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ORIGINAL ARTICLE

Financial assessment of groundwater and rainwater treatments for school clean water supply

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Abstract

The global primary school population has experienced a significant increase, in line with the pursuit of Sustainable Development Goal number 4 which strives to ensure inclusive, equitable, and high-quality education, fostering lifelong learning opportunities for all. However, not all schools, especially in developing countries, have access to a sufficient supply of clean water. For example, a 2021 World Bank study found that almost half (47%) of schools in Indonesia have no access to soap and flowing water, which is critical to disease prevention. In this study, we featured a case study of a school in Indonesia that mainly obtains its clean water supply from pumped underground water and treats it with reverse osmosis technology. This study analyzed the potential financial savings from adding combinations of a rainwater harvesting system, an adsorption–filtration system, an ultraviolet radiation disinfection system, and solar photovoltaics to the existing underground water pumping system in a case study school. We utilize local data encompassing factors such as rainfall intensity, facility investment, operation, and maintenance costs in the evaluation of financial performance for each scenario, employing methods such as net present value (NPV), benefit–cost ratio (BCR), and payback period. The findings indicate that the adoption of constructed scenario 1, incorporating an adsorption filtration system and UV disinfection, yields superior financial outcomes in this study. Scenario 1 results in 167,890 IDR NPV over its 12-year lifespan, 1.10 BCR, and a payback period as short as 2 months. The results from this study provide knowledge about the potential financial gains and technological alternatives for other schools in developing countries without access to a centralized clean water or energy supply.

Keywords Financial assessment · Net present value · Benefit–cost ratio · Reverse osmosis · Rainwater harvesting · Photovoltaics

Introduction

Rainwater harvesting (RWH) is one of the oldest ways to obtain a water supply (Campisano et al. 2017). Most water use from RWH was nonpotable (Alim et al. 2020; Severis et al. 2019). However, recent alternative materials and technological innovations can provide low-cost and effective rainwater treatment to produce potable water (Yang et al. 2019). Consequently, RWH has regained attention as part of decentralized water supply systems today (Alim et al. 2020).

The promotion of RWH occurs not only in low-income or rural communities, such as in some African countries (Fisher-Jeffes 2015), but also in developed countries such as Japan (MILT 2014), Germany (Schuetze 2013), Australia (ABS 2022), and the United States (Debusk et al. 2013). In addition to the environmental benefits, widespread adaptation is also due to its financial benefits (Campisano et al. 2017). However, little research has been conducted on the economic analysis of RWH in developing countries (Amos et al. 2018).

Schools are among the most attractive facilities that would benefit significantly from RWH implementation, as they serve many people daily. A study revealed that approximately 20% of a municipality's clean water supply is consumed by schools (Farina et al. 2011). In this study, we analyze the cost-saving potential of replacing groundwater

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pumping with RWH paired with a reverse osmosis (RO) system at a school in Indonesia.

To boost the environmental benefits of the proposed scenario, we also considered the use of Photovoltaics (PVs) for the required energy supply. The analysis results of this study would be useful for schools to decide whether changing their water and energy sources would be financially beneficial. The methods demonstrated in this study can help the growing school population in developing countries to assess strategies for meeting their needs for a clean water supply in financially sound ways.

Literature reviews

Challenges of clean water supply in Indonesian Schools

Indonesia has two seasons, rainy and dry, typically influenced by La Niña and El Niño events. During the rainy seasons, heavy rainfalls and severe local thunderstorms with variable intensities occur (The World Bank 2021). On the other hand, water scarcity occurs during the dry season. This situation leads to drastic fluctuations in groundwater availability throughout the year and makes rainwater harvesting and storage a sensible strategy.

A clean water supply in schools is crucial to help students focus on their studies. A recent World Bank study on Indonesia (Afkar et al. 2021) reported that among the 219,084 registered schools with available data, 47,393 schools, or approximately 22%, have no access to water at all. The study also noted that approximately half (47%) of the schools have no access to soap and flowing water, which is critical for disease prevention. Considering the recent COVID-19 pandemic, providing low-cost solutions for clean water supply for Indonesian schools has become urgent to ensure the health and safety of learning activities.

Effectiveness of reverse osmosis and adsorption–filtration systems to treat harvested rainwater

Reverse osmosis technology is often used to treat seawater or brackish water in decentralized communities to supply clean water and produce domestic potable water (Greenlee et al. 2009). The technology effectively treats high-sodium-containing water and can remove contaminants such as bacteria, viruses, nitrates, sulfates, fluoride, and arsenic (CDC 2008). However, it also removes healthy minerals such as magnesium, calcium, potassium, and sodium from water (Tappwater 2022). Considering the high mineral contents in rainwater, using RO to treat rainwater for potable water is not effective or efficient. The minerals would deteriorate the filter membrane early and result in a costly frequent membrane replacement (Liu et al. 2021).

Aside from the healthy minerals in rainwater, rainwater has another advantage: it does not contain human activity-related contaminants often found in groundwater (Lee et al. 2017). Common contaminants from human activities found in groundwater are bacteria, viruses, oils, nitrates, chemicals from septic systems, landfills, leakage from sewers, and spills of petroleum products (US EPA 2020).

Studies have shown that a low-cost adsorption–filtration system using a combined activated carbon and sand filtration (CACF) effectively treats harvested rainwater (Kendarto et al. 2017; Shaheed et al. 2017). However, it is only effective when the population of *E. coli* bacteria is less than 31 CFU/mL. In the case where *E. coli* bacteria are more than 31 CFU/mL, the system would not be able to eliminate it. Meanwhile, the Indonesian drinking water standard requires a 0 CFU/mL of *E. coli* bacteria content. To overcome high bacterial population problems, the Centers for Disease Controls and Prevention (CDC) recommends combining a filtration system with a disinfectant such as chlorine or ultraviolet (UV) treatment, as it could effectively eliminate viruses, bacteria, and parasites (CDC 2022).

Although a small amount of chlorine is safe for human consumption, the smell and taste may bother some people (Minnesota Department of Health 2022). An experiment using zeolite and activated carbon to treat harvested and chlorine-treated rainwater in West Java (the same province as the school case study in this study) has been performed and was proven effective in removing the chlorine smell (Kendarto et al. 2017). However, an additional step after disinfection treatment would increase the system's complexity, require continuous water quality testing, and require a strict schedule for inserting the chlorine additive. On the other hand, there is a growing trend in using UV radiation to produce potable water from harvested rainwater (Silva Vieira et al. 2013). Therefore, this study chose a UV lamp instead of chlorine as the disinfection agent.

Research gap identification on domestic rainwater harvesting studies for a school community

The RWH is a technology that collects and stores rainwater. Water can be used for commercial, domestic, and industrial purposes (Campisano et al. 2017). In a school community, RWH is known to provide multiple additional benefits, such as (1) reducing the cost of water bills, (2) educating schoolchildren on the impact of climate change on our water resources and on the methods used to adapt to climate change, (3) raising awareness among the public that RWH is an option to adapt to water problems caused by climate change (UNFCCC 2010), and (4) better management of stormwater drainage during periods of intense rainfall (Campisano et al. 2014; Palla et al. 2017).

