Rain Water Harvesting Technology: Drinking water fulfillment and water conservation nearby landfill area

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Rain Water Harvesting Technology: Drinking water fulfillment and water conservation nearby landfill area

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Abstract. The drawback of groundwater quality occurs due to minimum treatment of waste management in the landfill. The research objectives are to know the groundwater quality around the landfill study site, rainwater potential for drinking water purposes, and decreasing runoff due to rainwater harvesting technology implementation. The well water samples were collected from eight wells surrounding the landfill. Rainwater samples were collected from rainwater harvesting technology installation. Water quality parameters consist of total coliform, pH, and Total Dissolved Solids (TDS). Water conservation was observed by infiltration and precipitation. Total coliforms of well water are higher than rainwater. Furthermore, based on acidity and TDS values, well water is higher (pH 6.5-8.5 and TDS 188.8 $\pm$ 128.7 ppm, respectively) than rainwater (pH 6.1 $\pm$ 0.2 and TDS 8.4 $\pm$ 1.4 ppm, respectively). Based on three parameters, rainwater is more proper for drinking water than well water in the study site. Rainwater harvesting technology is able to reduce runoff by 58.42% with the rainwater catchment area around 7,095 m^2. Waste management in landfills should concern with groundwater pollution. Rainwater harvesting technology is a potential solution for drinking water supply in water crisis areas.
Keywords: drinking water, eco-hydrology, groundwater, landfill, rain harvesting

1. Introduction

The population growth is followed by an increase in domestic waste [1, 2]. As minimum waste management, it has been reported that 33% of 2 billion tons of solid waste is not managed safely [3]. Poor waste management leads to environmental pollution, especially of surface and groundwater [4-6]. Due to the waste accumulation, leachate enters the surface runoff and some of it has seeped into the groundwater. Several diseases in the community surrounding the landfill, such as diarrhea and indigestion, are caused by drinking water with coliform contamination [7, 8]. Precipitation, soil composition, and cover affect the degree of infiltration possible to transport bacterial contaminants [9].

The drawback of surface and groundwater was reported due to leachate from landfill [10]. Several influencing parameters were examined, namely distance and seasonal conditions. Bacterial contaminants spread up to 5 km from the landfill with increasing distance followed by decreasing bacterial contaminants [11]. The number of coliform bacterial infections was also reported to be higher in the rainy season than in the dry season, which was due to bacterial contamination involved in the infiltration process and surface runoff [11, 12]. Few studies present the relationship between water quality and spatial variability (i.e. horizontal distances and differences in height).

Soil and water conservation technologies have been developed in different regions of the world. Africa, which has a major scarcity problem, has indigenous technology [13]. Rain harvesting technology is known for various purposes such as: to meet the needs of drinking water, agriculture, household needs, etc. [14]. The use of rainwater for drinking water is still controversial. Some studies reported on the dangerous content of rainwater, e.g. microbiology, harmful minerals, and pathogenic organisms [15]. In Mexico, the properties of rainwater from roofs collector comply with national and international drinking water standards. Several factors contributed to the contradiction, namely: tree waste, water contaminants, mineral, and animal waste [16]. Research into the properties of rainwater for drinking water replenishment is therefore not yet known.

Based on the justifiable problem of groundwater quality and the problem of conserving water resources around the landfill, the study aims to (a) know the distribution of groundwater quality around the landfill by spatial variability, (b) the potential rainwater for drinking water source alternative; and (c) the potential of rainwater harvesting technology for water conservation.

2. Materials and method

2.1. *Study site*

The research was conducted around the Kaliori landfill, Banyumas Regency, Indonesia (Figure 1). The study site is at east longitude 109°17'19" - 109°17'35" and south latitude 7°29'43" - 7°29'30". The data was collected between mid to the end of 2018. The Kaliori landfill is the largest landfill in Banyumas Regency with a coverage of around 4.5 ha and processed around 400 tons d^{-1} of household waste. It comes from Banyumas people, which numbered about 1.7 million people in 2019. Banyumas population growth is 2.7% annually and 1,275 people/km^2 of population density.

