REVIEWS

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FEASIBILITY AND ADOPTION OF RAINWATER HARVESTING BY FARMERS

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ABSTRACT

Rainwater harvesting has been practiced for many years in several regions globally and is mainly used for domestic or agricultural purposes. Various studies on rainwater harvesting in dry or tropical areas of growing and developing countries for agricultural use have proved its benefits such as an increase in crop yields and facilitated a change to high-value crops. To optimize the advantages of rainwater harvesting, a design is required before it is constructed. The costs of this technology are affected by labor, materials, depreciation period, and running cost. Rainwater harvesting has been proved to be feasible, with a benefit cost ratio of up to 1.6 and internal rate return of up to 76%, although the net present value varies depending on the currency and location. Uncertainty with regard to rainwater harvesting technology still prevails and a common problem for small landholding farmers is having the finances required to begin. To address this problem, subsidies or access to loans is important.

Keywords: Adoption, Agriculture, Farmers, Feasibility, Rainwater harvesting

1. Historical Background of Rainwater Harvesting

Water scarcity has become an increasingly severe global problem due to factors such as climate change, water pollution, and the unsustainable consumption of water resources (Zhan *et al.*, 2009). This scarcity demands the maximum use of every drop of rainfall (Zreig *et al.*, 2000) and many methods have already been developed to deal with this. Rainwater harvesting (RWH) seems to be a beneficial method for minimizing water scarcity in developing countries (Helmreich and Horn, 2009; Dile *et al.*, 2013; Akter and Ahmed, 2015) and is a particularly useful adaptation to environmental stresses at the local scale (Pandey *et al.*, 2003).

RWH is one measure that enhances the resilience of human society towards a water shortage problem (Lee, 2016). Given these benefits, RWH is suitable for small farmers who are threatened by climate's unpredictability, unstable markets, and insecure conditions due to social, economic, and state politics (Fox *et al.*, 2005).

Over thousands of years, indigenous RWH and management regimes were used and have adapted to climate change (Pandey *et al.*, 2003). Surface run-off and RWH techniques were extensively practiced up to 4,000 years ago in Jordan, as seen in the example of Roman Pools near Ajlun, Madaba, and Mwagger (Abdulla and

Al-Shareef, 2009). In Sub-Saharan Africa, this method is used to overcome dry spells (Fox *et al.*, 2005), and a history of RWH has also been reported in India (Glendenning *et al.*, 2012) and Sri Lanka (Dharmasena, 1994).

Commonly, there are two types of RWH methods: (1) domestic usage, using rooftops as the catchment area (Abdulla and Al-Shareef, 2009; Mun and Han, 2012; Sturm *et al.*, 2009), and (2) agricultural usage, using the open field as the catchment area (Li *et al.*, 2006; Panigrahi *et al.*, 2007; Xiao *et al.*, 2007). This review focuses on RWH for agricultural uses especially small farm reservoir (SFR) in dry or tropical areas of growing and developing countries, and presents the economic advantages of SFR and methods to adopt RWH technology.

2. Definition and Design of RWH

RWH can be defined as the collection of rainwater run-off for domestic water supply and/or agricultural and environmental management (Worm and van Hattum, 2006). The technology comprises surface collection (catchments), water storage, and supplementary irrigation systems (He *et al.*, 2007). Domestic RWH usually uses rooftops as the catchment area and tanks

are used to store the water (Fig.1), whereas agricultural RWH commonly uses land areas as the catchment area and ponds are used to store the water (Fig.2) (Helmreich and Horn, 2009).

Fig.1 is the example of RWH which used rooftops as catchment area in Saya Town, Ama District, Aichi Prefecture, Japan (Itou *et al.*, 2002). This technology was used for watering vegetables inside a green house. Planting inside the green house cannot obtain rainfall directly due to be covered by plastic sheet, so needs alternative water resource. RWH was chosen as water resource, due to be more accessible and produce clean water. Rainfall run-off flows through roof top (1,080 m²) to roof gutter. Water from roof gutter then flows to tank (38.6 m³) through pipe. Using drip irrigation, stored water is used for watering vegetables. In this case, harvest ratio of annual rainfall was around 40%. And Fig.2 is example of RWH which used land areas as catchment area in Gondangrejo Sub-District, Karanganyar Regency, Central Java, Indonesia (Ariyanto *et al.*, 2016a, 2016b). This RWH was built in the paddy field for overcoming unstable rainfall and short drought which often occurred in this area. Catchment area is open field of 4,184 m². Rainfall run-off flows through catchment area to reservoir, built with tarpaulin lining for anticipating infiltration. The volume of reservoir was 132 m³, in which stored water was drained by pump machine or bucket to paddy field gradually based on rainfall

condition. Irrigation area that could be supplied by this reservoir was up to 4,080 m².

