considered in current plans.

Another limitation of this study relates to the imported and wastewater data obtained from the three cities. This data was often incomplete. Averages had to be drawn to estimate the data for the missing months. In addition this data is difficult to compare across cities, since inconsistent definitions and data sources may have been used. This limitation does not alter the conclusion that imported water is much less, quantitatively, than rainfall.

The data collected for evapotranspiration was generated from weather stations located in agricultural lands. The raw evapotranspiration estimates used for calculating the water balance were therefore larger than would be expected from cities themselves, given the prevalence of impervious, non-vegetated surfaces in urban areas. This limitation means that the evapotranspiration figures were possibly overestimated. The degree of overestimation is unlikely to exceed 20%, and does not materially affect the conclusions.

5. Conclusion

The aims of this study were to critically explore the use and potential of EbA in the climate change adaptation plans of three major South African cities, and to understand the potential for EbA to reduce the vulnerability of urban water systems to climate change, through the evaluation of high-level city water balances. Working towards this aim, I conducted a detailed policy review and assessment of the climate change adaptation plans of each city, and quantified a high-level water balance for each city.

With reference to my initial hypothesis, I conclude that urban water management can be improved by using EbA as one of the mechanisms to address the risks presented by climate change. The results presented in this project do not unequivocally support the idea that EbA can or should be the main pillar of urban climate adaptation plans in major South African cities; but nor do they reject EbA, as having no meaningful contribution. Soft infrastructure contributes considerably (perhaps dominantly) towards the urban water balance, with only a small fraction of the water balance managed by hard infrastructure. The definition and classification of the different water balance components is critical, and there is space for improvement in this regard. Rainfall is provided by soft infrastructure, but once it becomes runoff it is routed through both soft and hard infrastructure. Rainfall in these South African cities is an order of magnitude larger than the other flows in the water balances. In managing future likely decreases in rainfall, the cities would need to use drought related EbA actions such as maintain natural vegetation by using drought resistance plants or managed aquifer recharge. Cape Town is already implementing hard adaptation mechanisms but could improve resilience by incorporating soft infrastructure EbA actions.

Soft infrastructure will be more effectively managed by incorporating EbA within urban water management. Furthermore, the adaptation plans of the city could be significantly improved to incorporate EbA and associated actions. Cities can start to contribute to the management of soft infrastructure by including more EbA actions within adaptation plans, and by implementing more EbA driven projects.

A key challenge identified in this study was the classification of projects as “EbA”. Projects that are driven with EbA actions in mind differ to normative adaptation actions which have been implemented with general climate change adaptation in mind. The review of city adaptation plans found that there are projects which could be considered as EbA actions, but there is uncertainty as to whether they were designed as such, or whether they have were part of a ‘business as usual approach’, subsequently rebranded as EbA. Effective adaptation will demand transformative rather than just incremental approaches (Kates, Travis and Wilbanks, 2012).

Finally, it was also found that the climate change adaptation plans of the cities superficially include the term EbA. This could partially be due to the out-dated nature of the plans but also due to the fact that EbA within urban areas is a relatively new concept that needs to be better mainstreamed in and with all actors in the relevant City. EbA in itself is in its infancy and most of the work around it has been completed in rural areas. The potential for its application in urban areas is high, and incompletely explored. The emergence of various actions around green infrastructure, rethinking a co-created adaptation planning process in many of the Cities and the inclusion of science, practice and policy all bode well for further exploring and auctioning EbA approaches in water sensitive cities.

Annexure 1: City of Johannesburg Water Balance Data

Table 12: City of Johannesburg's Water Balance data for precipitation, bulk water (imported water), streamflow (stormwater) and evapotranspiration.

