Stormwater harvesting: Improving water security in South Africa's urban areas

AUTHORS:
Lloyd Fisher-Jeffes[1]
Kirsty Carden[1]
Neil P. Armitage[1]
Kevin Winter[2]

AFFILIATIONS:
[1]Department of Civil Engineering, University of Cape Town, Cape Town, South Africa
[2]Department of Environmental and Geographical Sciences, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Kirsty Carden

EMAIL:
Kirsty.carden@uct.ac.za

DATES:
Received: 26 May 2016
Revised: 02 Oct. 2016
Accepted: 05 Oct. 2016

KEYWORDS:
water scarcity; alternative water resources; flood management; climate change resilience; sustainable drainage

HOW TO CITE:
Fisher-Jeffes L, Carden K, Armitage NP, Winter K. Stormwater harvesting: Improving water security in South Africa's urban areas. S Afr J Sci. 2017;113(1/2), Art. #2016-0153, 4 pages. http://dx.doi.org/10.17159/sajs.2017/20160153

ARTICLE INCLUDES:
× Supplementary material
× Data set

FUNDING:
South African Water Research Commission

The drought experienced in South Africa in 2016 – one of the worst in decades – has left many urbanised parts of the country with limited access to water, and food production has been affected. If a future water crisis is to be averted, the country needs to conserve current water supplies, reduce its reliance on conventional surface water schemes, and seek alternative sources of water supply. Within urban areas, municipalities must find ways to adapt to, and mitigate the threats from, water insecurity resulting from, inter alia, droughts, climate change and increasing water demand driven by population growth and rising standards of living. Stormwater harvesting (SWH) is one possible alternative water resource that could supplement traditional urban water supplies, as well as simultaneously offer a range of social and environmental benefits. We set out three position statements relating to how SWH can: improve water security and increase resilience to climate change in urban areas; prevent frequent flooding; and provide additional benefits to society. We also identify priority research areas for the future in order to target and support the appropriate uptake of SWH in South Africa, including testing the viability of SWH through the use of real-time control and managed aquifer recharge.

Significance:

- Addresses water scarcity through building resilience to the impacts of climate change; improving the liveability of cities; and prioritising water-sensitive urban design.

Introduction

South Africa experienced the worst drought in decades in 2016. This current drought has left many towns and cities with extremely compromised water supply systems, and food production has been limited across the country, thus placing pressure on the already fragile economy. In order to avert a future water crisis, the country needs to reduce its reliance on conventional surface water schemes based on impoundments on rivers and to seek alternative sources of water supply. Within urban areas, municipalities must find ways to adapt to, and mitigate the threats from, water insecurity resulting from, inter alia, droughts, climate change and increasing water demand driven by population growth and rising standards of living. Stormwater harvesting (SWH) is one alternative water resource that could supplement traditional urban water supplies, as well as simultaneously offer a range of benefits including the management of flooding and the provision of recreational areas. For the purposes of this paper, SWH refers to the collection and storage of run-off from an urban region and its subsequent use irrespective of location, and is usually implemented by the relevant local authority.[1] In comparison, rainwater harvesting is the collection and storage of run-off from an individual property (usually from the roofs of buildings) and its subsequent private use within that property.[1]

Based on the results of recent research in South Africa[1], as well as a review of the relevant international literature, we set out three position statements in this paper relating to how SWH can contribute to: improving water security and increasing resilience to climate change in urban areas; preventing frequent flooding; and providing additional benefits to society, such as creating amenity and preserving biodiversity. We have included priority research areas for the future in order to identify and support the appropriate uptake of SWH in South Africa, as well as recommendations regarding issues that need to be addressed to enable this research.

