Pathways to water resilient South African cities (PaWS)

Understanding the impact of WSD / SuDS initiatives in terms of alleviating flooding, improving water quality and contributing to water security

A pilot project by the Universities of Cape Town and Copenhagen has compared the feasibility and efficiency of on-going and completed SuDS initiatives at two sites in the City of Johannesburg

Introduction: Why do we need SuDS?

How effective are the SuDS elements implemented in public/private developments in Johannesburg in response to policies such as the Stormwater management manual, and what are the benefits?

Water management is an essential part of urban sustainability and resilience from both a physical infrastructure and governance perspective. In terms of built water infrastructure, existing centralised water provision and management models are increasingly viewed as ill-suited to address the uncertainties presented by climate change and resource pressures. The 2030 Agenda acknowledges that sustainable management of water resources is crucial for social and economic development[1]. This is particularly relevant in sub-Saharan African cities like Johannesburg which faces a unique intersection of obstacles: growing rate of urbanization, rising poverty, informal development, water and sanitation infrastructure deficits, decrease in green space and the general impacts of climate change such as increased incidence of drought and flooding. Sustainable urban water management – through approaches such as Water Sensitive design (WSD) and Sustainable Drainage Systems (SuDS) – address some of the deficits of conventional urban water management by integrating built water infrastructure with green infrastructure in a decentralised manner. It unlocks the potential of stormwater as a resource and creates opportunities for the conservation of natural resources, protection from extreme climate change and improvement of water quality. WSD/SuDS include nature-based solutions that reduce runoff volumes and peak flows, improve infiltration, and reduce pollutant loads, thus helping to return urban rainfall-runoff processes to natural hydrological cycle flows. Sustainable water supply options such as rainwater and stormwater harvesting, groundwater, greywater recycling and treated wastewater use allow cities to function as catchments, thus realising the value of water in all its competing uses. With the release of its draft Stormwater Management Manual (SMM) in 2019, the City of Johannesburg (CoJ) encourages the implementation of water sensitive stormwater quality and quantity improvements (i.e. SuDS), specifically in large developments.

While South African cities like Johannesburg have begun considering building resilience through WSD/SuDS, little work has been done exploring the impact of the implementation of policies such as the SMM. The 'Pathways to water resilient South African cities (PaWS1)' project is a transdisciplinary collaboration between researchers from the Universities of Cape Town (UCT) and Copenhagen (UCPH), which aimed to generate knowledge on the integration of decentralised nature-based solutions into the urban water cycle to support and accelerate a transition towards water resilience in South African cities through a combination of physical experimentation and exploration of related governance aspects required to facilitate these transitions. In Johannesburg, this included the comparative evaluation of two SuDS initiatives that have emerged in response to the SMM, and an assessment of the efficiency these two SuDS systems in the overall water quality improvement of the stormwater quality.

[1] UN-Water, 2018. *SDG 6 Synthesis Report 2018 on Water and Sanitation*. New York: United Nations, pp.24–27.

Selection of study sites

Eight potential study sites were considered in consultation with officials from CoJ (Environmental Management) and Johannesburg Roads Agency (JRA). Two sites that have implemented aspects of WSD/SuDS in response to City and provincial level stormwater management and environmental impact management mandates were selected – a private development, The Reid Lifestyle Estate ('The Reid') and a public amenity, Observatory Golf Course ('Observatory'). Both sites are located in the Crocodile (West) River catchment; land use is predominantly residential and industrial, although some urban agriculture also exists (Figure 1).

Both selected sites feed into the Jukskei River; stormwater from The Reid flows into the Modderfontein Spruit while the Observatory outlet flows through a park and directly into the Jukskei River. See Figure 2 for a general layout of the sites. The Juskei River is one of three main rivers found in Johannesburg and originates in Bezuidenhout Valley before eventually joining the Crocodile River and flowing to Hartebeespoort Dam. It then flows in a north-westerly direction through the north of Johannesburg. Its tributaries include the Braamfontein, Sand, Edenvale, Klein Jukskei and Modderfontein Spruits.

