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Article

Suitability of Coastal Reservoirs for Stormwater Harvesting in South Africa

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Abstract: South Africa is a water stressed country experiencing mass urbanisation especially towards coastal cities. The country is already enduring the impacts of global warming and climate change with risk of water scarcity in many areas. The risk was evident with Cape Town near encounter with 'Day Zero' i.e., the day when water supplies would have been switched off and residents required to queue for daily water rations. The drought exposed the inadequacies of the existing water supply system. Paradoxically, in the same drought period, vast amounts of unutilized stormwater that could have augmented water supply run unabated into the ocean through rivers around the city. The study determined that the problem was not necessarily water shortage but lack of adequate water storage. This study investigated the suitability of coastal reservoirs for stormwater harvesting on the over 3000 km South African coastline. The objective was to identify suitable locations for coastal reservoirs. The study undertook a systematic process of selecting several candidate locations and eliminating unsuitable sites based on international best practice i.e., coastal topography, climate, hydrology, fluvial environment, catchment size and river water quality. Nine candidate sites were identified and ranked based on suitability and associated benefits. The identified locations in order of ranking include Knysna River, Berg River, Buffalo River, Kowie River, Thukela River, Orange River, Port of Richards Bay, Port of Durban, and Lourens River. The Knysna site, with a mean annual precipitation of 600 - 800 mm/annum and mean annual runoff of 100 - 500 Mm^3/annum, was determined to be the most optimal location.

Keywords: coastal reservoirs; stormwater harvesting; South Africa

1. Introduction

South Africa is experiencing rapid population growth and increased urbanization towards coastal cities. Subsequently, water scarcity and stress in these areas are becoming critical problems that need to be prioritized to meet the needs in the cities. South Africans have endured severe droughts that compounded inequitable access to safe water. The City of Cape Town's close encounter with 'Day Zero' is evidence that existing water supply and storage infrastructure are insufficient. It is becoming increasingly imperative for existing methods to be superseded by more innovative and sustainable solutions to address the water crises. Coastal reservoirs as a means of stormwater harvesting and storage in other countries have shown to be an optimal step towards that future.

2. Materials and Methods

For many years, the world has witnessed rapid population growth and an increase in urbanization especially towards coastal cities with about three billion people residing within 200 km of a coastline (Yang et al., 2013). Many cities around the globe are faced with water scarcity and water stress which will be exacerbated by climate change. Water scarcity is a complex challenge which intensifies the impacts of food insecurity, the deterioration of ecosystems, poverty, and water-related conflicts (Liu, Yang & Jiang, 2013). It is imperative that alternative methods to conventional urban water supply are adopted to face these challenges. Yang (2019) proposes that water shortages in coastal cities are a result of a lack of adequate water storage infrastructure as opposed to water scarcity. Coastal reservoirs have the potential to capture and store large volumes of storm water runoff and thus could become the most optimal solution for the future of sustainable urban water supply.

There are three main categories of coasts pursuant to the constitution of the seabed, how the sediments travel in the rivers, the structure of the nearby beach and the effects of erosion. The categories include silty-sandy, silty, and sandy coasts (Wu et al., 2017). South Africa's coastline stretches over 3000 km, with about 80% of which comprises beaches of sand and dunes that are habitat to a diverse range of flora and fauna (Schreiner et al., 2014). The country is water scarce due to mass urbanization and the expanding population size (Ward & Winter, 2016). In addition, the water resources in over 60% of the rivers in South Africa have already been allocated mainly for agriculture and urban water supply (Donnenfeld, Crookes & Hedde, 2018). Ward and Winter (2016) indicated that 57% of river ecosystems are threatened, of which 23% are classified as critically endangered, 19% endangered and 13% vulnerable. With a Mean Annual Precipitation and Mean Annual Runoff of 450 mm and 49 000 Mm3 respectively, South Africa is classified as water stressed (Du Plessis, 2019). In terms of water resources, the country is predominantly surface water i.e., 77%, with groundwater at 9% and return flows of 14% (Du Plessis, 2019). Inter-basin transfer schemes are used to supply 50% of the water needs in seven out of the nine provinces. However, water scarcity is still a critical challenge, particularly in the Western Cape, Northern Cape, and Eastern Cape, all of which are coastal provinces (Du Plessis, 2019). The phenomenon of 'Day Zero' was projected for the City of Cape Town in the Western Cape, following years of severe drought, that left water in major dams at critically low levels. Reduced rainfall and surface runoff contributed to rapid decrease in reservoir water quantities to 21% in 2017 (Bischoff-Mattson et al., 2020). 'Day Zero' would have been reached with water levels in the major dams supplying Cape Town falling below 13.5%. At this point, the city would have increased water restrictions to Level 7 and turned off water supply. Residents would have been expected to queue for daily water rations at several locations around the city.

