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Viability of investing in ecological infrastructure in South Africa's water supply areas

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Ecological infrastructure (natural ecosystems that provide important services and save on built infrastructure costs) can have an important role in securing water supply, particularly in water-scarce areas, but this importance is not reflected in investment decisions, partly due to a lack of evidence. In South Africa, one of the main threats to water supply is the proliferation of woody invasive alien plants which significantly reduce stream flow and water yields. We used existing spatial data and estimates of the impact of woody invasive plants on flows and water yields and on restoration costs to analyse the viability of investing in ecological infrastructure at the scale of major water supply areas. The analysis involved comparison of the costs and effects on water yields of catchment restoration with those of planned built infrastructure interventions designed to meet increasing water demands in the medium to long term. The cost-effectiveness analysis used the unit reference value as a measure of comparison, which is based on the discounted flows of costs and water supplied over a defined time. Restoration could supply 24% of the combined yield of planned built infrastructure interventions by 2050, and is not only cost-effective but has the added advantage of a range of co-benefits delivered by improving ecosystem health. This finding suggests that investing in ecological infrastructure should be considered ahead of new built-infrastructure projects.

Significance:

- Clearing invasive alien plants from South Africa's main water catchment areas could increase water yields by 997 million m^3 by 2050 relative to a business-as-usual approach, equivalent to a quarter of the yield gains through implementation of built infrastructure interventions planned over the same period.
- Invasive alien plant clearing would be more cost-effective than built infrastructure interventions in all water supply systems, except one, the Orange River System.
- These findings add to the growing body of literature that advocates for ecological infrastructure investments to secure hydrological ecosystem services.

Introduction

Water security is becoming increasingly important globally, especially in regions that already experience water scarcity in relation to increasing human demands due to low or declining rainfall and/or inadequate water supply infrastructure.[1] South Africa is a water-scarce country where these problems are exacerbated by the degradation and pollution of its surface water catchment areas. Catchment degradation takes the form of invasion by woody alien plants, indigenous bush encroachment and the loss of vegetative cover (hereafter referred to as desertification), with the first two reducing stream flows and the latter increasing the rates of sedimentation in reservoirs.

As is the case in most parts of the world, water security in South Africa has been addressed almost entirely through the planning and construction of water supply infrastructure, including sophisticated interlinked systems of reservoirs and inter-basin transfer schemes.[2] However, there is increasing evidence that it would be more efficient to integrate catchment conservation actions into water sector investment planning. Indeed, a large body of research has shown that reducing the extent of invasive alien plants (IAPs) can have significant impacts on stream flow and reservoir yields in South Africa[3-6], and there is growing evidence of the benefits of addressing bush encroachment and desertification[7]. Many studies have now shown that undertaking restoration and conservation measures in catchment areas not only has a positive return on investment, but can also be cost-effective in meeting water security goals.[8-12]

This kind of evidence has led to the idea of solving what were traditionally engineering problems using 'nature-based solutions', which is gaining traction globally as the exponential trajectory of human impacts on the environment start to reach a critical scale.[13] In South Africa, growing realisation of the impacts of catchment degradation on water supply led to the emergence of the Working for Water (WfW) programme and other government-funded land restoration programmes in the 1990s.[14,15] This is part of a growing global concern about the impact of ecological degradation, which has led to the declaration of 2021–2030 as the 'UN Decade on Ecosystem Restoration' to address the risks to biodiversity, water and food security[16] and commitments by signatories to the UNFCCC to achieve Land Degradation Neutrality by 2030 to reverse or offset the degradation that has taken place since 2000[17].

Natural ecosystems that provide important services that reduce the costs of built infrastructure can be referred to as 'ecological infrastructure'.[10,18] In water-supply areas, maintaining these ecosystems helps to maintain the overall quantity and quality of stream flows and reduces the seasonal variability in flows.[19-23] This saves on built infrastructure costs, such as water storage, flood mitigation measures and water treatment costs, as well as providing other environmental benefits. Where water security is also threatened by climate change, the restoration and protection of ecological infrastructure can also be regarded as ecosystem-based adaptation.[24]

There is a growing call for 'investing in ecological infrastructure' as a means to ensure the longevity and most efficient use of existing built infrastructure, towards securing a resilient, reliable water supply[25], especially in the context of rising water demand[26,27] and climate change, which threatens the capacity of existing built infrastructure.

