Water Conservation Initiative in a Public School from Tropical Country: Performance and Sustainability Assessments

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Abstract

Malaysia is a tropical country that gets high rainfall throughout the year that can be utilized for various activities including water conservation. Water conservation initiatives in Malaysia are mainly concentrated in commercial and residential buildings but public buildings such as schools have been underutilized. Thus, this study aims to conduct a water conservation initiative in a primary school in Malacca (Malaysia). Water audit were conducted to identify the highest water usage location and the most suitable water conservation method in a school setting. Lastly, the sustainability performance of the rainwater harvesting system was evaluated via the Sustainable Development Analytical Grid (SDAG) assessment tool. Water footprint findings demonstrated that approximately 60% of total water use was due to toilet use. The rainwater harvesting system was selected as this method enables the use of a renewable source (rainwater) and it conveniently fit with the existing building rooftop and plumbing system to engender high sustainability potential and collaboration opportunities. After several months of operation, environmental, social, and economic benefits were observed. Sustainable assessment has indicated that all the six dimensions were well balanced with scores greater than 50% and continued improvements will increase the project's sustainability in the future. This study approach is generalizable to any school worldwide with a similar water footprint as a water restoration at both local and global contexts to achieve United Nation's Sustainable Development Goals.

1. Introduction

Climate change, rising population and socio-economic development have had a considerable impact on water availability at both a local and global level (Sillmann et al. 2017). In Malaysia, for example, the Water Sustainability Index (WSI) analysis has shown a 31% decrease in 2002 indicating that water resources are rapidly decreasing due various challenges including climate change, pollution and urbanization. Furthermore, a rapid depletion of WSI is also influenced by high domestic consumption and in Malaysia it was 222 litres per total population in 2017 and it has increased to 226 liters in 2018, higher compared with the recommended water usage level by the United Nations (National Water Services Commission 2019). Malaysia Water Industry Guide (2017) has also stressed that Malaysia has the highest water use relative to neighbouring countries such as Thailand (90 liters/day) and Singapore (154 liters/day). Due to high water consumption and other factors, it is predicted that Malaysia will face a water shortage crisis effecting various sectors (household, agricultural and industry), economic and social development, and population growth.

Water conservation is a vital component of environmental improvement and ecological restoration (Li et al. 2020). Reuse of rainwater via a rainwater harvesting system is a small scale technology that can be applied in any community environment to manage water supply sustainably (Lemos et al. 2016). Rainwater harvesting has good potential for community use as it can save a considerable amount of water especially, during water shortage (Mimi et al. 2003). It minimizes soil runoff which results in healthier green space by maintaining soil nutrients (Hajani and Rahman 2014) and improving landscape qualities (Saeedi and Goodarzi 2020). Hitherto, the majority of rainwater harvesting systems have been installed in urban environments in mainly commercial and residential buildings (Evans and Sadler 2008; Hajani and Rahman 2014; Dean et al. 2016; Lani et al. 2018). Although public schools with suitable rooftops are a potentially viable location for a rainwater harvesting system, such utilization is limited. To date, rainwater harvesting system have been installed in Jurusalem (Isreal) schools and Seychelles and Taiwan have been able to conserve considerable amounts of water, increase water conservation awareness, and change water use behaviour among school children (Sung et al. 2010; Michele Martin and Shane Emilie 2012; The Jurusalem Foundation 2013). However, rainwater harvesting implementation in Malaysian schools is still hindered and more concentrated in residential and commercial buildings (Chan and Nittivatananon 2006; Shahid et al. 2017). Considering the high annual rainfall (2400mm) received throughout the year and the large rooftop catchment area, rainwater harvesting a well-positioned water conservation method not only in residential and commercial buildings but also in public buildings such as Malaysian schools (Lani et al. 2018).