Annual water demand in South Africa is projected to increase from about 15 km^3 in 2017 to 17.7 km^3 in 2030. Since the current water systems are unable to fully meet water needs, the increase will further exacerbate water scarcity. Yang (2019) showed that water scarcity and droughts around the world are largely due to insufficient water storage infrastructure and not necessarily water shortage. For example, in Cape Town, the mean surface runoff during the drought period (2015 – 2017) was about 540 GL/annum. This was greater than the mean annual water use in Cape Town of about 300 GL/annum over the same period. Yang, (2019) suggested that coastal reservoir would provide storage for the surface runoff and provide a water resource to cities. Table 1 presents various rivers in South Africa with potential sites for coastal reservoirs.

Table 1. Potential sites for coastal reservoirs in South Africa (Yang, 2019).

River	Length (km)	Catchment area (x10^3 km^2)	Rainfall (mm/year)	Annual runoff (GL/year)	Discharge to Ocean
Orange	200	855	700 - 800	11500	Atlantic
Gamtoos	645	34.6	400	30	Indian
Tugela	502	29.1	300	3780	Indian
Limpopo	1800	412.9	425 - 530	5360	Indian

In South Africa, inland reservoirs are one of the most frequently and conventionally used water storage infrastructure. There are over 650 inland dams of which the largest is the Gariep Dam in the Free State Province. The dams are dependent on rainfall, thus climate change that results in variability in rainfall patterns would reduce the reliability of the inland reservoirs to supply water and meet anticipated demand (Okedi, 2019). Moreover, construction of inland reservoirs often causes the

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forced displacement of many people from settlements which is not only expensive but socially complex and unsustainable (Sitharam et al., 2020). Table 2 presents a cost comparison of some urban water supply methods and shows that coastal reservoirs has relatively lower capital cost.

Table 2. Cost of various urban water supply methods (Liu, Yang & Jiang, 2013).

	Construction cost per m3 of water (US$)	Cost per m3 of water (US$)
Coastal reservoirs	2.67 - 6.01	0.15 - 0.25
Inland reservoirs	5.83 - 7.5	0.34 - 0.4
Desalination	6.41 - 10.08	0.43 - 1.13
Water recycling	5.57 - 8.30	1.44 - 1.53

Coastal reservoirs can be simply defined as reservoirs of freshwater encased by seawater. Their goal is to collect the freshwater surface runoff as it is discharged into the ocean at the mouth of a river without allowing it to be contaminated by salt water (Sitharam et al., 2020). They can be categorized according to geographical site location such as intertidal, estuary and gulf reservoirs (Yang et al., 2013). Coastal reservoirs can also be classified by the dam structure employed such as earth, soft and concrete dams, natural or synthetic (Yang et al., 2013). Coastal reservoirs are constructed for various purposes including augmentation of potable water supply, hydroelectric power stations, wastewater treatment plant water supply, recycling ship ballast water in harbors or flood prevention and control (Sitharam et al., 2020). Furthermore, coastal reservoirs can aid in increasing the supply of water for agricultural and industrial purposes (Liu, Yang & Jiang, 2013). They can even be used for the purpose of aquifer recharge (Yang & Ferguson, 2010). The first coastal reservoir was constructed in 1932 in Zuider Zee, Netherlands with the goal of producing potable water (Liu, Yang & Jiang, 2013). The two main types of coastal reservoirs developed are first generation reservoirs which were then followed by second generation reservoirs (Table 3).

Table 3. First- and second-generation coastal reservoirs (Sitharam et al., 2020).