One of the major challenges in the application of RWH for agriculture is effective utilization of limited amount of water harvested and stored in SFR mainly for supplemental irrigation (Ngigi *et al.*, 2005). Therefore, considering the size of SFR and the actual water demand is essential for the proper management of rainwater for agriculture (Yuan *et al.*, 2003; Balooni *et al.*, 2008; Contreras, 2013). Management can be organized at the individual or group level. Farmers with more farming experience can further improve their ability to manage RWH well (Wakeyo, 2013).

The design of SFR systems is important to optimize the SFR volume. Specific research on the design of SFR systems for agriculture is still limited. Ariyanto *et al.* (2016b) have conducted research of SFR in tropical area of Indonesia which has unstable rainfall in the rainy season and dry condition in the dry season, this research showed that the SFR volume could be calculated with some available data, such as irrigation area, crop pattern, catchment area, and climatic data (shown in equation 1).

$$SFR_{ref} = \frac{Q \times A}{1000} \dots \dots \dots (1)$$

where SFR_{ref} is reference SFR volume (m³), Q is runoff (mm)

Fig.1. RWH using rooftop of green house for catchment area and tank for storing water. (1.1: Water (run-off) flowing from rooftop to roof gutter, 1.2: Water flowing from roof gutter to pipe, 1.3: Water flowing from pipe to tank for being stored, 1.4: Water is used for watering vegetables. Photos by Itou *et al.*, 2002)

Fig.2. RWH using land surface for catchment area and reservoir for storing rain-off. (2.1: Water (run-off) flowing from catchment area to reservoir, 2.2: Water is stored in reservoir, 2.3: Water is used for watering paddy. Photo by Ariyanto *et al.* 2016a, 2016b)

and A is catchment area (m^2). In this research, Q can be calculated using the following formula.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \dots \dots \dots (2)$$

where S (mm) is the potential maximum soil moisture retention after runoff begins, which is expressed as a function of the curve number CN (a dimensionless value from 0 to 100):

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \dots \dots \dots (3)$$

CN was determined to be 78 from the land characteristics (good hydrology, field infiltration of 9.72 cm/h and permeability rate is of 4.73 cm/h).

Ariyanto *et al.* (2016b) also showed that with the availability of SFR volume, crop type, catchment area, and climatic data, the optimum irrigation area can be calculated. Two crop types (rice and peanut), five SFRs, and 2 year climatic data, were simulated to obtain optimum irrigation area.

The next part of an SFR design is selecting the lining material, which can be a soil base, tarpaulin seal, or concrete. Based on strength, concrete is the better option, but it is often not economically viable due to high construction costs. The most affordable material is a soil base, but Fox *et al.* (2005) stated that infiltration loss especially

in dry areas is a major problem in optimizing SFR. The infiltration rate of moisture in the soil and rainfall intensity and duration affect the amount of water to be harvested from a land surface (Amu-Mensah *et al.*, 2013). To overcome this, sealing technology becomes important. Furthermore, in their analysis, Fox *et al.* (2005) used four common sealing technologies; cement, thick (4 mm) rubber tarpaulin, thin (1 mm) plastic sheeting, and self-sealing (sediment transported with the harvested water causing clogging). Under cement sealing, more than 70% yield can be ensured, whereas self-sealing cannot succeed in the first year. Moreover, tarpaulin and plastic seals are limited due to their short durability.

3. Costs

The result of a cost-benefit analysis will be strongly affected by whether the labor to construct the RWH system was included as a cost (Fox *et al.*, 2005). Labor is the major capital expenditure in constructing SFR as they are manually dug by human power. Family labor does not require payment, which will save on SFR construction costs (Teshome, 2010). In family farm concept in growing and developing countries, family member is not accounted in economic calculation (Jervell, 1999). A review paper on household RWH in Ethiopia by Moges *et al.* (2011) showed

that farmers commonly hired labor for weeding and harvesting, and the remaining jobs were performed by family members whose cost was unaccounted. Thus, this family farm concept can save up to 50% of the cost. Fox *et al.* (2005) explained that there are three types of labor opportunity cost in Kenya: full opportunity cost, alternative opportunity cost, and zero opportunity cost. Gender equality is also important, and it does not discriminate between male or female family members as laborer in semi-arid or dry area of Brazil (De Moraes and Rocha, 2013). Gladwin (1985) reported some reasons why female family members helped in farming were generation income, helping children, lifestyle, personal autonomy, self-sufficiency, and to farm was the goal in itself.