Responding to the intermittent water scarcity period in Indonesia and considering the recent technological development of low-cost rainwater treatment for potable use, this study demonstrates how the combinations of these technologies would perform financially in a school setting. There are existing studies on the techno-economic analysis of rainwater harvesting, such as those done by Sousa et al. (2018) and Campos Cardoso et al. (2020) in Brazil, Ward et al. (2010) in the UK, Handia et al. (2003) in Zambia, and Amos et al. (2018) in Australia and Kenya. Handia et al. (2003) and Amos et al. (2018) highlighted the significant number of untapped potentials of rainwater harvesting, while (Ward et al. 2010) forecasted that the technology will gain momentum in the coming years. The results from previous studies also showed significant savings in water consumption. For example, up to 60% of nonpotable water savings (Sousa et al. 2018) and 80% of potable water savings (Campos Cardoso et al. 2020) were reported in Brazilian case studies. However, these studies were done for general urban settings rather than specifically for a school facility. A school facility has a specific number of people, peak times of the day, and active months of the year that affect the water volume required at a given time. Furthermore, the mentioned studies were performed in countries with very different socioeconomic and climate conditions than Indonesia. The novelty of this study lies in the developed framework to conduct a financial assessment of decentralized water treatment and supply that can be replicated in other school facilities, not limited to, but especially for, the Indonesian tropical climate.

Materials and methods

Study location and attributes

This study focuses on a case study school situated in the Parung subdistrict of the Bogor district, within West Java Province, Indonesia. The closest meteorology station is the *Citeko* station, located approximately 44 km northwest of the school. The station is located at latitude − 6.70 and longitude 106.85. Figure 1 depicts the fluctuation in daily rainfall and sunshine recorded by the station in 2021. The peak of sunshine is almost the opposite of the rainfall. The solar power generation potential is highest when there is no rainfall and vice versa. It can be predicted that the rainwater harvest potential would be highest when there is no sunlight for solar power. Such insights would be useful if the school decided to keep the existing groundwater pumping and add a rainwater harvesting system, as they would complement each other in different seasons.

The case study school, *School of the Universe*, is a member of Indonesia's environmentally focused school network, known as *Jaringan Sekolah Alam Nusantara*. Schools within this network integrate national curriculum objectives with environmental preservation concepts, fostering a holistic approach to student learning activities. As of 2020, 137 schools registered as network members located in various locations in Indonesia. *School of Universe* is one of the oldest member schools, with 250 students ranging from preschool, elementary, and middle school (junior high and high school levels merged into four years). The school has 100 staff, including teaching and administrative staff. Water and energy supply serve these 350 people and an average of 10 daily visitors for five days per week throughout the year, except for the 2-week semester breaks and national and religious holidays. For example, there were 139 school days in the 2021 academic year (Department of Education Youth and Sports, 2020). Therefore, the analysis demonstrated in

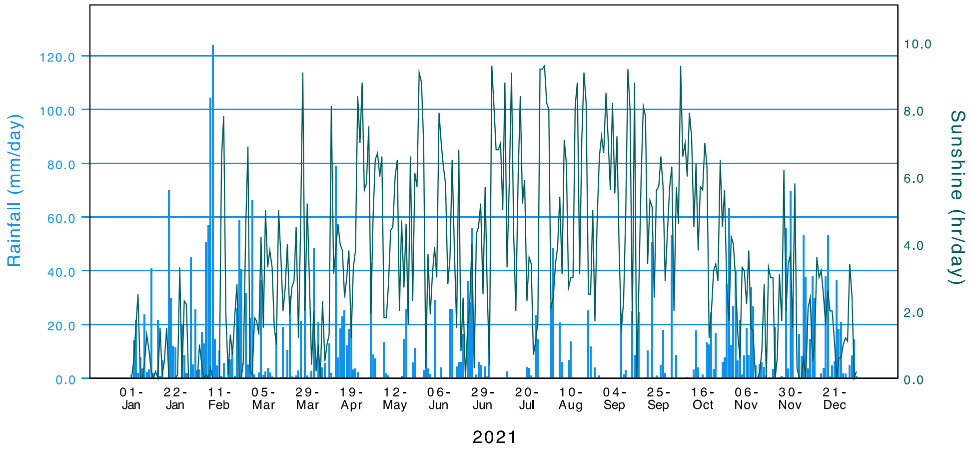


Fig. 1 Daily rainfall and sunshine recorded in the case study area in 2021 [created by the author from ((BMKG) Indonesian Meteorology Climatology and Geophysical Agency, 2022) data]

this study would be a practical guide for the rest of the 136 schools across Indonesia and potentially other schools with similar water supply challenges.

Actual images and satellite views of the *School of Universe* are shown in Fig. 2a–c. An existing rainwater harvesting system is already in place in one of the school buildings (Fig. 2a). However, the harvested water is not treated and is mainly used only for plant watering. A classroom building (Fig. 2b) is made of glass and has very low friction on the rooftop to allow efficient rainwater collection. Therefore, the rooftop dimension of this classroom is used in the calculation of this study.

Scope and boundaries

This study covers the analysis of the baseline scenario ("Water supply baseline scenario and inventory data") depicted in Fig. 3 and compares it with two constructed scenarios ("Constructed scenario system boundaries and inventory data") illustrated in Figs. 4 and 5. The baseline scenario represents the existing clean water supply system of the case study school, featuring an underground water pumping system equipped with RO. The two constructed scenarios propose the addition of a rainwater harvesting system to the baseline scenario, complemented by a UV radiation disinfection system. This addition ensures that the harvested rainwater is safe for use as potable water (Silva Vieira et al. 2013). In the second constructed scenario, a PV panel is introduced to replace the energy sourced from the main grid, powering the water pump. Notably, the PV is not intended to supply power to the UV lamp responsible for treating the rainwater due to insufficient sunlight during peak times of rain harvesting, as illustrated in Fig. 1.

Water supply baseline scenario and inventory data

The school utilizes a well, equipped with a bucket and pulley, to obtain water for washing and cleaning the area. For the potable water supply, electric power is employed to pump groundwater, which is subsequently treated using RO. Additionally, the school purchases 60 bottles of drinking water per month for staff and visitors, with each bottle containing 19 L, commonly referred to locally as 'aqua gallon' (see Figs. 3, 4, and 5). The system boundary of the baseline scenario is depicted in Fig. 3, and related prices are summarized in Table 1. These prices were obtained by inquiring with local vendors in the traditional market near the *School of Universe* in Parung, Bogor, Indonesia.

The water pump requires 750 W to start and 375 W for continuous operation. The specific type of water pump employed is a 40 m jet pump, signifying its suction capability to a depth of 40 m underground and the delivery of pressurized water up to 40 m through the distribution pipe, achieving a water flow rate of 85 L/min (Bukalapak 2022). The pump warranty is 3 years for the unit and 1 year for the parts. However, the average life span is approximately 10 years (A1 Well Drilling and Pump Service 2016). Electricity is also required to operate the RO, which is approximately 3 kWh/m^3 of treated water (Dashtpour and Al-Zubaidy 2012; Pinto 2020). The RO storage tank has a capacity equivalent to approximately three 19 L bottles and is continuously supplied by the water pump. The system's monthly electricity expenditure is estimated to be approximately 3,000,000 IDR. Given the grid electricity price of 1570 IDR/kWh, the monthly consumption is calculated at 1910 kWh, assuming an operational duration of 8 h per day for 22 days in a month. Considering a daily potable water requirement of 2 L per person, with 1 L consumed at the school, it is assumed that the remaining water supplied by the RO system is sufficient. With an average daily school population of 360 people, the daily potable water consumption is approximately 360 L, which is partially provided by purchased bottled water. The monthly potable water consumption supplied by the RO system (308 L) is considered a benefit in the cash flow calculation when valued at the commercial bottled water price.