	Description	Fluid inside reservoir	Large water body	Property difference
By location in the sea (first type)	Inside a river mouth (first generation)	Freshwater	Estuary	Salinity TN, TP, etc.
	Beside a river mouth in the sea (second generation)	Freshwater/fluid for intended use	Seawater	Salinity TN, TP, etc.
	Outside a river mouth (offshore/second generation)	Freshwater/fluid for intended use	Seawater	Salinity TN, TP, etc.

The main difference in the two types of coastal reservoirs is that first generation are located inside the river mouth whereas second generation are positioned next to or near the mouth of the river (Sitharam et al., 2020). The major problem with the first-generation reservoirs was the negative impacts on the environment by blocking the river from the sea and altering the fluvial ecosystems (Sitharam et al., 2020).

The optimum coastal reservoir is designed with a barrage or dyke of a minimum length to reduce construction costs (Yang & French, 2018). Other important factors that influence the effectiveness of coastal reservoirs include its shape and the geology of the landscape. The barrage needs to be at an adequate height that it can stand against surges in the tide and waves although the difference in water pressure on either side is only 10 meters (Yang & French, 2018). Yang (2013) defined the frameworks of an optimally designed coastal reservoir as the crucial separation of fresh river water from the salty or polluted water, the conservation of the freshwater from contaminated water and the mitigation of the intrusion of salt water. It is imperative that water quality is maintained as high as possible to impede eutrophication and the spread of algal bloom (Sitharam et al., 2020). Water quality improvement measures can be employed such as eco-agricultural wetlands to pre-treat the water as well as the inclusion of a bypass channel so that any contaminated water can be released (Sitharam et al., 2020). Improvements can also be made through the control of hydraulic gates to prevent the water from remaining stagnant (Yang & French, 2018). For the same purpose of stagnation mitigation, pumping stations can be installed to induce mobility in the water (Sitharam et al., 2020).

In general, the positioning of coastal reservoirs needs to consider shoreline stability, hydrology, and geology (Wu et al., 2017). In addition, the relationship between the principles of seabed sediment movement and coastal engineering must be examined to evade siltation, erosion, alterations to the coastline and damage to the estuaries (Wu et al., 2017). Building coastal reservoirs can be challenging due to the climate of the region, currents and tides, topography, and stormy weather (Wu et al., 2017).

There are currently no coastal reservoirs in South Africa. To determine the suitability of coastal reservoirs on the South African shoreline, it was necessary to evaluate and compare with international best practice and successful examples around the world. The largest coastal reservoir in the world is in Shanghai and provides water to about 75% of the 25 million people in one of the largest cities in the world (Yang, 2019). The 550 ML reservoir provides 2600 GL of water per year (Yang & French, 2018). The shape of the reservoir is elongated with a length of 22 km and a width of 3 km, with a reservoir area of 66.15 km^2 and 0.527 Gm^3 storage capacity (Wu, Yuan & Wei, 2017). The dyke extends 48.4 meters, and the reservoir is connected to the city by a pair of 7.21 km below ground pipelines of 5.84 meters in diameter with which 24 pumps facilitate the delivery (Yang, 2019). The pump and sluice gate system were positioned after analyzing the attributes of the tide, flow directions and the quality of the water over time (Wu, Yuan & Wei, 2017). The force of the tides allows freshwater to enter through the hydraulic sluice gate whilst the pumping station pushes freshwater into the reservoir through the drier seasons (Wu, Yuan & Wei, 2017). The reservoir is affected by much pollution therefore mitigation of eutrophication is imperative. A control system and a scheduling scheme have been put in place to ensure that a high standard of water quality is achieved (Wu, Yuan & Wei, 2017).

Other examples include the Marina Barrage coastal reservoir in Singapore which was constructed with the purpose of increasing the water supply, protecting the coast from flooding, and creating a tourism hub with aesthetic appeal (Yang et al., 2013). The system operates according to the tides with steel crest gates that extend over 26.8 meters and pumping stations for drainage. The dam was constructed over a width of 350 meters across the Marina channel. In South Australia, a coastal reservoir has been proposed near the mouth of the River Torrens in Adelaide (Lui et al., 2017). It will be separated into two sections as per the quality of water (Lui et al., 2017). One part will intake the water for potable purposes whilst the other will collect water for industrial use, irrigation, and desalination (Lui et al., 2017). The reservoir will have a 25 km^2 area with a capacity for storage of 250 GL. The dyke will stretch 16 km-long and three sluice gates will be implemented to operate according to the quality of the incoming stormwater runoff (Lui et al., 2017). Like many cities in South Africa, the causes of water scarcity in Adelaide are largely limited water storage rather than shortage of water. The water use in Adelaide is about 160 GL/annum which will increase to 370 GL/annum by 2050. The average flow in the Murray River is about 5000 GL/annum, over 30 times more than the water demand (Lui et al., 2017).