Furthermore, local masons should be trained to build the RWH system in order to further reduce construction costs (Alam *et al.*, 2012). Thus, to minimize construction costs, family labor, local materials and equipment, and local skill should be used as much as possible during the construction of RWH systems (Handia *et al.*, 2003; Alam, *et al.*, 2012). Rozaki *et al.* (2017) explained in their research that SFR cost include that of excavation and sealing material. Cost depends on the volume of SFR and the type of sealing material as shown in Fig.3. Ngigi *et al.* (2005) showed that for agriculture in Kenya, the investment cost to improve RWH is US\$ 650, which was the cost dominated by plastic lining.

Another aspect related to RWH construction costs is the depreciation period, which depends on the lining material: soil base, plastic sheet, or concrete. For example, Fox *et al.* (2005) set the depreciation period for a cement-lined reservoir as 20 years, tarpaulin plastic seal as 10 years, and thin plastic seal as 3 years.

4. Benefits

RWH has been proved to be an economically promising technology by many researchers (Fooladmand and Sepaskhah, 2004; Liang and Pieter van Dijk, 2011; Contreras, 2013; Komariah and Senge, 2013; Dile *et al.*, 2013; Zingiro *et al.*, 2014; Lage and Verburg, 2015; Zhou, 2015). First, applying RWH increased the crop yield of rice (Ngigi *et al.*, 2005; Hatibu *et al.*, 2006; Ariyanto *et al.*, 2016a); millet (Tabor, 1995), onion, wheat, and potato (Teshome, 2010; Hu *et al.*, 2014); corn (Yuan *et al.*, 2003); and other crops by overcoming drought with supplemental irrigation. Rozaki *et al.* (2017) showed that the main benefit of the SFR construction in tropical area of Indonesia is that the potential of planting twice a year, which was not possible earlier. In addition, Ngigi *et al.* (2005) showed that the profit per season in semi-arid or dry area of Kenya is of US\$ 250, which can be used by the farmers to payback the initial cost of four seasons (2 years).

Secondly, RWH enables farmers to cultivate high-value crops with very significant associated improvements in income and livelihood (Senkondo *et al.*, 2004). For example, Hatibu *et al.* (2006) in East Africa and Ngigi *et al.* (2005) in Kenya had shown that rice could be planted after the introduction of RWH instead of sorghum and maize that were grown when water supply was difficult. Another study by Teshome (2010) in Minjar Shenkora district of Ethiopia showed that after the construction of RWH systems, onion could be planted, which increased the income compared to the previously planted rain-fed teff (*Eragrostis tef*) and wheat. Rainwater harvesting also did increase farm incomes in different agro climatic regions of India as well (Kumar *et al.*, 2016).

Fig.3. Correlation of volume and cost of SFR. This correlation was analyzed from four SFRs of two different lining technology; tarpaulin and concrete. Based on Rozaki *et al.*, 2017.

The economic benefits of RWH are not only an increase in crop production but also increased production from the other economic activities related to RWH, such as fish production and water supply for domestic use or livestock (Contreras, 2013; Kumar *et al.*, 2016). Furthermore, other economic benefits were for women and children who could grow vegetables that improved household nutrition and provided income from the sale of some crops (Teshome, 2010). These improvements in economic conditions also led to food security, income generation, poverty reduction, and better livelihoods (Ngigi *et al.*, 2005).

The benefit of RWH can be obtained if reinforced by other supporting aspects such as markets in which RWH products can be sold to provide economic benefits (Hatibu *et al.*, 2006; Karpouzogluo and Barron, 2014). This kind of activity is related to the role of government, and Ngigi (2015) showed that with some assistance from the government and development agents, farmers have been adopting various RHM systems.

5. Feasibility

When applying an RWH system, it is necessary to consider the most appropriate crop whose growth will coincide with prevailing local rainfall events (Yuan *et al.*, 2003; Morales-Pinzon, 2014). Based on research by Liang and Pieter van Dijk (2011) in China as well as Pandey and Soupir (2011) in India, the feasibility of an RWH system depends on the size and material. The direct economic viability of an RWH system also depends on the balance of costs: investment and running and maintenance costs of the system (Silva *et al.*, 2015). Other factors that affect the feasibility are rainfall reliability and distribution, water management, soil characteristics, and types of crops (Ngigi *et al.*, 2005).

