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Designing School Rainwater Harvesting Systems in Water-Scarce Developing Countries

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Abstract

Many schools in water-scarce developing countries have insufficient and unreliable water supplies. This is being exacerbated by climate change and aging and poorly maintained water infrastructure. A lack of clean water increases the risks of diarrhoeal disease and concerns about health can result in school closures, affecting education outcomes as valuable teaching and learning time is lost. In these situations, rainwater harvesting systems can provide an alternative clean water supply that enables schools to continue to operate safely. However, there is limited research and guidance on school rainwater harvesting systems. In addition, there are also misconceptions about rainwater harvesting. These include that rainwater harvesting systems cannot provide sufficient water to meet needs, water produced is dirty and systems are unaffordable. This chapter addresses this context by showing how rainwater harvesting can provide sufficient, and affordable water supplies to schools in water-scarce areas. It may be of interest to school governing bodies, teachers, design professionals and government officials who want to develop rainwater harvesting systems in schools.

Introduction

Hotter temperatures, longer dry spells and an increasing number of droughts have led to water scarcity in many areas of the world (Diedhiou et al. 2018; Makki 2015; IPCC 2022). This situation is getting worse and UNESCO (2019) projects that two-thirds of the world's population will experience water scarcity for at least one month of the year and there will be a 40 % gap between water demand and supply by 2030. In developing countries, this situation is aggravated by rapid urbanization and a lack of capacity and resources to scale up existing water supply systems (UN-Habitat and IHS-Erasmus University Rotterdam 2018). Existing infrastructure that is already struggling to meet demand, may also not be adequately maintained resulting in high levels of leakage, breakdowns, and an increasingly unreliable water supply (Wensley and Mackintosh, 2015).

Eighty-eight per cent of deaths caused by diarrheal disease are attributed to a lack of water and inadequate sanitation (WHO 2009). Nearly all these deaths are in developing countries and 84% are children. Inadequate water supplies and poor sanitation is one of the main causes of child mortality and it is estimated that 443 million school days are lost per year from water-related illnesses (UNDP 2006). Schools need water for drinking, cleaning, and flushing toilets (if they have water-borne sanitation) (Jasper and Bartram 2012). A lack of water usually means schools must close and children are sent home. Teaching and learning are disrupted leading to poorer educational achievement and outcomes (Harbison and Hanushek 1992; White 2004). It is therefore important that schools that have unreliable water supplies or water shortages investigate how water supplies can be made more reliable, sufficient, and resilient.

One of the most effective ways of achieving ways of developing a more resilient water supply is through onsite water storage and rainwater harvesting (Thuy et al. 2019). Onsite water storage enable schools to operate when there are outages from municipal supplies. This storage can be fed from municipal systems, rainwater harvesting, or both. As rainwater is effectively free, schools can benefit from reduced costs. Rainwater harvesting systems reduce the reliance on external water supplies and enable schools to use their supply to supplement or meet their requirements. In areas with reliable local water supply systems, rainwater harvesting systems may provide a supplementary or backup system whereas, in drought-stricken areas, rainwater harvesting systems may be the sole supply of water (Cook, et al. 2013).

Internationally, there is an increasing interest in rainwater harvesting as a way of building more resilient water systems in cities and buildings. Rainwater harvesting systems can help address water shortages whilst avoiding the need to develop new large-scale water infrastructure. Ghaffarian Hoseini et al. (2016) point out that rainwater harvesting systems may be able to meet 80–90% of household water consumption globally. Steffen et al (2012) show how the widespread installation of rainwater harvesting systems in cities can be used to avoid the need to construct new water supply systems. However, despite the potential of rainwater harvesting systems, these have not been widely implemented.

Given the benefits of rainwater harvesting systems and the disruption to education caused by water shortages, it is surprising that these systems are not more widely used in schools. The slow adoption of rainwater harvesting systems may be due to the following factors. First, rainwater harvesting may be considered expensive (Rahman et al. 2014; Campisano et al, 2017; Akuffobea-Essilfie et al. 2020). Second, there are widely held concerns about the quality of water from rainwater harvesting systems (Rahman et al. 2014; Fewtrell and Kay 2007). Third, a lack of awareness and information may hinder the adoption of rainwater harvesting systems as a means of tackling local water shortages (Akuffobea-Essilfie et al. 2020; Sheikh 2020). Fourth, concerns about regulations and maintenance can also be an obstacle to implementation (Campisano et al. 2017).