Position 1: Stormwater harvesting improves water security

The Atlantis Water Resource Management Scheme (AWRMS) has been in operation since 1979[2] and provides a useful South African example of SWH on a large scale. An important design aspect of this SWH system was the use of the town of Atlantis as a significant component of the catchment. The town was planned with separate residential and industrial areas, which allowed for the separation of high- and low-quality wastewater effluent. Stormwater and higher-quality treated municipal effluent are used to recharge an unconfined aquifer for later extraction and use. Low-quality water is disposed through recharge near the coast in such a way as to create a hydraulic barrier between the cleaner groundwater and the seawater.[3] The AWRMS has successfully ensured a supply of water for the town of Atlantis over the last 37 years, with approximately 30% of the groundwater supply augmented through artificial recharge. Interestingly, the establishment of the scheme was initially in response to the need to find an alternative to marine wastewater discharge[2], but after many successful years in operation, it is now seen internationally as an exemplar of a stormwater and wastewater reuse scheme[4].

Aside from the AWRMS, SWH has not been widely exploited in South Africa, and is limited to a number of small on-site systems used for irrigation at factories or distribution centres – even though the possibility of widespread use of stormwater as a resource in the country was mooted some time ago.[5] The reasons for this are not entirely clear, but may relate to issues of social perception, as well as institutional processes associated with the operation and maintenance of such schemes.[2]

Fisher-Jeffes[1] undertook one of the few detailed studies of the viability of SWH in South Africa, focusing on the residential areas of the Liesbeek River Catchment in Cape Town. Whilst it was acknowledged that there is significant climatic variation across South Africa, he found that SWH had the potential to reduce the total current residential potable water demand of the catchment by more than 20% if the stored stormwater was used for non-potable purposes such as irrigation and toilet flushing – a significant saving for the City of Cape Town. However, in order for such reductions in water demand to be realised, the vast majority of residents and businesses would be required to make use of harvested stormwater. This requirement would likely necessitate changes in the regulations related to the supply of water in the City of Cape Town. Additionally, as Ellis et al.[6] indicated as part of their research in South Africa, significant social and institutional barriers – similar to those encountered elsewhere in the world[7-10] – may be an impediment to the adoption of SWH. This highlights the need for further research that accounts for the local context as most of the existing research into the implications of SWH has been undertaken in developed countries. International examples of large-scale SWH include:

- Singapore – which has one of the most comprehensive SWH systems that has proven itself to be a useful high-quality water resource.[11]
- USA and Australia – harvested stormwater is used for a range of end uses including irrigation, toilet flushing, commercial and industrial uses.[4]

Of significant concern to water resource planners is the uncertainty of the effects of climate change on water resources. For example, Fisher-Jeffes[1] highlighted that for a catchment in Cape Town, evaporation is expected to increase, while precipitation is expected to decrease. Using adjusted run-off data, the analysis showed that, based on the expected changes in evaporation and precipitation from 31 different climate change scenarios, it is very likely that SWH systems (as with other water resource schemes) will be negatively impacted by climate change. Losses could, however, be reduced through the use of managed aquifer recharge in place of open storage – as is the case for the AWRMS.

While local and international examples provide support for the wider adoption of SWH to address water security in South Africa, local climatic factors can influence its viability. In Cape Town, for example, the Mediterranean-type climate results in most of the harvestable stormwater being available during the wet winter months, when the reservoirs are typically filling in any case. Harvesting stormwater during this time may seem unnecessary; however, it could be utilised as a way to reduce normal demand from the city's reservoirs during the wet winter months (by increasing the rate at and level to which these reservoirs fill up) – thereby ensuring an increase in the availability of water during the dry summer months.

Position 2: Stormwater harvesting prevents flooding

SWH schemes all make use of some form of storage system. Some make use of retention ponds, while others make use of temporary detention ponds before either infiltrating or injecting water into an aquifer – also known as managed aquifer recharge. In either case – detention or retention – run-off is detained in an open storage system. The functioning of detention and retention ponds is well known[12,13]: by storing run-off volume, downstream flows are attenuated, resulting in reduced flooding. International case studies have demonstrated these benefits of SWH systems.[4]

Fisher-Jeffes[1] demonstrated the impact that such reductions in peak flows might have on flooding (and flood risks) using a two-dimensional flooding model. Figure 1 illustrates the flood hazard levels – using the City of Cape Town's definition of flood hazard (a combination of depth and velocity of water)[14] – for a storm event on 12 July 2009, with and without SWH. It is evident that SWH has the potential to significantly reduce flood risks in storm events.