The lack of investment in ecological infrastructure is often attributed to a lack of information.[18,27,28] Indeed, there is limited information on the extent to which investing in ecological infrastructure for water security is viable, and where such investments should be prioritised in South Africa.[28] Decision-makers require sound evidence of the feasibility and likelihood of maximising return-on-investment for an intervention before they are willing to invest. To this end, our study aimed to determine the cost-effectiveness of investing in the clearing and long-term control of IAPs to secure water supply in relation to that of planned built infrastructure.

A viability analysis was carried out for each of South Africa's main water supply systems (WSSs) that serve the country's major population centres. WSSs include the surface and underground water source areas, reservoirs, water treatment works and reticulation networks that are managed by water service providers (water service providers), which are semi-autonomous parastatal water boards or metropolitan municipalities. The water service providers sell bulk water to municipalities or directly to water users, and are expected to invest in the management, maintenance and augmentation of these systems with some assistance from the national Department of Water and Sanitation. Our analysis suggests that, for nearly all water supply systems, investments in ecological infrastructure would be comparatively cost-effective and should be introduced ahead of costly engineering projects.

Data and methods

Study area

The analysis was carried out for each of South Africa's 11 regional WSSs (Figure 1). WSSs are an appropriate unit of analysis because they are the scale at which the Department of Water and Sanitation undertakes its regional water supply infrastructure planning through 'reconciliation strategy studies' (Figure 2). These studies estimate the water demand trajectory and lay out plans for a series of (usually built) infrastructure investments to meet demands over time as they grow with the population. Within each WSS, our focus was on the catchment areas of existing large water supply reservoirs (large dams) as being the ecological infrastructure of interest.

Delineating dam catchment areas

The analysis was carried out for the catchment areas of the existing large bulk water supply dams in each WSS: 64 large dams (wall height 5–15 m; capacity >3 million m^3) either owned and managed by the relevant water service providers or owned by the Department of Water and Sanitation but managed by the relevant water service providers, as listed in the 'South African Register of Large Dams'.[30] Their catchment areas were delineated using ArcGIS software's 'Watershed' tool (ArcMap version 10.4.1). This delineation resulted in a combined catchment area of 230 500 km^2, equivalent to 18.9% of South Africa's land area (Figure 1). Finally, the quaternary catchments within the delineated catchments were identified.[31]

Extent of IAP coverage in catchment areas

The National Invasive Alien Plant Survey (NIAPS) data set[32] was used to estimate the extent of IAP coverage in each of the large dam catchment areas. While the NIAPS data set is outdated and has its limitations (see Preston et al.[33]), it was the best data set available at national scale. This study focused on gums (*Eucalyptus* spp.), pines (*Pinus* spp.) and wattles (*Acacia* spp.) as the three most dominant, thirsty invaders in South Africa.[5] NIAPS data were extracted for the selected quaternary catchments and analysed in Microsoft Excel. The 2010 extents were projected to current (2022) and future (2050) extents using a logistic population growth model (Equation 1):

$$\frac{dp}{dt} = rP_{t-1}\left(1 - \frac{P_t}{K}\right) \quad \text{Equation 1}$$

whereby r is the growth rate, P is the population size, t is the relevant time step, and K is the carrying capacity. K was defined as 'invadable land', which included all land that was not classified as "built-up", "cultivated", "mines and quarries" or "waterbodies" in the South African National