Year	Precipitation (mm)	Precipitation (m)	Area (m2)	Precipitation (m3)	Bulk water (m3)	Inputs	Streamflow (m3)	Ea (mm)	Ep (mm)	Ea (m)	Ep (m)	Ea (m3)	Ep (m3)
2000	919	0.92	1,841,000,000	1,692,511,235	337,693,750	2,030,204,985	789,668,482	530	1,168.91	0.53	1.17	976,509,630	2,151,957,308
2001	666	0.67	1,841,000,000	1,226,462,323	385,123,530	1,611,585,853	301,510,750	532	1,172.07	0.53	1.17	979,152,231	2,157,780,870
2002	639	0.64	1,841,000,000	1,176,517,774	421,630,960	1,598,148,734	260,625,441	557	1,226.79	0.56	1.23	1,024,865,550	2,258,520,390
2003	507	0.51	1,841,000,000	932,882,210	483,594,220	1,416,476,430	196,862,712	559	1,232.44	0.56	1.23	1,029,585,584	2,268,922,040
2004	754	0.75	1,841,000,000	1,388,529,710	496,752,140	1,885,281,850	254,520,742	514	1,133.45	0.51	1.13	946,890,891	2,086,685,793
2005	713	0.71	1,841,000,000	1,311,890,661	506,565,680	1,818,456,341	294,702,062	550	1,213.11	0.55	1.21	1,013,440,066	2,233,341,782
2006	803	0.80	1,841,000,000	1,477,610,355	522,792,790	2,000,403,145	512,835,630	517	1,140.22	0.52	1.14	952,544,606	2,099,145,020
2007	613	0.61	1,841,000,000	1,128,087,597	567,101,696	1,695,189,292	373,778,251	533	1,175.58	0.53	1.18	982,084,500	2,164,242,780
2008	711	0.71	1,841,000,000	1,308,357,129	571,820,300	1,880,177,429	548,794,340	523	1,151.56	0.52	1.15	962,018,090	2,120,021,960
2009	860	0.86	1,841,000,000	1,582,933,371	589,143,960	2,172,077,331	529,366,467	491	1,081.37	0.49	1.08	903,381,068	1,990,802,170
2010	834	0.83	1,841,000,000	1,534,978,290	578,742,390	2,113,720,680	791,251,530	546	1,204.24	0.55	1.20	1,006,027,185	2,217,005,840
2011	633	0.63	1,841,000,000	1,165,442,081	646,441,610	1,811,883,691	771,492,155	561	1,236.86	0.56	1.24	1,033,278,071	2,277,059,260
2012	715	0.71	1,841,000,000	1,315,483,581	660,223,620	1,975,707,201	613,735,638	573	1,263.79	0.57	1.26	1,055,775,507	2,326,637,390
2013	598	0.60	1,841,000,000	1,101,808,806	707,037,521	1,808,846,328	532,592,032	575	1,266.74	0.57	1.27	1,058,239,949	2,332,068,340
2014	673	0.67	1,841,000,000	1,238,636,677	666,171,815	1,904,808,493	719,112,538	528	1,163.21	0.53	1.16	971,750,550	2,141,469,610
2015	520	0.52	1,841,000,000	957,112,145	688,866,685	1,645,978,830	482,462,178	601	1,324.72	0.60	1.32	1,106,676,686	2,438,809,520

Table 13: City of Johannesburg's Water Balance data for wastewater, aquifer storage, dam storage and soil storage.

Year	Wastewater (m3)	Output	Output - Input	Storage (m3)	Aquifer (m3)	Dam Storage (Mm3)	Field capacity	Soil depth (m)	Soil Storage (Mm3)	Aquifer (Mm3)
2000	302,107,000	2,068,285,112	38,080,127	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2001	297,789,000	1,578,451,981	-33,133,871	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2002	307,792,000	1,593,282,991	-4,865,743	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2003	306,460,000	1,532,908,296	116,431,866	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2004	336,062,000	1,537,473,632	-347,808,217	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2005	333,488,000	1,641,630,129	-176,826,213	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2006	341,171,000	1,806,551,236	-193,851,908	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2007	331,021,000	1,686,883,751	-8,305,541	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2008	352,586,000	1,863,398,430	-16,778,999	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2009	354,305,000	1,787,052,535	-385,024,796	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2010	384,276,000	2,181,554,715	67,834,035	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2011	362,982,000	2,167,752,225	355,868,535	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2012	344,141,000	2,013,652,144	37,944,944	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2013	364,409,700	1,955,241,681	146,395,354	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2014	357,000,600	2,047,863,688	143,055,195	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865
2015	317,825,200	1,906,964,064	260,985,234	34,622,000	3,864,868,000	0.35	0.2	1	368.20	3,865

Annexure 2: City of Cape Town Water Balance Data

Table 14: City of Cape Town's Water Balance data for precipitation, bulk water (imported water), streamflow (stormwater) and evapotranspiration.