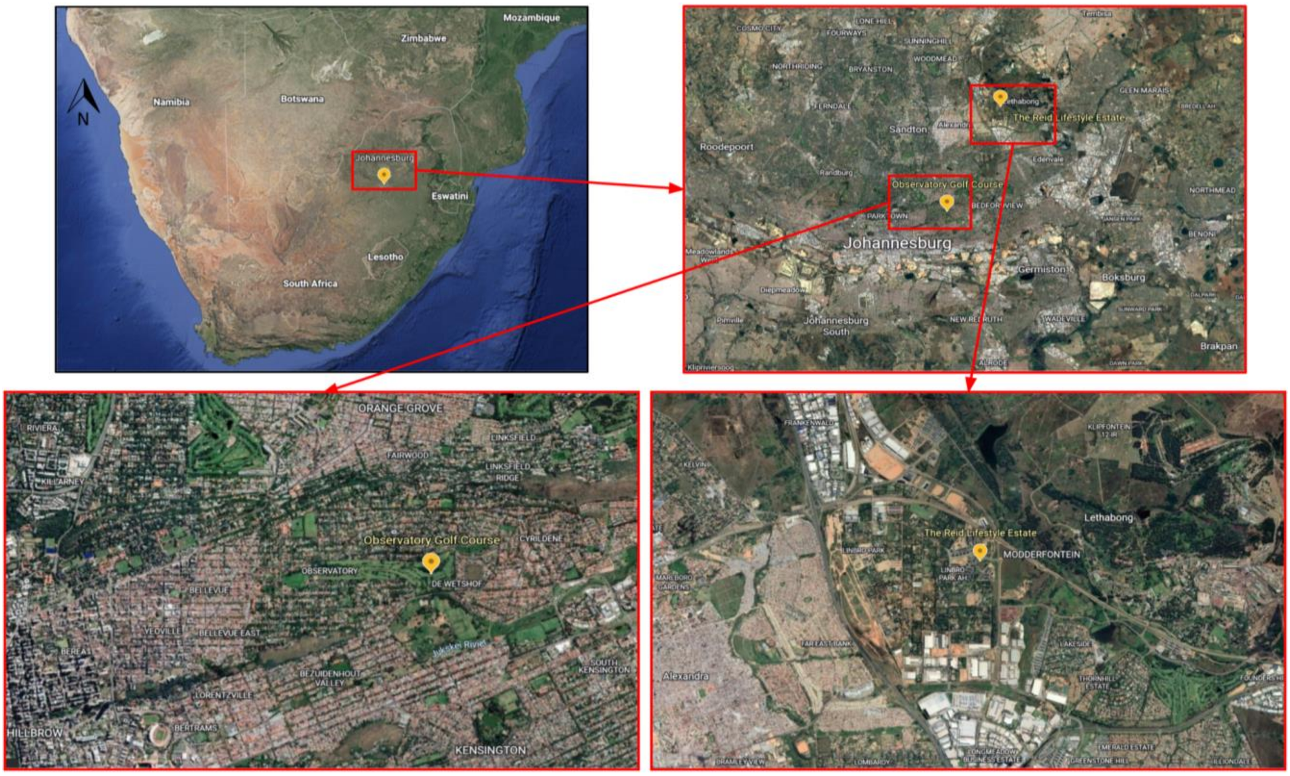


Figure 1: Location of sites - a) Johannesburg within South Africa; b) within Johannesburg; c) The Reid; d) Observatory

Figure 2: General layout of sites; a) The Reid; b) Observatory

What did we do? Methods and Results

Physical experiment

The objectives of the physical experiment were to: (a) assess and compare the efficiency of the implemented SuDS at the two selected sites in terms of pollutant removal and overall water quality improvement of stormwater; (b) gain insight into the SuDS processes (physical, chemical, institutional) in selected public and private developments in CoJ; (c) determine the relationship between efficiency and variability of stormwater quantity and quality, and (d) evaluate the effect of design and maintenance on SuDS efficiency. Physical surveying and water quality monitoring were carried out to reach these objectives.