However, once rainwater harvesting systems are installed, they appear to be well-liked and supported by users (Gould1997; Fuentes-Galván et al. 2018; Sunkemo and Essa 2022). Regulations and incentives supportive of rainwater harvesting have also been found to be valuable in encouraging greater adoption of the technology (Domenech and Saurí 2011). In addition to the supply of water, rainwater harvesting systems can provide other benefits, such as being a useful teaching and learning resource in schools (Kerlin et al., 2015; Campisano et al., 2017).

This chapter aims to contribute to improved knowledge about rainwater harvesting systems in schools in water scarce areas. It addresses misconceptions about rainwater harvesting by showing how rainwater harvesting systems work and can contribute to water resilience in schools. A case study is undertaken to investigate the design of rainwater harvesting systems in school in water scarce areas. The case study is used to address questions about the sufficiency and affordability of rainwater harvesting systems. Analysis of the results from the case study show that rainwater harvesting systems can be developed that are affordable and provide sufficient water to meet a school’s needs. Findings from the study are important as they indicate that implementing rainwater harvesting systems could help avoid disruption to education from water shortages and therefore make a valuable contribution to sustainable development in water-scarce countries.

School rainwater harvesting

In most respects, rainwater harvesting systems in schools are similar to systems in commercial and domestic buildings, however, they are different in the following ways. Schools tend to be located on larger sites which have a range of buildings with roof surfaces that can be used for rainwater collection. They also usually have hard surfaces, such as basketball courts that can also be used for rainwater collection. They tend to have larger sites with available space that can be used for rainwater tanks. Schools also have varied populations over a year, as the school is occupied during term time and then empty during holiday periods. Within term times, occupancy can also vary widely and numbers at a school may double, for instance, during a large sporting event. These factors are considered in the different elements of a school rainwater harvesting system that are described next.

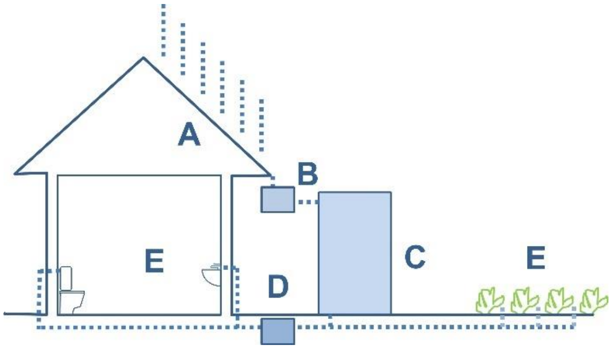


Fig. 1. A school rainwater harvesting system (Diagram by the author)

The elements of a school rainwater harvesting system are shown in Figure 1. These are as follows:

A. Rainwater collection surface
B. Filtration system
C. Rainwater tanks
D. Additional filtration (if necessary)
E. Water uses, including drinking, washing, cleaning, flushing toilets and irrigation

Rainwater collection surfaces

Schools are usually good candidates for rainwater harvesting because of the large roof areas that can be used as collection areas to harvest rainwater. They also usually have sufficient additional spaces where rainwater harvesting tanks can be located. In addition, schools have significant water requirements associated with cleaning, irrigation and flushing toilets which can be readily met through rainwater harvesting.

The main collection surface in schools used for harvesting rain are the roofs of buildings. However, schools may also have hard external surfaces such as external assembly areas, recreational yards and tennis, basketball and netball courts that can be used. Roofs work for rainwater harvesting as water can be gravity-fed into tanks located below them. Water harvested off yards and sports courts at ground level must be directed to sumps and underground tanks or pumped up to tanks. In general, hard surfaces at ground level may receive more dust and detritus which makes water from these surfaces more difficult to clean.

The quality and quantity of rainwater harvested off surfaces is dependent on the material of the collection surface and the extent to which it is exposed to dust and detritus that may affect the quality of runoff. The amount of runoff is dependent on the runoff coefficient of the surface. This is shown in Table 1 and represents the proportion of water harvested off a surface. Thus, from Table 1, one would expect to harvest 90% of the water from a corrugated roof, and between 70 and 95% from a pavement or a road.