Hitherto, studies have focused on rainwater harvesting system design (Campisano et al. 2013; Notaro et al. 2017; Saeedi and Goodarzi 2020), performance (Amos and Rahman 2016; Bashar et al. 2018), water and energy savings potential (Domènech and Saurí 2011; Rahman et al. 2012), benefit-cost analysis (Domènech and Saurí 2011; Rahman et al. 2012; Dallman et al. 2016; Bashar et al. 2018) and rainwater quality for potable and non-potable purposes (Sung et al. 2010; Kus et al. 2011; van der Sterren et al. 2013). Only a few studies, however, have provided a systemic assessment of the overall rainwater harvesting system's sustainability and the short and long term impact of this system (Nguyen et al. 2013; Melville-Shreeva et al. 2014; Ghimire and Johnston 2019). A sustainability assessment of rainwater harvesting will provide insight into environmental impact, societal gains, as well as economic viability. Furthermore, sustainability assessment findings make the performance visible, makes inputs from different stakeholders possible, creates a coherent framework from which to generate ideas for performance improvements and policy makers. Sustainability assessment tools vary widely depending on project purpose and scope, indicator selection and prioritization, data availability, budget, time and target group. The diversity in these tools have raised concerns on the final conclusion about the sustainability performance (Cloquell-Ballester et al. 2006; de Olde et al. 2017). Among the sustainability assessment tools being utilized, Sustainable Development Analytical Grid (SDAG) was created and refined over past 25 years and has been recognized by United Nations as part of SDG Acceleration Toolkit. Sustainable Development Analytical Grid (SDAG) consists of assessment methodology which covers six dimensions (economic, environment, social, ethics and governance) as was developed by Waas et al., (2011) and five Ps (People, Planet, Prosperity, Peace and Partnership) by United Nations (2020). Sustainable Development Analytical Grid (SDAG) which developed in accordance with the sustainable development conceptualization, can be adapted to various type of projects and scopes from local to national levels, target groups, and policies. Furthermore, the scientific robustness of the methodology which addresses all 17 sustainable development goals is flexible, simple, user-friendly and accessible for free, and have made the SDAG is a distinguished sustainability assessment tool relative to other sustainability assessment tools (Villeneuve and Riffon 2012).

The study aims is to estimate the school water footprint and to identify the most suitable water conservation method for Convent Infant Jesus (1) Primary School in Malacca (Malaysia). Furthermore, performance via the benefits derived from the selected water conservation method in this school were also explored. Lastly, the sustainability performance of rainwater harvesting system in school was also was evaluated using the Sustainable Development Analytical Grid (SDAG) assessment tool based on environmental, economic, governance, ethical, and social dimensions to foster both short and long term action driving toward sustainability. This water conservation initiative is also in response to restoration measures at both local and global contexts in achieving United Nation's Sustainable Development Goals.

2. Material And Methods

2.1 Study area & School Selection

Malacca is located in the southern region of the Peninsular Malaysia and is approximately 148 kilometres from Malaysia's capital city Kuala Lumpur. Malacca is a tropical country with high temperatures, high humidity, and abundant rainfall all year round. The mean monthly rainfall in Malacca is 152.4 mm. The highest rainfall occurs between the months of October and March with an average monthly rainfall of 170 mm. The average annual percentage of humidity in Malacca is 83.0%. The study area climate information indicated that the significant amount of rainwater should be utilized for daily use in Malacca.

Convent Infant Jesus (1) Primary School in Malacca (Malaysia) is the first all-girls school in Malacca; it was established in 1957 with an enrolment of 469 female students and 36 teachers and is also one of the oldest schools in Malaysia. This school, which is located in the heart of Malacca City, is an area that has been recognized as a World Heritage Site by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) since 2008.

2.2 Water Footprint in School

In order to obtain a water footprint in school, a school water audit was conducted from August to September 2019. Prior to the water audit, 15 school children were trained to perform water audits in four locations, namely, in the canteen(s), toilet(s), the prayer room(s) and garden. A water audit module was developed in the Malay language for this school by adapting the School Water Audit (National Wildlife Federation 2012) and Eco-Schools USA Water Audit (National Wildlife Federation 2012) guidelines. Water use was recorded manually in a water audit form for one month by the school children at the previously mentioned selected school locations. Water use data in water audit form in each school location was calculated to obtain overall water footprint in school environment. Water footprint information then was used to determine the highest water use in school locations and assist in the selection of the suitable potential way to reduce the highest water use in school.