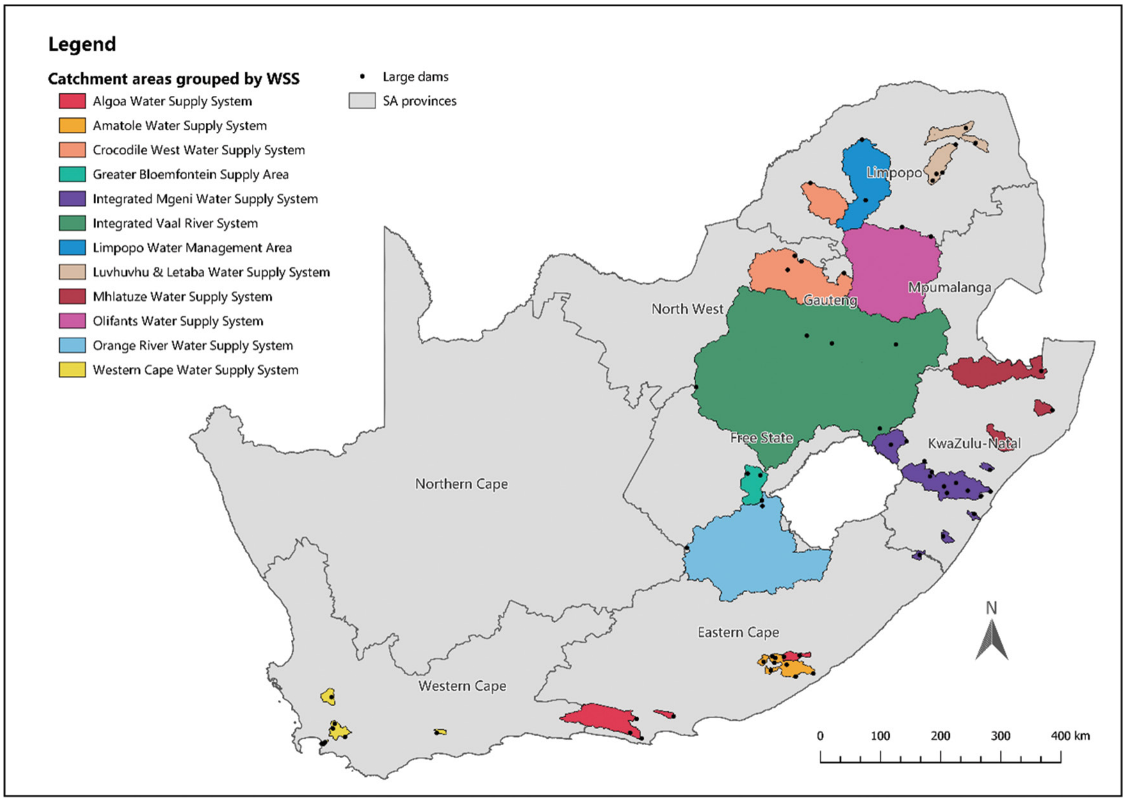
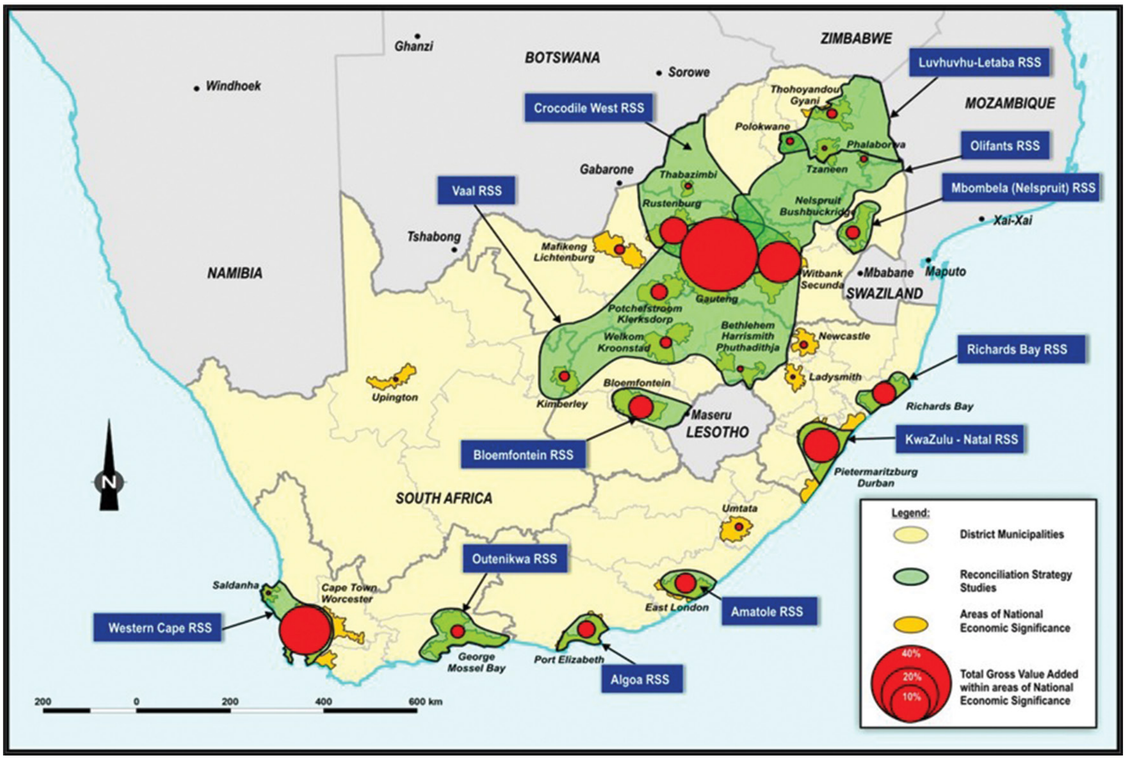