Table 1. Runoff coefficients (Farreny et al. 2020; Goel 2011).

Roof type/surface	Runoff Coefficient
Sloping corrugated metal roof sheeting and tiled roofing	0.9
Flat concrete roofing with gravel topping	0.8
Level cement surfaces, such as driveways and tennis courts	0.8
Pavements and roads	0.70–0.95
Parks and pastures	0.05–0.30

Filtration system

To avoid dust and detritus from polluting rainwater harvesting, filters are normally included between the collection surface and rainwater tanks. These include ‘first-flush’ filters designed to remove dust and detritus that flow into the system with the first rains. To ensure that these filters are effective, they must be well-designed and regularly maintained. Therefore, schools should ensure these are regularly inspected and cleaned as necessary. In general, losses from filters are low unless they are poorly maintained and blocked. First flush filters can result in no flows to rainwater tanks if rainfall is very light, as initial water flows are diverted to remove dirt on collection surfaces.

Rainwater tanks

Once filtered, rain is stored in rainwater tanks. In the simplest systems, these tanks are placed directly under gutters and downpipes and are associated with the collection surface of a particular building. This arrangement is easy to construct and maintain. More complex systems direct water to central large tanks but are more difficult to construct and manage. Rainwater tanks are usually the most expensive element of a rainwater harvesting system so care should be taken that these are correctly specified and sized.

Simple rainwater harvesting tanks are usually made of plastic and steel which are located on a concrete base and vary from 2,000 to 20,000 litres. Large rainwater tanks may be constructed of concrete, be centrally located, be underground and fed from multiple collection surfaces and be over 20,000 litres. In schools, it is important that tanks cannot be accessed by students but are designed to be easily inspected and cared for by maintenance staff. Rainwater tanks should include an indicator system that enables water volumes to be readily ascertained and managed.

The sizing of rainwater tanks is complex, and care should be taken not to rely on simple calculations which may oversize rainwater tanks. Instead, modelling flows into rainwater harvesting systems and flows out through use, over a year should be used to calculate the size of a tank. Examples of this are shown in the case study presented later in the chapter.

Filters

Where quality of water is important, for instance, for drinking, an additional filter may be included between the tank and the use of the water. If water will be used for drinking, water mustn't be polluted or dirty. This is achieved by ensuring that collection surfaces are clean, and any detritus or dirt is removed from runoff. The quality of water and its suitability for drinking can also be confirmed through tests. Water labs can test water for contaminants such as bacteria and heavy metals to ensure that water is safe for drinking.

Water uses

Rainwater in schools can be used for cleaning such as washing cooking utensils and equipment and mopping floors. It may also be used for flushing toilets and urinals as well as for irrigation of sports fields, food gardens and ornamental beds. Rainwater can also be used for drinking if of a suitable quality (see Filters, above). Where harvested rainwater is considered not suitable for drinking, this should be clearly labelled as "Non-potable water – not suitable for drinking".

Table 2 shows volumes of water used for different activities in schools. Levels of consumption depend on the efficiency of the equipment. For instance, inefficient toilets and urinals can lead to levels of water consumption of over 30 litres per occupant, while this can be less than 15 litres in a school with efficient systems (Gibberd, 2021).

Table 2. Water uses in schools (Gibberd 2021)

Water use per occupant per occupied school day	Litres
Drinking water*	2 - 3
Cleaning and washing*	2 - 6
Flushing toilets and urinals**	15 – 30
Irrigation, topping up swimming pools, and other uses**	10 – 30
Overall (Litres per student per day)	**10 – 70**

*Applicable to all schools

**Not applicable to all schools, as some school may not have water-based sanitation, irrigation and swimming pools.

Table 2 also shows that water use in schools can vary widely. Where water is extremely scarce, water use may only be 5-10 litres per person. This is achieved by using water for drinking and some cleaning, with all other uses of water such as toilet flushing, being avoided. In schools, with a plentiful supply of water, water use may be over 70 litres per person per day, as water is not only used for drinking and cleaning, but also for flushing toilets, irrigation and topping up swimming pools.