In the study, the criteria used to identify suitable locations for coastal reservoirs on the South African coastline were based on best practice and exemplars worldwide. Hydrology and climate data was collected on various potential sites and used to conduct quantitative and qualitative assessment to determine the most suitable sites and provide rankings based on preference of the locations. Using ESRI ArcGIS online mapping tool and Cape Farm Mapper developed for the Western Cape Department of Agriculture, the study identified river mouth locations of every perennial river

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discharging into the South African coast. location was systematically evaluated and analyzed for the suitability of the construction of a coastal reservoir. Additional data used included aerial and satellite imagery from Google Earth, Google Maps and Google Street View as well as the map and layers provided by the Groundwater Database for the Western Cape Province. The suitability criteria were based on coastal topography, the river system and fluvial environment, the presence of an estuary, the proximity of major settlements and the mean annual runoff through the river mouth to the ocean. Each location was compared to the characteristics of existing coastal reservoirs such as the Marina Barrage in Singapore, also viewed through mapping tools. The shortlisted locations were given a characteristic rating of suitable (green) or unsuitable (red) per suitability criterion and ultimately assigned an overall suitability rating. The locations that received an overall suitable (green) rating were then selected as candidate sites which would undergo a ranking to determine the most optimal. The shortlisted locations were assigned a rating of suitable or unsuitable as described in Table 4.

Table 4. Description of suitability criteria.

Characteristic Suitability Criteria	Description	Suitable	Unsuitable
A - Coastal Topography	The shape of the coastline, type of coast (sandy or rocky), narrowness of the river mouth and landforms surrounding the exit including sand dunes, beaches, cliffs, and slopes.	Wide or canalized river mouth exit (concrete or natural), non-obstructive beach, or sandy shore.	Narrow river mouth; rocks obstructing exit; large beach obstructing exit.
B - River System and Fluvial Environment	The physical characteristics of the river including its width, terrain along its banks, tributaries, how it meanders and water quality. The fluvial environment describes the sedimentation and deposition around the river mouth which affect the river depth.	Wide enough river for sufficient discharge, stable banks, lower levels of pollution and sedimentation. Sandbars or sedimentation do not obstruct flow of river or block exit.	Narrow river; eroded banks; river meanders parallel to coast; poor river water quality. Presence of large sandbars or mudflats or sedimentation obstructing river mouth or resulting in shallow exit.
C - Existence of Estuary	Presence of an estuary at the river mouth, its ecosystem and whether it is protected.	Monitored or protected estuary.	Degraded estuary.
D - Proximity to Major Settlement	Whether a major city or town is nearby to benefit from potential water supply.	Major town or city nearby.	Major town or city far away or uninhabited land.
E - Mean Annual Runoff	The volume of runoff per year at the mouth of the river.	Less than 25 (mm/annum for each 1 x 1 minute grid cell)	Greater than 25 (mm/annum for each 1 x 1 minute grid cell)

The data collected for each candidate site included river catchment size, the sub-catchment codes around the river mouth (WR2012), the stream gauge station nearest to the river mouth (WR2012) as

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well as the river length. The mean annual precipitation for each catchment was found using Cape Farm Mapper and the WR2012 Water Management Area Mean Annual Precipitation maps for comparison. The mean annual runoff of the sub-catchments around the river mouth from Cape Farm Mapper and the naturalized mean annual runoff from the WR2012 WMA Runoff maps were obtained for comparison. Finally, water quality data in the form of Total Dissolved Solids (TDS) concentrations near the river mouth were collected from the WR2012 WMA TDS map. The quantitative data collected for each candidate site as well as the qualitative characteristic suitability ratings, evaluated using the mapping tools, were used to rank the selected candidate sites from most suitable to least suitable. Through the process of elimination, river mouth locations were disqualified immediately if the river was non-perennial, seasonal or completely obstructed from meeting the ocean.