Figure 1: Spatial distribution of dam catchment areas (coloured by water supply system) included in the analyses.



Source: CC-BY-3.0 South African Department of Water and Sanitation[29]

Figure 2: The regions and scales of the 12 reconciliation strategy studies (RSS) conducted and published by the South African Department of Water and Sanitation.

Land-Cover data set 2020.[34] For *r*, a conservative rate of increase in cover of 7.5% per annum was used for wattles, pines and gums, based on the literature.[35,36]

Cost-effectiveness analysis

Overview

To derive the costs of interventions for catchment restoration (i.e. IAP clearing), information was gathered from literature that addressed the spread of IAPs[5,7,36] and methods of calculating estimates of the cost to clear IAPs per hectare. Similarly, all information pertaining to built infrastructure interventions was retrieved from reports published by the Department of Water and Sanitation, which provides access to reconciliation strategy studies for bulk water supply augmentation options for each WSS in South Africa. These reports included relevant cost and yield information.

Unit reference values (URVs) can be used as a direct measure of the benefits derived from water resource interventions and are commonly used to assess the feasibility of projects in the water supply sector.[37] This assessment is done by calculating the cost per cubic meter (ZAR/m^3) of water over the lifetime of the project. URVs were used as a measure to compare the financial costs and benefits (additional water gain) derived from ecological infrastructure and built infrastructure interventions in this study. All analyses assumed that interventions would be implemented in 2022 and were evaluated up to 2050, assuming a 28-year project lifespan for IAP clearing and management.

Assessment of planned built infrastructure development

Each of the study focus regions is depicted in Figure 2. To determine the planned sequence of infrastructure development per WSS, each of the relevant reconciliation strategy reports was retrieved from online repositories and was analysed for interventions planned to take place between 2022 and 2050. Yield gains and URVs for each water supply option were then extracted directly from the reconciliation strategy reports, or estimated based on similar types of projects in other water supply systems. The URVs of each intervention were reported in 2022 Rands.

Costs of clearing IAPs

Cost estimates for clearing IAPs in South Africa were based on person-day estimates provided by the Working for Water (WfW) programme. Person-day estimates are derived from data collected over the lifespan of the WfW programme and are based on the costs to clear different groups and age classes of IAPs in riparian and landscape settings using different treatment methods over time.[7] Therefore, regression models (Table 1) were used to calculate the person-day estimates required to clear one hectare of gum, pine and wattle. The cost to clear IAPs under the WfW programme was some ZAR500 (in 2022) per condensed hectare (c.ha).[36]

Based on this, the cost of initial and follow-up clearing events for gums, pines and wattles was calculated for each relevant quaternary catchment. It was assumed that the first two follow-up clearing events would take place in 3-year intervals after the initial clear in 2022 and every 6 years thereafter until 2050. A discount rate of 8% was used to determine the present value of costs over the period. Investment in clearing IAPs is considered inefficient at densities below 5%, so a threshold was applied to the base year (2022) whereby all quaternary catchments with an IAP infestation of less than 5% were excluded from the cost model.