Water consumption figures of between 10 and 30 litres per student per day are common in schools in water-scarce countries. For instance, Nunes et al (2019) indicate that water consumption in schools in Brazil ranges from 11 and 18 litres per student per day. Figures are similar in Spain where figures are between 4 and 16 litres per student per day (Morote et al. 2020). In Italy, water use per student per day is between 10 and 70 litres, with lower figures in primary schools and higher figures in secondary schools where there may be irrigated sports fields (Farina et al. 2011).

Designing school rainwater harvesting systems

The first step in designing a rainwater harvesting system is to ensure that water is used efficiently in the school, as this helps to reduce the size of the rainwater harvesting system required. A review of Table 2 indicates that savings are unlikely to be achieved through reducing drinking water and cleaning water consumption. However, considerable savings can be achieved through more efficient fittings. For instance, water consumption for toilets can be cut in half by replacing inefficient 9-litre WC flush cisterns with efficient 4.5 litre flush cisterns and 2-litre urinal flush mechanisms with 1-litre flush mechanisms.

Even greater savings can be achieved by using very water-efficient sanitation systems such as aqua-privy, and dry or composting toilet systems. Specifying these systems can reduce water consumption at schools by over 50%. Similarly, irrigation and the topping up of swimming pools and ponds can be reduced. Where necessary, water use can be minimised by through xeriscape landscaping (an approach that eliminates the need for irrigation) and by removing swimming and other pools.

Rainfall patterns

Local rainfall patterns are an important input for the design of a rainwater harvesting system. Rainfall data can be obtained at a range of frequencies, including hourly, daily, and monthly rainfall. Monthly rainfall data is the most readily available and is shown as mm per month, as indicated in Table 3 (Climate Data 2023).

A review of monthly data can be used to identify the type of rainwater harvesting system that will be required. Where rainfall varies widely over the year, with several months with limited rainfall larger rainwater tanks and collection surfaces will be required to meet shortfalls during the dry season. Where rainfall is constant throughout the year, a much smaller system will suffice.

Table 3. Rainfall and occupancy days over a year (Climate Data 2023).

Month	Rainfall (mm/month)	Occupancy days
Jan	49	10
Feb	53	20
Mar	56	23
Apr	47	13
May	28	23
Jun	27	17
Jul	28	10
Aug	43	23
Sep	37	20
Oct	53	16
Nov	61	22
Dec	51	9
Totals	**533**	**206**

Occupancy

The design of rainwater harvesting systems can be optimised by understanding patterns of water use in schools. This includes identifying occupants of the school and when they are at the school.

School occupants include students, teachers, and administrative and maintenance staff. They may also include temporary occupants such as parents who come for an evening event, or a team from another school who may come for a sporting event. School terms usually mean that there are prolonged periods when the school may have very few occupants (i.e., during holidays).

Thus, while a residential building may be occupied for 365 days of the year, schools may only be occupied for 206 days of the year (the school terms) as shown in Table 3. Understanding these patterns of occupancy is valuable for ensuring systems are correctly sized. School rainwater harvesting systems may be over specified if they are sized for full occupancy throughout the year and therefore will be unnecessarily expensive.

Ideally, patterns of occupancy of the building should align with rainfall patterns to ensure that water is available for use when people are at the school rather than having to provide extensive additional storage of water to cater for occupancy during dry periods. When this alignment happens, rainwater harvesting systems can be much smaller and therefore more affordable. Thus, where school calendars can be flexible, aligning occupancies with rainfall patterns could be used to develop more affordable and resilient rainwater harvesting systems.

Case study

A case study of a rainwater harvesting system is undertaken to investigate the affordability and sufficiency of these systems for meeting a school's water needs in a water scarce area. The case study is near Loerie in the Eastern Cape, in South Africa. South Africa is classified as having an "extremely high" baseline water stress (Kuzma et al. 2023). Baseline water stress measures the ratio of total water demand to available renewable water supplies. According to the Koppen Geiger climate classification, the case study site in the Eastern Cape is in an area classified as BsH, Arid, Stepp, Hot Arid (CSIR 2023).

Average monthly temperatures vary from 21.7 °C in February to 14.2 °C in July. The site currently has between 30-45 very hot days per year, with hot days being when maximum temperatures exceed 35°C (CSIR 2023a). As a result of climate change, average temperatures are projected to increase by 1-2°C by 2050. In addition, up to 10 additional very hot days relative to a baseline period of 1961–1990, are likely to be experienced (CSIR 2023a).