Water quality and flow measurements were conducted using identified sampling locations at the study sites (Figure 3). Samples were analysed in order to gain insights into spatial and temporal gradients within a water body or system. The selection of appropriate water quality parameters (Table 1) to monitor was based on catchment guidelines and the importance of certain indicators, their possible interdependencies and the possibility and affordability of chemical analyses. Due to the size and dynamic nature of both sites, sampling locations were carefully selected and kept consistent to gather representative, repeatable data. To allow for seasonal variations, sampling campaigns were planned during the winter and summer, coinciding with dry and wet seasons in the region. A water quality aggregate approach was used to gain an overview of water quality changes and simplify the comparison between different sites and seasons.

A Water Quality Indicator (WQI) aggregated seven parameter (pH, EC, E. Coli, PO_4, NH_3, NO_3 and SO_4) values from each water sample location into single numbers using an equation that takes into account quality guidelines. A WQI number between 0 and 25 indicates excellent water quality and a number larger than 100 indicates that the water is of poor quality. Following this, removal efficiencies were calculated that assisted with understanding the changes in various pollutants through the systems. These were then analysed both in the direction as flow as well as with pond depth.

Table 1: Selected parameters for analysis

Parameter		Unit	Limit[1]
Orthophosphate	PO42-P	mg/l	0.5
Nitrate	NO3-N	mg/l	1
Nitrite	NO2-N	mg/l	1
Ammonium	NH4-N	mg/l	0.1
Sulfate	SO42-	mg/l	70
Chlorine	Cl-	mg/l	60
Chemical Oxygen Demand	COD	mg/l	
Escherichia coli	E.Coli	counts/100ml	130
Total Coliforms	T. Coli	counts/100ml	
Dissolved Oxygen	DO	mg/l	6
Temperature	T	C	
pH			6.5 - 9
Oxidation Reduction Potential	ORP	mV	
Electric Conductivity	EC	mS/m	65
Total Dissolved Solids	TDS	mg/l	
Total Suspended Solids	TSS	mg/l	100[2]

[1] (DWS, 2017)
[2] (DWF, 1996)