Table 1: Regression models used to calculate the number of person-days required to clear one hectare of gum, pine, and wattle species, where I_{ha} is the invadable hectares in the relevant quaternary catchment, and *x* is the average percentage density per pixel

Species	Initial clearing	Follow-ups
Gums (*Eucalyptus* spp.)	$I_{ha}(2.4254\,e^{0.028x})$	$I_{ha}(1.7074\,e^{0.1(0.028x)})$
Pines (*Pinus* spp.)	$I_{ha}(2.0647\,e^{0.027x})$	$I_{ha}(1.6161\,e^{0.1(0.027x)})$
Wattles (*Acacia* spp.)	$I_{ha}(2.0057\,e^{0.028x})$	$I_{ha}(0.2006\,e^{0.1(0.028x)})$

Source: Turpie et al.[36]

Calculating URVs for IAP clearing

The URV for securing water supply through clearing IAPs is derived by dividing the total present value of costs (PV_c) by the present value of water supplied (PV_w), as shown in Equation 2. The total PV_c to clear IAPs from an area is the sum of initial and follow-up PV_c costs. The initial PV_c is the product of the number of person-days required to clear IAPs in the first year and the cost to clear one condensed hectare of infested land, while the PV_c of one follow-up event is the product of the number of person-days required to clear IAPs in a follow-up event and the cost to clear one condensed hectare of infested land.

$$URV\,(R/m^3) = \frac{PV_c}{PV_w} \qquad \text{Equation 2}$$

The PV_w is based on the quantity of water gained if IAPs are removed from catchment areas by 2050. To determine this, estimates of streamflow reduction as a result of IAPs were extracted at the primary catchment level.[5] A factor to represent the amount of water used by IAPs per unit area was calculated for all primary catchments and then applied to each relevant quaternary catchment. The gain in streamflow was then converted into a gain in yield by applying a ratio between water flow and yield based on Cullis et al.[38], who estimated changes in yield due to IAPs in all of South Africa's major water management areas. The relevant stream flow to yield ratio was applied to each quaternary catchment according to the water management area within which it is located. This was calculated for the period between 2022 and 2050 using Equation 3, where W_t is the quantity of water at year t, and r is the discount rate.

$$PV_w = \sum \left(\frac{W_t}{(1+r)^t} \right) \qquad \text{Equation 3}$$

Results

Extent and spread of IAPs

IAP coverage of all catchment areas combined was estimated to be approximately 623 000 c.ha in 2022, or 2.7% of the total area considered. Without intervention, this would quadruple to an estimated 2.5 million c.ha, or 10.9% of the area, by 2050 (Table 2). The Amatole WSS had the highest percentage cover of IAPs in both 2022 (22%) and 2050 (58%; Figure 3). Conversely, the Orange River System was estimated to have the lowest level of infestation in both 2022 (0.3%) and 2050 (1.6%) (Table 2).

Overall, gum and wattle were more prolific than pine in most WSSs. Wattle was shown to have the most drastic spread by 2050, having the highest average coverage (9.5%) among all three species. The Amatole WSS's high percentage of invaded area was dominated by wattle infestation, covering 29.3% of the WSS total catchment area by 2050.

Cost-effectiveness analysis

The Integrated Vaal River System was estimated to have the greatest number of condensed hectares infested with IAPs by 2050 (approximately 922 000 c.ha; Table 2), resulting in the highest PV_c to remove them (ZAR4.7 billion), while the Luvuvhu-Letaba WSS had the lowest number of condensed hectares (approximately 25 000 c.ha), requiring the lowest allocation of investment for IAP removal (ZAR71.8 million).

Across all 11 water supply systems considered, a total of 52 planned water supply projects were specified in the relevant reconciliation strategy studies between 2022 and 2050. Combined, planned built infrastructure interventions would result in yield gains of approximately 4 173 million m^3/a. On the other hand, the amount of water that could be gained by removing IAPs from bulk water supply catchment areas would increase exponentially between 2022 and 2050 (because IAP cover, and hence water lost in the absence of clearing, increases exponentially), amounting to a gain in stream flow of about 1 595 million m^3 and a gain in yield of about 997 million m^3 (Table 2). This is approximately 24% of the amount of water that could be gained through implementation of built infrastructure interventions (such as dam augmentation and desalination projects, and water transfer schemes) in the same time frame. As a reference, the reliable yield of surface water sources in South Africa as at 2019 was 10 200 million m^3/a.[39]

When the URVs and yield gains of IAP clearing are compared with those of planned built infrastructure developments, it becomes clear that IAP clearing is a cost-effective intervention for securing water supply. IAP clearing was the most cost-effective water supply option for all WSSs except for the Orange River System, which showed relatively low water gains for the associated URV (Figure 4). Overall, IAP clearing was the most cost-effective augmentation option.