Constructed scenario system boundaries and inventory data

In constructed scenario 1 (Fig. 4), several components are added to the baseline scenario, including: (1) a rainwater collection system, (2) an adsorption and filtration system utilizing gravel, activated carbon, and zeolite sand (as illustrated in Fig. 6) to treat the harvested rainwater, and (3) a UV lamp serving as a disinfection agent to eliminate pathogens like *E. coli*, effectively conditioning the water for potable use (Silva Vieira et al. 2013). On rainy days, the primary source of potable water is the harvested rainwater, thus eliminating the need for electricity to operate the pump.

Scenario 2 (Fig. 5) mirrors scenario 1, with the key distinction that the electricity sourced from the grid to power the pump and RO is substituted with electricity generated by the PVs. It's important to note that the infrastructure in the baseline scenario is intentionally maintained in all three scenarios (baseline scenario, constructed scenario 1, and constructed scenario 2), under the assumption that the groundwater system must cater to water demand on days when there is insufficient rainwater supply.

Estimation of harvested rainwater and solar power generation potential methods

In determining the monthly harvestable rainwater in the school area, this study assesses the precipitation rate derived from data compiled by the Indonesian Meteorology

Fig. 2 Actual images of the case study school. **a** The front and back view of the school building with existing rainwater harvesting systems (− 6.440610, 106.733782), **b** classroom building with largest roof area (− 6.440624, 106.734302), **c** satellite view from Google Maps

(c)

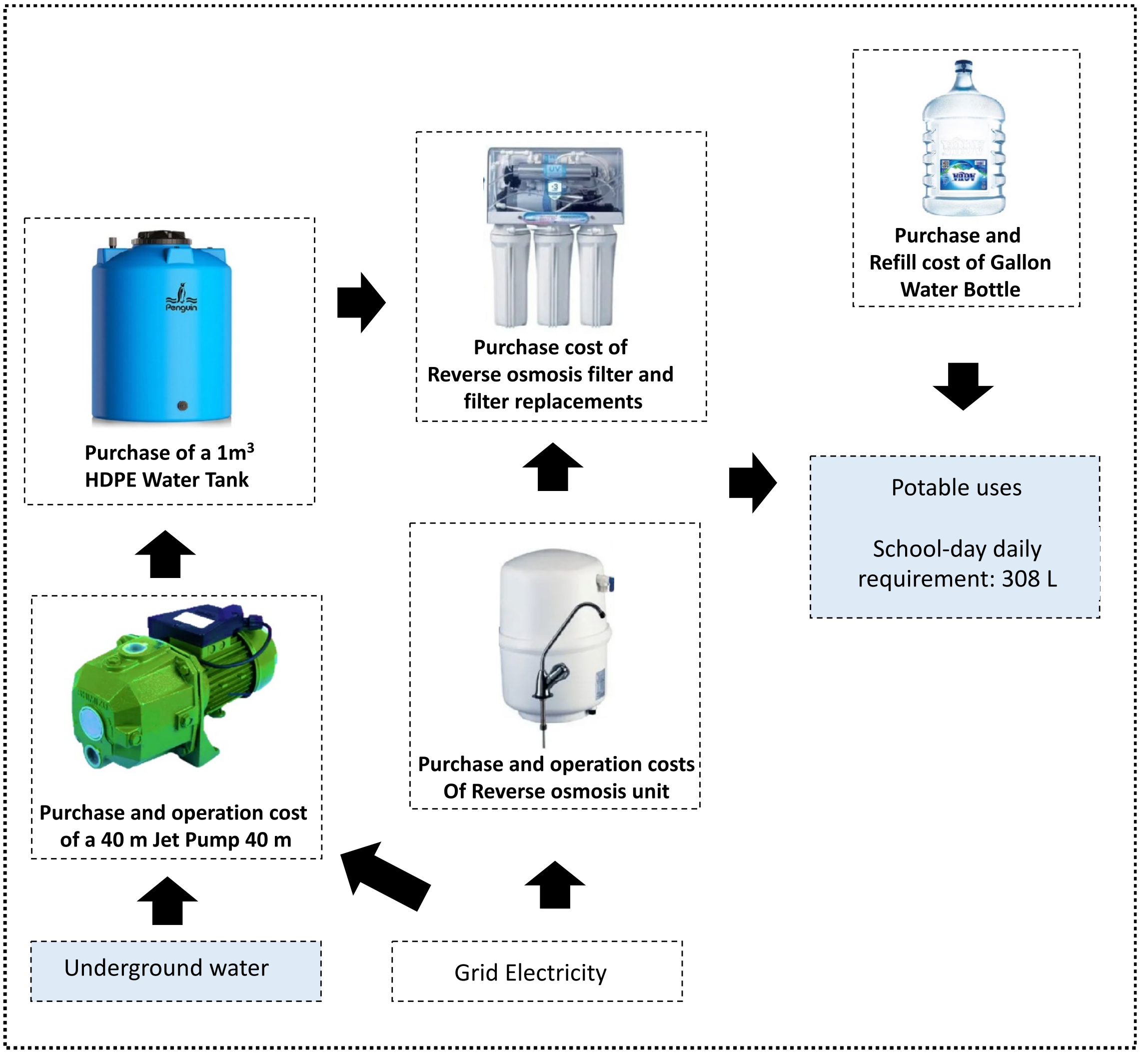


Fig. 3 The system boundary of the baseline scenario: underground water pumping + RO

Climatology and Geophysical Agency (BMKG) in 2022 (Fig. 1). The analysis adopts the *School of Universe's* most extensive roof area available. The runoff coefficient is estimated using the spectrum proposed in a previous study by Goel (2011). Equation 1 from Al-Batsh et al. (2019), is employed, where RWH_{pot} represents the potential harvestable rainwater, R is the rainfall rate in mm/day, A is the roof area for the water catchment in m^2, and C is the runoff coefficient. To estimate how much electricity can be generated from the PV in the school area every month, this study uses Eq. 2 from Dynamicslr (2022). where E_{pot} is the energy generation potential in Wh/day, S is the sunlight hour/day, W is the PV capacity in watts, and EC is the energy conversion efficiency coefficient.

$$\text{RWH}_{\text{pot}} = R \times A \times \text{RC}, \tag{1}$$

$$E_{\text{pot}} = S \times W \times \text{EC}. \tag{2}$$

Financial assessment and sensitivity analysis methods

This study employs three financial measurement methods to assess the proposed scenarios for their financial viability and magnitude of benefit. The three methods include the benefit–cost ratio (BCR), net present value (NPV), and payback period. These methods are commonly utilized in financial assessment studies to identify the most economically viable scenario among various technology combinations (Ali et al. 2012; Pandyaswargo et al. 2022a; Pandyaswargo and Premakumara 2014). Their effectiveness in water treatment financial analyses is also evident in a previous study (Amos et al. 2018). A BCR value exceeding 1 suggests a profitable system, while a BCR value below 1 indicates a higher cost