3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn. A total of 25 potential sites for coastal reservoirs were identified on the South African shoreline as shown in Table 5. Based on suitability criteria described in Table 4, the sites were assessed and assigned ranking of suitable or unsuitable as presented in Table 5.

Table 5. Shortlisted rivers and suitability ratings.

	River Name	Characteristic Suitability Ratings					
		A	B	C	D	E	Rank
1	Orange River	1	1	1	1	1	1
2	Olifants River	2	2	2	2	2	2
3	Berg River	3	3	3	3	3	3
4	Hout Bay River	4	4	4	4	4	4
5	Salt River	5	5	5	5	5	5
6	Diep River	6	6	6	6	6	6
7	Eeerste River	7	7	7	7	7	7
8	Lourens River	8	8	8	8	8	8
9	Onrus River	9	9	9	9	9	9
10	Heuningnes River	10	10	10	10	10	10
11	Breede River	11	11	11	11	11	11
12	Duiwenhoks	12	12	12	12	12	12
13	Goukou River, Still Bay	13	13	13	13	13	13
14	Gourits River	14	14	14	14	14	14
15	Hartenbos River	15	15	15	15	15	15
16	Knysna River	16	16	16	16	16	16
17	Bloukrans River	17	17	17	17	17	17
18	Kowie River	18	18	18	18	18	18
19	Buffalo River	19	19	19	19	19	19
20	Gamtoos River	20	20	20	20	20	20
21	Port of Durban	21	21	21	21	21	21
22	Tugela River	22	22	22	22	22	22
23	Port of Richards Bay	23	23	23	23	23	23
24	Mfolozi River	24	24	24	24	24	24
25	Limpopo River	25	25	25	25	25	25

In the assessment, potential rivers such as the Olifants were given an overall unsuitable rating (red) since it flows into a major estuary surrounded by wetlands. Other negative factors included narrow and shallow mouth due to the extent of the sand bars, beaches, and sedimentation.

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Additionally, with a generally low mean annual runoff, the volume of stormwater runoff was relatively low compared to other sites. Finally, the nine rivers listed in Table 6 were selected as overall suitable candidate sites. Based on international best practice and exemplars worldwide, it is evident that these locations have many of the qualitative characteristics that are optimal for construction of a second-generation coastal reservoir for stormwater harvesting. As presented in Table 6 with assigned color coding indicating suitability, the nine candidate sites include: the Orange River, Berg River, Lourens River, Knysna River, Kowie River, Buffalo River, Port of Durban, Tugela/Thukela River and the Port of Richards Bay.

Table 6. Selected candidate sites.

	River Name	Province	Characteristic Suitability Ratings					
			A	B	C	D	E	Final rating
1	Orange River	Northern Cape						
2	Berg River	Western Cape						
3	Lourens River							
4	Knysna River							
5	Kowie River	Eastern Cape						
6	Buffalo River							
7	Port of Durban	KwaZulu Natal						
8	Tugela River							
9	Port of Richards Bay							

The volume of stormwater runoff harvested at the mouth of a river depends on the surface runoff and rainfall (Du Plessis, 2019). It was important to collect rainfall data for the regions in which the selected sites are situated. MAP and MAR data was collected from the ArcGIS online mapping tool, Cape Farm Mapper, and the Water Resources of South Africa 2012 Study (WR2012). The WR2012 data for the naturalized MAR was estimated by subtracting the effects of man-made infrastructure such as irrigation operations, dams, abstractions, and wastewater treatment plant return flows (Bailey & Pitman, 2016). The WR2012 data has been described as the mean annual runoff data most frequently used by the Department of Water and Sanitation (Bailey & Pitman, 2016). The data collected on all nine potential sites is summarized in Table 7. Stormwater runoff often carries multiple pollutants which can affect the quality of the river water into which it flows. It was crucial to consider the water quality in the proposed locations of the coastal reservoirs. River water quality can vary along its length from its tributaries to its exit at the mouth as it can be degraded by anthropogenic activities such as agriculture, industrial operations, deforestation and wetland destruction, urbanisation and other forms of human settlement that introduce pollutants into the waterways (Du Plessis, 2019). Total Dissolved Solids (TDS) is indicative of the different inorganic soluble salts i.e., salinity in the river water (DEAT, 2006). TDS data, measured in milligrams per litre, for each candidate site was collected from WR2012 TDS GIS map. This allowed for an evaluation of the water quality in the sub-catchments near the river mouth of each candidate site. The summary of results are provided in Tables 7. In the ranking, the study initially focused largely on mean annual runoff and mean annual precipitation values. Based on this criteria, Port of Richards Bay would have been the most optimal site as shown in Table 7.