Table 2: The total condensed hectares (c.ha) that would be infested in 2050 if no clearing was pursued, the water gained by 2050 with intervention and the present value (PV) in 2022 Rands of the investment required to clear invasive alien plants in existing bulk water supply infrastructure catchment areas of each relevant water supply system (WSS) between 2022 and 2050

WSS	Area infested by 2050 without intervention (c.ha)	Increase in stream flow by 2050 with intervention (million m^3)	Increase in yield by 2050 with intervention (million m^3)	PV of clearing costs (ZAR millions)
Algoa WSS	145 657	103.9	43.9	740.80
Amatole WSS	92 804	87.7	42.7	578.89
Crocodile West WSS	235 377	66.5	35.8	1414.64
Integrated Mgeni WSS	227 610	303.9	148.9	1231.66
Integrated Vaal River System	922 233	423.4	338.7	4696.02
Limpopo North	61 764	22.8	12.3	136.84
Luvuvhu-Letaba WSS	24 929	11.8	6.8	71.80
Olifants WSS	524 977	263.0	193.6	3078.45
Orange River System	45 818	26.0	14.3	145.45
Richard's Bay WSS	188 057	180.4	89.2	889.88
Western Cape WSS	46 326	105.4	71.0	325.93
Total	**2 515 554**	**1595.4**	**997.1**	**13 310**

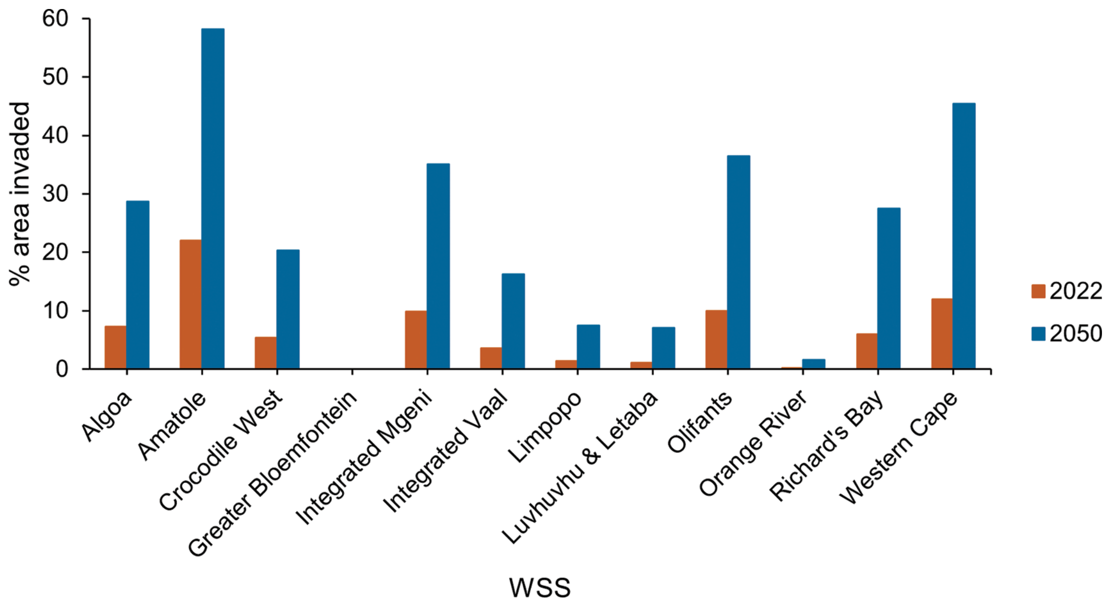


Figure 3: Present (2022) and future (2050) percentage area of invasive alien plants in each water supply system (WSS).

The URVs for built infrastructure ranged from ZAR0.48/m^3 for the new Vioolsdrift Dam augmentation project in the Orange River System[40] to ZAR44.36/m^3 for the Zambezi River transfer scheme in the Crocodile West WSS[41], while the URVs for IAP clearing ranged from ZAR0.79/m^3 for the Western Cape WSS to ZAR7.18/m^3 for the Crocodile West WSS (Table 3). Of all the 11 water supply systems analysed, only IAP clearing in the Orange River System was less cost-effective than planned built infrastructure options. This finding can be explained by the low levels of estimated invasion in this water supply area, so removal of IAPs would not result in a significant gain in additional water when compared to the built alternatives which had significantly higher yields.

