

ASOCSA2017- 018

Water Resilience in Urban Areas

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ABSTRACT AND KEYWORDS

Purpose of this paper

A simple water resilience assessment framework for urban areas is proposed. This framework is described and critically evaluated to ascertain its potential value in relation to water resilience planning.

Design/methodology/approach

The design of the research consists of the following steps. Firstly, a literature review is carried out to identify the key mechanisms that can be used to improve water resilience in urban areas in South Africa. Secondly, a simple framework based on the mechanisms is derived. Thirdly, this framework is evaluated in terms of its potential value as a means of improving urban water resilience. Fourthly, conclusions are drawn and recommendations made for further research.

Findings

The paper indicates that a framework to assess water resilience in South African urban contexts can be derived. It also finds that while this framework shows potential as a means to improving urban water resilience, further research, and development, can be undertaken to improve this.

Research limitations/implications

The research is limited to the development of a framework. Findings are limited to this field of investigation and do not purport to make claims beyond this.

Practical implications

The practical implications of the study are that methodologies for assessing urban water resilience can be derived and may be a valuable input for planning, and developing, more resilient urban infrastructure.

What is original/value of paper

The paper is carried out in a field where there has been limited research to date. It proposes a simple framework that can be used to support the assessment of water resilience in an urban area. It will be of interest to researchers of urban resilience, water systems and urban climate adaptation and mitigation strategies. It will also be of interest to municipal officials working on water systems within urban areas.

Key words

Water resilience, urban resilience, climate change, WRAF

1. INTRODUCTION

Climate change is predicted to have significant impacts on water systems in urban areas and cities in South Africa (Muller, 2007; Department of Environmental Affairs, 2011). Higher temperatures will intensify demands made on already stretched water systems. Longer dry spells and droughts will increase the possibility of water shortages and outages. Storms and associated flooding are likely to affect water supply systems and affect water quality (Englebrecht, 2017; UNEP, 2014).

At the same time, rapid urban growth is placing increasing demands on existing water systems (South African Cities Network, 2014). Informal settlements and new townships developing on the periphery of cities and rapidly growing small towns all have to be supplied with water (Brikké and Vairavamoorthy, 2016). Increasing densities, demographic transformation and changing lifestyles in existing urban areas are also leading to increased consumption of water (WHO, 2009; South African Cities Network, 2014). New land uses and the proliferation of impervious landscapes are resulting in amplified runoff and storm water flows and flooding (Roberts, 2010).

Ageing water delivery infrastructure has not always been maintained adequately leading to significant losses of water through leakage (Wensley and Mackintosh, 2015; South African Cities Network, 2014; SAICE 2011; Brikké and Vairavamoorthy, 2016). Limited resources and capacity have meant that municipalities struggle to keep up with these demands and water service backlogs exist and are growing in many urban areas (Wensley and Mackintosh, 2015; Fatti and Patel, 2013; Muller, 2007).

However, the development of new water systems in unserved areas and the upgrading of existing systems offers the opportunity to develop systems that are more resilient to current and future issues such as climate change (Brikké and Vairavamoorthy, 2016; Muller, 2007). As water and sanitation infrastructure may last over 100 years before being upgraded it is important that future variations, such as climate change, that may occur during its lifetime are taken into account (Muller, 2007).

Therefore, there is a requirement to understand the relationship between urban water systems and climate change (South African Cities Network, 2014; Folke et al, 2011). The potential impacts of climate change on urban water systems need to be ascertained and their vulnerabilities identified (WHO, 2009). To ensure water services are maintained, vulnerabilities must be addressed and systems strengthened to manage climate change impacts. Hazards, such as flooding resulting from extreme weather events, need to be mitigated against through physical interventions and effective planning and management. The ability of urban water systems to weather climate change impacts and maintain water services can be referred to as the water resilience (NIAC, 2009; Resilience Alliance, 2010).

This paper investigates the water resilience within South African urban areas. It proposes an outline Water Resilience Assessment Framework (WRAF) that can be used as a basis for assessing the resilience of water systems within an urban area. The WRAF has been developed to explore

vulnerabilities and resilience of urban water systems in relation to climate change. The paper will be structured in the following way. Firstly, climate change predictions for South Africa are outlined. Secondly, urban water systems are introduced. Thirdly, the Water Resilience Assessment Framework is presented. Fourthly, the WRAF is discussed and critically reviewed and proposals for further development made. Finally, conclusions and recommendations for further research are provided.