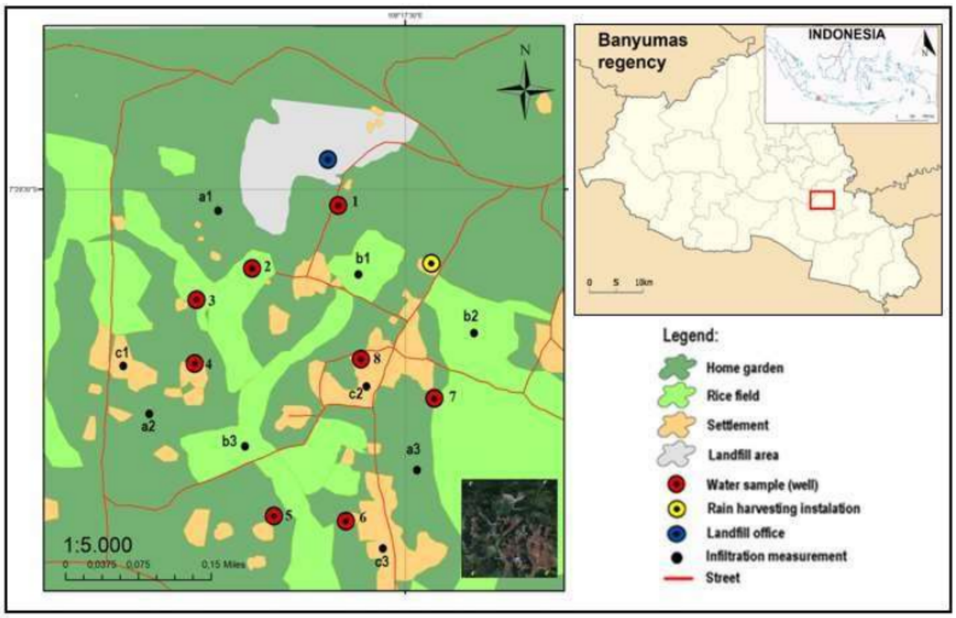

Figure 1. The study site of Kaliori Landfill area, Banyumas regency, Indonesia.

The site of this study is a hilly area north of the Serayu River at elevation between 57.6-64.4 m above sea level. Climate classified as Koppen classification that a humid tropical climate with an air temperature of 26.3^{0}C. The land use land cover (LULC) is divided into 3 types, namely: paddy field (Figure 2a), home gardens dominated by teak and banana plants (Figure 2b), and settlements consisting of houses and yards scattered sporadically (Figure 2c). Since 2018, the Kaliori landfill area has been used for dumping with approximately 3.5 ha of coverage area (Figure 2d). The drawback condition of the landfill is present because of the large volume of public disposal. Since 2018, the surrounding community protested against the government over the pollution of surface water in rivers and paddy fields (Figure 2e). Changes in source water quality around the landfill are also possible due to waste contamination at the landfill (Figure 2f).

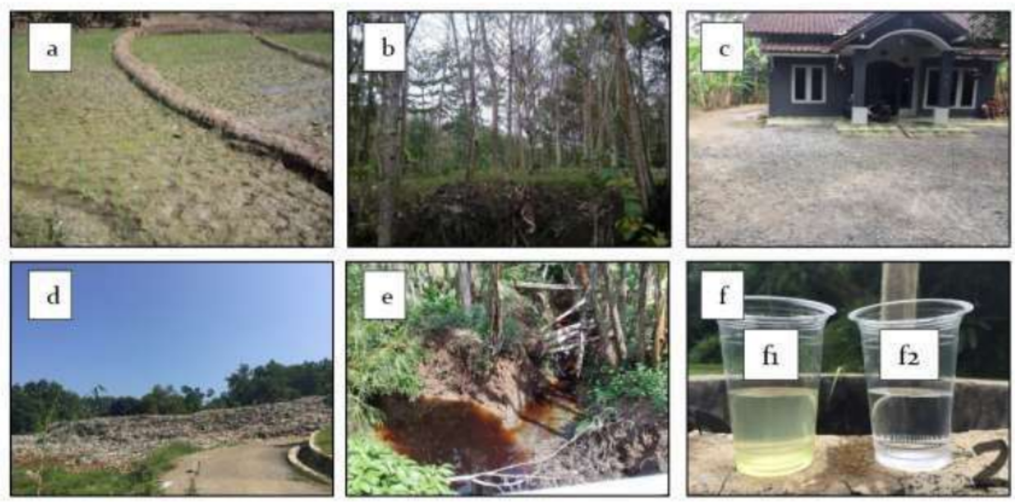

Figure 2. Land use land cover of the study site has three classifications, i.e. paddy field (a), home garden (b), and settlement (c). The Kaliori landfill condition (d) affected the surface water (e) and the well water quality (f1) as compared to rainwater (f2)

2.2. *Water quality measurement*

Water quality tests were performed on well and rainwater samples. The well water samples were collected from eight wells scattered throughout the landfill using the purposive sampling method based on variations in distance and different heights. Meanwhile, rainwater is collected from the rainwater harvesting technology installed in one of the resident's houses (Figure 1). The measured water quality includes physical and microbiological parameters, namely: total coliforms, pH, and TDS. The drinking water standard refers to the regulation of the national drinking water quality standard.