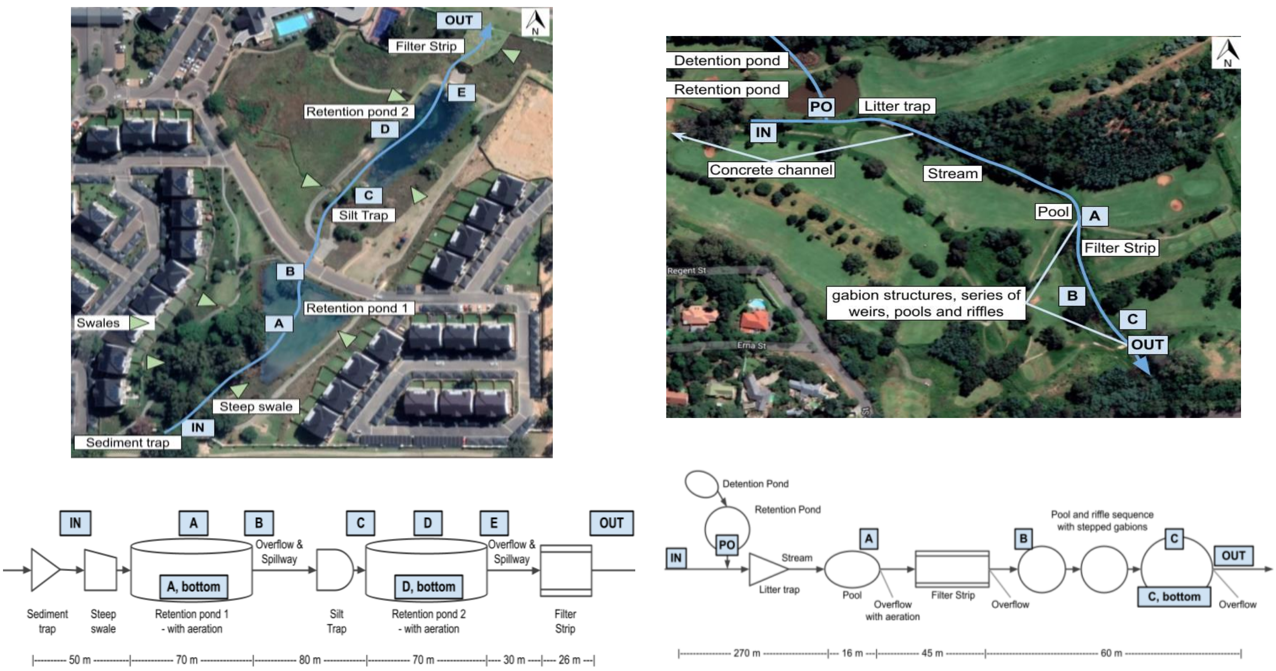


Figure 3: Design and layout of sampling sites, with distances between SuDS elements – a) The Reid; b) Observatory

The Reid stormwater system

Stormwater from agricultural/construction/industrial activities in the upstream catchment enters the property along the southern boundary and then flows through a SuDS treatment train comprising:

- a sediment trap along southern boundary wall
- two retention ponds with mechanical aeration
- swales at inlet and around ponds
- spillways at outlets of both ponds
- a silt trap
- a filter-strip/wetland before northern boundary

The first pond has a section that remains shaded for most of the day. It has the largest volume and constitutes more than half of the site's water retention volume.The second pond is deeper than the first but has a smaller surface area. The filter strip has dense reed growth and is mainly shaded during the summer (growth season). The water drops 3-4m before flowing over a series of steps at the pond outlets.

Observatory stormwater system

Stormwater from upstream rapidly-densifying inner-city areas enters the property on the western side and flows in a concrete channel through a series of ponds (with outlets into the channel) and then enters the SuDS treatment train comprising the following:

- a concrete channel with litter trap
- a stream
- gabion structures in series of weirs, pools and riffles
- a filter strip / wetland

The pool at A is very shallow. The sequence of pools from B to Out is slightly deeper and partially shaded and retains most of the water. The biggest vertical drop at this site is after pool A (>3m), with two smaller drops further down contributing to aeration. The filter strip has a large surface area with full sun

Comparative results – hydraulic retention and water quality

Mean inflows to the sites, waterbody volumes and related hydraulic retention times (HRT) are listed in Table 2. The inflows from side and inlet streams were also considered during sampling campaigns but, based on their relatively low contributions, they were not included for constant monitoring although some grab samples were taken. Whilst the two systems have similar characteristics in terms of SuDS features, i.e., vegetation and vertical drops in water flow through the system, the main physical differences include:

- Deeper ponds with large surface areas at The Reid compared to shallow pools at Observatory
- Water retention volume at Observatory only 5% of The Reid
- Inlet flow rates at Observatory 250% higher than The Reid
- HRT at Observatory only 1.5% of The Reid
- Submerged vegetation and algae present in ponds at The Reid
- Gross litter constantly present at Observatory
- Extreme water level changes during storms at Observatory