2. CLIMATE CHANGE PROJECTIONS

Climate change projections have been calculated for South Africa to support the development of urban climate change adaptation and mitigation strategies. Projections are provided at an 8 x 8km grid resolution for the years 2030, 2050 and 2100 (Englebrecht, 2017). This creates a basis for understanding how climate change will affect urban areas. Impacts across South Africa will vary depending on location but broad trends can be summarised as follows:

- **Hotter temperatures:** Temperature increases of 1 to 2.5°C in the southern coastal areas and 3°C in the northern areas of South Africa are expected for the period 2021 to 2050, relative to temperatures in the period 1961 – 1990.
- **Colder temperatures:** Minimum temperatures are projected to decrease by 2 to 3 °C for the period 2021 – 2050, relative to the period 1961 -1990.
- **Very hot days:** An increase in very hot days is projected for the period 2021 – 20150, relative to 1961 – 1990.
- **Changes in rainfall:** Increases in rainfall are projected in the central interior and east coast, while reductions are expected in the western interior and the north-eastern parts of South Africa in the period 2021-2050, relative to the period 1971 – 2000.
- **Extreme rainfall events:** Extreme rainfall events are projected over most of eastern South Africa with reductions in these events projected for Lesotho and Kwa-Zulu Natal Midlands for the period 2021- 2050, relative to the period 1961 – 2000.
- **Increased wind speeds:** Increased wind speeds are projected for the northern interior region of South Africa for the period 2021-2050, relative to the period 1961 – 2000.

Applying these climate change projections to cities and urban areas can be used to ascertain the impact of these changes on city systems, such as urban water systems.

3. URBAN WATER SYSTEMS

An urban water system can be described as the facilities and equipment comprising the physical infrastructure, the water services provided to a

community by the infrastructure, the people using the water services, and the organisations that manage the infrastructure (EPA, 2015). It can be divided into the following components: water resources, water distribution, water uses, water reuse and runoff and storm water. These are briefly outlined below and are illustrated in figure 1.

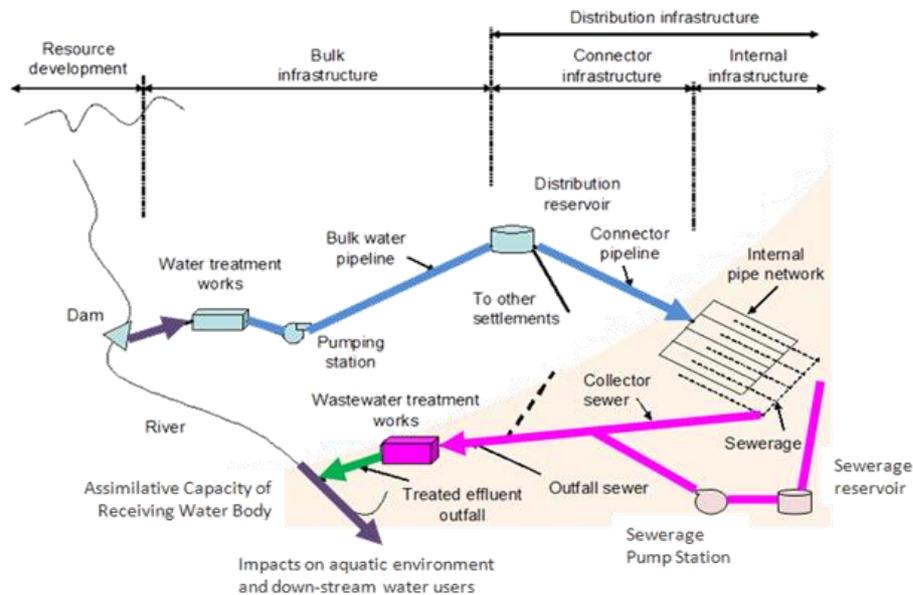


Figure 1 An urban water system (Wensley and Mackintosh, 2015).

- **Water Resources:** Water Resources refers to the sources of water used within an urban area. This may include dams, rivers and boreholes.
- **Water Distribution:** Water Distribution refers to systems which transfer water from the source to where it is used and includes bulk, connector and internal pipe networks. It also includes distribution reservoirs.
- **Water Use:** This refers to how water is used within urban areas and includes drinking, irrigation, cleaning and waterborne sanitation.
- **Water Reuse:** This refers to water that has been used and has been captured for reuse or treatment. It includes greywater and blackwater (sewage) systems.
- **Runoff and Stormwater:** This refers to water flows resulting from precipitation such as rainfall within the urban area as well within catchment areas of rivers and streams that flow through an urban area.

