Evaluation on Rainwater Harvesting Suitability in Indonesia

- Case Study of Four Small Farm Reservoirs in Wonosari Village, Central Java, Indonesia -

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Abstract: Erratic rainfall as an effect of climate change has become a serious problem for agricultural development in Indonesia. Rainwater harvesting technology (RWH), which has been successfully applied in several areas in the world, exhibits great potential as a method of addressing this issue. In the present study, we analyze the benefit-cost ratio (B/C) of two lining materials, tarpaulin and concrete to evaluate the suitability of four small farm reservoirs (SFR). The results are as follows. (1) Applying SFR is economically beneficial, as indicated by the income increase through the rise of yield possibility in the 2nd crop season. (2) It is important to estimate the optimum irrigation area in order to obtain the maximum B/C value. (3) The relationship between the B/C value, the catchment area, and the SFR volume is clarified for the optimum irrigation area. (4) SFR concrete is more acceptable than tarpaulin in terms of the B/C value due to its longer depreciation period with less running cost.

Keywords: Rainwater harvesting; Small farm reservoir; Feasibility; Indonesian agriculture

1 Introduction

The application of water harvesting technologies with storage components for supplemental irrigation is one strategy for mitigating short-term drought damage to crop production (Fox *et al.*, 2005). Rainwater harvesting (RWH) is particularly useful for adapting to environmental stress at the local scale (Pandey *et al.*, 2003). RWH consists of three main components: a rainwater collection surface (catchments), a water storage tank, and supplementary irrigation systems. The major advantages of this system are that it is simple, cheap, replicable, efficient, and adaptable (He *et al.*, 2007).

This technology also can be an economically viable option for improving agricultural production and livelihoods of smallholder farmers in poorly irrigated rural areas (Ngigi *et al.* 2005; Komariah and Masateru, 2013). Improvement in livelihood after applying RWH is well documented in many regions worldwide (Dharmasena, 1994; Glendenning *et al.*, 2012; Fox *et al.*, 2005). RWH cannot only improve agriculture production, but it can also allow utilizing the available area to collect rainwater for human activities (Yuan *et al.*, 2003). Technological, ecological, social, economic, and political factors must be considered in the development of RWH (He *et al.*, 2007).

Many Indonesian people rely completely on farming. Recently, their farming is facing various problems such as erratic rainfall due to climate change. Thus, alternative water sources, like RWH, are urgently required. A common type of RWH in rural Indonesia is the small reservoirs built in the farm, which is called the small farm reservoir (SFR).

This type of RWH is most applicable for farmers having small landholding. Four SFRs were built to analyze whether this technology is suitable for small landholding farmers in Indonesia. Two different SFR lining types were analyzed, i.e., tarpaulin and concrete, which have often been used for sealing the inside of reservoirs in RWH (Panigrahi *et al.*, 2005; Fox *et al.*, 2005; Carvajal *et al.*, 2014). The objectives of the present research are to determine which lining type is more suitable and economically acceptable and to suggest an appropriate method for the large-scale implementation of this technology.

2 Materials and methods

2.1 The study area

This research was conducted in Wonosari Village, Gondangrejo Sub-District, Karanganyar Regency, Central Java Province, Indonesia. From the 495.6 hectares of this area, 147.0 hectares function as paddy fields. There are no irrigation channels established yet in these fields, so they are currently only rain-fed (Gondangrejo, 2015). This situation makes their farming susceptible to the effects of climate change. Rozaki *et al.* (2016a) showed that the farming conditions in this area have significantly changed due to climate change.

Figure 1: Ten-day precipitation in the research site during the study interval 2013/2014

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The climate of this area is classified as tropical; the dry season lasts from April/May to September/October and the rainy season from October/November to March/April, in a typical year. According to the Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG), the rainy season starts when the 10-day rainfall exceeds 50 mm for two consecutive 10-day intervals. In addition, a short drought period is defined as an isolated period within a rainy season, when the total rainfall is less than 50 mm per 10-day interval.