The most commonly used methods to calculate the feasibility of RWH are yield comparisons, gross margin analyses, and investment analyses (Senkondo *et al.*, 2004). In an investment analysis, the net present value (NPV) and internal rate of return (IRR) are often used to analyze the feasibility of an RWH system (Senkondo *et al.*, 2004; Morales-Pinzon *et al.*, 2014; Matos *et al.*, 2015). In an investment analysis of RWH, this technology is assumed as a project. NPV evaluates RWH by converting all future cash flows into their present equivalent value in cash. The RWH is feasible when the NPV value is positive (Badiru and Omitaomu, 2007). The equation to calculate NPV (Dayananda *et al.*, 2012) is presented as follows.

$$NPV = \sum_{t=1}^n \frac{C_t}{(1+r)^t} - CO \dots\dots\dots (4)$$

where t is the time of cash flow, r is the discount rate, n is the depreciation period, C_t is the net cash inflow at time t , and CO is cash outflow.

IRR is known as the discount rate that makes the NPV of all cash inflows of a project equal to zero. A feasible project is one whose IRR is positive and higher than the decided discount rate (Gallagher and Andrew, 2007). Equation (4) can be used to analyze the IRR.

Senkondo *et al.* (2004) used NPV, IRR, and a benefit to cost ratio (B/C) to evaluate the RWH in semi-arid or dry area of Tanzania. The B/C ratio is the ratio of discounted benefits to costs. If its value is more than one, then the project is acceptable; if it is less than one, then the project is not acceptable. A ratio of one indicates a break-even situation for the RWH. Below is Equation (5).

$$\frac{B}{C} = \frac{\sum_{t=1}^n B_t (1+r)^{-t}}{\sum_{t=1}^n C_t (1+r)^{-t}} \dots\dots\dots (5)$$

where B_t is the benefit (receipt) at time t , r is the discount rate and C_t is the cost (disbursement) at time t (Badiru and Omitaomu, 2007).

Senkondo *et al.* (2004) defined that the RWH benefit was due to the increase of NPV through the application of RWH and their analysis was applied to three crops in semi-arid or dry area of Tanzania: paddy rice, onion, and maize. Paddy rice and onion could not be planted without RWH, while maize could. Each crop was located in a different area with a different RWH system. Paddy rice used a bunded basin called a *majaluba*, onion used an RWH storage structure called a *ndiva*, and maize used canals (head, middle, and tail). Their depreciation period was 10 years, after which it was assumed that the RWH structures would need to be re-constructed or undergo a major restoration. The economic analysis results of NPV, IRR, and B/C ratio at the discount rate of 20 % (local bank discount rate) are presented in Table 1.

Senkondo *et al.* (2004) showed that maize, paddy, and onion are feasible under an RWH application because the NPV is positive and the IRR is higher than the discount rate of 20% (Table 1). The NPV analysis showed that onion was the most feasible crop with the highest NPV value, and the IRR analysis showed that maize was the most feasible crop with the highest IRR value. The B/C ratio analysis showed that only paddy had a ratio ≤ 1 , meaning that the cost was higher than or equal to the benefit. Among the three crops, onion was the most feasible with the highest NPV. NPV is considered first because this analysis shows the value of cash, while the other analyses show the rate.

Table 1: Economic analysis of RWH (after Senkondo *et al.*, 2004).

Crop	NPV (Tanzanian Shillings)	B/C ratio	IRR (%)
Maize	202,460	1.6	57
Paddy	7,549	1.0	31
Onion	1,155,384	1.5	38

Rozaki *et al.* (2017) used B/C ratio to analyze the feasibility of RWH in tropical area of Indonesia for two different sealing technologies, tarpaulin and concrete, using four SFRs for cultivating rice with a discount rate of 9%, which showed that tarpaulin and concrete could produce B/C ratio up to 1.69 and 1.28, respectively. Ngigi *et al.* (2005) research in arid and semi-arid or dry area of Kenya also obtained a B/C ratio of 1.53 and recommended enlarging the reservoir to obtain more benefits. Matos *et al.* (2015) obtained IRR at a discount rate of 5%, with the result ranging from 23% to 76%. Morales-Pinzon *et al.* (2014) obtained NPV of greater than 270 €. Rozaki *et al.* (2017) stated that if the catchment area and the volume of SFR are decided, under the assumption that farmer cultivates the optimum irrigation area, the B/C ratio can be accurately estimated. They also showed that increasing the catchment area can increase the B/C ratio.

6. Adoption

Adoption is the main purpose in technology development, because it is the indicator that the technology is useful and accepted. The process is not easy because internal and external factors are complicated and affect the decision of adoption. In standard investment theory, the best investment strategy is the one that brings the highest economic profit. Economists make the point that when a new technology is introduced, its success depends on it being both technically and economically viable (Fox *et al.*, 2005).