2.3 Selection of water conservation method in school

Water footprint information was used to determine the water use in each of the four designated locations at the school. Then, all water conservation methods were screened and discussed over a series of meetings with the school headmaster, teachers, the Teacher and Parents Association, and non-governmental organizations. The factors assessed during the series of discussions included expertise availability, financial concerns, sustainability potential, effects of existing sewage system and opportunities for school and stakeholder interaction (policy makers, NGOs, and researchers). Furthermore, performance through benefits gained from the water conservation method implication in school were also explored.

2.4 Sustainability Assessment

The Sustainable Development Analytical Grid (SDAG), developed by Villeneuve and Riffon (2012) was utilized for a sustainability assessment of the rainwater harvesting system. The SDAG is an assessment tool based on six dimensions, namely, economic, ecological, social, ethical and governance dimensions containing 32 themes and 101 objectives. The ethical dimension addresses the need of fairness, equality and coherence; the ecological dimension covers the need for good environmental quality and long-term availability of resources and the social dimension explores the material needs to maintain and improve the mechanisms that allow societies to meet their needs through exchanges of available resources. The governance dimension examines the need of participation, democracy and inclusion while cultural dimension covers the need of cultural traits for enhancement and protection.

Each dimension is divided into separate themes and objectives which are then weighted and evaluated. In this study, a simplified SDAG was used by weighing and evaluating sections of each dimension to obtain a sustainability assessment of the rainwater harvesting system due to the prolonged school closure to combat COVID-19 transmission from July 2020. Information needed for each objective in each dimension was collected via previous studies, which involved interviews with the school headmaster, teachers, students, and school and state education authority reports. In the weighing step, the value assigned to each objective was discussed between the researchers and school headmaster until a common decision was made via consensus. In weighing step, values ranging from one to three were used to qualify the level of objective achievement and detailed information about these values were presented in Supplementary 1. During the evaluation step, the percentage value reflects the current actions performance of rainwater harvesting system project for every objective in the SDAG. The percentage values served as a guide of evaluation to determine the project performance for each objective is presented in Supplementary 2. A Microsoft Excel spreadsheet, which included a user guide in English, was used to automatically calculate all of the values and present the sustainability assessment findings of the current rainwater harvesting system (Supplementary 3). Table 1 presents the assessment rating from below 20–100% representing the performance of the rainwater harvesting system project based on each dimension (economic, environmental, social, ethical and governance). It should be noted that the assessment of actual and projected measures and the improvements' feasibility of SDAG were not performed as the current rainwater harvesting system needs more time to operate in order to collect data for these sections.

Table 1
Rating interpretation of each dimension SDAG

Value	Rating interpretation
Below 20%	Dimension or theme is not considered in the project
Between 20% and 39%	Dimension or theme is insufficiently considered in the project
Between 40% and 59%	Dimension or theme is moderately considered in the project
Between 60% and 79%	Dimension or theme is considered in the project
Between 80% and 100%	Dimension or theme is strongly considered in the project

3. Results And Discussion

3.1 Water Footprint findings

Figure 1 presents the water footprint in school from August to September 2019 from data collected using water the audit forms from the canteen, toilet, garden and prayer room. The highest water use was recorded with toilet use while the lowest water use was recorded in the prayer room. Similar findings were reported by Farina et al. (2011) in the Emilia-Romagna region (Italy) and Morote et al. (2020) in the City of Alicante (Southern Spain) with the highest water use recorded in school lavatory. This finding can be attributed to student water use, mainly from toilet use, at the school. According to Morote et al. (2020), factors such as school characteristics (number of students, staffs, school size), water use amount per activity and water-saving devices are associated with water use in school. This school had six toilets each with a conventional 6-litre flushing capacity which contributed to the highest water use relative to other selected locations.

3.2 Possible water conservation methods suitability

Based on the water footprint findings, the most suitable water conservation method was determined for the lavatory, which used the most water relative to other selected locations.. Table 2 presents the conservation methods evaluated by the school and other parties (i.e., researcher, Teacher and Parents Association and non-governmental organization). Ultimately, rainwater harvesting technology was selected because this method would allow for the utilization of a renewable source (rainwater) from the building rooftop while utilizing the existing plumping system with construction outside of the lavatory. Furthermore, this method would create a long term collaboration between the school and other parties which increases the sustainability of the rainwater harvesting technology. Although the behavioural change method is a low cost, it requires water conservation expertise (in order to develop a module), longer time to train students, high dependency on students for implementation and it has potentially low sustainability. On the other hand, water saving devices are capable to reducing water use with high sustainability potential but it would require replacement of existing plumbing equipment which would involve high cost and affect the old school building.