Annual average rainfall is 533 mm, and the driest month is June, with 27 mm. November has the highest rainfall with an average 61 mm (Table 3). Projections indicate that climate change will result in drier conditions and that a drop in annual rainfall of between 25 and 100mm by 2050 is expected relative to a baseline period 1961–1990 (CSIR 2023a). Over the last 8 years, the school site has experienced drought conditions and water restriction have been in place (Plaatjies 2023).

The case study school is shown in Figure 2. This shows large roof and yard areas available as collection surfaces. Figure 3 shows a plan of the school with the roof collection surfaces shown in dark grey. The roofs of the building are made of corrugated iron and have a runoff coefficient of 0.9 (Table 1). The roof collection surface area available for rainwater harvesting is 2,160 m^2 on a school site of 67,500 m^2. The school has a total of 210 occupants, with 202 being students and 8 full-time staff.

Figure 2. Photographs of the case study school (Photographs by the author).

Figure 3. A plan of the school indicating the site and the roof collection surface (Diagram by the author).

Methods and Materials

To develop and analyse an off-grid resilient water system that could supply sufficient water for a school in a water-scarce area the following steps were taken.

First, a brief for the water system is developed. The water restrictions of the last 8 years and worsening conditions projected in future (presented above) for the site indicate that the key objective for the design of the water system is to achieve an off-grid resilient water supply that provides sufficient water to enable the school to operate despite local shortages.

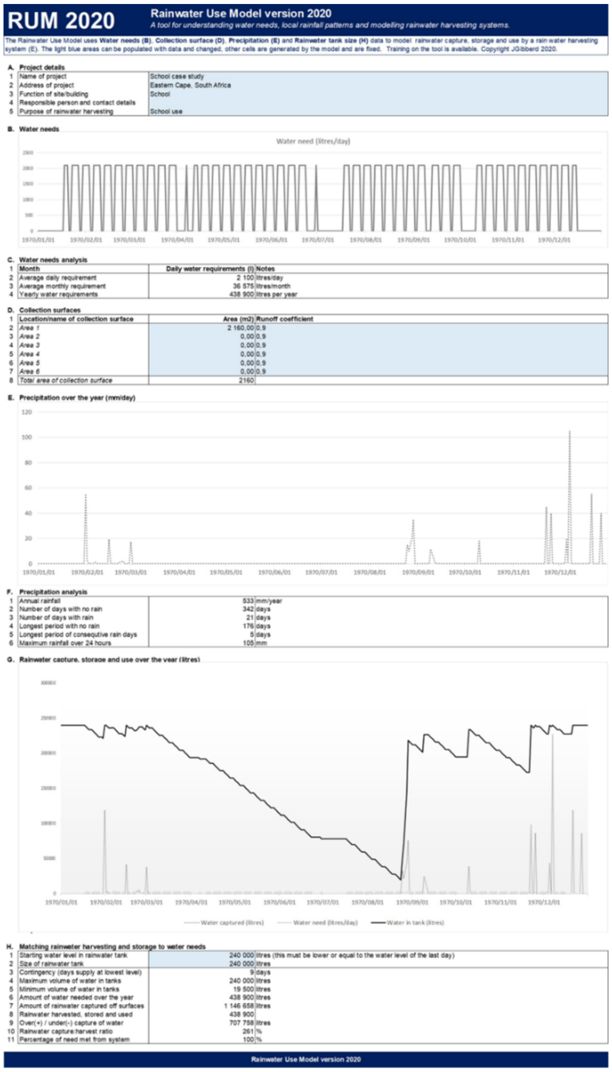
Second, a suitable rainwater harvesting modelling tool that could simulate water consumption and rainwater harvesting water volumes over a year was selected. The Rainwater Use Model (RUM), shown in Figure 4, met this specification and was chosen. The Rainwater Use Model was developed by Gibberd (2020) and has been applied to a range of different building types.

Third, as the RUM uses daily rainfall patterns, appropriate local climate data were identified. Daily annual rainfall patterns were reviewed to identify a year when annual rainfall was similar to the average rainfall of 533mm (Table 3). The year selected had an annual rainfall of 531mm and is entered into the RUM and shown in Figure 4, Graph E.