Discussion

There is growing awareness of the important role of ecological infrastructure in achieving water security.[27,28,42] However, ecosystem degradation is resulting in the loss of valuable hydrological ecosystem services that increase the costs of water supply. Investing in restoration and conservation of catchment areas can effectively support existing built infrastructure and delay the need for more expensive engineered solutions. This not only reduces costs over the long term, but also generates a range of co-benefits.

This study has shown that, from a water supply perspective alone, securing hydrological ecosystem services through catchment restoration is cost-effective and should be considered as a priority action towards achieving water security in South Africa. Broadly, the yield gained (997 million m^3) from clearing IAPs from South Africa's key water supply areas equates to approximately 19% of the capacity of the Gariep Dam, the largest dam in South Africa. IAP clearing was more cost-effective than planned built infrastructure options in all but one of the 11 WSSs analysed, the exception being the Orange River System, where invasion levels are relatively low.

This study's findings build on a number of smaller-scale studies that have demonstrated restoration measures as being cost-effective in securing hydrological ecosystem services. Clearing IAPs was found to be a cost-effective intervention in a quaternary catchment of the Olifants River with a URV of ZAR1.44/m^3, which compared favourably with a URV of ZAR2.93/m^3 for the De Hoop Dam.[43] In a comparison between the uMngeni and Baviaanskloof-Tsitsikamma catchment areas, uMngeni had more severe levels of degradation, which consequently resulted in a higher URV for restoration of ecological infrastructure (ZAR2.50/m^3) than the Baviaanskloof-Tsitsikamma (ZAR1.17/m^3).[9] In two quaternary catchments in northern KwaZulu-Natal, IAP clearing was more economical than raising the wall of Hazelmere Dam, with a URV of ZAR2.50/m^3 compared to ZAR3.67/m^3.[44]

Investing in catchment restoration also becomes increasingly attractive as built augmentation options become progressively more expensive due to (1) the cheaper interventions being implemented first[45] and (2) more costly maintenance due to the impacts of catchment degradation which shortens the projected lifespan of reservoirs and related infrastructure[9]. Furthermore, investing in ecological infrastructure for water supply also delivers co-benefits such as biodiversity conservation, flood risk reduction, reduced sedimentation, carbon sequestration and other ecosystem services.[7,10,15,28,44,46] Although the benefits of catchment restoration are undeniable, the associated water supply benefits would not be deliverable to consumers without functional built infrastructure, so we emphasise that ecological infrastructure investment should go hand in hand with the proper maintenance of existing infrastructure.[39]

To date, the water service providers, which stand to gain significantly from improvements in catchment health through cost savings, have been slow to invest in ecological infrastructure. Indeed, only 1 of the 11 water supply systems has formally acknowledged and actively incorporated catchment restoration as a key intervention in their planning and budgeting for securing water in the long term. IAP clearing is included as a prioritised augmentation option in the Western Cape WSS reconciliation strategy.[47] The net URV of ZAR1.20/m^3 reported in the reconciliation strategy is slightly higher than that of ZAR0.79/m^3 estimated in this study, but still significantly lower than the range of URVs determined for built infrastructure augmentation options in the WSS (ZAR2.57–18.77/m^3).

While some other water reconciliation strategies, namely those of uMgeni and Richard's Bay[48,49], acknowledge the importance of catchment restoration and the maintenance of ecological infrastructure, they do not quantify the yield that could be obtained from removing IAPs and do not account for it in reconciliation scenarios or water balances developed for the WSS. The reason for this, stated in the KZN Coastal Reconciliation Strategy, is due to a "lack of quantifiable data"[48]. In the Western Cape WSS there has been considerable research undertaken to assess the impact of IAPs on water supply, which has provided the information needed to secure support and funding to undertake restoration activities in important water source areas. An outcome of this research has been the formation of the Greater Cape Town Water Fund (GCTWF), which since 2018, has successfully brought together and linked beneficiaries and stakeholders in pursuit of a common goal of securing water.[50] The GCTWF operates at a large scale, focusing restoration efforts, particularly IAP clearing, in the catchments that feed the Western Cape WSS. These restoration efforts have been guided by scientific research that has determined priority areas for IAP clearing based on cost-effectiveness and return on investment.[36,50] In developing the Business Case for the

Figure 4: (a–l) Unit reference value (URV; ZAR/m³) and yield gained (million m³) through implementation of interventions for each water supply system (WSS), and (g) the average URV and yield gained per intervention type across all water supply systems.