Table 2
Possible water conservation methods suitability in school lavatory

Water conservation method	Expertise availability	Financial	Effect to the existing lavatory	Opportunities for collaboration	Sustainability potential
Rainwater harvesting technology	• Require experienced contractor with rainwater harvesting system construction	• Able to use the renewable source (rainwater) and the utilize building rooftop • Need to consider the best equipment with lowest cost • Able to utilize existing plumb ing system in lavatory building	• No effect to the existing lavatory • Will be constructed outside lavatory	• Will create collaboration opportunities between school and other parties	• High sustainability potential
Behaviour changes	• Need water conservation expertise to develop module • Highly dependent on the student • Straightforward method • Time required to train all the students.	• Low cost	• No effect to the existing lavatory	• Will create collaboration opportunities between school and other parties	• Low sustainability potential

Water conservation method	Expertise availability	Financial	Effect to the existing lavatory	Opportunities for collaboration	Sustainability potential
Water saving devices	• Need water conservation expertise to suggest the best water saving device for school toilet	• High cost to purchase the water saving device which will result in finance burden to the school • Existing school lavatory • is an old building and needs additional financial to improve the building	• Involve replacement of existing plumbing equipments•	• Less collaboration opportunities between school and other parties	• High sustainability potential

3.3 Rainwater harvesting system installation and its performance in school building

A suitable rainwater harvesting system was determined based on the rooftop area, gutter type, storage tank size, roof catchment runoff, placement of the storage tank, and the distribution pipe, which was contingent on the rainwater harvesting system design guide by the National Hydraulic Research Institute of Malaysia (2016). The school building with the highest water use was selected and examined to calculate the rooftop area. The rooftop area had a single sloping roof exposed to wind; this factor, along with the runoff coefficient and mean monthly rainfall were utilized to estimate the monthly water supply stored. Based on said characteristics, the National Hydraulic Research Institute of Malaysia design guide provided information about the monthly water supply stored (National Hydraulic Research Institute of Malaysia 2016). The monthly collectible rainwater calculation and information about the installed rainwater harvesting system are provided in Supplementary 4 and 5. The collected rainwater was delivered to polyethylene storage tank using a PVC gutter and down-pipe system. The 300 gallon polyethylene storage tank was installed near the lavatory while a 200 gallon polyethylene storage tank was installed on top of the lavatory roof. Furthermore, wire mesh was placed over the top of the down-pipes to prevent dry leaves and debris from entering the storage tank. Excess water was fed into a nearby canal using PVC pipes. A float valve was attached to both of the polyethylene storage tanks to indicate the water level. An installed water pump fills the tank until maximum capacity at which point a valve switches the water pump off. When a low water level is detected a probe activates a valve to which pumps tap water into the storage tank. The rainwater collected from the harvesting system was stored in two polyethylene storage tanks, both of which were utilized to flush 6L from each of the six toilets in the lavatory (Supplementary 6). The collected rainwater in polyethylene storage tanks were utilized to flush the 6L flush toilets (Supplementary 6). There are six toilets in this school lavatory, which have utilized the collected rainwater from rainwater harvesting system for flushing purposes. With total of 1892.71L (500 gallon) of rainwater stored in two polyethylene storage tanks, the six toilets utilize 36L water. The water audit findings indicated an average of 75 flushings total for six toilets per week. A total of 1800L of water per month is required for toilet flushing. With total of 1892.71L collected rainwater in the polyethylene storage tanks in the rainwater harvesting system, this leads to a water saving efficiency of 100% in lavatory.