Fourth, levels of water consumption are established for the school. To ensure that the system would be resilient, it was decided to minimise water consumption at the school and a volume of 10 litres per person was allowed. This covers drinking water, basic hygiene practices and some cleaning and washing and is based on the figures in Table 2. Since it does not allow for flushing toilets, dry sanitation is required. The level of consumption is then multiplied by the number of occupants and the days the school is occupied (days of the school term) to generate Graph B, in Figure 4. Days the school is occupied is taken from the school calendar shown in Table 3. This shows that there are periods when there is no water consumption at the school. This is over weekends and during holidays.

Fifth, rainfall is multiplied by the area of the collection surface (2,160m^2) and by the runoff coefficient (0.9) to generate rainwater harvesting volumes per day over the year. This is shown in Graph G, in Figure 4.

Sixth, water tank sizes are entered into the RUM on a trial-and-error basis until the required performance is achieved (in this case off-grid performance). Figure 4 shows that a volume of 240,000 litres achieves sufficient storage for the rainwater harvesting system to fully meet the water needs of the school. The yellow line in Graph G in Figure 4, shows rainwater volumes in the tanks over a year.



RUM 2020 **Rainwater Use Model version 2020**

A tool for understanding water needs, local rainfall patterns and modelling rainwater harvesting systems.

The Rainwater Use Model uses **Water needs (B)**, **Collection surface (D)**, **Precipitation (E)** and **Rainwater tank size (H)** data to model rainwater capture, storage and use by a rain water harvesting system (E). The light blue areas can be populated with data and changed, other cells are generated by the model and are fixed. Training on the tool is available. Copyright JGibberd 2020.

A. Project details

1	Name of project	School case study
2	Address of project	Eastern Cape, South Africa
3	Function of site/building	School
4	Responsible person and contact details	
5	Purpose of rainwater harvesting	School use

B. Water needs

C. Water needs analysis

1	Month	Daily water requirements (l)	Notes
2	Average daily requirement	2 100	litres/day
3	Average monthly requirement	36 575	litres/month
4	Yearly water requirements	438 900	litres per year

D. Collection surfaces

1	Location/name of collection surface	Area (m2)	Runoff coefficient
2	*Area 1*	2 160,00	0,9
3	*Area 2*	0,00	0,9
4	*Area 3*	0,00	0,9
5	*Area 4*	0,00	0,9
6	*Area 5*	0,00	0,9
7	*Area 6*	0,00	0,9
8	*Total area of collection surface*	2160	

E. Precipitation over the year (mm/day)

F. Precipitation analysis

1	Annual rainfall	533	mm/year
2	Number of days with no rain	342	days
3	Number of days with rain	21	days
4	Longest period with no rain	176	days
5	Longest period of consequtive rain days	5	days
6	Maximum rainfall over 24 hours	105	mm

G. Rainwater capture, storage and use over the year (litres)

H. Matching rainwater harvesting and storage to water needs

1	Starting water level in rainwater tank	240 000	litres (this must be lower or equal to the water level of the last day)
2	Size of rainwater tank	240 000	litres
3	Contingency (days supply at lowest level)	9	days
4	Maximum volume of water in tanks	240 000	litres
5	Minimum volume of water in tanks	19 500	litres
6	Amount of water needed over the year	438 900	litres
7	Amount of rainwater captured off surfaces	1 146 658	litres
8	Rainwater harvested, stored and used	438 900	
9	Over(+) / under(-) capture of water	707 758	litres
10	Rainwater capture:harvest ratio	261	%
11	Percentage of need met from system	100	%

Rainwater Use Model version 2020

Figure 4. Rainwater Use Model (RUM) results for the case study school (Reports by the author)

Results

Completing the steps above enables water consumption, rainwater harvesting and rainwater tank volumes to be simulated over a year and this is shown in Graph G of Figure 4.

Graph G shows how at the beginning of the year, the rainwater tanks are full and hold 240,000 litres (the yellow line). However, ongoing consumption (the orange line) and lack of rainfall (the blue line), mean that volumes drop steadily. There is some respite in July when water is not used as the school is on holiday, and therefore rainwater tank volumes remain steady. However, after this, volumes continue to drop and only recover in September when there is rainfall.