Table 3: A summary of the overall extent of invasive alien plants (% IAP coverage) within each water supply system (WSS) without intervention, as well as the unit reference values (URVs) associated with built infrastructure and IAP clearing. URVs are reported in 2022 Rands.

WSS	% IAPs		Range of built infrastructure URVs (ZAR/m^3)	URV IAP clearing (ZAR/m^3)
	2022	2050		
Algoa WSS	7.26	28.68	6.77 – 25.62	2.99
Amatole WSS	22.00	58.22	8.46 – 28.66	1.97
Crocodile West WSS	5.43	20.35	12.38 – 44.36	7.18
Integrated Mgeni WSS	9.84	35.12	4.54 – 21.91	1.43
Integrated Vaal River System	3.61	16.30	11.80 – 17.61	2.78
Limpopo WMA North	1.40	7.50	17.95[a]	2.53
Luvuvhu-Letaba WSS	1.14	7.10	3.98 – 17.32[b]	2.60
Olifants WSS	9.96	36.51	4.50 – 31.92	2.82
Orange River System	0.27	1.61	0.48 – 0.84	2.45
Richard's Bay WSS	6.03	27.50	2.22 – 19.36	2.01
Western Cape WSS	11.97	45.49	2.57 – 18.77	0.79

[a]*Only one planned built infrastructure intervention.*

[b]*Values based on the average URVs of similar projects due to deficient data.*

GCTWF, the URVs to clear IAPs ranged from ZAR0.30/m^3 to ZAR0.80/m^3 in the top seven priority sub-catchments.[36] The URV for clearing IAPs in the Western Cape WSS determined in this study falls at the upper end of this range. The success of the GCTWF hinges on its ability as an independent entity to securely manage funds from multiple sources and undertake restoration activities effectively and efficiently, following best practice guidelines for IAP clearing. Recent research suggests that there is a sufficient consumer surplus and potential to raise domestic water tariffs to cover the estimated costs required to restore catchment areas supplying water to some of these municipalities.[51,52]

The results from this study provide evidence at scale that investing in ecological infrastructure is a cost-effective and worthwhile long-term option for all of South Africa's water supply systems. However, given that state budgets remain the primary source of restoration funding in the country and are heavily constrained, catchment partnerships and water funds are most likely needed to succeed in leveraging the investment needed to restore these important catchments.

Conclusions

We found that investing in IAP clearing is a viable means of addressing growing water demands in 10 of South Africa's 11 major water supply areas. IAP clearing would lead to a total estimated streamflow gain of 1595 million m^3 and a yield gain of 997 million m^3 by 2050, equivalent to a quarter of the yield gains through implementation of built infrastructure interventions over the same period. The URVs for built infrastructure ranged from ZAR0.48/m^3 to ZAR44.36/m^3, while the URVs for IAP clearing ranged from ZAR0.79/m^3 to ZAR7.18/m^3. All URVs for IAP clearing were lower than that of built infrastructure interventions, except for just one water supply system, the Orange River System. Therefore, IAP clearing should be considered a formal intervention for securing future water supply alongside built infrastructure options in South Africa's water supply systems. These findings add to the growing body of literature that advocates for ecological infrastructure investments to secure hydrological ecosystem services by showing that such approaches can be more cost-effective than built infrastructure development options. The findings should be used to leverage and prioritise investments in ecological infrastructure in South Africa and to encourage the initiation of new partnerships and funds for priority catchment areas.

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Competing interests

We have no competing interests to declare.

Authors' contributions

K.M.E.W.: Data collection, data analysis, data curation, writing – initial draft, project management. J.K.T.: Student supervision, conceptualisation, project leadership, writing – initial draft, methodology. G.K.L.: Student supervision, project leadership, writing – initial draft, methodology, funding acquisition.

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