The total number of coliforms was used in the two-stage of the Most Probable Number (MPN) tests, namely the presumptive and the confirmatory test [17]. Before starting the test, the equipment was sterilized using an electric autoclave at 121°C. The pH and TDS values were measured directly in the field with standard pH and TDS meters, respectively [18]. The interaction relationship between spatial variability and each water quality parameter was statistically analyzed by multiple linear regression with a confidence level of 95%.

2.3. *Soil characteristics*

Soil properties measured in this study include soil texture and porosity. Analysis of the soil texture using the pipette method with the percentage of sand, silt, and clay particles. The starting point for the determination is that organic substances are oxidized with H2O2 and the soluble salts are removed from the soil with HCl when heated. The remaining material is a mineral made up of sand, silt, and clay. Sand can be separated by wet sieving while dust and clay are separated by Stoke's law.
Determining ground texture with the texture triangle [19]

Porosity, or soil pore space, is the volume of all pores in an intact volume of soil, expressed as a percentage. Porosity consists of the space between sand, silt, and clay particles and the space between soil aggregates. Depending on size, soil porosity is classified into capillary pore spaces, which can inhibit the movement of water in capillary movement, and non-capillary pore spaces, which can provide opportunities for rapid air movement and seepage, so they are often called drainage pores. Soil porosity is a function of bulk density and particle density (Eq. 1)

$$\text{Soil porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right).100 \qquad (1)$$

2.4. *Infiltration rate and capacity*
Infiltration measurements were performed 3 times for each type of soil cover (Figure 1). Measurements with a double-ring infiltrometer. This analysis was performed to determine the infiltration rate and capacity in each land cover. The data from the field infiltration rate measurement is then calculated using the Horton model equation (Eq. 2).

$$f = f_c + (f_0 - f_c)e^{-Kt} \qquad (2)$$

Note:
f = Infiltration capacity *(*cm. h^{-1}*)*
fc = infiltration rate at a constant rate (cm. h^{-1})
fo = initial infiltration rate (cm. h^{-1})
K = constant geophysical
t = time
e = 2.718

2.5. *The rain harvesting technology and runoff*
Rain Harvesting Technology is a rain collector whose main input comes from rainwater falling on the roof surface of the house. The collected rainwater is then stored in a water reservoir with a capacity of 1,000 l. The rain collection technology is equipped with vertical drainage under the water reservoir. Pipe installation and water storage with polyvinyl chloride (PVC). Rainwater that exceeds the water storage capacity is then channeled into the ground through infiltration wells with a capacity of 3,000 l. If a house has a roof area of approximately 60 m^2, the vertical drainage can absorb rainwater with an intensity of approximately 50 mm. d^{-1}. The potential of rain collection technology to reduce runoff was analyzed using a water balance equation approach applying the relationship between inflow and outflow [20] (Eq. 3-4).

$$Ro = P - \Delta S \qquad (3)$$
$$Ro = P - I - Et \qquad (4)$$

Noted: Ro= *runoff*, ΔS= water storage; P= precipitation, I= infiltration, and Et= evapotranspiration. Because of instantaneous rain data, the Et value is ~0. Thus, the equation for the potential of rain harvesting technology to reduce runoff is a function of runoff, rainfall, and infiltration (Equation 5).

$$Ro = P - I \qquad (5)$$

3. Results and discussion
3.1. *Water quality*
The total levels of coliforms in the wells around the landfill site were mostly above the usual drinking water standard, with the exception of the furthest away wells 5 and 6 (> 500 m). Meanwhile, well no. 1 is the highest total coliform count with over 1,600 colonies. 100 ml^{-1}. The rainwater has a total coliform content below the national standard (Figure 3). The horizontal distance has a significant relationship with the total coliform content, but no relationship was found for the height difference parameter (Table 2). Distance between sources of bacteria (e.g. septic tanks, landfills) has also been found to be a factor in the spread of coliform bacteria [11, 21, 22]. However, several studies state that there is no correlation between distance and the spread of coliform bacteria [23]. It is caused by several factors such as soil conditions, rainfall intensity, pH, temperature, groundwater flow, and geology [24]. A sandy soil and high porosity structure facilitate the flow of leachate and microbial contaminants [25]. In the rainy season, the infiltration process is greater. Thus, coliform bacteria can enter the soil and contaminate groundwater [26, 27].