Figure 2 summarizes the amount of water use before (in 2019) and after (in 2020) rainwater harvesting system installation. In January 2020, the water use was higher due to additional water being was used for school cleaning prior to the school reopening after a long break in December, 2019. There was a reduction in water use between February 2020 and March 2020 relative to the previous year which indicated the impact of rainwater harvesting system. Furthermore, the rainwater harvesting system also provided water for the school lavatory due a major water crisis between the end of January 2020 and February 2020, which affected approximately 551,000 domestic consumers (Personal Communication; The Sun Daily 2020; TheStar 2020). However due to Movement Control Order which ended on 14 April 2020, water use in April 2020 was high as school buildings were cleaned before the school reopening in mid-April 2020. Another water use reductions between 91 m^3 and 215m^3 was seen from May 2020 to July 2020 before the school reclosed again due to Covid-19. With several months of school operation in year of 2020, it can be seen that the rainwater harvesting system at school lavatory has resulted in significant reductions between 24m^3 and 278m^3 of water use in 2020 compared to 2019.

Besides water use reductions, performance of the rainwater harvesting system installed in school lavatory has resulted in other benefits as shown in Table 3. In terms environmental benefits, the rainwater harvesting system has minimized the amount of rainfall runoff around the lavatory building which has led to decreased erosion caused by falling rain. Personal communication with the school headmaster and teachers, revealed that the rainwater harvesting system provided continuous water supply, even during the water shortage period in Malacca. Utilization of collected rainwater has also reduced the reliance on treated pipe water, especially in lavatory. The social benefits engendered by rainwater harvesting system implementation created a good teamwork and solidarity between school teachers and children in a common cause to reduce water use in school. This teamwork was seen through series of briefings by the school headmaster in a weekly assembly and teachers in each class along with Eco-school committee members in charge at each location to share the importance of water conservation via infographics. Awareness to utilize renewable source has been done through continuous education activities such as a quiz, or with integration into subject content (Malay, English, Mathematics, Arts, Moral Education). These educational activities have increased the student’s participation in water use reduction and encouraged students to attend to social/environmental responsibility. This project has also created collaboration opportunities between the Parent-Teacher Association, Universiti Putra Malaysia, and Green Growth Asia Foundation. Regarding the economic benefits, the rainwater harvesting system in the school lavatory reduced water bill costs by USD285 in a five month period with reductions in treated water use between $24m^3$ and $278m^3$.

Table 3
Benefits of rainwater harvesting system implementation in the selected school

	Benefits
Environmental	• Minimizing the amount of rainfall runoff • Able to deliver continuous water supply even during water shortage period in Malacca • Reduce in dependency treated water from pipes
Social	• Good teamwork among school teachers and children to reduce water use in school • Awareness to utilize renewable sources • Has raised students involvement on water savings in school • Has helped students to focus on social responsibility • Able to build partnerships between school, universities, local municipals and non-governmental organization
Economy	• Reduce water bills • Treated water use reduction

3.4 Sustainability assessment of rainwater harvesting system in school lavatory

Figure 3 illustrates the sustainability polygon of each dimension of rainwater harvesting system installed in in school lavatory. A detailed sustainability assessment for each dimension is attached in Supplementary 6. The governance dimension had the highest score at 95% and the social dimension had the lowest score at 66%. The findings also indicated that each dimension in sustainability assessment was balanced with scores greater than 50% and continued improvement will further drive the future project's sustainability potential. The sustainability potential of the rainwater harvesting system will be able to create continuous water saving awareness in school children. This can also help them effect change in their home.

The highest score was on the governance dimension indicating a proper functioning project that included participation from various parties, including the Parent-Teachers Association, university (Universiti Putra Malaysia), and non-governmental organization (Green Growth Asia Foundation). In addition, there was a transparent decision-making process, project monitoring and risk management. An 81% on the ethical dimension indicated that this project has engendered originality and innovation while sharing common equity value in water conservation. On the other hand, the ecological dimension was reflected by the utilization of renewable resources via harvesting rooftop rainwater in order to reduce treated water use to restore and limit land impact and while optimizing land use and landscape diversity. In the social dimension, this project has demonstrated a sense of solidarity and common cause that to conserve water. This can was observable via their teamwork, ongoing effort to educate school children, and willingness to change their behaviour to use rainwater for flushing purposes. The economical dimension has demonstrated that responsible consumption of renewable rainwater contributes to wealth creation via water bill savings. Furthermore, the government's rebate program incentivizes and boosts the school's water conservation initiative, which, in turn, saves money on the water bill so more can be spent on teachers and students. In a nutshell, sustainability assessment of rainwater harvesting system has provided a better understanding of the equilibrium between each dimension and the overall impact in the form of gains for the school. The rainwater harvesting system performance, particularly in governance and ethical dimensions, bode well for stakeholders and children. While the sustainability performance data regarding the rainwater harvesting system (especially in environmental, economic and social dimensions) has provided a coherent understanding that these dimensions could use further improvements to ensure that the overall impact and performance are apparent at all levels for long term sustainability. By allowing a longer study of rainwater harvesting system operation, more information can be gleaned through various sources to improve the environmental, economic and social dimension scores.