The Water Resilience Assessment Framework is structured around these components and provides a basis for assessing resilience within each of these.

4. WATER RESILIENCE ASSESSMENT FRAMEWORK

Assessing resilience is a highly complex task. It is particularly complex when it includes a large multifaceted entity such as an urban area or city, and multi-layered system such as an urban water system (EPA, 2015; WHO, 2009; Piketh, Vogel, Dunsmore, Culwick, Engelbrecht and Akoon, 2014). There are also a wide range of approaches and perspectives that can be applied to assessing water resilience (EPA, 2015). The WRAF approach does not attempt to replicate, or develop these approaches, but instead aims to provide an overview of the water system in relation to climate change in order to identify key issues which should be investigated through more detailed studies and analysis. Therefore, the framework provides a means of identifying key climate change hazards and vulnerabilities within the system enabling these to be studied in more detail.

The WRAF is presented in Table 1. The first column refers to the component of the system such as water resources, water distribution, water use and water reuse. The second column provides a set of questions for each component. These assist in understanding key issues that relate to the resilience of systems within the component. The third column provides water resilience indicators that can be used to measure resilience within the water component. These can be used in more detailed assessments and can be compared to benchmarks and to other cities and urban areas. The fourth column lists potential measures that can be used to increase water resilience within the component.

More resilient urban water systems will require many changes in the way systems are designed and operated. This includes shifts in how systems are identified and described. For instance, instead of referring to 'sewage', the WRAF refers to 'grey water and black water reuse'. Grey water is water produced after water is used for cleaning, such as water from showers or baths. Blackwater is what is commonly referred to as sewage. Grey water is still relatively clean and can be easily reused for other purposes, such as irrigating plants or for flushing WCs. The WRAF, therefore, refer to grey water as this can be used to reduce mains potable water use and may be an important way of increasing the resilience of urban water systems to climate change in some areas. The third column within the WRAF provides potential measures to include resilience on the water component, in order to illustrate potential alternative approaches that may be used. Potential shifts in the way water systems are described and understood are addressed in more detail in the Discussion that follows the presentation of the framework in Table 1.

Table 1 The Water Resilience Assessment Framework

1	2	3	4
Water system component	Questions	Water resilience indicators	Potential measures to increase resilience
Water Resources	<ol style="list-style-type: none"> 1. What are the water sources for the urban area? Is there a diversity of sources? Are there unexploited alternative sources of water that can be used near existing water sources? 2. What are the capacities of current water sources? How do these compare to the rate of water use in urban areas? 3. How does the capacity of these sources vary over a year? What are the patterns of water use and replenishment of water in these sources over a year? Is there a particular period when water capacity is low? 4. What is the quality of water from sources? Is, or can, water quality be affected, by, for instance, flood erosion or discharges from factories? 5. How is water treated and filtered before being distributed? How reliable are these systems? 6. How secure are water sources? Are they prone to damage, by floods, or other means? 7. Which climate change predictions will affect local water resources? 8. How will climate change predictions affect water sources? 	<p>Diversity in water sources (number of sources and capacities of sources)</p> <p>Days of water supply without replenishment (days-worth of supply available)</p> <p>Years without water restrictions not having to be imposed (years / set rolling period ie 20 years)</p> <p>Quality of water from the resource</p> <p>Loss of water from resource through leakage / evaporation (% of water lost)</p> <p>Number of incidents requiring repairs per year</p> <p>Expenditure on maintenances (% expenditure on maintenance relative to replacement value of infrastructure)</p>	<p>Increase capacity of existing water resources (WHO, 2009)</p> <p>Identify additional water sources such as additional dams, desalination plants and boreholes (WHO, 2009; Kiker, 2000)</p> <p>Installation of early warning systems (WHO, 2009)</p> <p>Rainwater harvesting (Lee et al, 2016)</p> <p>Water catchment areas conservation and enhancement (Muller, 2007)</p> <p>Alien plant removal programmes.</p> <p>Improved technical capacity and systems to plan and manage resources (WHO 2009; SAICE, 2011)</p>
Water	1. What systems are used to	Leakage rates	Leakage