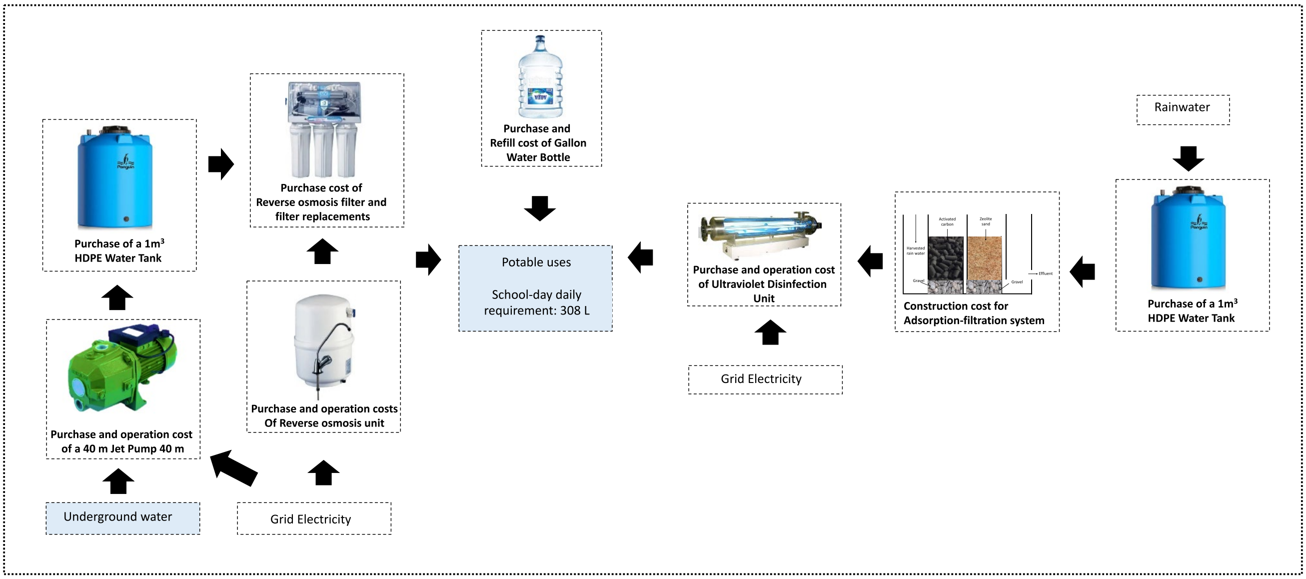


Fig. 4 Constructed scenario 1: [Underground water pumping + RO system] + [RWH + adsorption and filtration system + UV]

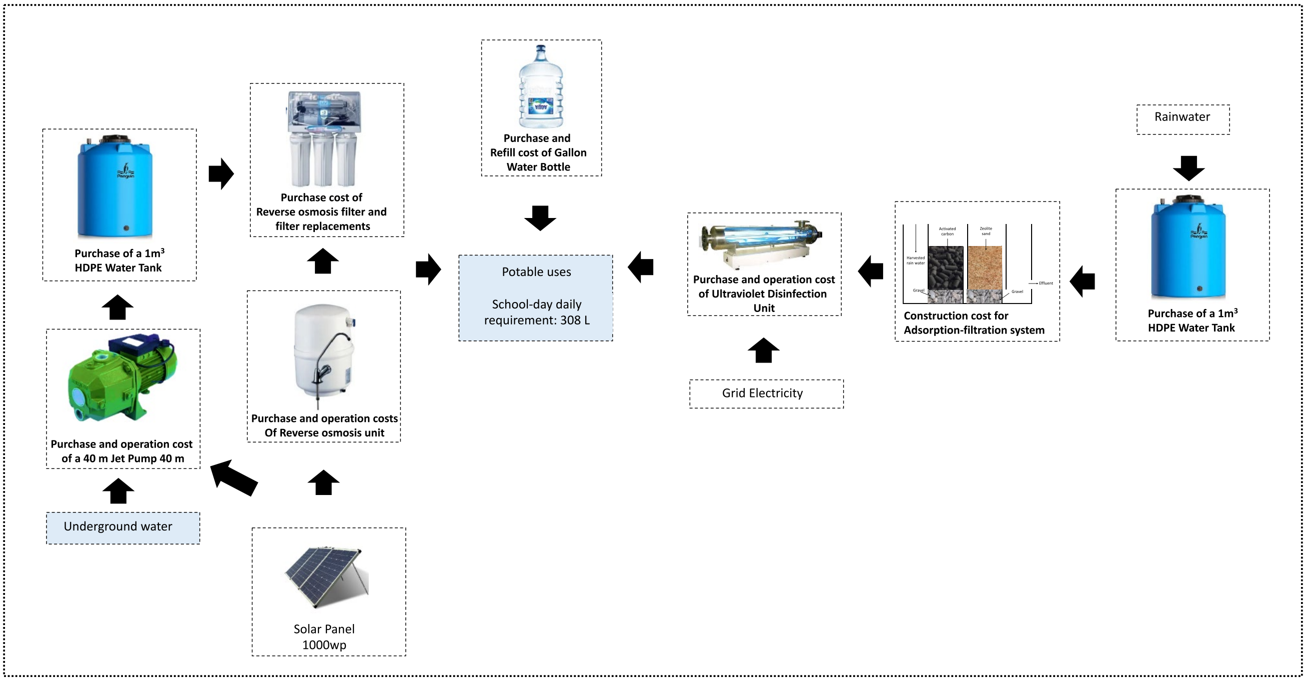


Fig. 5 Constructed scenario 2: [Underground water pumping + RO] + [RWH + adsorption and filtration system + UV + PV]

compared to the benefits, resulting in a financial loss over the system's assumed 12-year lifespan. The chosen lifespan aligns with the approximate 10–15 years' lifespan of the RO unit used in all three scenarios, as indicated by Fresh Water Systems (2022).