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Table 7. Initial ranking of the nine candidate sites based on MAR and MAP.

Rank	River/Port Name	Discharge Ocean	Province	Catchment Size (km²)	MAP (mm/annum)	MAR (million m³/ annum)	TDS (mg/litre)
1st	Richards Bay	Indian	KwaZulu Natal	4 209	1000 - 1500	50 - 500	0 - 500
2nd	Thukela River		KwaZulu Natal	29 100	800 - 1500	50 - 500	0 - 500
3rd	Knysna River		Western Cape	480	600 - 800	100 - 500	0 - 500
4th	Lourens River		Western Cape	105	500 - 800	100 - 500	0 - 500
5th	Durban		KwaZulu Natal	264	800 - 1000	50 - 200	0 - 500
6th	Buffalo River		Eastern Cape	1 276	600 - 800	50 - 200	500 - 1000
7th	Kowie River		Eastern Cape	769	400 - 700	20 - 100	500 - 1000
8th	Berg River	Atlantic	Western Cape	8 980	200 - 300	2.5 - 10	500 - 1000
9th	Orange River		Northern Cape	32 6173	50 - 800	0 – 2.5	0 - 500

Port of Richards Bay site would potentially be able to harvest and store the highest quantity of stormwater in a coastal reservoir. However, it was important to consider qualitative characteristics of the sites that would determine the economic feasibility, purpose and needs as well as the highest benefit from the construction of a coastal reservoir for stormwater harvesting.

Thus, the following critical factors were considered:

i) It would be expensive and economically less feasible to halt operations at the busiest and most valuable commercial harbours, such as the Port of Richards Bay and Port of Durban, for the implementation of a coastal reservoir.

ii) Some sites such as the Lourens and Thukela Rivers had additional challenge that would be required to excavate the large sandbars obstructing the direct drainage of their rivers into the ocean.

iii) Certain sites, such as the Berg River, Kowie River and Buffalo River, have exits that have been canalized by breakwaters and flat adjacent topography. This would simplify the construction of a second-generation coastal reservoir such as the one proposed for the River Torrens in Adelaide, Australia, as discussed in the Literature Review.

iv) A site such as the Knysna River Estuary would require the construction of the dam walls and sluice gates inside of the lagoon, nearer to the Knysna River Mouth, to avoid saltwater intrusion. This would otherwise pose a challenge if the dam wall was constructed, further out, between the Knysna Heads.

v) The Berg River, for example, would benefit from the augmentation of the water supply for irrigation to the surrounding agricultural lands. The stormwater collected could decrease the water stress to which farming practices contribute, especially in the critical Western Cape Province.

vi) The harbors, on the other hand, could benefit from the recycling of ship ballast water using a coastal reservoir.

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vii) The numerous wastewater treatment plants of the Buffalo River Catchment could benefit from an augmented water supply for operations.
viii) The Orange River site, although catering to a crucial catchment of South Africa, is the most remote location and a large complex reticulation system would be required for water distribution.

The Lourens River was determined to be the least favorable site due to the sandbar excavation challenge coupled with the fact that its catchment is the smallest of the candidate sites. Although the Lourens River Estuary does not have the lowest MAP or MAR, its shallow exit would result in low volumes of water being collected in the coastal reservoir.

The Berg River has been recognized as a strong contender for the construction of a coastal reservoir for stormwater harvesting. The Berg River mouth has suitable topography with its canalized exit and flat beaches making it viable for a second-generation coastal reservoir. It has been indicated as having a relatively lower range of MAP (200 - 300 mm/annum) and subsequent MAR (less than 10 million m3/annum) across the catchment. However, its relatively larger catchment size, river length and multiple tributaries indicate that the Berg River Catchment could still provide an adequate total runoff for harvesting to augment the water supplied for irrigation. The final rankings are provided in Table 8.