Climate data were obtained for the research location from October 2013 until July 2014. As can be seen in Figure 1, the rainy season started from the 2nd 10-day interval of October 2013, and the following dry season started from the 1st 10-day interval of May 2014. During this rainy season, six short droughts occurred. In this area, there are generally two crop seasons per year. The 1st crop season (CS1) lasts from November to February, for which planting takes place by rain-fed farming during the rainy season. The 2nd crop season (CS2) is from March to June, but CS2 is risky and often fails without irrigation, because the dry season starts during this crop season.

2.2 Methods

In the research site, four SFRs with irrigated rain-fed paddy fields were selected for detailed observation and analysis. The specifications of each SFR are listed in Table 1. The owners of those SFRs were interviewed using a structured and a semi-structured questionnaire covering a broad range of socioeconomic aspects related to the application of SFR. The interviews were conducted in June–August 2014.

Two different SFR lining types were examined, tarpaulin and concrete. The suitability and acceptability of the two linings were analyzed mainly in economic terms, using the physical and economic data of the SFRs. The SFR construction cost comprises excavation cost by human power and lining cost (tarpaulin or concrete).

Economic analysis was carried out based on two consecutive seasons, 2012/2013 (only CS1 in case that SFR was not built) and 2013/2014 (two crop seasons; CS1 and CS2 in case that SFR was available). Indonesian Rupiah (IDR) which equal with 0.008 Japanese Yen (on December 12th, 2016) was used as the economic unit. The income potential from the farming varied with the farm resources, the market prices for the farmed products, and the human employment cost (Jervell, 1999). In this research, family members who were involved in the farming were not accounted for in the

cost analysis. Family members usually only help in farming when they are free, and they do not expect any monetary compensation by helping their family in farming. First, we calculated the net income from CS2 for 2013/2014 based on the actual irrigation area. Afterward, we estimated the net income based on the optimum irrigation area. In this research, the optimum area was decided by the method (Ariyanto *et al.*, 2016) that the irrigation area could be maximized under the given catchment area and SFR volume based on the water balance analysis.

Benefit-cost ratio (B/C) analysis was used to determine if the project was economically acceptable (Equation (1)). In this analysis, the ratio of project benefits to project costs at a discounted rate was calculated according to the following equation.

$$\frac{B}{C} = \frac{\sum_{t=1}^n B_t(1+i)^{-t}}{\sum_{t=1}^n C_t(1+i)^{-t}} \quad (1)$$

where B_t and C_t are the benefit (receipt) and the cost (disbursement) at time t , respectively, while i is discount rate which is 9% (from Bank Rakyat Indonesia). Discount rate itself is the interest rate that is used to find a present value. If B/C is greater than one, the project is economically acceptable. If the ratio is less than one, the project is not acceptable. A ratio of one indicates a break-even situation for the project (Badiru and Omitaoumu, 2007).

3 Results and discussion

3.1 Reservoir construction

The SFRs sizes (Table 1) are determined based on the water balance between the inflow from the catchment area and the water demand of the irrigation area under proper water management of the SFR (Ariyanto *et al.*, 2016). The average excavation cost is assumed IDR 18,181 per m³ based on the survey results in the test site (Table 2). In the case of SFR1, which has a volume of 35.1 m³, the excavation cost is IDR 638,181 (=18,181 IDR/m³ × 35.1 m³). Using family member as the main labor resource in construction significantly reduces this cost (Teshome *et al.*, 2010).