Table 2: Hydraulic data for both sites

The Reid

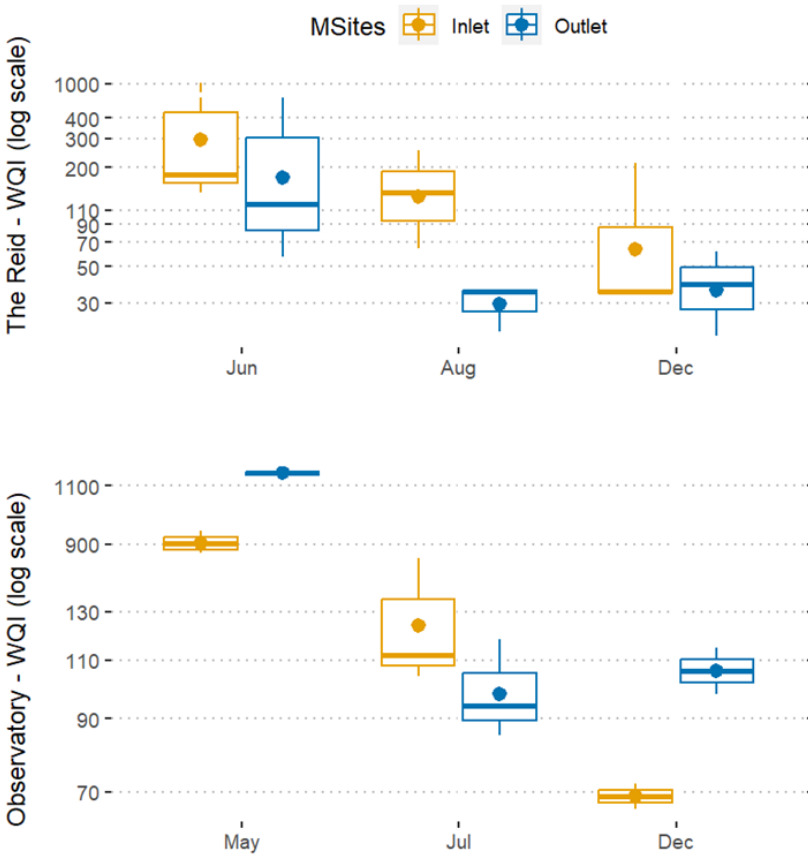
	June	August	December
Average Side Flow (m3/s)	0.004	0.003	0.004
Average Inlet Flow (m3/s)	0.030	0.020	0.045
Volume (m3)	7,600	7,600	7,600
HRT (hours)	70	106	47
HRT (days)	3	4	2

Observatory

	May	July	December
Average Side Flow (m3/s)	0.001	0.002	0.001
Average Inlet Flow (m3/s)	0.088	0.082	0.161
Volume (m3)	411	411	411
HRT (hours)	1.3	1.4	0.7
HRT (days)	0.05	0.06	0.03

Based on WQI values, stormwater quality improved through The Reid system by 30%, 80% and 57% in June, August and December respectively (Figure 4). Stormwater quality improved (by 22%) in Observatory during July but declined through the system by 27% and 53% in May and December respectively. Overall, treatment efficiency at The Reid was greater than at Observatory, even when considering separate parameters and pollutants. For example, E. Coli and COD decreased in all months at an average of 89% and 15%. TSS, EC, NH_4 and NO_3 also decreased in two of the three sampling campaigns with an average of 62%, 35%, 75% and 57% respectively. Observatory showed limited capacity to treat stormwater inflows and thereby improve water quality.

For both sites, the months with the greatest improvement in average water quality (based on WQI) were July and August; i.e., dry winter months. This coincided with the longest HRT per site, but not the best inlet water quality. The site with the greatest improvement of overall water quality (based on WQI) was The Reid, which is also the site with far larger volume and longer HRT. From this and the comparison of inlet concentrations between sites, the overall water quality improvements correlate best with the water retention volume and HRT but not necessarily the inlet quality or environmental changes in different seasons.



The Reid	mean (sd)
Jun	
Inlet	444 (491)
Outlet	312 (388)
Aug	
Inlet	153 (96)
Outlet	30 (9)
Dec	
Inlet	94 (103)
Outlet	40 (22)

Observatory	mean (sd)
May	
Inlet	904 (54)
Outlet	1149 (18)
Jul	
Inlet	127 (33)
Outlet	99 (17)
Dec	
Inlet	69 (4)
Outlet	106 (12)

Figure 4: Average monthly WQI per site

Figure 4 highlights the WQI results as calculated for samples taken at the in- and outlets of both sites. The tables on the right-hand side indicate the mean and standard deviation values per monthly sampling campaign. The graphs on the left-hand side indicate the mean, median, quartile values and range per month. Note that the WQI of The Reid decreased during all months while Observatory only saw an average decrease during July.