The NPV assesses the current value of an investment's future cash flow stream (Harvard Business Review 2014). A positive NPV indicates a financially beneficial system, and the magnitude of the NPV value correlates with the financial attractiveness of the system. Additionally, the payback period offers a rule of thumb for gauging how quickly the invested money is recouped through financial gains. This period is calculated as the time from the investment to when the cumulative cash flow turns positive. Equations for the BCR, NPV, and payback period are denoted by Eqs. 3, 4, and 5, respectively. In these

Table 1 Inventory data of water supply of the baseline scenario

Items	Quantity	Price/unit[b]	Monthly expenditure
Bottled drinking water	60 bottles[a]/month	20,000 IDR/bottles	300,000 IDR
Electricity for the water pump and RO operation	1910 kWh/month	1570 IDR/kWh	3,000,000 IDR
RO unit	1 unit	2,000,000 IDR/unit	–
RO filter	2 units/year	200,000 IDR/unit	–
HDPE water tank (1 m^3 capacity)	1 unit	2,000,000 IDR/unit	–
Jet pump 40 m	1 unit	2,130,000 IDR/unit	–

[a] 1 bottle = 19 L

[b] Actual prices surveyed by the authors at the *Pasar Parung* traditional market, which is located 2 km from the school

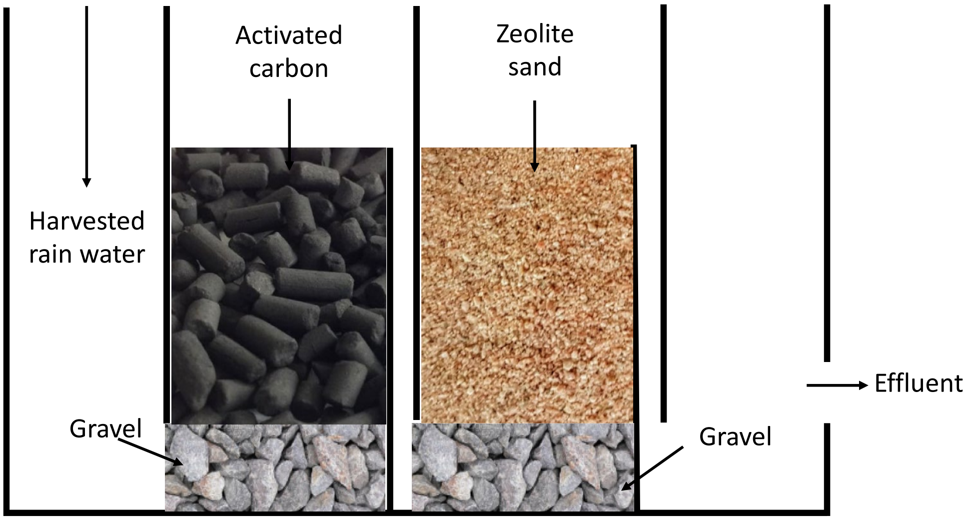


Fig. 6 Adsorption filtration system design, adapted by authors considering the (Kendarto et al. 2017; Shaheed et al. 2017) studies and (CAWST 2009) guideline

equations, *B* represents the benefit, *C* is the cost, *t* signifies time, and *n* denotes the system's lifespan. The interest rate is represented by *i,* and r indicates the year in which the cash flow occurs.

$$\mathrm{BCR} = \frac{\sum_{t=0}^{n} B_t/(1+r)^t}{\sum_{t=0}^{n} C_t/(1+r)^t}, \tag{3}$$

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t}, \tag{4}$$

$$\text{Payback period} = \frac{\text{Initial cost of investment} + \text{Monthly cost of operation}}{\text{Monthly Cash Flow}}. \tag{5}$$

To incorporate the anticipated changes in fluctuations in interest rates and electricity prices, this study also performed a sensitivity analysis. These parameters were set to three levels of sensitivity, standard, pessimistic, and optimistic, so that practitioners could anticipate changes in the financial performance of the water treatment system of their choice under various circumstances.

Results

Rainwater harvest and solar power potentials

This study utilizes the daily rainfall rate of the school area (Fig. 1), considered the school's largest available roof area for rainwater catchment (64 m^2), and assumed a runoff coefficient of 0.75. The resulting daily rainwater harvesting potential ($\mathrm{RWH}_{\mathrm{pot}}$) was calculated using Eq. 1 and the results are presented in Fig. 7. Concurrently, the solar power potential was determined by applying Eq. 2, which factors in sunlight hours per day (Fig. 1), the total PV capacity (1000 W), and an energy conversion efficiency coefficient set at 0.7. The outcomes of the energy generation potential are also illustrated in Fig. 7.

Since both RWH and solar power potential exhibit daily fluctuations (Fig. 7), meeting the daily demand for