A further opportunity exists for stormwater managers to actively manage SWH systems using real-time control in such a manner that, prior to a predicted storm event, the storage is partially emptied. In this way, significant attenuation could be achieved without compromising the ability to meet water demand. This option would require the development of a calibrated run-off model that could make use of predicted rainfall to estimate the run-off for a particular storm. Based on the anticipated run-off, the stormwater manager could partially empty the SWH system's storage a day or more before the rain event (depending on the availability of rainfall predictions), resulting in an increase in the pre-event flow rate in the river, but a decrease in the peak flows, which could prevent flooding.

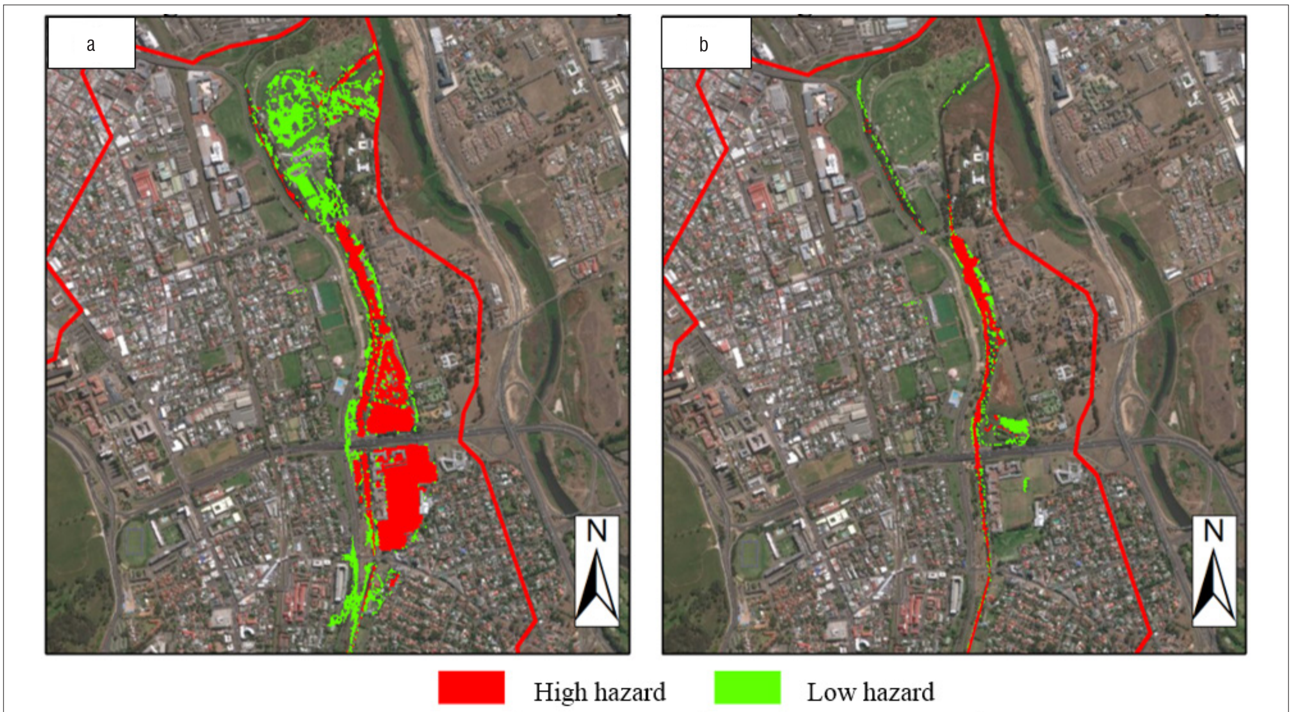

Figure 1: Flooding in the Liesbeek River Catchment on 12 July 2009 shown (a) without and (b) with stormwater harvesting.[1]

