Net-Positive Water Systems for Schools in Drought-Stricken Areas

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Abstract
In many areas of the world, climate change is leading to higher temperatures and water scarcity. At the same time, rapid urbanisation is increasing the demand for existing water resources. As a result in many drought-stricken areas, water costs have rapidly increased and supplies are becoming more unreliable. Schools in drought-stricken areas are particularly vulnerable. Limited resources mean that schools struggle to pay additional costs for water. Health risks also mean that schools have to close when there is no water. Closing schools significantly affects the quality of education as teaching is disrupted and learning time is lost. It is, therefore, important to find alternative affordable and reliable water solutions for schools in drought-stricken areas. Rainwater harvesting offers a potential solution but there is limited research and guidance on how these systems work at schools. This paper addresses this gap by investigating whether a rainwater harvesting system can be developed that would enable schools to become more resilient to water scarcity and outages. Modelling carried out indicates that a rainwater harvesting system has the potential of generating sufficient water to exceed the water needs of the school and therefore enables it to be water net-positive. The study shows that the business case for rainwater harvesting appears weak where there is a reliable local municipal water supply. However, this changes when schools are faced with punitive drought tariffs and increasing water outages which force closures.

Keywords
Schools, rainwater harvesting, net-positive water systems

1 Introduction

Climate change is leading to the increased occurrence of droughts and water scarcity in South Africa. Rapid urbanisation has meant that there is increasing pressure on existing systems and municipal water supplies are becoming increasingly unreliable. This can have a devasting effect on schools that have to close as they require water for drinking, cleaning and flushing toilets. Unplanned school closures disrupt teaching schedules and valuable learning time is lost, negatively affecting the quality of education. To avoid deteriorating education outcomes it is important to identify alternative reliable and affordable water supplies. One option is a rainwater harvesting system that captures rainwater from roofs and hard surfaces when it rains and stores this. Water captured in this way is then available for drinking, cleaning and flushing toilets. While the approach appears promising, limited research on school rainwater harvesting systems has been carried out (Sturm, *et al.,* 2009).

This paper addresses this gap by presenting a case study of a school in a drought-stricken area of South Africa. Analysis of the school is carried out and rainwater harvesting systems are modelled to investigate potential impacts and applicability of the approach. The study aims to address the following questions:

- What are the patterns of water use in the school?
- Can a rainwater harvesting water system meet the water needs of the school?
- How financially feasible is a rainwater harvesting system at the school?

2 Water, Climate Change, Schools and Rainwater Harvesting Systems

Water use is increasing at twice the rate of population growth, and it is estimated that 450 million people in 29 countries suffer from water shortages (UNEP, 2008; UN-Water, 2019). In South Africa, rapid urban growth is increasing demands on existing water systems (South African Cities Network, 2014). Available capacity is rapidly being used and an increasing number of towns in South Africa have water requirements that exceed availability (Department of Water Affairs, 2013).

Climate change is exacerbating this situation (Muller, 2007; Department of Environmental Affairs, 2011). Higher temperatures are increasing demands on already stretched water systems and the more frequent droughts result in water shortages and outages (Englebrecht, 2017; UNEP, 2014). In many municipalities, ageing water delivery infrastructure has not always been maintained leading to significant losses of water through leakage (Wensley and Mackintosh, 2015; South African Cities Network, 2014; SAICE, 2011; Brikké and Vairavamoorthy, 2016). These factors have combined to result in increasingly unreliable water supplies in many areas.

Schools are particularly vulnerable to water shortages and unreliable supplies as they rely on water for drinking, cleaning and flushing toilets and outages can lead to school closure because of health concerns. Closing schools can have devastating knock-on effects as learning time is lost and exam results drop (Jasper, *et al.*, 2012).

Water shortages are also resulting in rapidly rising water costs as municipalities try to reduce water consumption by increasing tariffs. Schools with fixed government funding and limited fee income from parents find it difficult to absorb additional costs for water. It is therefore not only important to investigate ways of reducing the vulnerability of schools to water shortages, but also to make sure that solutions are affordable.