Limitations

Although the rainwater harvesting system installed in the toilet demonstrated the potential for reduced water use, continuous assessment on the system's performance was curtailed due to the prolonged school closure caused by the COVID-19 pandemic. Thus, the overall water use and benefits were limited to five months (January, February, May, June, July) in 2020. Even though a simplified sustainability assessment developed by Villeneuve and Riffon (2012) was utilized to understand the sustainability of rainwater harvesting system installed in the lavatory, it has provided a complete understanding of each dimension regarding the sustainability performance of this project. In order to improve the sustainability of this project, input from key stakeholders (local municipal council, school teachers, Parent Teacher Association representative) would further benefit the school community and ensure the project's sustainability. Furthermore, greater assessment time the rainwater will generate more information about each dimension, including environmental, economic and social dimensions.

Conclusion

This study has demonstrated the potential of a water conservation initiative in a school by first determining the water footprint and then utilizing a renewable resource (i.e., rainwater) via a rainwater harvesting system. More specifically, this study revealed the benefits of rainwater harvesting lavatories and rendered a sustainability assessment of the rainwater harvesting system for the school. Water footprint findings indicated that more than 50% of water use is from flushing and handwashing activities in the lavatory. Among the various conservation methods aimed at reducing water use in toilet construction, the rainwater harvesting method was selected as rooftop runoff could be used to collect the renewable source (rainwater) while utilizing the existing plumbing system with a minimal effect to the existing toilets. Benefits gained from the rainwater harvesting system in the school lavatory can be seen from environmental, social and economic perspectives. Sustainability assessment of the rainwater harvesting system in the school lavatory showed that each of the dimensions was well balanced. Lastly, the sustainability assessment established a clear perspective of the project aim and direction towards improvement for long term sustainability.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

None

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Authors' contributions

SMP has contributed to the study design, perform the data analysis and write the paper.

ST has helped in data collection and write the paper.