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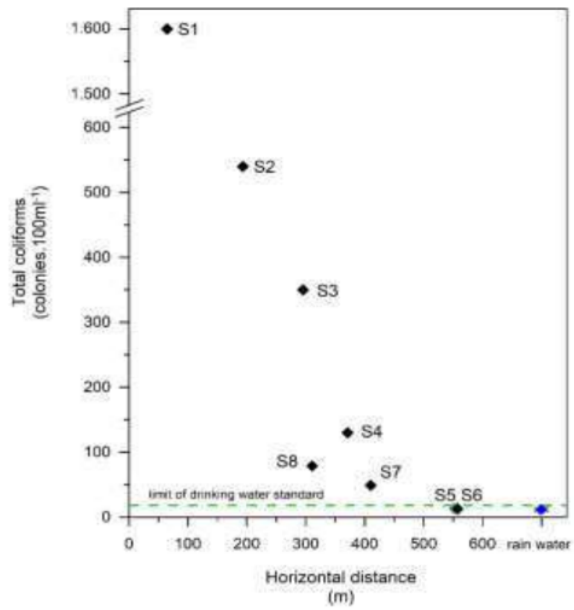

Figure 3. Total coliforms of water samples from eight wells (S1-8) and rainwater regarding horizontal distance from the landfill

The TDS in eight well samples was below the standard drinking water standard, although the values varied (Figure 4). Based on horizontal distance and height difference, landfills have no correlation with TDS. The rainwater sample also has a low TDS value (Table 1). The highest TDS value was in well no. 5. It occurred due to the well location such as in a valley and contamination occurs around the well [28].

Table 1. Water sampling location and quality

Water sample	Altitude (m above sea level)	Total coliforms (col.100ml-1)	TDS (ppm)	pH
S1	58	>1600	154	8,2
S2	45	540	201	7,5
S3	44	350	38	6,7
S4	46	130	203	7,4
S5	39	13	471	7,2
S6	47	13	210	7,4
S7	44	49	93	7,2
S8	53	79	140	7,7
Rainwater	78	12 + 2,6	8,4 + 1,4	6,1 + 0,2

Table 2. Multiple linear regression of well water quality and distance

No	Dependent variables (Y_n)	Independent variables (X_n)	Path coefficient (β)	p-value	R^2	Coefficient
1	Total coliforms	X_1 X_2	-2,194 -21,,581	0,049*) 0,480	0,73	0,03*)
2	TDS	X_1 X_2	0,294 3,497	0,497 0,771	0,26	0,48
3	pH	X_1 X_2	0,0001 - 0,063	0,878 0,054	0,68	0,06

Noted: Xn are independent variables namely horizontal (X_1) and altitude difference (X_2) between well water sampling location and landfill; *)significant different test at 95% confidence level.

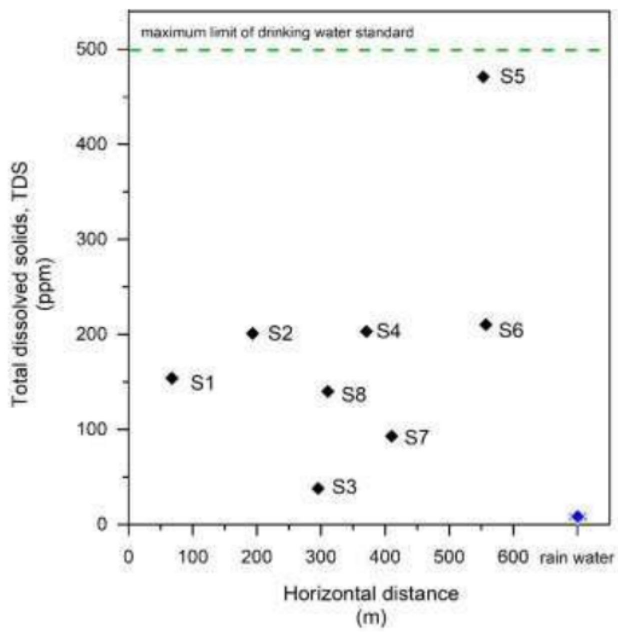

Figure 4. Total dissolved solids (TDS) of water samples from eight wells (S1-8) and rainwater regarding to horizontal distance from the landfill.