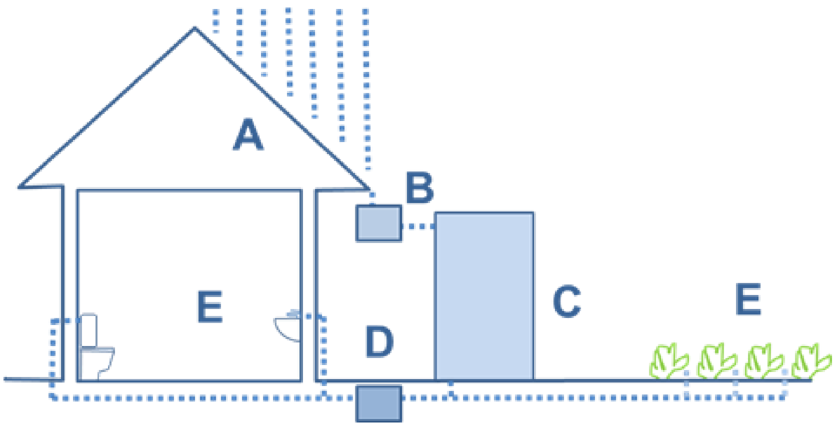

Figure 1. Elements of a rainwater harvesting system (author).

Rainwater harvesting systems capture rainwater for uses such as drinking, washing, irrigation and flushing toilets. Figure 1 shows the main elements of a rainwater harvesting system. Rainwater collection surfaces (A) harvest rainwater. Water is usually filtered near the collection surface (B) to remove debris and dust before being directed to a rainwater tank (C). Stored water may then be filtered (D) and used for drinking, cleaning and flushing toilets and irrigation (E).

Rainwater harvesting systems can be simple and consist of a small tank or can be complex and large and include pumps, header tanks, filtration and purification systems.

The methodology describes the analysis and modelling process that is used to design a simple rainwater harvesting system at a school. It shows how this can be evaluated in relation to water needs and financial viability.

3 Methodology

The methodology for the study aims to address the research questions identified in the introduction through analysis of a school in a drought-stricken area of South Africa. It consists of the following steps.

Firstly, data on the school is captured including photographs and plans. The population, schedule and water equipment in the school is also recorded to establish water requirements and water use patterns for the school over a year.

Secondly, an analysis is carried out to provide inputs for the design of the rainwater harvesting system. This includes an analysis of collection surfaces and the local climate. This establishes the volumes and patterns of water that can be captured by the rainwater harvesting system.

Thirdly, patterns of water consumption at the school are compared to patterns of rainwater harvested. This indicates whether harvested water meets requirements.

Finally, outline financial calculations are carried out to establish the cost of the rainwater harvesting system. Capital costs are compared to savings achieved through reduced, or avoided, use of water from the municipality to understand the business case for rainwater harvesting systems.

4 Case Study School

The case study school is near Loerie in the Eastern Cape, in South Africa. The area has experienced severe droughts and water rationing over the last 5 years. Figure 2 shows photographs of the school indicating the large roof areas available as collection surfaces.

Figure 2. Photographs of the Eastern Cape school.

Figure 3 shows a plan of the school with the main collection surfaces shown in dark grey (roofs). The roofs of the building are corrugated iron and can be used as the collection surfaces and have a runoff coefficient of 0.9. The collection surface area available for rainwater harvesting is 2,160 m^2 on a school site of 67,500m^2. The school has 202 learners and 8 full-time staff equivalents and therefore has 210 occupants on site.

Figure 3. A plan of the school indicating the site and the roof collection surface.

Figure 4 shows rainfall patterns for Loerie over a year. It shows that most rain falls in summer (November – March). It also shows that there is substantial rainfall in winter with a monthly rainfall of 60 to 70 mm for May, June, July, August and September.

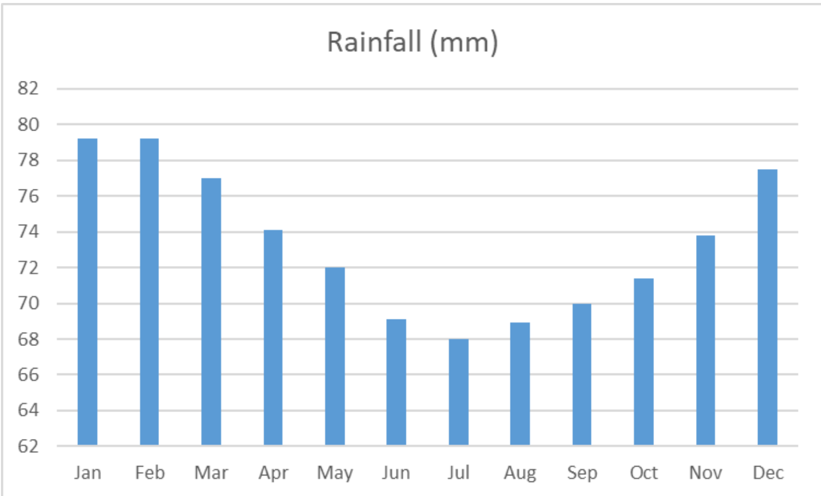

Figure 4. Monthly rainfall in Loerie, Eastern Cape.