Key lessons from the physical experiment

The treatment efficiencies observed at The Reid can be ascribed to the design and layout of the SuDS, with a functioning sediment trap, a retention pond and a silt trap that serves as a buffer to the second pond where most quality improvements were seen. This proved particularly valuable during the rainy season (December sampling) when resuspension of sediment and mixing occurred in the first pond but largely left the second unaffected. Designing for a greater water retention volume enabled processes that are vital for water quality improvements and ensured sufficient HRT even during summer months with high rainfall. Additionally, the silt trap and the filter strip contributed substantially to water quality improvements.

The main failing of the Observatory system can be attributed to the lack of water retention volume, that also results in very short HRT. The system also did not contain any elements that could serve as a buffer for variations in inlet quantity or quality. This was emphasised when comparing the performance of the filter strips in the two study sites; although their physical attributes were similar, the strip at Observatory was found to have a negative impact on water quality thus highlighting the fact that an element like a filter strip is of no use in a system with high flow rates and negligible HRT.

Both sites receive stormwater that is highly polluted, likely a result of failing infrastructure in the catchment or other illegal discharges. In the case of The Reid, a private development forced to comply with the city's new requirements for treating stormwater, additional costs might be incurred in the future to maintain this system and continue treatment of the received stormwater without upstream intervention. Meantime, in Observatory, a public development, an opportunity to treat stormwater has been missed and thus downstream land users and the environment will ultimately carry the 'costs' of treatment.

Governance evaluation

The City of Johannesburg is actively seeking to build resilience to projected climate change impacts, whilst addressing on-going infrastructure deficits. This is evidenced by the city's presence in transnational city climate networks such as C40 Cities and Resilient Cities as well as by its recent efforts towards water sensitive city benchmarking and the drafting of a Water Security Strategy.

The Observatory Golf Course and The Reid sites represent efforts towards water sensitive futures that incorporate sustainable management of stormwater through SuDS by a public entity (JRA in conjuction with the golf course) and by a private developer (Balwin Properties), respectively. For Observatory Golf Course the impetus for experimenting with and implementing SuDS was driven by poor quality stormwater flowing through the golf course from upstream areas battling with issues of urban decay. For The Reid, the private developer pursued SuDS as part of compliance with development approvals and environmental impact management for the new residential estate.

Concurrent with the physical assessment of the two sites, an online survey, interviews, focus groups and workshops were conducted to explore the governance dynamics that accompany experimentation and implementation of SuDS in the city.

The Reid stormwater system: SuDS development by a private developer

The Reid's SuDS treatment train has performed reasonably well over the first three years under the management of the developer. Development of the estate is almost complete and due to be handed over to the Home Owners' Association (HOA) in early 2023. The main challenge for the SuDS installation at The Reid is to equip the HOA with understanding and addressing the different aspects of operation and maintenance (Figure 5 shows the draft schedule and highlights the extent of these activities).

The Observatory Golf Course: Experimentation with SuDS by public actor in partnership with Golf course

The implementation of the litter trap as part of a SuDS train was done by JRA as part of a stormwater management intervention to address poor quality stormwater coming onto the site. JRA procured consultancy services for the design of the litter trap and downstream gabion works. The SuDS train has not resulted in improvements to the quality of the stormwater released from the Obs golf course owing to the limited hydraulic retention time. Two governance challenges persist – maintenance and clearing of the litter trap as well as the lack of clarity on whose responsibility it is to address (as yet unarticulated) maintenance needs.

Autumn /Winter:

- Pull out grasses, reeds, and algae from dams - compost when dry for use around the estate
- Check silt levels in the silt dam
- Silt should be removed via TLB or Extractor every 5- 10 years depending on the level.
- Freshen up haybales on outer perimeter
- Check the gabions for signs of wear and tear
- Check the pumps
- Check the in lets and outlets
- Pull out invasive plants
- Clean streams of algae and debris
- Bare sections on top wetland area to be crosscut and/or wetland grass seed sown
- Cut all grasses –Kikuyu must be cut down

Spring/ Summer:

- Do not remove grasses and reeds
- Sow either grassland seed mix or grass mix if needed
- Pull out dandelions/ black jacks

Monthly:

- Check outlet areas for blockages, signs of wear and tear

Weekly:

- Cut Kikuyu grass around wetland area
- De weed
- Move gravel back up the paths
- Check mouse boxes
- Clear the perimeter of litter and debris, sweep the road of any sand/ silt that has accumulated.