The tarpaulin cost results from the tarpaulin size multiplied with the local tarpaulin price, IDR 18,000 per m². Tarpaulin should cover the inside surface of the SFR and the area one meter around it. In case of SFR1, the tarpaulin size is 82.2 m² (= 24 × (1 + 1.3) + 9 × 3) (Table 2). The co-

Table 1: SFRs specification (Ariyanto, 2016)

Dimensions: unit	SFR1	SFR2	SFR3	SFR4
Catchment area (A_c) : m ²	817	4,184	4,068	1,826
SFR volume (V_{sfr})= $L*W*H$:m ³	35.1	132.5	182.6	113.6
Length(L), Width(W), Height(H) of SFR :m	9,3,1.3	25,5,1.06	22,5,1.66	20,4,1.42
Landholding area (A_l) :m ²	3,500	4,200	5,700	3,500
Optimum irrigation area (A_{opt}) :m ²	962	4,080	5,624	3,499
Harvesting ratio (H_r) *	0.3	0.1	0.24	0.31
Water storage index (WSI) **	0.13	0.32	0.19	0.2

* H_r is defined as the equation (4), ** WSI is defined as the equation (3)

Table 2: SFR construction cost

Type	Dimensions	Unit	SFR1	SFR2	SFR3	SFR4
Excavation	① Volume	m ³	35.1	132.5	182.6	113.6
	② =18,181 × ①	IDR	638,181	2,409,090	3,320,000	2,065,454
Tarpaulin	③ Size	m ²	82.2	248.6	253.64	196.16
	④ =18,000 × ③	IDR	1,479,600	4,474,800	4,565,520	3,530,880
Concrete	⑤ Wall size*	m ³	4.68	9.54	13.45	10.22
	⑥ =600,000 × ⑤	IDR	2,808,000	5,724,000	8,067,600	6,134,400
	⑦ Bottom size**	m ³	0.54	2.5	2.2	1.6
	⑧ =800,000 × ⑦	IDR	432,000	2,000,000	1,760,000	1,280,000
SFR-Tarpaulin	⑨ =②+④	IDR	2,117,781	6,883,890	7,885,520	5,596,334
SFR-Concrete	⑩ =②+⑥+⑧	IDR	3,878,181	10,133,090	13,147,600	9,479,854

*Stone masonry **Screed concrete

st of SFR1 tarpaulin is IDR 2,117,781(= IDR 638,181 + 18,000 IDR/m² × 82.2 m²).

Concrete lining is stone masonry with stone thickness of 15 cm for the wall and screed concrete with thickness of 2 cm for the bottom. In the present model, this cost is calculated based on the local prices of stone masonry and screed concrete, which are IDR 600,000 per m³ and IDR 800,000 per m³, respectively. SFR1 requires stone masonry of 4.68 m³(= 24 × 1.3 × 0.15) and screed concrete of 0.54 m³(= 9 × 3 × 0.02) (Table 2). This configuration allows us to extend the SFR durability and reduce the construction cost, in comparison to using concrete with a steel frame. Based on results of the local survey, with good maintenance, this SFR is expected to function appropriately for 10 years or more. After 10 years, this SFR can be repaired at a lower cost than the construction cost, because only the broken part should be repaired. The cost of the concrete for SFR1 is IDR 3,878,181 (= IDR 638,181 + 600,000 IDR/m³ × 4.68 m³ + 800,000 IDR/m³ × 0.54 m³) (Table 2).

3.2 Net income

The farmers in the study area had a different way in managing their farmland, because there was no particular standard procedure established. Thus, the expenses were not only influenced by the land area, but also by the farming's management abilities and methods. The farmers owning the examined SFRs applied various techniques to draw up water from the SFR; using pump machines, siphons, and buckets. All SFR owners used pump machines, except SFR1 owner, who obtained a pump machine from the Sebelas Maret University. They transport the water to the entire irrigation area with plastic pipe which connected to

pump machine. In SFR3, which is located higher than the irrigation area, the farmer could use siphon technique and water will flow to the entire irrigation area. Buckets were also used for drawing up the water, when the irrigation water volume was insufficient. Farmers utilized the water stored in SFRs carefully, considering the crop and the weather conditions.