Analysis of the site and rainfall can be used to design a rainwater harvesting system. Figure 5 shows that 1,695 kl of water can be harvested off the roofs of the school. Water required for the school to operate is calculated to be 15,975 litres per day and 134,300 litres per month based on the calculations in Figure 6.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Rainfall (mm)	79	79	77	74	72	69	68	69	70	71	74	78	880
Area	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	
Factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Harvested (litres)	152 539	152 539	148 302	142 717	138 672	133 087	130 968	132 701	134 820	137 516	142 139	149 265	1 695 265
Consumption (litres)	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	1 611 600
Difference (litres)	18 239	18 239	14 002	8 417	4 372	-1 213	-3 332	-1 599	520	3 216	7 839	14 965	83 665

Figure 5. Rainfall harvested, water used at the school under conventional conditions and the difference (author).

Reference to Figure 5 shows that the rainwater collected will be almost sufficient to meet all the water needs of the school throughout the year. The exceptions are June, July and August when an additional 1,000 to 3,300 litres per month are required. These figures are reflected by the negative (-ive) values in the ‘Difference’ row.

The small additional amount of water required for June, July, and August could be addressed by improving the efficiency of the toilets, urinals and wash hand basin taps. Calculations for conventional fittings and use are indicated on the left in Figure 6 and those of efficient fittings and use are shown on the right.

Female Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	4	9	36
WC (half flush)	0	0	0
Wash handbasin	4	1	4
Water used per person per day (litres)			**40**

Female Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	1	6	6
WC (half flush)	3	4.5	13.5
Wash handbasin	4	0.5	2
Water used per person per day (litres)			**21.5**

Male Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	1	9	9
Urinals	3	0.5	1.5
Wash handbasin	4	1	4
Water used per person per day (litres)			**14.5**

Male Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	1	6	6
Urinals	3	0.5	1.5
Wash handbasin	4	0.5	2
Water used per person per day (litres)			**9.5**

	Number	Consumption (litres)	Totals
Female Users	105	40	4 200
Male Users	105	14.5	1 523
Water used in the school per day (litres)			**5 723**

	Number	Consumption (litres)	Totals
Female Users	105	21.5	2 258
Male Users	105	9.5	998
Water used in the school per day (litres)			**3 255**

	Number	Consumption (litres)	Totals
Drinking water	210	2	420
Cleaning water	5	20	100
			520

	Number	Consumption (litres)	Totals
Drinking water	210	2	420
Cleaning water	5	20	100
			520

Water used in WCs, urinals and washhandbasins	5 723
Water used for drinking and cleaning	520
Daily water use in the school (litres)	6 715
Monthly water use in the school (litres)	134 300

Water used in WCs, urinals and washhandbasins	3 255
Water used for drinking and cleaning	520
Daily water use in the school (litres)	3 775
Monthly water use in the school (litres)	75 500

Figure 6. Water consumption in schools (conventional left, water-efficient right)(author).

Figure 7 shows that this intervention results in the rainwater harvesting volumes being substantially above requirements throughout the year. This is reflected in the large positive (+ive) values in the 'Difference" row. These positive values represent available water that could build a significant 'buffer' of stored water that would enable the school to be resilient to drier years when the rainfall was irregular and dropped below the average.

This arrangement would enable the building and water systems to be defined as net water positive. Net water positive buildings are defined in the following way:

'designed, constructed and operated to greatly reduce total water consumption, and then use harvested, recycled and reused water such that the amounts of water consumed is the same as the amounts of water that is produced (Net Zero), or if the water recycled/ produced is greater than the water consumed (Net Positive)' (GBCSA, 2017).