Distribution	<p>distribute water?</p> <ol style="list-style-type: none"> 2. What is the condition of water distribution systems? Is the system prone to breakages and leaks? 3. What powers the water distribution system? Where are pumping stations how are these powered? How reliable are these systems? 4. Where is the water distribution system located? Is it located where it may be vulnerable to damage from flooding and other issues? 5. Is there redundancy within the water distribution system? How easy is it to maintain water supply if there is a failure in one, or more, parts of the system? 6. Which climate change predictions will affect the water distribution system? 7. How will climate change predictions affect water distribution systems? 	<p>in water distribution system (% of water lost)</p> <p>Days of supply outage/year (EPA 2015)</p> <p>Number of incidents requiring repairs per year</p> <p>Expenditure on maintenance (% expenditure on maintenance relative to replace value of distribution)</p>	<p>management programme (WHO, 2009)</p> <p>Pressure management systems to reduce leakage and water use (WHO, 2009)</p> <p>Maintenance and infrastructure replacement programmes (WHO, 2009)</p> <p>Water network loops (EPA, 2015)</p> <p>Integrated piping systems (WHO, 2009)</p> <p>Water monitoring systems to pick up water leaks</p> <p>Improved technical capacity and systems to plan and manage distribution systems (South African Cities Network, 2014. SAICE, 2011). WHO, 2009)</p>
Water Use	<ol style="list-style-type: none"> 1. Does all of the water used in the urban area come from the water sources (A), or are there local sources of water that are used to supplement, or as an alternative to this, such as boreholes and rainwater harvesting systems? What is the capacity of these alternative sources? Are there other local unexploited water sources that can be used? What are the capacities of these sources? 	<p>Residential water consumption rates (L /person / day)</p> <p>Commercial water consumption rates for (L/value of products / services produced)</p> <p>Households / properties with wasteful water</p>	<p>Water demand management programmes(WHO, 2009; Kiker, 2000)</p> <p>Water efficient fitting incentive programme (WHO, 2009)</p> <p>Water efficient fittings bylaw</p> <p>Water metering and sub-metering</p>

	<p>2. How accessible is the water supply in the urban area? Is the water supplied within properties or through standpipes, tankers, or in other ways?</p> <p>3. How is water used in the urban area? What are the quantities and proportions of water used in the respective segments, such as residential households, or commercial offices, that make up the urban area?</p> <p>4. How reliable is the water supply in the urban area? How often is water not available in the urban area? Does the water pressure vary?</p> <p>5. What are the patterns of water use in the urban area? What are the water-use flows for a typical 24 hour, through a typical week and through a typical year?</p> <p>6. What are the rates of water use in installed equipment with the urban area? For instance, within residential dwellings, what are flow rates for showers and taps and the flush rates for WCs?</p> <p>7. Are there local measures to increase the resilience of the water systems? For instance, is the provision for water storage on site? Are there water emergency plans for the local area?</p> <p>8. Which climate change predictions will affect water use in the urban area?</p> <p>9. How will climate change predictions affect water use in the urban area?</p>	<p>uses ie irrigation of ornamental plants and swimming pools</p> <p>Reduction of potable water use through grey water and rainwater harvesting.</p> <p>Loss of water on usage sites through leakage (% of water lost)</p> <p>Number of incidents requiring repairs per year</p> <p>Expenditure on maintenances (% expenditure on maintenance relative to replace value of infrastructure)</p> <p>Water storage on site (l/person)</p> <p>Water emergency plans in place</p>	<p>Rainwater harvesting (Kiker, 2000)</p> <p>Sustainable urban drainage systems (WHO, 2009)</p> <p>Grey water systems (WHO, 2009)</p> <p>Penalties/high tariffs for high water usage</p> <p>Banning inefficient water devices</p> <p>Banning wasteful water uses such as ornamental water pools and irrigation of ornamental plants.</p> <p>Non-waterborne / dry sanitation system</p> <p>Increased onsite storage of water</p> <p>Water emergency plans</p>
Water Reuse	<p>1. Where is grey and black water produced in the urban</p>	<p>Amount of water reused within the (% of</p>	<p>Incentives to introduce grey</p>