Table 8. Rankings of the Nine Candidate Sites Considering all Factors.

Rank	**River/Port Name**	**Discharge point**	**Province**	**Catchment Size (km2)**	**MAP (mm/annum)**	**MAR (million m3/annum)**	**TDS (mg/litre)**
1st	Knysna River	Indian Ocean	Western Cape	480	600-800	100-500	0-500
2nd	Berg River	Atlantic Ocean	Western Cape	8 980	200-300	2,5-10	500-1000
3rd	Buffalo River	Indian Ocean	Eastern Cape	1 276	600-800	50-200	500-1000
4th	Kowie River	Indian Ocean	Eastern Cape	769	400-700	20-100	500-1000
5th	Thukela River	Indian Ocean	KwaZulu Natal	29 100	800-1500	50-500	0-500
6th	Orange River	Atlantic Ocean	Northern Cape	32 6173	50-800	0-2,5	0-500
7th	Port of Richards Bay	Indian Ocean	KwaZulu Natal	4 209	1000-1500	50-500	0-500
8th	Port of Durban	Indian Ocean	KwaZulu Natal	264	800-1000	50-200	0-500
9th	Lourens River	Indian Ocean	Western Cape	105	500-800	100-500	0-500

Finally, the Knysna River site was selected as the most suitable location. With the estuarine bay, Knysna River site has strikingly similar characteristics to the Marina Barrage of Singapore. The construction of a coastal reservoir inside the Knysna Bay has the potential to emulate the water augmentation success of the Marina Barrage project. In addition, the various land uses in the catchment could benefit from the supplementary water supply and tourism in the area could be boosted further. It is also evident that this site has one of the relatively higher MAPs (600 - 800 mm/annum) and MARs (100 - 500 million m^3/annum) in comparison to the rest of the sites, as shown in Table 9. Ultimately, the Knysna River site is the most optimal location for the construction of a coastal reservoir for stormwater harvesting, after considering all critical factors.

Conclusion

South Africa's reliance on its already existing traditional inland surface water sources is becoming increasingly risky in the face of rapid urbanisation and climate change. The near occurrence of 'Day Zero' in the city of Cape Town exposed how the current water supply and storage infrastructure, especially in the water stressed coastal provinces, are unsustainable and inadequate. Thus, more sustainable, and innovative solutions are required to construct a water secure future for the country. It was discussed how the complex water shortage issue is that of a lack of sufficient storage capacity as opposed to a lack of accessible water (Yang, 2019). Coastal reservoirs have the capability to augment water supply by harvesting and storing the vast volumes of mostly unutilized stormwater runoff that drain into the South African coast.

This study identified a list of potentially suitable locations for coastal reservoirs along the South African coastline. The candidate sites were analyzed qualitatively and quantitatively based on coastal topography, hydrology, climatology, fluvial environment, catchment size and river water quality. After the consideration of multiple additional critical factors, the rankings of the nine candidate sites were produced. The final selected sites in order of ranking included Knysna River, Berg River, Buffalo River, Kowie River, Thukela River, Orange River, Port of Richards Bay, Port of Durban, and Lourens River.

Ultimately, the Knysna River site was selected as the most optimal location for the construction of a coastal reservoir for stormwater harvesting due to its advantageous characteristics as an open estuarine bay. The augmented water supply could benefit the various land uses of the Knysna River Catchment as well as bolster further tourism as Singapore's Marina Barrage has demonstrated. With its location in the water stressed Western Cape Province, the Knysna River coastal reservoir has the potential to lead South Africa into a future of water security.

Author Contributions: Reitumetse Mokgele executed the research project including the development of a detailed literature review, the generation of a suitable methodology, the analysis of the data, the comparison and reporting of the results, the drafting of the research report, and the application of the feedback and revisions after each review by the corresponding author. John Okedi ORCID – (https://orcid.org/0000-0001-7707-2721) proposed the research topic, managed, and supervised the study, assisted in the paper writing, formatted the paper for submission and is the corresponding author.

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