Year	Precipitation (mm)	Precipitation (m)	Area (m2)	Precipitation (m3)	Bulk water (m3)	Inputs	Streamflow (m3)	Ea (mm)	Ep (mm)	Ea (m)	Ep (m)	Ea (m3)	Ep (m3)
2000	380.74	0.38	2,953,000,000	1,124,321,193	295,701,758	1,420,022,951	698,133,776	200	1,071	0.20	1.07	591,536,024	3,163,426,237
2001	611.50	0.61	2,953,000,000	1,805,759,500	295,701,758	2,101,461,258	1,286,893,808	200	1,071	0.20	1.07	591,536,024	3,163,426,237
2002	553.37	0.55	2,953,000,000	1,634,116,375	295,701,758	1,929,818,133	1,031,853,093	200	1,071	0.20	1.07	591,536,024	3,163,426,237
2003	414.40	0.41	2,953,000,000	1,223,716,489	277,484,971	1,501,201,460	607,556,608	176	941	0.18	0.94	519,376,951	2,777,532,740
2004	573.44	0.57	2,953,000,000	1,693,377,716	273,878,599	1,967,256,315	574,482,304	197	1,054	0.20	1.05	581,995,065	3,112,402,940
2005	531.83	0.53	2,953,000,000	1,570,492,648	244,647,544	1,815,140,192	1,280,036,042	204	1,093	0.20	1.09	603,359,218	3,226,654,510
2006	537.05	0.54	2,953,000,000	1,585,895,227	285,283,467	1,871,178,694	988,912,196	207	1,105	0.21	1.11	610,432,745	3,264,482,440
2007	655.43	0.66	2,953,000,000	1,935,490,159	293,453,451	2,228,943,610	1,349,766,270	206	1,104	0.21	1.10	609,571,332	3,259,875,760
2008	576.36	0.58	2,953,000,000	1,702,001,818	300,312,528	2,002,314,346	1,597,114,208	183	978	0.18	0.98	540,139,218	2,888,565,540
2009	512.99	0.51	2,953,000,000	1,514,855,443	301,731,808	1,816,587,251	1,205,729,057	210	1,125	0.21	1.12	620,935,360	3,320,648,500
2010	394.99	0.39	2,953,000,000	1,166,401,443	310,575,356	1,476,976,799	608,365,158	222	1,189	0.22	1.19	656,656,399	3,511,678,070
2011	419.64	0.42	2,953,000,000	1,239,185,468	315,927,912	1,555,113,380	529,542,296	230	1,232	0.23	1.23	680,301,088	3,638,125,530
2012	526.55	0.53	2,953,000,000	1,554,888,727	314,581,092	1,869,469,819	1,152,207,415	233	1,248	0.23	1.25	688,876,567	3,683,985,620
2013	662.14	0.66	2,953,000,000	1,955,288,682	293,915,423	2,249,204,105	1,805,343,834	191	1,020	0.19	1.02	563,270,372	3,012,266,710
2014	535.89	0.54	2,953,000,000	1,582,472,432	305,346,562	1,887,818,994	1,143,531,634	167	893	0.17	0.89	492,905,060	2,635,965,920
2015	445.05	0.45	2,953,000,000	1,314,219,227	326,984,138	1,641,203,365	466,594,511	177	946	0.18	0.95	522,148,934	2,792,356,800

Table 15: City of Cape Town's Water Balance data for wastewater, aquifer storage, dam storage and soil storage.

Year	Wastewater (m3)	Output	Output – Input	Storage (m3)	Aquifer	Dam Storage (Mm3)	Field capacity	Soil depth (m)	Soil Storage (Mm3)	Aquifer(Mm3)
2000	190,299,853	1,479,969,653	-59,946,702	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2001	207,312,136	2,085,741,967	15,719,290	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2002	196,757,564	1,820,146,681	109,671,452	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2003	189,303,302	1,316,236,861	184,964,599	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2004	203,077,033	1,359,554,402	607,701,913	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2005	204,735,966	2,088,131,225	-272,991,034	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2006	206,622,068	1,805,967,009	65,211,685	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2007	237,746,498	2,197,084,100	31,859,510	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2008	238,851,362	2,376,104,788	-373,790,442	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2009	247,320,754	2,073,985,172	-257,397,921	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2010	237,183,449	1,502,205,006	-25,228,207	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2011	219,054,062	1,428,897,446	126,215,934	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2012	234,339,610	2,075,423,592	-205,953,773	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2013	248,706,275	2,617,320,481	-368,116,376	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2014	249,757,180	1,886,193,875	1,625,119	313,098	837,478,670	0.31	0.2	1.00	590.60	837
2015	232,004,968	1,220,748,413	420,454,952	313,098	837,478,670	0.31	0.2	1.00	590.60	837

Annexure 3: City of Durban Water Balance Data

Table 16: City of Durban's Water Balance data for precipitation, bulk water (imported water), streamflow (stormwater) and evapotranspiration.