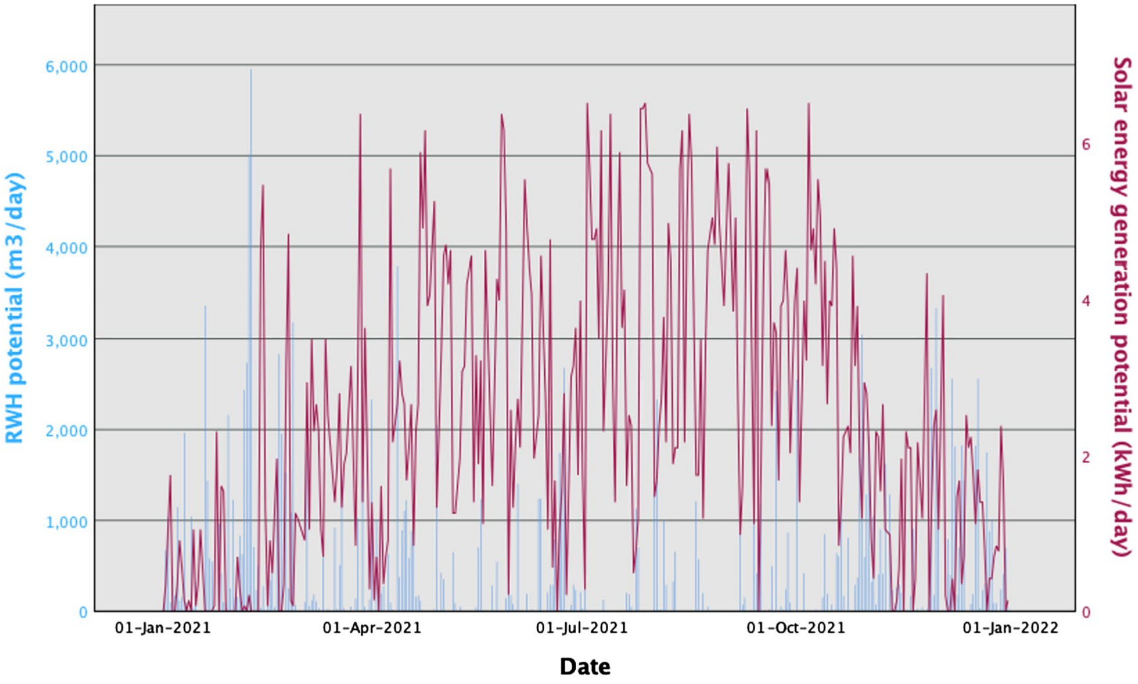


Fig. 7 Harvested rainwater and solar energy generation potential

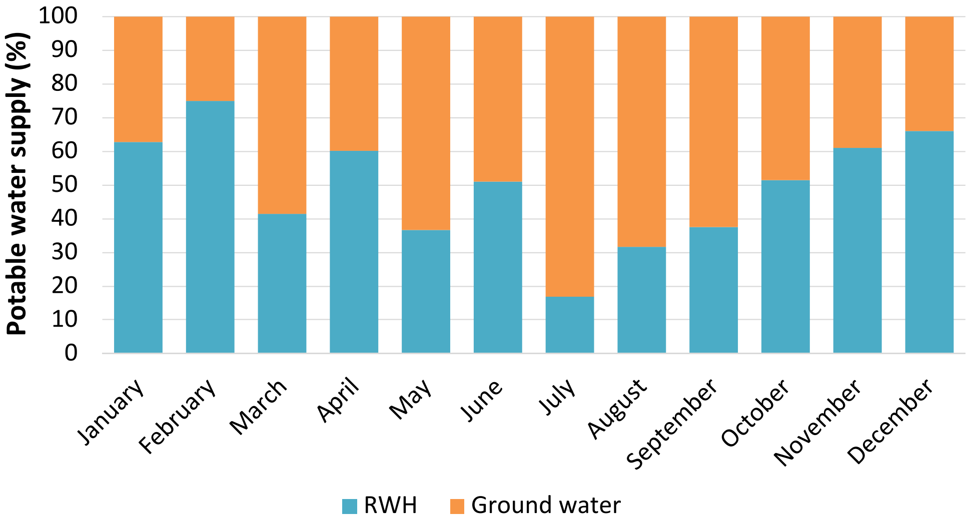
potable water (308 m^3/day) requires a combination of both sources, depending on RWH availability. For instance, on days with high rainfall intensity, the water supply from RWH alone would be sufficient to meet 100% of the daily water demand. However, during the dry seasons and days with lower rainwater intensity, groundwater needs to complement the water supply. Figure 8 depicts the estimated monthly portion of water sources over the year based on the calculated 2021 RWH potential.

In scenario 2, the PV system supplies the power demand for the underground water pump and RO. When there is insufficient sunlight to provide the required energy, power from the grid must be purchased. Therefore, we also calculated the proportions of power sources (86 kWh/day) and presented the monthly PV/grid electricity sufficiency average in Fig. 9. The financial assessment of constructed scenario 2 assumes the proportion of this electricity source in the calculation, considering electricity from PV as a benefit and valuing it at the grid price in cash flow analysis.

NPV, BCR, and payback time

The costs arising from additional items that must be purchased for the constructed scenarios are listed in Table 2.

Fig. 8 Average monthly rate of RWH supply sufficiency and the remaining potable water demand sufficed by groundwater



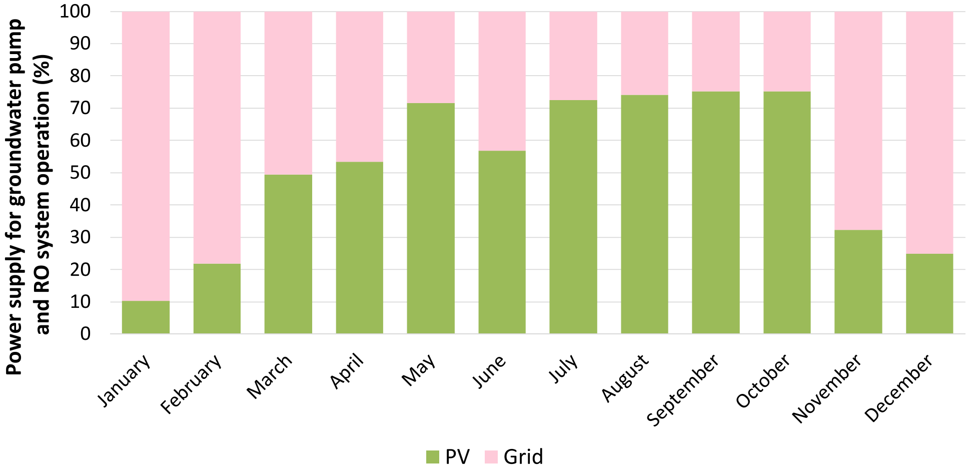


Fig. 9 Average monthly rate of PV power supply sufficiency and the remaining power demand sufficed by grid electricity

Table 2 Additional inventory data for the constructed scenarios

Items	Quantity	Price/unit[a]
PVC Gutter	1 m	50,000 IDR/meter
PVC pipe (3 inches diameter)	2 units	75,000 IDR/unit
PVC pipe joints	1 Package	200,000 IDR/package
Filter	2 units	75,000 IDR/unit
Platform tank	1 unit	200,000 IDR/unit
Zeolite sand	25 kg	1000 IDR/kg
Gravel	1 m^3	300,000 IDR/m^3
Activated Carbon	25 kg	13,800 IDR/kg
Ultraviolet (UV) lamp set 40 W	1 unit	750,000 IDR/unit
Filter building construction	1 unit	2,000,000 IDR/unit
PV 1000 wp	2 unit	7,205,000 IDR/unit

PVC polyvinyl chloride

[a] Actual prices in the local market surveyed by the authors (*Pasar Parung*, located 2 km from the school and *Bukalapak*, Indonesian online marketplace (Bukalapak 2022)

The calculation of BCR and NPV utilized Eqs. 3 and 4, respectively, with an assumed discount rate of 4.25% (Central Bureau of Statistics 2022). In Fig. 10a, b, and c, we present the NPV, BCR, and payback time results.

Concerning NPV, only constructed scenario 1 exhibits a positive value, while the NPV is negative for both the Baseline and constructed scenario 2 (Fig. 10a). Both the Baseline Scenario and constructed scenario 2 result in negative NPV values. In terms of BCR, only constructed scenario 2 yields a value exceeding 1. Notably, the payback time for all scenarios is achievable within the second month of operation.

These findings suggest that, while the proposed constructed scenarios incorporating RWH can enhance the financial attractiveness of the water supply system in the school, the addition of PV units does not improve the financial gains. This is primarily due to the high investment cost of the PV system resulting in the higher per kWh electricity generation cost compared to the electricity price from the grid under the assumed 12-year lifespan of the water pump. To explore how these financial assessment results might change with future alterations in the discount rate and electricity price, a sensitivity analysis ("Sensitivity analysis") is conducted.

Sensitivity analysis

The parameters for sensitivity analysis are the following: (1) the fluctuations of the predicted discount rate and (2) changes in electricity price due to a lift of subsidy. Historically, the interest rate in the Bank of Indonesia has been fluctuating with a decreasing trend in the past ten years (Trading Economics 2022). The range of fluctuation is between three and seven percent. Therefore, the pessimistic scenario in this study adopts a discount rate of 7%, while the optimistic scenario adopts a rate of 3%. In other words, because the standard scenario's discount rate is 4.6% (Central Bureau of Statistics 2022), the future cash flow is valued at 2.4% less under the pessimistic scenario and 1.6% more under the optimistic scenario.

In terms of electricity prices, the Indonesian government has been subsidizing them for a long time. However, in the past few years, subsidies for upper-economy households have gradually decreased (The Ministry of Finance 2023). Moreover, although Indonesia still has abundant coal stores, it has pledged to close some of its coal plants in the coming decades as a climate change mitigation commitment (Hadijah 2022). Considering these trends, the price of electricity is expected to continue to rise. Therefore, the pessimistic scenario in the sensitivity analysis adopts the lowest voltage nonsubsidy price (1352 IDR/kWh). On the other hand, the optimistic scenario adopts the highest voltage nonsubsidy price (1644 IDR/kWh).

Figure 11a–c compare NPV, BCR, and payback time under the standard, pessimistic, and optimistic scenarios.