	<p>area and in what quantities? Are these produced separately, on in one stream?</p> <p>2. What are the patterns of grey and black water production in the urban area? What are the flows for a typical 24 hour, through a typical week and through a typical year?</p> <p>3. What is the condition of grey and black water systems? Is the system prone to breakages and leaks?</p> <p>4. What powers grey and black water distribution systems? Where are pumping stations how are these powered? How reliable are these systems?</p> <p>5. Where are the grey and black water distribution systems located? Is it located where it may be vulnerable to damage from flooding and other issues?</p> <p>6. Is there redundancy within the grey and black water distribution system? How easy is it to maintain flows if there is a failure in one, or more, parts of the system?</p> <p>7. Which climate change predictions will affect the grey and black water distribution system?</p> <p>8. How will climate change predictions affect grey and black water distribution systems?</p>	<p>grey water used as percentage of total water used)</p> <p>Reduction of potable mains water use through reuse of water (% reduction of waters potable water consumption)</p> <p>Number of incidents requiring repairs per year</p> <p>Expenditure on maintenances (% expenditure on maintenance relative to replace value of infrastructure)</p>	<p>water systems</p> <p>Precinct grey water systems</p> <p>Onsite ecological sanitation (WHO 2009)</p> <p>Improved technical capacity and systems to plan and manage water reuse systems (WHO, 2009)</p>
Runoff and storm water	<p>1. Where are the current rivers, streams and stormwater flows within the urban area? Do these currently overflow and cause flooding after heavy rain? Does detritus or other obstacles exacerbate this? What are the flow</p>	<p>Percentage of rainwater retained onsite (%)</p> <p>Percentage of site area that has impervious</p>	<p>Rainwater harvesting systems (Lee, Mokhtar, Hanafiah, Halim, and Badusah, 2016)</p> <p>Increase area of</p>

	<p>patterns after heavy rain fall event in the catchment area and within the urban area, what the flow patterns over a typical day, what are the typical flow patterns over a year? How can peak flows be reduced? Are there ways of reducing runoff in the catchment area and contributing urban areas? Are there safe areas along water courses that can be flooded or where water can be stored to reduce peak flows?</p> <p>2. Where is the stormwater distribution system? Does this overflow and cause flooding currently after heavy rain? Does detritus or other obstacles exacerbate this? What are the flow patterns after heavy rain fall event within the urban area, what are the patterns over flows over a year? How can peak flows be reduced? Are there ways of reducing runoff in the contributing urban areas? Are there safe areas along stormwater distribution systems that can be flooded, or where water can be stored to reduce peak flows?</p> <p>3. Which locations within the urban area are responsible for large flows of runoff? What are the patterns of flows of this runoff after heavy rain? What can be done to reduce this runoff? Can the extent of absorptive surfaces within these areas be increased to increase onsite retention of runoff? Can rainwater harvesting systems and retention and detention ponds be used to reduce runoff? Can sustainable urban drainage systems, including swales, be used to reduced runoff?</p> <p>4. Which climate change</p>	<p>surfaces</p> <p>Reduction in volume of flows through sustainable urban drainage systems</p> <p>Reduction in peak flow through sustainable urban drainage systems.</p> <p>Number of flooding incidents per year</p> <p>Expenditure on maintenance (% expenditure on maintenance relative to replace value of infrastructure)</p>	<p>pervious surfaces and soft landscaping</p> <p>Detention Systems (Woods-Ballard et al, 2007)</p> <p>Stormwater wetlands (Woods-Ballard et al, 2007)</p> <p>Infiltration basins (Woods-Ballard et al, 2007)</p> <p>Check dams (Woods-Ballard, Kellagher, Martin, Jefferies, Bray, and Shaffer, 2007)</p> <p>Swales(Woods-Ballard et al, 2007)</p> <p>Green roofs (Woods-Ballard et al, 2007)</p> <p>Soakaways (Woods-Ballard et al, 2007)</p> <p>Filter strips (Woods-Ballard et al, 2007)</p> <p>Infiltration trenches(Woods-Ballard et al, 2007)</p> <p>Bioretention(Woods-Ballard et al, 2007)</p> <p>Pervious pavements(Woods-Ballard et al, 2007)</p> <p>Geocellular / modular systems(Woods-Ballard et al,</p>
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	<p>projections will affect runoff and stormwater systems?</p> <p>5. How will climate change projectionss affect affect runoof and stormwater systems?</p>		<p>2007)</p> <p>Sand filters (Woods-Ballard et al, 2007)</p>
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5.DISCUSSION