In this case, the volume of additional, net positive water could be substantial (790 kl) and can be shared with the local community if this is required because of water shortages or used to irrigate school gardens.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Rainfall (mm)	79	79	77	74	72	69	68	69	70	71	74	78	880
Area	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	
Factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Harvested (litres)	152 539	152 539	148 302	142 717	138 672	133 087	130 968	132 701	134 820	137 516	142 139	149 265	1 695 265
Consumption (litres)	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	906 000
Difference (litres)	77 039	77 039	72 802	67 217	63 172	57 587	55 468	57 201	59 320	62 016	66 639	73 765	789 265

Figure 7. Rainfall harvested, water used at the school under efficient conditions and the difference (author).

The data from Figure 7 can also be used to propose the size of rainwater harvesting tanks. The drought and irregular conditions suggest that at least 3 months of water supply should be stored. This provides a figure of about 210kl of water.

In the existing school, a simple way of providing this volume would be through the installation of 21 free-standing plastic tanks of 10,000 litres located close to collection surfaces. These would be connected to downpipes off roofs and placed on concrete stands. They would then be connected to bathrooms, drinking taps and kitchens and a pressure pump used to supply water. As water will be used for drinking an additional allowance should be made for filtration. The approximate cost of this system in South Africa Rand (ZAR) is indicated in figure 8. At the time of writing the exchange rate between the South African Rand and the United States Dollar was about15 Rand to the Dollar.

Component	Cost	Number	Totals
Tanks	10 000	21	210 000
Bases	2 000	21	42 000
Collection plumbling	1 000	21	21 000
Distribution plumbing	1 000	21	21 000
Drinking water filtration	2 000	3	6 000
Capital Cost			**300 000**

Figure 8. Capital costs of a rainwater harvesting system at the school in South African Rands (R).

Component	Volume (kl)	Months	Tariff (R/kl)	Monthly fixed charge	Annual saving (R)
Rainwater harvesting	75.50	12.00	14.08	149.70	14,552.88

Figure 9. Annual savings generated by a rainwater harvesting system at the school.

Component	Capital Cost	Annual saving (R)	Payback period (Years)
Rainwater harvesting	300,000	14,553	21

Figure 10. Payback period of a rainwater harvesting system at the school.

Figure 9 shows that the proposed system could achieve annual savings of around R14,552, based on a water tariff of 14.08/kl and a monthly fixed charge of R149.70 (Kouga, 2021). This would be slightly reduced as the cost of maintenance and electricity for pumps are not reflected. Using this level of savings would provide a payback period of 21 years, as shown in Figure 10.

The above calculations are based on a normal year, where emergency or punitive tariffs have not been applied. Punitive tariffs are much higher than normal tariffs, for instance, the City of Cape Town's emergency tariff for schools is R41.67 per kl for water (City of Cape Town, 2021). If there are severe shortages and water tankers are required, costs increase further. For instance, the rate for the delivery of water is R1,576 per kl in Buffalo City in the Eastern Cape (Buffalo City, 2021). Under these types of conditions, payback periods for the rainwater harvesting system drop markedly and would be under 10 years.

5 Discussion

The results indicate that a rainwater harvesting system could enable the school to be self-sufficient in water. This, however, requires highly efficient fittings and careful use of water. Conventional fittings and use of water result in water consumption levels of 6,715 litres per day, or about 32 litres per person per day compared to the 3,775 litres per day or 18 litres per person per day for efficient fittings and water use. The figures for efficient use are similar to consumption rates of 20 litres per person per day used in dry areas such as Namibia (Sturm, *et al.,* 2009).

In the proposed system, rainwater is captured off roofs and if you divide the catchment area (2,140 m^2) by the number of occupants (210), there is about $10m^2$ of catchment area per occupant. The rainwater harvesting system captures significant amounts of water from these surfaces and stores this. The entire volume of storage divided by the number of occupants indicates that 1,000 litres are harvested and stored per person. This amount may be reduced through modelling at a finer grain, for instance, through the use of daily rainfall data. Care however should be taken to ensure that a buffer is retained in case of prolonged dry periods.

A review of the findings indicates that for a school to be water neutral or water positive, in this climate zone the following factors must be in place. Firstly, water consumption at the school must not exceed 20 litres per occupant per day. Secondly, there must be at least $10m^2$ of roof catchment area per occupant. Thirdly, there must be at least 1,000 litres of rainwater harvesting storage volume. The relationship between these factors is shown in Figure 11.