At the lowest point, water levels in the tanks are only sufficient for a further 9 days of operation before water will run out. This point however is not reached, as there is rainfall and tanks are rapidly filled by several short periods of heavy rainfall.

The results prompt several additional questions about the design of the rainwater harvesting system. These are:

- How much would the rainwater harvesting system cost?
- How could you increase the contingency or safety buffer of the system to help ensure that water would not run out in a very dry year?
- If there was a decision to have water-borne sanitation, what would this mean for the design of the system?

Costs of a rainwater harvesting system

The design of the rainwater harvesting system is very simple and consists of roofs, gutters and rainwater tanks underneath the gutters with some plumbing from tanks to locations where water can be used for drinking and washing. Therefore, the capital costs of the system consist of plumbing from gutters to tanks and from tanks to where water is used, stand-alone 10,000-litre plastic tanks and concrete bases for the tanks. The costs of this infrastructure are estimated to be about $20,000, as shown in Table 4. If this figure is divided by the number of learners (200) costs per learner are about $1,000 per learner. In new schools in remote areas, this capital cost is likely to be considerably lower than developing and maintaining a mains grid connection. However, in schools in an urban area, capital costs for a rainwater harvesting system of this size are likely to be higher than a municipal connection as only short links to existing infrastructure are required.

An analysis of the operating costs and payback period of the rainwater harvesting system is also undertaken. Table 4 shows that the cost of water from the local authority is R15 per kilolitre. This increases to about R20 per kilolitre under drought conditions. These tariffs can be multiplied by the annual consumption of water to get annual water costs for the school of between R6,600 and R8,600/year. Given the capital cost of the rainwater harvesting system is R490,000, the payback period is between 50 and 70 years, as shown in Table 4. The very long payback period indicates that the rainwater harvesting system does not make sense, if viewed purely from a commercial perspective. However, viewed from an education perspective, costs may be justified in relation to the negative long term and large-scale impacts associated with disruption and poor education outcomes that are avoided.

Table 4. Capital costs and payback periods of rainwater harvesting system at a school (Gibberd 2023; Kouga 2023)

Component	Cost (Rand)	Number	Totals
Tanks	15,000	24	360,000
Bases	3,000	24	72,000
Collection plumbing	1,000	24	24,000
Distribution plumbing	1,000	26	24,000
Drinking water filtration	2,000	6	12,000
Capital cost in South African Rand (R)			492,000
Capital costs in USD, at an exchange rate of R17 to the USD			20,118

Water tariff schools - normal (R/KL)	15.00
Water tariff for schools - drought (R/KL)	20.12

Water consumption per year (litres/year)	440,000
Payback for normal conditions (years)	74
Payback for drought conditions (years)	57

Determining and increasing safety margins of the rainwater harvesting system

As shown in the introduction, there are severe negative impacts if a school runs out of water. So, what can be done to avoid this? This is addressed in the case study by ensuring that simulations are based on data from an average rainfall year and through the concept of contingencies.

The contingency level in the RUM is shown in Table H of Figure 4 and is the number of days that operations could continue at the school when water levels in rainwater tanks are at their lowest levels. In the current design, the contingency is 9 days. This means that without the rainfall in September, water at the school would run out.

The contingency, or margin of safety, for the rainwater harvesting system, can be increased in this case by changing the capacity of the rainwater harvesting system or reducing consumption levels. Adding rainwater harvesting capacity to a volume of 280,000 litres in the system increases the contingency to 28 days, for the same climatic year.

The implications of water-borne sanitation for rainwater harvesting systems

The implications of water-borne sanitation for the case study are modelled by increasing the levels of water consumption from 10 litres per person per day to 25 litres per person per day (Based on Table 2). This dramatically increases water consumption at the school and the rainwater harvesting system must be redesigned to be able to meet this demand. Achieving this demand requires a much larger collection surface and rainwater harvesting tanks. Figure 5 shows a solution based on a 5,000m^2 collection surface and water storage of 600,000 litres. This system provides a similar contingency as the original design of about 9 days. The example shows that it is possible to design a rainwater harvesting system for the school that accommodates waterborne sanitation. However, this system requires use of external hard paving, sumps, pumps, and rainwater tanks that are over double the capacity of the system required for dry sanitation. This will result in a far more expensive system.