The Water Resilience Assessment Framework provides a way of beginning to understand and address, the resilience of urban water systems in relation to climate change. The framework appears to be very simple and is easy to understand. It consists of a structure that reflects the form of urban water systems and includes components on water resources, water distribution, water use and water reuse. Within each of these components, there are a series of questions that can be worked through to understand key parameters within the respective component of the water system in relation to climate change. Within each component, there are also a set of indicators. These indicators provide a more detailed and quantified view of the resilience of the system. An initial review of the WRAF suggests that it provides a flexible and structured way of considering water resilience in relation to climate change within an urban area. However, while the simplicity of the approach and framework is attractive, it also raises a number of issues that need to be addressed in more detail. In particular, these relate to the approach and its value as means of assessing and improving water resilience in urban areas, and are as follows:

- Are the objectives set out for the Water Resilience Assessment Framework appropriate?
- Is the structure of the Water Resilience Assessment Framework applicable?
- Can the Water Resilience Assessment Framework make a useful contribution to the assessment of water resilience in urban areas? If so, how should it be developed?

5.1 Objectives of the WRAF

A review of the WRAF indicates that it does not provide a comprehensive and detailed methodology for the assessment of water resilience of an urban area. Instead, it aims to “provide an overview of the water system in relation to climate and change and resilience, in order to identify key issues which should be considered in order to scope more detailed studies and analysis”. A secondary, implicit objective, of the framework, appears to be to encourage a questioning of current conventional water systems. This

indicated by comparing questions and indicators within the WRAF with conventional a water system, as represented in figure 1. For instance, the WRAF refers to 'grey and black water' instead of 'sewage', in order to emphasize the potential of using greywater within a water system as a way of improving its resilience.

The objectives of the WRAF appear to be appropriate to urban water systems for a number of reasons. Firstly, the resilience of the water system is related to the entirety of the system, and not just one component. For instance, even if water resources are resilient, if water distribution is not, the system will fail. It is, therefore, important to have a holistic approach. Secondly, given the scale and complexity of urban water systems, it is useful to have an overview, which can be used to help structure and prioritise resilience improvement interventions. A simple overview also provides a valuable means of communicating key issues related to water and climate change within a municipality or council, where key decisions related to infrastructure planning and budgeting may be made by elected councillors and officials who do not have a technical background.

The simplicity of the WRAF and the terminology may also be valuable in encouraging increased involvement of stakeholders in decision-making about water systems and a questioning of conventional systems. Both of these are valuable in the development of resilient water systems (Tompkins and Adger, 2005; Hallegate, 2008). For example, highly efficient resilient water systems may require changes in water consumption patterns and user behaviour and it is, therefore, important to have strong local support for these changes. Resilient systems may also require innovative alternative technologies to be introduced, such as grey water systems, which local municipalities and officials will be required to understand and support (Camacho, 2009; Zimmerman, 2011).

5.2 Structure of the WRAF

The structure of the WRAF follows the basic structure of an urban water system and addresses each component including water sources, water distribution, water use, water reuse and runoff and stormwater. Each of these components has questions, indicators and potential measures to increase resilience which can be used to develop an understanding of resilience within each of the components of the water system.

This structure appears to work well for a number of reasons. Firstly, the structure aligns well with the different responsibilities and mandates of stakeholders involved in urban water systems (Wensley and Mackintosh, 2015). Water resources are governed by national departments, such as the Department of Water Affairs, and water boards, who work with a range of stakeholders to plan and manage water resources. Water distribution within urban areas and cities is the responsibility of local municipalities. Water use depends on user behaviour and installed equipment but can be influenced

through bylaws, incentives and penalties developed by municipalities. Water reuse, runoff and storm water within urban areas and cities is the responsibility currently mainly the responsibility of local municipalities. However, municipalities can introduce measures, such as guidance, bylaws, regulations and incentives to encourage property owners to implement infrastructure such as rainwater harvesting systems, retention and detention ponds and sustainable urban drainage systems to increase local water resilience. Within each of these components, the potential measures that can be taken to improve resilience (column 4) illustrate the type of interventions that may be employed and can be used to inform the identification and application of practical measures to increase resilience.

The WRAF structure which provides key questions and performance indicator per component can be used to allocate responsibility for action to the parties most able to address and achieve this. This is valuable as it can be used to ensure that collective responsibility to achieve improved water resilience in a complex large-scale system is achieved.