Position 3: Stormwater harvesting provides additional benefits

There is extensive literature on the value of the substantial benefits that natural assets – parks, wetlands, ponds etc. – can offer society.[15,16] In one such study, De Wit et al.[15] investigated the value of natural assets in the City of Cape Town. Through their own investigation and review of the literature, the authors monetised the value of different natural assets and ecosystem goods and services – including amenity value, biodiversity values, and water treatment capabilities. Whilst parks, wetlands and open spaces, such as those that might be created for SWH systems are typically considered to provide a positive amenity value, De Wit et al.[15] note that some can create negative amenity, particularly if they are not maintained, or even provide a risk to society. Fisher-Jeffes[1] equated the positive amenity generated by SWH to an estimated ZAR2–7.2 million per year in 2013 for the Liesbeek River Catchment – a catchment of only 2600 hectares. It is also worth recognising that by using harvested stormwater it will be possible to delay, and possibly avoid, the need for future water schemes based on impoundments on rivers. In so doing, SWH indirectly protects the ecosystem services that are naturally provided from being destroyed. Furthermore, if intentionally designed, SWH can offer significant multifunctional use and amenity benefits – such as recreational areas – and can aid in supporting biodiversity and mitigating urban 'heat island' effects, e.g. through the formation of 'blue-green' corridors with indigenous vegetation.[17]

Future research

Current research in South Africa has thus far focused on the financial, economic, technical and practical viability of SWH and has highlighted the need for further investigation, including into the social aspects of SWH – such as whether all sectors of South African society would be willing to use harvested stormwater, and if so, for which end uses they would be willing to use it? The preliminary study in the Liesbeek River Catchment[1] highlighted the potential for conducting future research into using SWH combined with real-time control to significantly reduce flooding during major storm events, as well as mitigating water scarcity. Similarly, research is required to determine whether SWH might be especially valuable as a water supply during droughts, as run-off from urbanised areas is typically greater than that from natural catchments during these events because of the extent of impervious areas. The experience and knowledge from the AWRMS should be expanded into studies on the viability of managed aquifer recharge systems to store and treat stormwater – using both confined as well as unconfined aquifers.

Most importantly, research thus far has highlighted that many issues need to be addressed to enable future studies, including the installation of basic monitoring and data logging (rainfall, flow and quality) equipment across urban areas in South Africa, to address the urgent need for basic calibration data.

Conclusions

Stormwater harvesting offers an alternative water supply source – one that is almost entirely untapped in South Africa – that could ensure improved water security for towns and cities across the country. While stormwater could be treated to potable standards – as has been done in Singapore – it may not be economically feasible or desirable and it may be preferable to use the stored water for non-potable purposes. SWH systems – especially those enhanced with real-time control – could offer additional benefits by mitigating flooding through storing run-off, thereby attenuating downstream flows. SWH can be designed to offer multifunctional use and amenity benefits, and can, through the formation of 'blue-green' corridors, aid in supporting biodiversity and mitigating urban 'heat island' effects.

In conclusion, while there is currently a need for ongoing research to quantify the additional benefits of optimally designed, built and operated SWH systems, indications are that SWH has the potential to contribute to improving water security and increase resilience to the impacts of climate change in urban areas, as well as simultaneously offer a range of social and environmental benefits.

Acknowledgements

We acknowledge the South African Water Research Commission for funding this study as part of project no. K5/2412: A feasibility study to evaluate the potential of using water-sensitive design principles to strengthen planning for water sensitive cities of the future.

Authors' contributions

L.F-J. was responsible for the background research (supervised by N.P.A.), and wrote the manuscript together with K.C., who was the project leader. L.F-J., N.P.A. and K.W. were key researchers on this project. Both N.P.A. and K.W. provided critical reviews of the paper, which was then revised into its final state by L.F-J. and K.C.