The acidity of the water is in the range of the drinking water standards (pH 6.5-8.5), while for rainwater it is below the threshold of 6.1 + 0.2 (Figure 5). The parameters of horizontal distance and site height are not related to the acidity of the water (Table 2). The low acidity is an unsuitable condition for coliform bacteria, while the most optimal pH for the growth environment for coliform bacteria is between 5 and 6.4 [29].

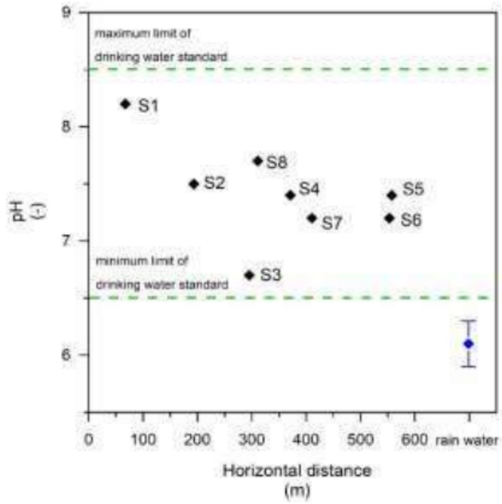

Figure 5. The water pH from eight wells (S1-8) and rainwater regarding horizontal distance from the landfill.

3.2. Soil characteristic and infiltration process

Infiltration is the process of moving water vertically from the soil surface to the soil, usually through rain. The amount of water that can enter the soil through the infiltration process is influenced by several factors, including the type of soil cover and the physical properties of the soil (texture and porosity). The soil texture around the study area is homogeneous, dominated by clay, with a porosity of each type of soil cover ranging from 51.3-64.2%. The home garden is the dominant LULC (i.e. 100,245 m^2) and is an uninhabited area with a roof area of approximately 7,095 m^2. Wet farmland planted with rice is located in the valley area with an area of approximately 66,633 m^2 (Table 3).

Table 3. Soil texture, infiltration characteristics, and area of study site across three LULC types

No	LULC	Area (m^2)	Soil texture	Soil porosity (%) ± se	Infiltration rate (mm. h^{-1}) ± se	Infiltration capacity (mm. h^{-1}) ± se
1	Paddy field	66,633	Clay	64.2 ± 3.5	1.1 ± 0.3	0.6 ± 0.2
2	Settlement:					
	a. Roof area	7,095	-	-	-	-
	b. Yard	30,661	Clay	59.4 ± 2.2	6.1 ± 0.8	5.9 ± 0.4
3	Home garden	100,245	Clay	51.3 ± 2.4	8.5 ± 1.4	7.3 ± 1.4

The finer soil structure (e.g. clay) has denser soil pores than the coarser soil structure (e.g. sand), which hinders the penetration of water into the soil [30]. The pore space in sandy soils (coarse structure) is small because the volume of the small pores it contains is very small and is good for the movement of water and air. In addition, the water-holding capacity is also low. In contrast, fine-textured soils generally have more pore space but are composed of small pores, so their water-holding capacity is higher. Thus, the greater the number and the greater the pore size of the soil, the greater the infiltration capacity [31].

The type of soil cover influences the size of the infiltration. Home gardens had the highest infiltration rates (8.5 + 1.4 mm.h^{-1}) compared to paddy fields and yards (1.1 + 0.3 mm.h^{-1} and 6.1 + 0.8 mm.h^{-1}, respectively; Figure 6). The more vegetation on the ground cover, the greater both the infiltration rate and the infiltration capacity. The type, location, and variation of vegetation influence the size of the infiltration [32-34]. Meanwhile, the highest infiltration capacity is also shown in the vegetable garden, then in the yard, and in the paddy fields (Table 3). Less infiltration capacity in the paddy field is due to the saturation state, thus all soil pores are filled with water [35]. Vegetation function can effectively reflect the soil ability to absorb rainwater, maintain or increase infiltration rate, and demonstrate water-holding capacity [36, 37].