Secondly, by considering the water system holistically, the framework supports the possibility of increased coordination and integration. For instance, where assessments indicate that it will be difficult to make conventional water sources such as dams resilient, a greater emphasis can be placed on alternative measures within the system, such as reducing water use through increased efficiency of water equipment and the installation of rain harvesting and grey water systems.

Thirdly, the two-part structure of the WRAF offers the possibility of assessments being undertaken in a range of ways and levels. The Question part can be used by stakeholders and decision-makers to understand the key water issues related to climate change and water in their areas in order to begin to develop plans to address this. The Indicators part provides insight into how resilience performance may be defined in terms of targets and monitoring and evaluation processes that can be included in strategic plans. It also provides a means of developing benchmarks and comparing performances between urban areas and towns which supports continuous improvement and learning and sharing of good practice (McAllister, 2013).

Fourthly, providing 'potential measures to increase resilience' is useful as illustrates, in a practical way, some of the measures that may be taken to improve resilience. While some of these measures may not be applied in all situations, it is valuable to include them as a way of illustrating the need for alternative approaches. It also helps to show that approaches can be very simple and cost-effective.

5.3 Value of the WRAF

The review indicates that Water Resilience Assessment Framework could make a valuable contribution to the assessment of water resilience of urban

water systems. It appears to offer an approach that supports the effective integration of water resilience and climate change into current water infrastructure development and planning processes.

The simplicity and the non-technical language in the WRAF can be used to develop awareness about climate change and water systems in decision-makers and stakeholders. In particular, it may play a valuable role in helping identify, and communicate, climate change risk and vulnerabilities to urban stakeholders such as mayors, councillors, urban planners and water engineers to ensure that this is addressed in infrastructure projects (Government Office for Science, 2012; Howe, 2012). This would help ensure that long-term urban planning, budgeting and legislative processes such as development of Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs) plan for improved water resilience (Kiker, 2000). Similarly, it could be used to promote municipal bylaws which required new infrastructure and buildings to be more water efficient and resilient.

It is interesting to note however that the WRAF does not have a strong emphasis on social aspects of resilience. For instance, it has been argued that communities should be actively engaged in developing and implementing climate change strategies (Tompkins and Adger, 2005; Hallegate, 2008, Fatti and Patel, 2013 Brikké, and Vairavamoorth, 2016). In addition, Environmental Protection Agency (2015) suggests that communities need to be prepared for water emergencies and that this should be formalised in local plans. This aspect should, therefore, be researched further and developed in practical measures and indicators in the development of the WRAF.

Similarly, while the WRAF makes reference to the resilience of water distribution systems, this is not addressed in much detail. This is a complex area and while it is not recommended that the WRAF include measures of resilience in relation to water network resilience, it may be valuable to make references to these approaches and how they can be used to improve resilience of a system (EPA, 2015).

The WRAF includes a list of potential measures that may be used to increase water resilience. This illustrates that measures may be simple, easy-to-implement and low cost. It, therefore, encourages municipalities and other stakeholders to consider these, and where appropriate, pilot, and implement these. The incorporation of water resilience indicators enables monitoring and evaluation of water systems and encourages improved performance. Thus, pilot programmes can be evaluated using indicators, to identify optimal approaches which may be implemented at a larger scale. In addition, indicators are valuable as the support ongoing monitoring and provide a means of comparing performance between urban areas.

5.4 Further Development of WRAF

The initial version of the WRAF provides a promising basis for further development. It is recommended that further development focusses on two aspects of the framework. The first aspects should develop the high-level rapid appraisal aspect to ensure that this supported more effectively. This could include more detailed sub-questions and criteria that be used to provide a simple 'water resilience rating' of the urban system. The simplicity of the current WRAF, however, should be retained and technical complex language should be avoided.

The second aspect of the WRAF that should be developed is the decision making and implementation support aspect. Instead of just including a list of potential measure to improve resilience and water resilience indicators, the framework should provide more structured and detailed guidance. This could include a manual with step-by-step guidance on carrying out resilience assessments and then using these to develop implementation plans.

6. CONCLUSIONS AND RECOMMENDATIONS

The Water Resilience Assessment Framework provides useful insight into the resilience of urban water systems to climate change. In particular, it provides a simple framework that could be used to support awareness and improved decision making about climate change and water resilience in non-technical decision makers such as municipal officials. Further research and development of the framework is recommended. Further development should include the development of a more detailed rapid-appraisal tools and manual which can be used to assess urban water systems. It is also recommended that the framework is developed to support implementation through the provision of step-by-step guidance.

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