The main benefit of the SFR construction is that the possibility to achieve a higher yield in CS2, as long there is enough water in the SFR. In Kenya, farmers who have not adopted RWH only have 40% chance to obtain a harvest. Thus, adopting RWH technologies would increase the chance of producing a good harvest (Ngigi *et al.*, 2005). Hatibu *et al.* (2006) showed that farmers who have not adopted rainwater harvesting could only grow sorghum or maize with great difficulty. When farmers under the same situation adopted rainwater harvesting, they were able to produce paddy or vegetables as well.

The net income (income minus cost) in three cases is presented in Tables 3–5. The price of rice is assumed 4,000 IDR/kg based on the local market. Table 6 shows the average cost for producing 1 kg rice for each crop seasons, as calculated from the average actual cost for all SFRs farming. Labor contributes with the highest cost, because planting, harvesting, and weeding relies on employed human power. Tillage refers to the rental price of tilling machine, which was the highest in CS2 in 2013/2014, because the production was lowest of all crop seasons. Pump is determined by the price of gasoline, which is consumed for pumping water from SFR only in CS2, because irrigation was not needed for cultivating the paddy field in the CS1.

Table 3: Net income of CS1 in 2012/2013

Items (Unit)	SFR1	SFR2	SFR3	SFR4
① Actual cultivated area (m ²)	3,500	4,200	5,700	3,500
② Actual Production (kg)	680	750	1,000	860
③ Productivity (=②/①)(kg/m ²)	0.19	0.18	0.18	0.25
④ Income (=②×4,000 IDR/kg)(IDR)	2,720,000	3,000,000	4,000,000	3,440,000
⑤ Cost (IDR)	675,000	867,000	972,500	956,000
⑥ Cost per production (=⑤/②)(IDR/kg)	993	1,156	973	1,112
⑦ Net income (=④-⑤) (IDR)	2,045,000	2,133,000	3,027,500	2,484,000

Table 4: Net income of CS1 in 2013/2014

Items (Unit)	SFR1	SFR2	SFR3	SFR4
① Actual cultivated area (m ²)	3,500	4,200	5,700	3,500
② Actual Production (kg)	700	800	1,040	750
③ Productivity (=②/①) (kg/m ²)	0.20	0.19	0.18	0.21
④ Income (=②×4,000 IDR/kg) (IDR)	2,800,000	3,200,000	4,160,000	3,000,000
⑤ Cost (IDR)	705,000	937,000	1,047,500	886,000
⑥ Cost per production (=⑤/②) (IDR/kg)	1,007	1,171	1,007	1,181
⑦ Net income (=④-⑤) (IDR)	2,095,000	2,263,000	3,112,500	2,114,000

Table 5: Net income of CS2 in 2013/2014

Items (Unit)	SFR1	SFR2	SFR3	SFR4
① Actual cultivated area (m ²)	781	1,733	2,968	3,270
② Actual Production (kg)	150	350	520	700
③ Productivity (=②/①) (kg/m ²)	0.19	0.20	0.18	0.21
④ Income (=②×4,000 IDR/kg)(IDR)	600,000	1,400,000	2,080,000	2,800,000
⑤ Cost (IDR)	177,400	415,500	553,250	822,750
⑥ Cost per production (=⑤/②)(IDR/kg)	1,183	1,187	1,064	1,175
⑦ Net income (=④-⑤) (IDR)	422,600	984,500	1,526,750	1,977,250

Table 6: Average cost (IDR) for producing rice (1 kg) (unit: IDR/kg) per Crop Season (CS)

Type	2012/2013	2013/2014	
	CS1	CS1	CS2
Tillage/Machine	350	350	401
Seed	84	61	47
Fertilizer	72	93	106
Pesticide	63	94	93
Labor	486	489	448
Pump	-	-	51
Total	1,055	1,087	1,145