The more informed people are of the benefits of RWH, the more motivated they will be, and adoption of RWH systems will increase. The positive benefits of RWH are the need to be informed, such as through extension programs which succeeded in Kenya, Burkina Faso (Fox *et al.*, 2005), China (He *et al.*, 2007; Wu *et al.*, 2015) and Rwanda (Zingiro *et al.*, 2014). The economic benefit is affected by the starting point of RWH construction: catchment area, water storage, and irrigation facilities. They are the basic factors that impact the costs of RWH and supplemental irrigation in agriculture (Yuan, 2003).

The required investment is assumed to be covered through a loan, since it is unlikely that a small landholding farmer would otherwise be able to provide the capital necessary for the investment. The loan is repayable in fixed annual installments at a fixed interest rate (Fox *et al.*, 2005). Access to a loan is one of the critical inputs required by small-scale farmers to implement new agricultural technologies that boost agricultural productivity (Brehanu and Fufa, 2008). Without access to a loan, RWH is often unaffordable to an individual farmer (He *et al.*, 2007); the limit of extension, credit, and assistance will also hamper the adoption of an RWH system (Wu *et al.*, 2015). Baguma and Loiskandl (2010) showed that a subsidy provision was statistically significant for the adoption of RWH technologies in rural Uganda. Several countries, such as in Spain, Brazil, and Australia,

also have tried to provide a subsidy when adopting RWH technology for domestic (Domenech and Sauri, 2011). It is the role of government to provide subsidies to small landholding farmers for the construction of RWH systems (Balooni *et al.*, 2008).

Adoption is not always about showing the positive aspects of the technology, but also any negative impacts or challenges that may emerge during its implementation. Researchers and development agents more often confront farmers with only the positive aspect of a technology, while farmers are also concerned about the failure of technology. In some cases, even once the positive results has been shown to farmers, their skepticism regarding the use of RWH technologies prevails, particularly in low-precipitation areas. This is because the socio-economic features of the farmers may certainly influence the perception and attitudes towards RWH systems (Domenech and Sauri, 2011; Kumar, 2016). In other words, we need to understand the farmers' goals and decision-making dilemma under risky and uncertain conditions given that food self-sufficiency is the primary goal for most subsistence farmers (Ngigi *et al.*, 2005).

The adoption RWH technologies by farmers is affected by their educational background, physical assets, household size, farm income, group membership, active labor force size, contact with extension, participation in a government project, and positive attitudes towards RWH. The adoption will increase with the support of credit access and advisory and technical training. The close relationship of researchers or government advisors increases the adoption rate (He *et al.*, 2007; Wakeyo, 2013; Zingiro *et al.*, 2014; Kimani *et al.*, 2015; Wu *et al.*, 2015; Kumar *et al.*, 2016). The flow of adoption can be seen in Fig.4.

7. Conclusion

RWH is a common technology used to overcome water deficit in getting less rainfall and has been practiced since a long time. In dry or tropical areas of growing and developing countries, RWH provides various benefits, such as increase in the crop yield, change to high-valued crops, fish production, and livestock use. RWH also results in doubling of the income because of the potential of planting twice a year. Therefore, investing money in RWH will be a right choice for farmers in dry or tropical areas to obtain higher income. The costs of this technology are affected by labor, sealing materials, depreciable period, and running costs. With the availability of crop type, catchment area, and climate data, SFR volume can be calculated to obtain the optimum result. Further research is essential for improving the SFR volume, whose results can assist in good SFR construction using calculations, enabling the cost and benefit to be calculated before beginning the construction.

The method, such as NPV, IRR, B/C ratio, or other economic analysis, to analyze the feasibility of RWH can be chosen based

Fig.4. RWTH adoption diagram. This diagram was designed from various references (Yuan, 2003; Fox *et al.*, 2005; Ngigi *et al.*, 2005; He *et al.*, 2007; Brehanu and Fufa, 2008; Balooni *et al.*, 2008; Domenech and Sauri, 2011; Wakeyo, 2013; Zingiro *et al.*, 2014; Kimani *et al.*, 2015; Wu *et al.*, 2015; Kumar *et al.*, 2016).

on the requirement; however, to confirm whether RWTH is feasible, the use of more than one method is advisable. Some studies have proven that RWTH is feasible technology, with a B/C ratio of up to 1.6 and IRR of up to 76%. Because of the initial high cost, farmers can borrow the initial cost, which can be repaid over a long period and with a small discount rate to obtain the optimum benefit. Therefore, subsidies and access to credit with a small flat loan interest are needed to boost the RWTH adoption. In this case, government or other parties play important roles in providing good access to subsidies or credit for farmers.

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