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Figures

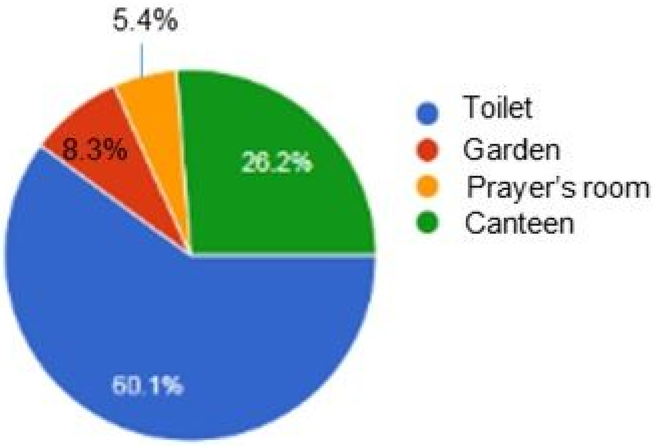

Figure 1

Water footprint based on water use in school from August to September 2019

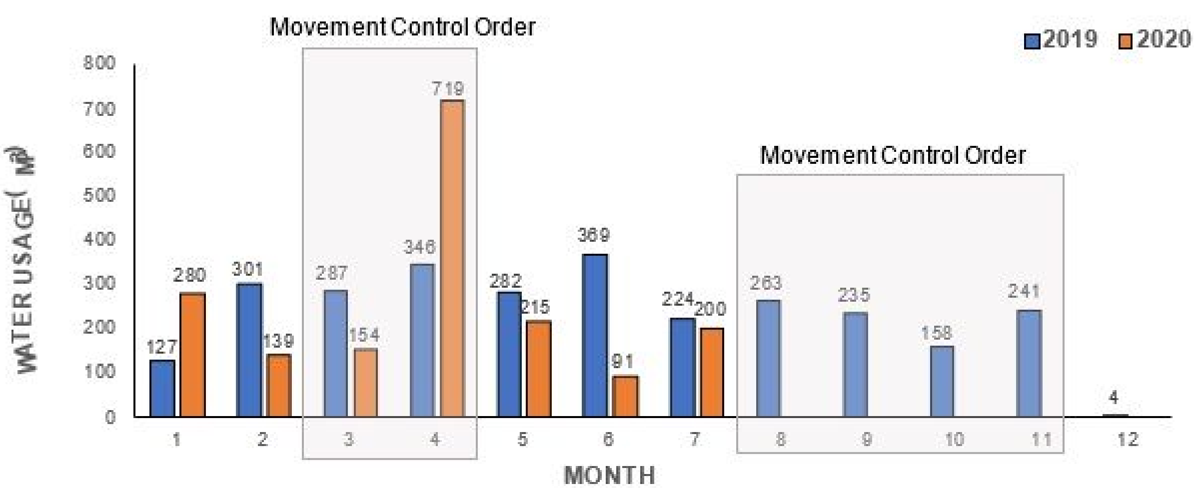

Figure 2

Water use before and after rainwater harvesting system construction in school

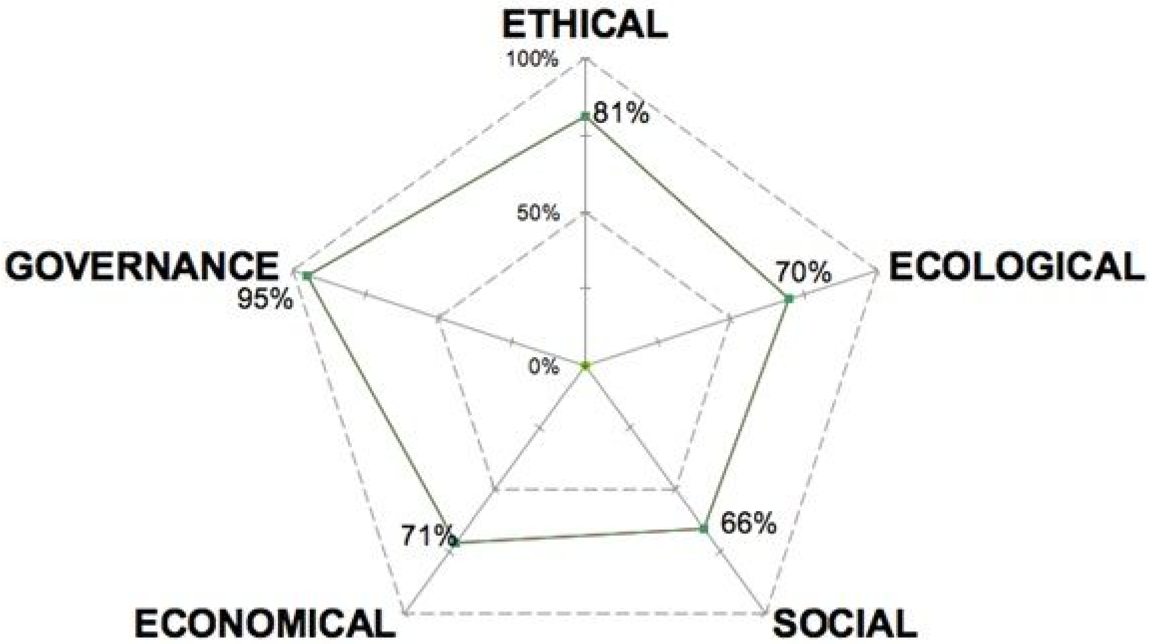

Figure 3

Sustainability polygon of each dimension of rainwater harvesting system installed in in school lavatory

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementary1.docx
- Supplementary3.xls