Year	Precipitation (mm)	Precipitation (m)	Area (m2)	Precipitation (m3)	Bulk water (kl)	Inputs	Streamflow (m3)	Ea (mm)	Ep (mm)	Ea (m)	Ep (m)	Ea (m3)	Ep (m3)
2000	853.27	0.85	2,650,000,000	2,261,158,721	285,922,183	2,547,080,904	674,523,812	759	896	0.76	0.8958	2,010,625,969	2,373,936,502
2001	955.28	0.96	2,650,000,000	2,531,489,535	285,922,183	2,817,411,717	511,421,097	876	1,034	0.88	1.0344	2,321,724,423	2,741,248,964
2002	945.79	0.95	2,650,000,000	2,506,345,349	274,901,152	2,781,246,501	449,487,321	902	1,065	0.90	1.0647	2,389,588,282	2,821,375,500
2003	665.28	0.67	2,650,000,000	1,762,989,535	278,519,065	2,041,508,600	225,789,468	706	834	0.71	0.8341	1,872,042,787	2,210,312,000
2004	785.66	0.79	2,650,000,000	2,082,006,395	286,798,935	2,368,805,330	304,336,136	791	934	0.79	0.9342	2,096,801,042	2,475,683,000
2005	716.87	0.72	2,650,000,000	1,899,711,047	292,184,110	2,191,895,157	298,023,782	718	848	0.72	0.8480	1,903,195,619	2,247,094,000
2006	1,004.00	1.00	2,650,000,000	2,660,600,000	297,207,651	2,957,807,651	561,183,346	678	801	0.68	0.8007	1,797,033,592	2,121,749,000
2007	907.10	0.91	2,650,000,000	2,403,827,326	310,849,897	2,714,677,223	365,761,384	753	889	0.75	0.8894	1,996,115,449	2,356,804,000
2008	793.98	0.79	2,650,000,000	2,104,038,372	329,787,326	2,433,825,698	323,156,114	743	877	0.74	0.8772	1,968,800,610	2,324,553,500
2009	820.53	0.82	2,650,000,000	2,174,417,442	329,533,754	2,503,951,196	567,307,948	720	850	0.72	0.8498	1,907,392,723	2,252,049,500
2010	722.09	0.72	2,650,000,000	1,913,546,512	326,870,392	2,240,416,904	283,116,404	703	830	0.70	0.8297	1,862,189,694	2,198,678,500
2011	933.45	0.93	2,650,000,000	2,473,651,744	314,654,091	2,788,305,835	502,121,718	717	847	0.72	0.8470	1,900,996,068	2,244,497,000
2012	878.43	0.88	2,650,000,000	2,327,840,116	318,153,504	2,645,993,620	641,813,858	760	898	0.76	0.8976	2,014,548,716	2,378,568,071
2013	913.37	0.91	2,650,000,000	2,420,436,047	325,767,822	2,746,203,869	534,998,746	845	998	0.85	0.9981	2,240,220,779	2,645,018,000
2014	595.20	0.60	2,650,000,000	1,577,273,837	338,073,455	1,915,347,292	164,758,816	829	979	0.83	0.9786	2,196,319,526	2,593,184,000
2015	707.20	0.71	2,650,000,000	1,874,073,837	335,634,442	2,209,708,279	252,603,084	639	754	0.64	0.7541	1,692,420,228	1,998,232,500

Table 17: City of Durban's Water Balance data for wastewater, aquifer storage, dam storage and soil storage.

Year	Wastewater (m3)	Output	Output – Input	Storage (m3)	Aquifer	Dam Storage (Mm3)	Field capacity	Soil depth (m)	Soil Storage (Mm3)	Aquifer (Mm3)
2000	175,211,894	3,223,672,208	-676,591,305	315,115	313,734,220	0.32	0.2	1	530.00	314
2001	175,211,894	3,427,881,956	-610,470,238	315,115	313,734,220	0.32	0.2	1	530.00	314
2002	175,211,894	3,446,074,716	-664,828,215	315,115	313,734,220	0.32	0.2	1	530.00	314
2003	175,211,894	2,611,313,362	-569,804,762	315,115	313,734,220	0.32	0.2	1	530.00	314
2004	175,211,894	2,955,231,031	-586,425,700	315,115	313,734,220	0.32	0.2	1	530.00	314
2005	169,424,397	2,714,542,179	-522,647,022	315,115	313,734,220	0.32	0.2	1	530.00	314
2006	181,407,391	2,864,339,737	93,467,914	315,115	313,734,220	0.32	0.2	1	530.00	314
2007	136,910,189	2,859,475,573	-144,798,351	315,115	313,734,220	0.32	0.2	1	530.00	314
2008	184,266,334	2,831,975,948	-398,150,250	315,115	313,734,220	0.32	0.2	1	530.00	314
2009	188,845,339	3,008,202,787	-504,251,591	315,115	313,734,220	0.32	0.2	1	530.00	314
2010	171,191,761	2,652,986,665	-412,569,761	315,115	313,734,220	0.32	0.2	1	530.00	314
2011	201,765,065	2,948,383,783	-160,077,948	315,115	313,734,220	0.32	0.2	1	530.00	314
2012	207,117,905	3,227,499,834	-581,506,214	315,115	313,734,220	0.32	0.2	1	530.00	314
2013	168,361,790	3,348,378,536	-602,174,668	315,115	313,734,220	0.32	0.2	1	530.00	314
2014	157,897,430	2,915,840,246	-1,000,492,954	315,115	313,734,220	0.32	0.2	1	530.00	314
2015	160,143,236	2,410,978,820	-201,270,541	315,115	313,734,220	0.32	0.2	1	530.00	314

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