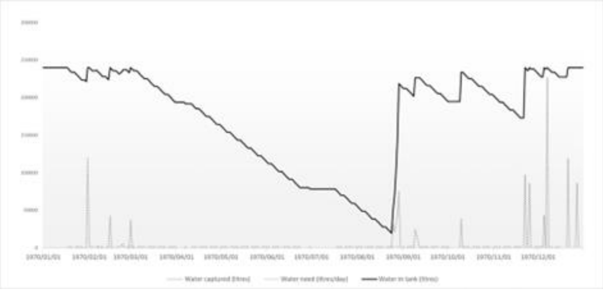


Figure 5. Rainwater Use Model (RUM) results for 5,000m^2 collection surfaces and 600,000-litre rainwater tanks (Report by the author).

Discussion

An analysis of the case study provides the following findings for the design of rainwater harvesting systems in schools. First, the case study shows that it is possible to design rainwater harvesting for a school in an area with only about 500mm of annual rainfall that enables a school to be off grid and not reliant on external water sources. This system allows schools to continue to operate even if there are local water shortages.

Second, it shows that the cost of the system is approximately $1,000 per student. By being off grid, the school could achieve operational savings by not having to pay for connection charges and water consumption from municipal supplies. Water charges can be increased by 30% during drought periods (Kouga 2023). While the system has long payback periods (see Table 4), it does enable the school to have control over water costs and to budget and manage these more easily.

Third, the case study shows water consumption must be reduced to about 10 litres per person per day in order for a simple rainwater harvesting system to cater for all of the school's water needs. This can only be achieved by avoiding waterborne sanitation and therefore the school would have to have a dry sanitation system such as an aqua privy or composting system. This may be a useful teaching tool as it can be used to show how compost or fertilizer from the system can be used to maintain fertility in soils. This is particularly relevant to schools in farming areas.

Fourth, the case study shows the implications of waterborne sanitation. To accommodate waterborne sanitation, a figure of 25 litres per person per day is used and therefore, much greater volumes of water are consumed. To cater for this, a much larger rainwater harvesting system is required and the case study shows that the area of rainwater collection has to more than double to 5,000m^2. Similarly, rainwater harvesting tanks must increase to 600,000 litres. Thus, the case study shows that while it is possible to accommodate water-borne sanitation with a rainwater harvesting system, it requires a much bigger and more complex system. For instance, additional collection surfaces in the form of external hard surfaces such as netball courts and yards would be required. These, in turn, require additional filtration and pumps which would need to be supplied with electricity and maintained. This level of increased cost and complexity may be difficult to justify in schools with limited resources and capacity for maintenance.

Fifth, the case study shows how the risk of running out of water can be addressed by using average rainfall years and contingency targets. It shows how the rainwater harvesting system can be modified to improve contingency periods. This aspect enables a school to understand the risks of the system and plan for them. Thus, to make the system more affordable, a school may have shorter contingency periods in the initial system. However, over time contingencies could be increased, and the risk of running out of water reduced, by adding more storage and catchment area to the system. In this way, the school can increase the resilience of the system to enable it to cope with climate change.

Conclusions and recommendations

The study shows that simple rainwater harvesting systems can be designed to meet all the water needs of a school in a water-scarce climate. This requires water consumption levels at schools to be around 10 litres per person per day and for dry sanitation to be used. The study shows that the cost of this system, at about $1,000 per student/person, is not prohibitive and could make a valuable contribution to local sustainable development by avoiding disruption and improving education outcomes.

It confirms that waterborne sanitation places large increased demands for water which can be met by a rainwater harvesting system. While this rainwater harvesting solution is possible, the study suggests that the additional costs and the complexity associated with achieving this, may not make this worthwhile. Instead, lower rates of water consumption, simpler rainwater harvesting systems that can be expanded easily, combined with dry sanitation systems, are recommended.

A significant finding of the study is the potential for schools in water-scarce areas to develop water-resilient off-grid water systems at low cost by using rainwater harvesting. Implementing rainwater harvesting could significantly reduce disruption to education from water shortages and help reduce the pressure on mains water systems.

A recommendation from the study is that further research on rain water harvesting systems in schools in water-scarce areas is undertaken to develop effective guidance that will enable schools to improve the resilience of their water supplies and ensure that disruptions to education because of water shortages are avoided.

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