3.3 Acceptability

In the research site, farmers planted rice only during the 1st crop season (CS1) in the period of 2012/2013 before the construction of SFR. Meanwhile, farmers could plant in CS1 and CS2 in 2013/2014, after SFR constructed. In CS2, in 2013/2014, the SFR owner planted some parts of their landholding, because he was afraid that the water stored in the SFR would not be sufficient for irrigation. Ariyanto *et al.* (2016) proved that the optimum irrigation area was larger than the SFR owners had planted. Thus, optimizing the cultivation area is necessary to maximize the benefits. Table 7 shows the net income estimated from the optimum irrigation area. The production from optimum irrigation area in CS2 of 2013/2014 (Table 7②) is estimated by mul-

tiplying the productivity of CS2 of 2013/2014 in Table 5③ with optimum irrigation area (Table 7①). Furthermore, the cost from optimum irrigation area in CS2 of 2013/2014 (Table 7⑤) is estimated by multiplying the cost per production of CS2 of 2013/2014 in Table 5⑥ with the estimated production (Table 7②).

Table 8 shows the result of *B/C* analysis by using the equation (1), from both actual and optimum irrigation areas. SFR tarpaulin is estimated to stand for three years, whereas SFR concrete stands for ten years. Thus, the depreciation period is set at ten years. The cost to replace the tarpaulin sheet every three years, i.e., in the 4th, the 7th year, and the 10th year, is included in the running cost for SFR tarpaulin, whereas the running cost for SFR concrete is assumed zero, because the cleaning of the SFR every year is considered to be done by family members.

The benefit is defined as the difference between the total net income before and after SFR constructs. The net income before SFR construction is regarded as the net income of 2012/2013, when farmer planted only in CS1. On the other hand, the net income after SFR construction refers to the net income of 2013/2014, when farmers could plant in both CS1 and CS2. Both tarpaulin and concrete linings are assumed to produce the same yield and income.

Table 7: Estimated net income from optimum irrigated area of CS2 in 2013/2014

Items (Unit)	SFR1	SFR2	SFR3	SFR4
① Optimum irrigated area (m ²)	962	4,080	5,624	3,499
② Estimated production(kg)	185	824	985	749
③ Productivity (=②/①) (kg/m ²)	0.19	0.20	0.18	0.21
④ Income(=②×4,000 IDR/kg)(IDR)	739,052	3,296,018	3,941,348	2,996,086
⑤ Cost(IDR)	218,513	978,211	1,048,342	880,368
⑥ Cost per production(=⑤/②) (IDR/kg)	1,183	1,187	1,064	1,175
⑦ Net income(=④-⑤) (IDR)	520,539	2,317,807	2,893,006	2,115,717

Table 8: Estimations of B/C

Materials	SFR1		SFR2		SFR3		SFR4	
	Actual	Optimum	Actual	Optimum	Actual	Optimum	Actual	Optimum
Tarpaulin	0.66	0.83	0.51	1.14	0.69	1.28	0.92	1.01
Concrete	0.79	1.03	0.75	1.69	0.84	1.58	1.15	1.29

Table 8 shows that all SFRs of tarpaulin with actual irrigation area are not acceptable with less than one of B/C value, whereas three SFRs (SFR2, SFR3, and STR4) with optimum irrigation area are acceptable with more than one of B/C value. On the contrary, SFR of concrete with actual irrigation area is acceptable only for SFR4, whereas all SFRs with optimum irrigation area are acceptable based on the B/C values. These results suggest that it is necessary to estimate the optimum irrigation area before applying SFR. Furthermore, it is clarified that B/C values of all cases of SFR concrete are higher than SFR tarpaulin.