Number of occupants	Maximum daily consumption of water (Litres)	Minimum area of catchment surface (m2)	Minimum rainwater harvesting volume (litres)
1	20	10	1000

Figure 11. Relationship between occupants, water consumption, catchment area and rainwater harvesting volume

A review of rainfall patterns in other areas of South Africa show that dry seasons can be more severe and longer in other areas. For instance, Figure 12 shows that there are 5 months of the year with less than 20mm of rain in areas like Pretoria, in the North of South Africa. This means that levels of stored water must be significantly higher and there may be insufficient area for a roof-based rainwater harvesting system to provide for all the water needs at the school.

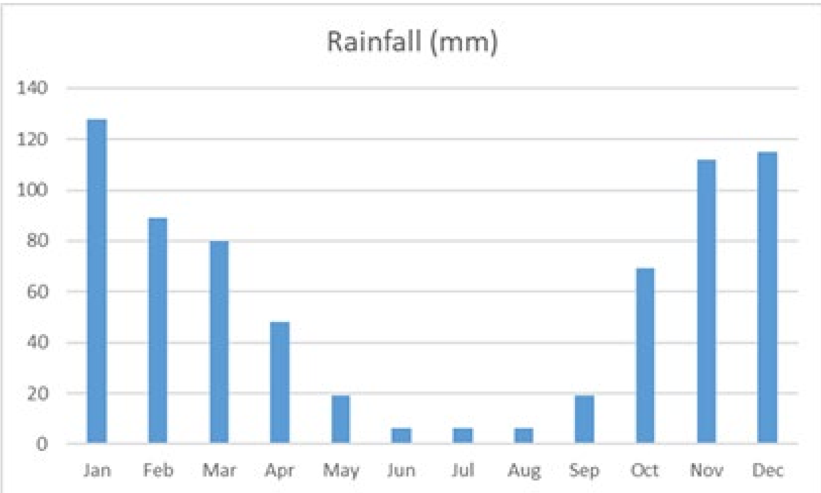

Figure 12. Monthly rainfall in Pretoria, South Africa

Financial analysis shows that the payback period for the proposed rainwater harvesting system is over 21 years. Other studies indicate that around 20 years has been the norm for rainwater harvesting systems (Imteaz *et al.,* 2011; Roebuck *et al.,* 2011). Roebuck *et al.,* (2011) confirm that this type of payback period does not make business sense where there are reliable municipal water supplies.

However, where water supplies are unreliable, an off-grid rainwater harvesting system provides significant value by enabling business continuity and avoiding disruption in times of water shortages. Emergency or punitive tariffs during drought periods also have a marked effect on the business case for rainwater harvesting systems enabling this to drop to less than 10 years.

The most valuable impact of net positive water systems is that education disruption and school closures are avoided This precludes a wide range of potential negative impacts associated with poor education that would impact learners, parents, and the local economy.

Amos *et al.* (2016) suggest that rainwater harvesting systems in developing countries can have benefits that are often ignored in developed countries such as increased flexibility during water restrictions and the creation of local jobs. Rahman *et al*., (2012) argue that benefits such as business continuity provide a strong rationale for rainwater harvesting systems to be subsidised.

6 Conclusions and Recommendations

The study investigates the potential impacts and feasibility of installing a rainwater harvesting system in a school in a drought-stricken area of South Africa. Findings from the study indicate that rainwater harvesting systems can be easily designed and installed cost-effectively at a school. This system harvests water from roofs of school buildings, stores this water in a system of tanks and uses this water for drinking, cleaning, and flushing toilets.

Modelling based on conventional fittings and water use indicates that water consumption per person per day under conventional conditions is approximately 32 litres and that a roof-based rainwater harvesting system in the selected climate will not meet this need. However, if more efficient systems and careful use of water are applied to reduce water consumption to 18 litres per person per day, it appears that a roof-based rainwater harvesting system can meet all the water needs of the school and result in the school becoming water net-positive.

An analysis of the financial viability of the system indicates that the payback period is approximately 20 years. This suggests that there is not a strong business case for a rainwater harvesting system in schools where there is a reliable, affordable municipal supply. This however changes when water supplies become unreliable and result in the school having to close. In this situation, the case for rainwater harvesting systems becomes much stronger as it enables schools to remain open and continue to achieve their main function which is to deliver good quality education.

The study shows that it is possible to develop a simple roof-based rainwater harvesting system for a school in a drought-stricken area that meets all its water needs. This is a significant finding as it presents an important way of avoiding disruption and closures of schools that can negatively affect educational outcomes. It is recommended that further research in this area be carried out to develop guidelines for the development of rainwater harvesting systems for schools in drought-stricken areas.

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