References

1. Fisher-Jeffes L. The viability of rainwater and stormwater harvesting in the residential areas of the Liesbeek River Catchment, Cape Town [PhD thesis]. Cape Town: University of Cape Town; 2015.
2. South African Department of Water Affairs and Forestry (DWAF). The Atlantis Water Resource Management Scheme: 30 years of artificial groundwater recharge. Pretoria: DWAF; 2010. p. 76.
3. Murray EC, Tredoux G. Planning water resource management: The case for managing aquifer recharge. In: Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference; 2004 May 2–6; Cape Town, South Africa. Johannesburg: Water Institute of South Africa; 2004. p. 430–437.
4. Philp M, Mcmahon J, Heyenga S, Marinoni O, Jenkins G, Maheepala S, et al. Review of stormwater harvesting practices. Technical report no. 9. Queensland: Urban Water Security Research Alliance; 2008.
5. Wright A. Urban stormwater, correctly managed, is a resource rather than a nuisance. In: Proceedings of the Water Institute of South Africa 1996 Biennial Conference & Exhibition; 1996 May 20–23; Port Elizabeth, South Africa. Johannesburg: Water Institute of South Africa; 1996. 8 pages. Available from: http://www.ewisa.co.za/literature/files/1996%20-%2032.pdf
6. Ellis D, Armitage NP, Carden K. Water sensitive design drivers and barriers. In: Proceedings of the Water Institute of South Africa (WISA) 2016 Biennial Conference; 2016 May 15–19; Durban, South Africa. Johannesburg: Water Institute of South Africa; 2016.
7. Brown R, Farrelly M, Keath N. Summary report: Perceptions of institutional drivers and barriers to sustainable urban water management in Australia. Melbourne: National Urban Water Governance Programme; 2007.
8. Nurick SD, Cattell K. An investigation into the mechanisms driving large property owning organisations to implement green building features. In: Proceedings of the South African Council for Quantity Surveyors Profession (SACQSP) 2013 Conference; 2013 June 20–21; Cape Town, South Africa. Cape Town: SACQSP; 2013. p 92–104.
9. Tjandraatmadja G, Cook S, Chacko P, Myers B, Sharma AK, Pezzaniti D. Water sensitive urban design impediments and potential: Contributions to the SA Urban Water Blueprint – Post-implementation assessment and impediments to WSUD. Adelaide: Goyder Institute for Water Research; 2014.
10. Dobbie M, Brooks K, Brown R. Risk perceptions of Australian urban water practitioners towards alternative water systems, including stormwater harvesting and quality treatment systems [document on the Internet]. c2012 [cited 2013 Aug 29]. Available from: http://waterforliveability.org.au/wp-content/uploads/Project6-SocietyInstitutions-Apr2012.pdf
11. Lim MH, Leong YH, Tiew KN, Seah H. Urban stormwater harvesting: A valuable water resource of Singapore. Water Pract Technol. 2011;6(4), Art. #wpt20110067. http://dx.doi.org/10.2166/wpt.2011.0067
12. Armitage N, Vice M, Fisher-Jeffes L, Winter K, Spiegel A, Dunstan J. The South African guidelines for sustainable drainage systems. Report TT558/13. Pretoria: Water Research Commission; 2013.
13. Woods-Ballard B, Kellagher R, Martin P, Jefferies C, Bray R, Shaffer P, et al. The SuDS manual [homepage on the Internet]. London: CIRIA; 2007. Available from: http://www.ciria.org/Resources/Free_publications/SuDS_manual_C753.aspx
14. City of Cape Town: Catchment, Stormwater and River Management. Floodplain and River Corridor Management Policy. Cape Town: Catchment, Stormwater and River Management, Directorate of Transport, Roads and Major Projects; 2009. p. 19.

15. De Wit M, Van Zyl H, Crookes D, Blignaught J, Jayiya T, Goiset V, et al. Investing in natural assets: A business case for the environment in the City of Cape Town [document on the Internet]. c2009 [cited 2010 Aug 25]. Available from: http://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/EnvResEconomics-Final_Report_2009-08-18.pdf

16. Kumar P, editor. The economics of ecosystems & biodiversity: Ecological and economic foundations. London and Washington: Earth Scan; 2010.

17. Schaffler A, Christopher N, Bobbins K, Otto E, Nhlozi M, De Wit M, et al. State of green infrastructure in the Gauteng City-Region. Johannesburg: Gauteng City-Region Observatory; 2013. Available from: http://www.gcro.ac.za/media/reports/sogi_final_P6nDjP5.pdf