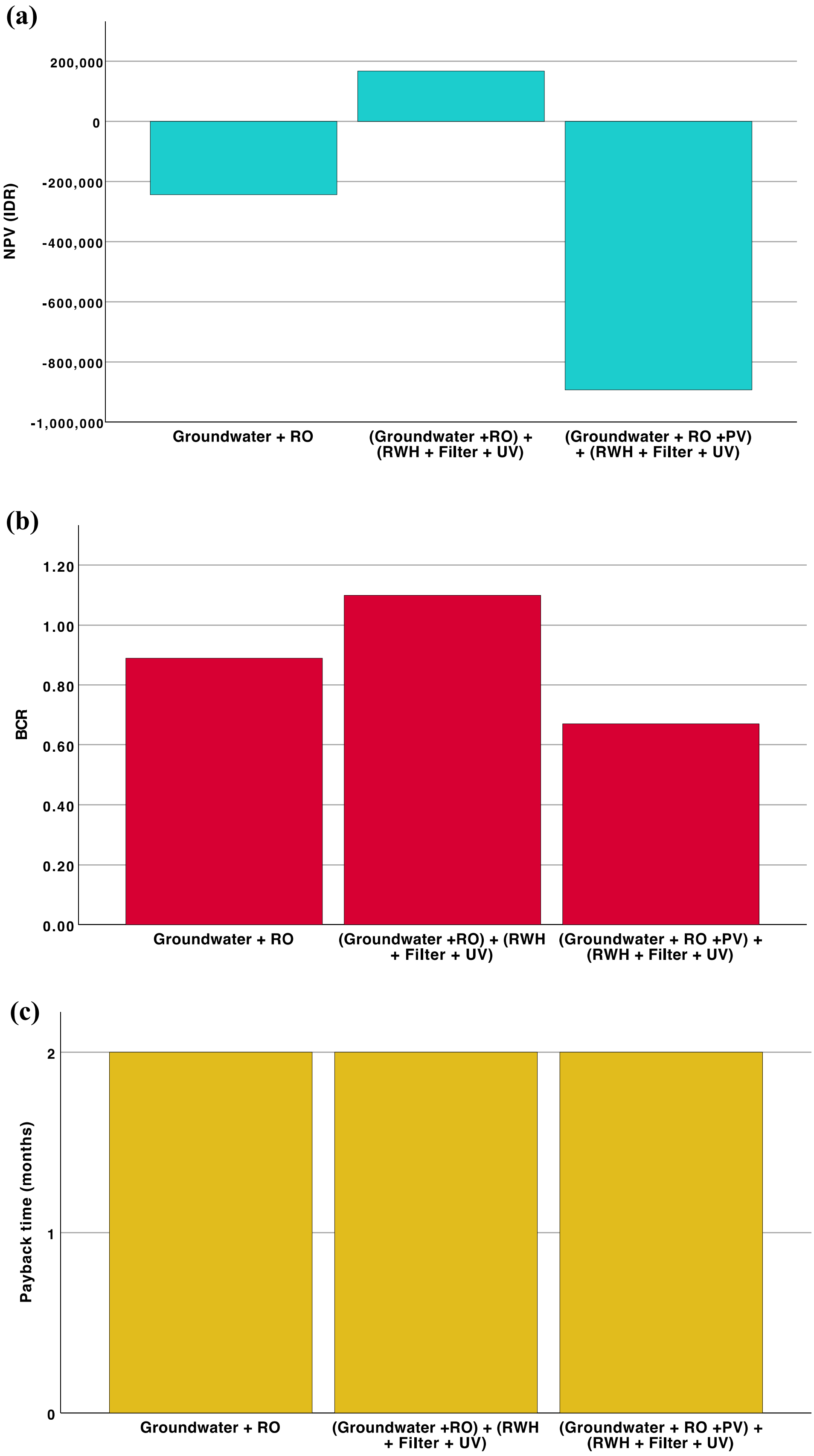


Fig. 10 **a** NPV, **b** BCR, **c** payback time for the three scenarios

Under all scenarios, the NPV of constructed scenario 1 is still the only one that produces a positive result. Additionally, in terms of BCR, scenario 1 is still the only system that can yield a ratio of more than 1. However, all scenarios have the same payback time of 2 months, which remains unchanged with the discount rate and electricity price fluctuation.

Since the only difference between constructed scenarios 1 and 2 is the existence of PV, the observed NPV results imply that if the benefit of electricity generated by the PV is valued at the grid price, the system would not be financially attractive. The BCRs of constructed scenario 2 under all financial scenarios are also lower than the baseline scenario. This observation also implies the weak position of PV-generated electricity if it is priced at the same level as grid electricity.

Discussions

Despite the poor financial performance of constructed scenario 2 (the one with a PV system), it must be noted that under rigorous maintenance, the lifespan of a PV can reach 30 years (Office of Energy Efficiency and Renewable Energy 2020). By ensuring the use of PV for 30 years, the per kWh price of electricity generated may be reduced. However, reinvestment will be required for the battery, groundwater pump, RO system, and other elements with shorter lifespans. Previous studies have shown that many communities in developing countries have failed to perform the required battery reinvestments to extend the useful life of PVs (Hong et al. 2015; Hong and Abe 2012; Pandyaswargo et al. 2014, 2020). Therefore, the assumed 12-year span in this study remains relevant.

Moreover, there are other benefits that are overseen by just considering the financial assessment results. For example, the environmental and educational benefit of replacing fossil-based fuel with PV is yet to be reflected. The negative NPV of constructed scenario 2 is only slightly over 1,000,000 IDR, equivalent to about 67 USD as of July 2023. It is a reasonable price for providing school students access to experience and exposure to a renewable energy system. Furthermore, the monetization of the Feed-In-Tariff (FIT) in Indonesia must be ensured so that the per kWh electricity generated by the PV system can be valued at a higher price than the conventional fossil-based grid electricity. Presently, there are still uncertainties about monetizing the mechanisms in Indonesia (Bridle et al. 2018; Pandyaswargo et al. 2022b).

Compared to other rainwater treatment feasibility assessment studies in developed and developing countries (Amos et al. 2016, 2018) using the same methods, the BCR for scenario 1 in this study is more promising, with a value higher than 1. Influencing factors include the more favorable rainfall situation in Indonesia compared to case studies in drier countries such as Australia and Kenya, as well as the utilization of different technologies in their proposed scenarios.

For schools in remote areas without electricity connections, the costs for grid extensions must be considered in financial assessments. In the case of Indonesia, grid extension costs are typically assessed and funded by the government. When grid extension is deemed exorbitantly expensive due to geographical challenges and other issues, a system powered solely by renewable energy becomes the only viable option. Various existing techno-economic assessment studies can be referenced to estimate the cost of establishing such systems, such as those performed by Veilleux et al. (2020) in Thailand, Xu et al. (2019) in Myanmar, and Pandyaswargo et al. (2022b) in Indonesia. The Indonesian study also showed that the current price of renewable-derived energy in the off-grid area is still higher than the national price cap. Nevertheless, Indonesia has almost reached its universal electrification goals (99.45% in 2022) (International Trade Administration 2022). Some areas in Indonesia still experience poor-quality electricity supply (Institute for Essential Services Reform 2023). In the case of poor electricity supply quality and reliability, reducing electricity dependency for potable water supply, such as the RWH system demonstrated in this study, should be prioritized.