3.4 Analysis of relation between B/C and SFR dimensions

Benefit is directly influenced by irrigation area, because the crop yield is in proportion to irrigation area. And irrigation area is decided by the volume of SFR and inflow from catchment area (A_c). However, the construction cost of SFR per its volume decreases along with the increase of SFR volume (V_{SFR}), because the construction cost is almost in proportion to lining area. Therefore, B/C value is expected to have correlation with two variables of WSI and A_c as the following equation (2).

$$\frac{B}{C} = a \times H_r A_c + b \times WSI + c \quad (2)$$

WSI (m) is a storage index proposed by Ariyanto *et al.* (2016) that expresses a SFR storage capacity (V_{SFR}) per a catchment area weighted the harvesting ratio (H_r), and the amount of rainfall stored by the SFR (Eq.(3)).

$$WSI = \frac{V_{SFR}}{H_r \cdot A_c} \quad (3)$$

where H_r is the harvesting ratio, which is assumed to be a constant as following equation (4), although it is influenced by the amount of rainfall (R), and the soil and landscape characteristics of the catchment area (Ariyanto *et al.*, 2015).

$$H_r = \frac{Q_{inflow}}{R \cdot A_c} \quad (4)$$

where Q_{inflow} is the inflow amount from the catchment area into the SFR during rainfall, and R is rainfall.

Table 9: Multiple regression analysis

Materials	a	b	c	r
Tarpaulin	0.55×10^{-3}	1.27	0.493	0.987
Concrete	0.56×10^{-3}	3.31	0.386	0.983

Table 9 shows that, from the results of multiple regression analysis, there is an extremely strong regression among three variables: B/C , WSI , and $H_r A_c$, with more than 0.98 of multiple correlation coefficients in both cases of tarpaulin and concrete. Furthermore, it is revealed that the partial regression coefficients (a) of $H_r A_c$ in both cases are almost same, but a partial regression coefficient (b) of WSI in SFR concrete is around three times bigger than tarpaulin. This suggests that the increase of SFR volume (V_{SFR}) heightens the B/C value in concrete lining more than tarpaulin under the same catchment area (A_c).

Figures 2 and 3 express the relationship among the three variables B/C , $H_r A_c$, and WSI based on the above multiple regression analysis. These figures show that B/C values increase along with the increase of $H_r A_c$ and WSI . If the catchment area (A_c) and the volume of the SFR (V_{SFR}) are decided, under the assumption that farmer cultivates the optimum irrigation area, the B/C values can be estimated accurately. Thus, whether the SFR construction will produce positive result or not can be known before construction commences.

Figure 2: The relationship between B/C , WSI , and $H_r \cdot A_c$ of SFR tarpaulin Figure 3: The relationship between B/C , WSI , and $H_r \cdot A_c$ of SFR concrete

4 Conclusion

It was clarified by Ariyanto *et al.* (2015) that the presence of SFR enabled farmers to cultivate paddy twice a year, because SFR could supply irrigation water during short drought and dry season in the 2nd crop season. In addition, the optimum irrigation area must be estimated as proposed by Ariyanto *et al.* (2016) in order to gain the maximum benefit of SFR, because B/C values for actual irrigation areas decided by farmers are lower than one, and not acceptable for almost all SFRs as can be seen in Table 8. Furthermore, the above results indicate that it is important to identify the catchment area (A_c) appropriately, in order to maximize the SFR benefits. Increasing the catchment area (A_c) can increase the B/C value through the water storage index (WSI). The B/C value can be estimated from Figs. 2 and 3 from the lining material, the catchment area (A_c), the harvest ratio (H_r), and the SFR volume (V_{SFR}) before the SFR construction commences.

Based on the analysis of the concrete and tarpaulin B/C values, concrete is recommended as lining material of SFR. The construction cost of SFR tarpaulin is lower, but its running cost is higher compared to SFR concrete, because tarpaulin needs to be replaced every three years with additional lining cost. On the contrary, the construction cost of SFR concrete is high, but the running cost is very low because it can stand for ten years and only requires periodic cleaning after construction, which can be done by the farmer and his family. Nevertheless, the high cost of constructing an SFR with concrete cannot be paid in a lump sum by common farmers, who rely only on farming. Thus, the subsidy or supporting system such as loan with long payback period with small interest from government is required to make this technology more accessible (Rozaki *et al.*, 2016b).

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