Daily:

- Place bird feed in feeders
- Clean benches and wooden decks
- Check bins

Figure 5: Draft maintenance schedule for SuDS installations at The Reid

Key governance insights gained

Some key insights have been obtained from the governance experimentation as part of this research:

- Operation and maintenance – remains a key challenge at both sites. There is lack of clarity on ***roles and responsibility*** of different stakeholders involved, while the costs and funding mechanisms also remain unclear. Maintenance plans are best formulated as part of project design and implementation with clarity on the likely responsibilities of different stakeholders.
- Skills and capacity deficits – from both sites there are issues of ***lack of skills and capacity*** in terms of understanding the scope and scale action required for: (1) successful SuDS implementation and maintenance, (2) regulation and enforcement, and (3) understanding the city's complicated geology.
- Upstream activities – SuDS installations on both sites are struggling to handle the ***poor quality of stormwater*** coming from upstream into their installations; this is evidenced by the following

quote from The Reid "[…] You can come up with solutions to your impact on the site as required by the city's regulations yet there is no regulatory accounting for the quality of water you are receiving from upstream."

- Learning via enforcement and evaluation – Both sites highlight the importance of ***regulatory follow-up for enforcement and evaluation*** of the performance of SuDS installations. In general there is a need for a more coherent narrative around WSUD/SuDS in the city which can be facilitated by a SuDS or green infrastructure asset register accompanied by showcasing real-life SuDS projects more systematically.

Conclusions and recommendations for future studies

The study has shown that SuDS can have a positive impact on stormwater quality and can remediate urban drainage challenges. Considering these systems in future urban planning could be beneficial to receiving water bodies and enable environmental protection. However, the careful design and construction of SuDS – as infrastructure assets – is required to ensure sufficient water retention volume and HRT to support the various processes that can improve water quality. This highlights the importance of consultants having a full understanding of the benefits and limitations of WSD/SuDS. Haphazard application of elements of nature-based solutions can damage the reputation thereof – like other engineered systems they have minimum design criteria, ideal operating conditions and real limits in coping capacity. On the other hand, well-designed, maintained and monitored SuDS elements can function within a complementary treatment train that minimises the impact of polluted water on the environment.

Further research into the conditions that can enable the adoption of WSD/SuDS in Johannesburg as well as a better understanding of the functionality and efficiencies of WSD/SuDS installations are necessary. Such studies might consider:

- Additional pollutants such as metals, organic carbons, synthetic organic chemicals, microplastics, pharmaceuticals and emerging contaminants.
- Parameters such as turbidity and dissolved oxygen might facilitate greater understanding of system processes.
- A greater understanding of the role that litter plays in these systems is needed, considering that systems receiving stormwater are inundated with litter from upstream activities.
- Further insights into the contents of and dynamics at the soil-water interface could provide guidance on water quality processes and maintenance.
- Further insights are needed on the practical challenges accompanying SuDS implementation for different actors. These include gaining a better understanding of coordination issues between city departments as well as gaining a catchment-wide view of the impact of different stormwater management choices by developers and residents. It is also vital to further explore the practical realities of public and private practitioners 'doing' sustainability in day-to-day practice at different scales. Such studies would shine a light on the often unseen socio-political work that goes into enabling the adoption of more sustainable water management approaches like SuDS in an African city. Such insights would lend granularity to the WSD/SuDS pathway thus informing and supporting the transition towards a water resilient future in Johannesburg.
- Finally, more case studies of SuDS initiatives are needed to showcase the work already done towards achieving water sensitive futures at different scales as well as to provide opportunities for learning about different aspects of WSD/SuDS in the city and ensuring their broader uptake.