Conclusion

Efforts to realize Sustainable Development Goal (SDG) number 4 (achieving inclusive and equitable quality education for all) have positively influenced the increasing number of schools in developing countries. However, because many of these schools lack a centralized clean water supply, the demand for affordable means to obtain clean and potable water is rising. In support of SDG number 6 (clean water and sanitation for all) in schools, the present study has demonstrated three scenarios of decentralized water treatment in an Indonesian school. The scenarios included combinations of RO, RWH, an adsorption and filtration system, a UV lamp, and a PV. The financial analysis results showed that the scenario utilizing RWH, Filter, and UV is the most financially attractive. On the other hand, including PV does not add any financial benefit, even under the optimistic scenario. This situation may be improved by (1) making full use of the PVs' potential lifespan by equipping the communities with the knowledge and skills for maintaining PVs, and (2) ensuring FIT implementation to support the financial performance of the PV scenario.

The present study's limitations are (1) The system's lifespan limit that followed the groundwater pump lifespan instead of the PV panel life span; (2) The noninclusion of

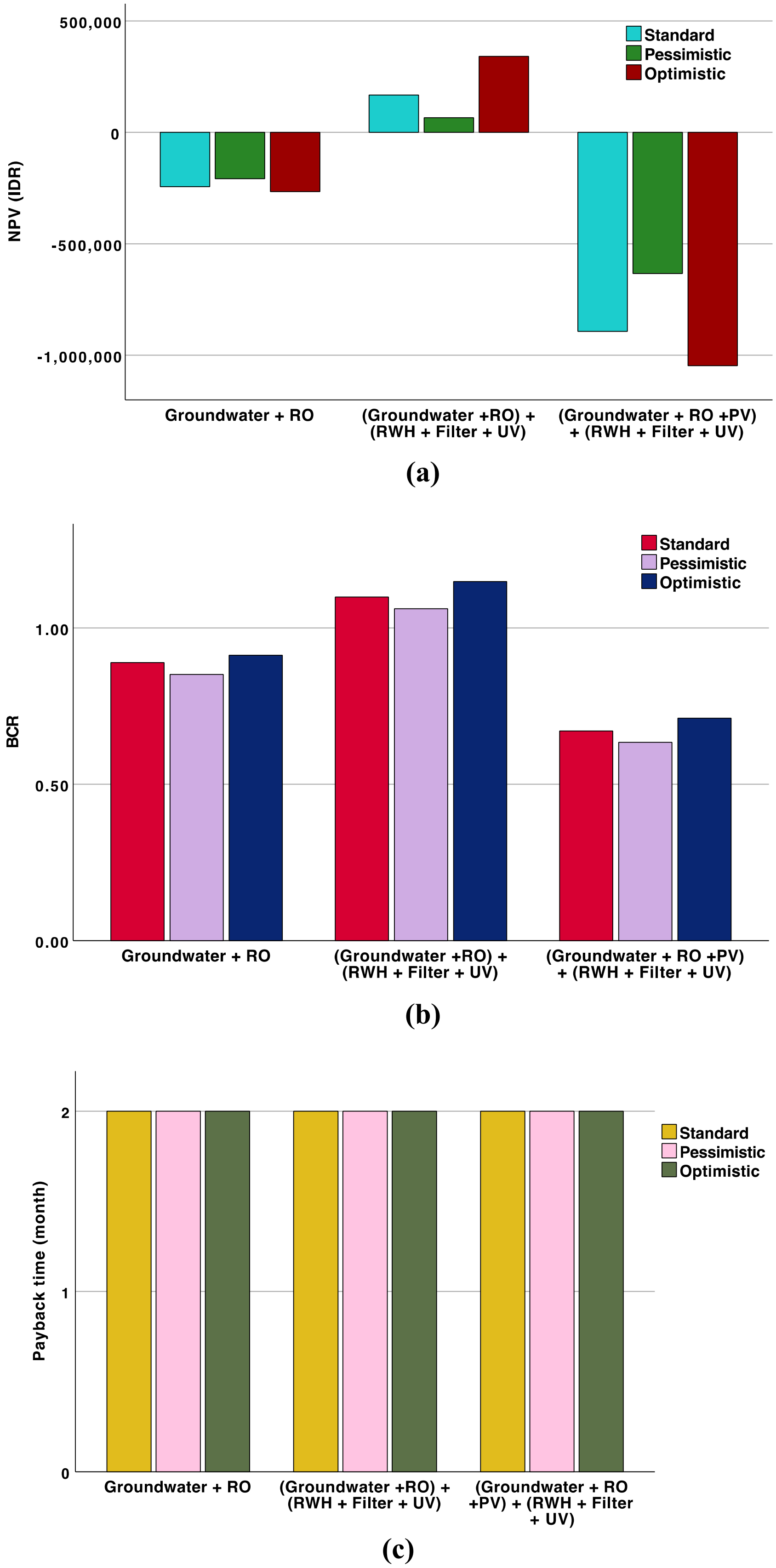


Fig. 11 **a** NPV, **b** BCR, **c** payback time of the scenarios under standard, pessimistic, and optimistic circumstances

externalities, such as the environmental and educational benefits that may be gained by including PV in the system; and (3) The incorporation of local prices in this study signifies that the outcomes are applicable solely to the specific case study school under consideration. Should other schools wish to emulate the methodology employed in this study, it is imperative that they utilize prices tailored to their respective locations.

For school practitioners, the calculation process in this study could be used as a guide to estimate the financial gains expected from utilizing rainwater or groundwater for the clean water supply in their school community. The nonfinancial education benefits of the system can be reaped by integrating the practice and maintenance of the water system into the study curriculum and activities. Moreover, since the case study school belongs to a network of environment-oriented schools in Indonesia, it is also recommended that the schools share their practices and education activities around the clean water supply system so that they can learn from each other. For example, sharing information among the schools in the network about the optimal tank and roof sizing, tank or UV lamp supplier with the best cost performance, and designs and local materials for the filter.

For policymakers, FIT mechanisms should be materialized and bank-guaranteed so that schools can be confident in taking the most sustainable solution for their clean-water system.

This study has opened venues for further research, including the monetization of external and nonfinancial benefits to be reflected in calculations, the exploration of locally available adsorption–filtration system materials in each province, and the design of low-cost storage for harvested rainwater and generated solar energy in schools.

In this study, we have addressed the pressing challenges faced by schools in developing countries, particularly in ensuring access to clean and potable water. By presenting and analyzing decentralized water treatment scenarios in an Indonesian school, the study highlights viable strategies for meeting water needs through a combination of RWH, filtration, UV treatment, and solar power. Findings in this study contribute to the broader discourse on sustainable and resilient water supply systems in educational institutions, aligning with global goals related to water access, sanitation, and renewable energy.

Essentially, in this study serves as a resource for guiding decision-makers in adopting effective, financially viable, and environmentally sustainable solutions to enhance clean water accessibility in school communities, especially in regions facing resource challenges.

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Data availability All primary data analyzed during this study are included in this published article. The generated results datasets are available from the corresponding author on reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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