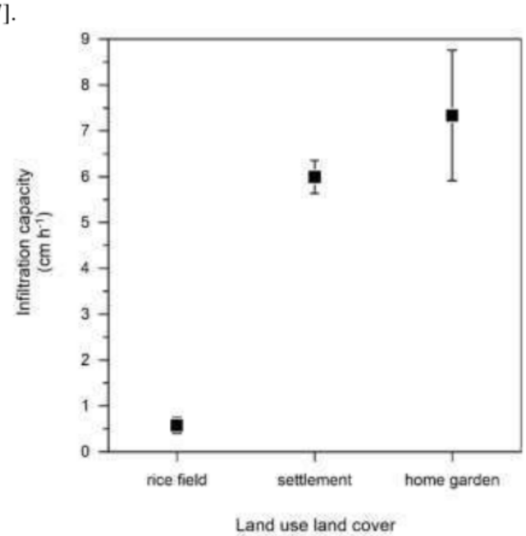

Figure 6. The infiltration capacity of the three LULC types.

3.3. *The rain harvesting technology reduces runoff and increases infiltration*

The discharge is determined by precipitation and the rainwater collection area. Smaller catchment areas have greater potential for drainage [38]. The run-off process takes place when the soil is saturated and can no longer absorb water [39]. Rain harvesting technology is a simple technology that can be used to collect, capture and store rainwater [13-15]. The watershed can be in the form of house roofs, building roofs, and floor surfaces. In this study, the roof of the house is used as a rainwater collection area.

Based on the results of instantaneous precipitation measurements in the field over 2 months, the average daily precipitation value is 12.26 mm. The highest rainfall reached 69.9 mm with a duration until 6 hours. Changes in soil water storage in this study consisted of infiltration and evaporation. Evaporation is neglected as no evaporation process takes place during a rainy moment. Percolation value is the average of water that the soil seeps on each cover during 1 hour period. The infiltration volume of each land cover is then multiplied by the area according to the land cover map. Based on the precipitation, infiltration, and evaporation values, there is no run-off. Furthermore, low rainfall in the study area leads to good infiltration of the water.

The scenario of using rain harvesting technology is used when the rainfall exceeds the infiltration capacity. The rainfall scenario (i.e. 25 mm) has the potential to have a 303,847 l runoff. Reducing runoff will require increasing the infiltration rate through vertical drainage that part of the rain harvesting technology. If assumed that rain harvesting technology is installed in all roof houses in the study site (7,095 m^2 in total), it may able to convert rain into the infiltration of 4,811,972 l. Thus, the rain harvesting approach potentially reduces runoff to 58.42% (Figure 7), and groundwater replenishment in the rainy season will increase groundwater reserves during the dry season [40, 41].

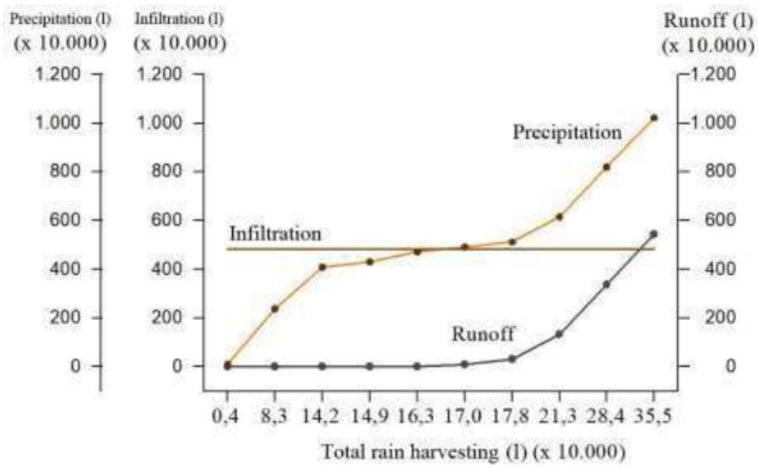

Figure 7. Decreasing surface runoff due to total rain harvesting scenario.

4. Conclusion

The lack of waste disposal at the disposal site impacts the surrounding well water, particularly total coliforms within a closed distance (< 500m). Rainwater is potentially a water source for drinking water. In addition, applying rain harvesting technology can significantly reduce runoff and increase groundwater recharge. If the groundwater recharge can be optimally carried out during the rainy season, the availability of groundwater in the dry season is sufficient. Rain harvesting technology has the potential to the drinking water source and conserves groundwater.

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