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Impact Assessment of Hillside Rainwater Harvesting Ponds on Agriculture Income: Case Study of Ntarama Sector in Rwanda

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Abstract

Nowadays, rainwater harvesting (RWH) technology is increasingly adopted as a strategic pathway for reducing poverty in rural drought prone areas for enhancing agricultural productivity and boosting farm income. The aim of this study is to assess the level of adoption and the impacts of RWH ponds on farm income in Ntarama sector of Bugesera District in Eastern Province of Rwanda. Fifteen farm ponds were visited and the level at which households adopted RWH ponds, their impact on farm income and performance in storing water were assessed. Interviews and questionnaires methods were used to farm ponds beneficiaries and the storage capacity of farm ponds was calculated to ensure that they meet irrigation water demand. Then, Microsoft excel was used as a data analysis tool. The results show that 42.5% of households have adopted RWH ponds and the adoption level of RWH ponds fails due to the lack of training about the role and use of RWH ponds before their implementation. Beside this the low level of public involvement during the site selection for ponds associated with social conflicts among water users was observed. However, it is further revealed that the use of RWH ponds positively impacts on agricultural income on 1/4 hectare per year by about 2,325,000 RWF (3100USD). The studied portion of area can bear 222 ponds of 120 m^3 each if all the rain is harvested throughout the year instead of being three ponds. Furthermore, we found that the quantity of rainwater harvested of 328.5 m^3 as a total of the 3 ponds was still too less to meet irrigation water demand. As negative impacts, the RWH technology can cause dangerous effects such as social conflicts, breeding site for mosquitoes, water related diseases, accidents and others with a level of severity of 32%, 24%, 20%, 16% and 8%, respectively. This happens when the RWH ponds are not properly managed.

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Keywords

Farm Income, Impact Assessment, Rainwater Harvesting Ponds and Technology, Rwanda

1. Introduction

Rainwater harvesting locally collects and stores rainfall through different technologies for future use to meet the demands of human consumption or human activities. The art of rainwater harvesting has been practiced since the first human settlements. It has been a key entry point in local water management, buffering supplies of rainfall to service the human demand of freshwater. As it involves the alteration of natural landscape water flows, it requires water managers to carefully consider the tradeoffs. However, it can create multiple benefits even if it is offering synergies between different water demands and users at a specific location [1].

Rainfall and soil water are fundamental parts of all terrestrial and aquatic ecosystems which supply goods and services for human well-being. Availability and quality of water determines ecosystem productivity, both for agricultural and natural systems. There is an increasing demand on water resources for the development to maintain healthy ecosystems, which puts water resources under pressure. Ecosystem services suffer when rain and soil water becomes scarce due to changes from wet to dry seasons. Thus, Conservation of the environment and sustainable utilization of land and water resources have remained one of the major policy issues of concern in many developing regions [2].

Although Rwanda is known as an equatorial country with high rainfall, poor water management, low soil fertility, unreliable and erratic rainfall have continued to threaten food production in major arid and semi-arid regions of the country. Therefore in 2007, the government of Rwanda and non-governmental organizations introduced a national food security strategy based on the promotion and implementation of small scale irrigation. The initiative involved the introduction of RWH technologies at household level as an alternative intervention to mitigate the effects of the erratic nature of rainfall in the arid and semi-arid parts of Rwanda for achieving the Millennium Development Goals of reducing underdevelopment and poverty by achieving economic growth [3].

In Rwanda, about 80% of population depend on agriculture. However, agricultural activities in the country are largely subsistence-based and this therefore affects economic development. Due to the population increase in the highland areas, more and more marginal areas are being used for agriculture which led to the degradation of the natural resources. One of the major challenges to rural development in the country is how to promote food production to meet the ever-increasing demand of the growing population due to the fact that rainfall in the arid and semi-arid areas is generally insufficient to meet the basic needs of crop production. In degraded areas with poor vegetation cover and infertile soil, rainfall is lost almost completely through direct evaporation or uncontrolled runoff. Various technologies of rainwater harvesting (such as RWH ponds, dam reservoirs, groundwater recharge, etc.) are available, through which rainwater is captured, stored and used at the time of water scarcity. **Table 1** shows the list of various items required for the construction of rainwater harvesting ponds [4].

Rainwater harvesting can be broadly defined as a collection and concentration of runoff or direct precipitation for productive purposes like crop, fodder, pasture or trees production, livestock and domestic water supply [5]. In recent years, the government of Rwanda has defined a National Agricultural Policy whose main objective is to transform subsistence agriculture to modern agriculture [6], but some factors, mainly droughts and mismanagement of rainwater in some parts of the country specifically in Bugesera District, stop the way for achieving the main objective of National Agriculture Policy.

This study aims to evaluate the performance, the adoption level of RWH ponds by households and then assess their impacts on farm income in Ntarama Sector of Bugesera District in Rwanda. The study will not only contribute to the understanding of how adoption of RWH ponds would change the smallholder farmers' lives, but also will inform policy on how to take appropriate actions towards sustainable water harvesting technologies. **Figure 1** shows a typical RWH pond installed to irrigate cabbages during dry period.

2. Study Area

2.1. Description of the Study Area

The District of Bugesera (**Figure 2**) is a large plateau located at an altitude of 1300 m to 1500 m and bordered by

Table 1. Various items required for the construction of a RWH Pond.

N	Activities/materials	Quantity per 120 m^3 ponds
1	Sheeting (Polythene rolls 0.8 mm)	250 m^2
2	Construction of silt trap	1
3	Barbed wire	1 roll
4	Fencing post	25
5	Building nails	1 kg
6	Fencing staples	1 kg
7	Sheeting installation	1
8	Excavation of pond and silt trap	1

Figure 1. Rainwater harvesting pond.

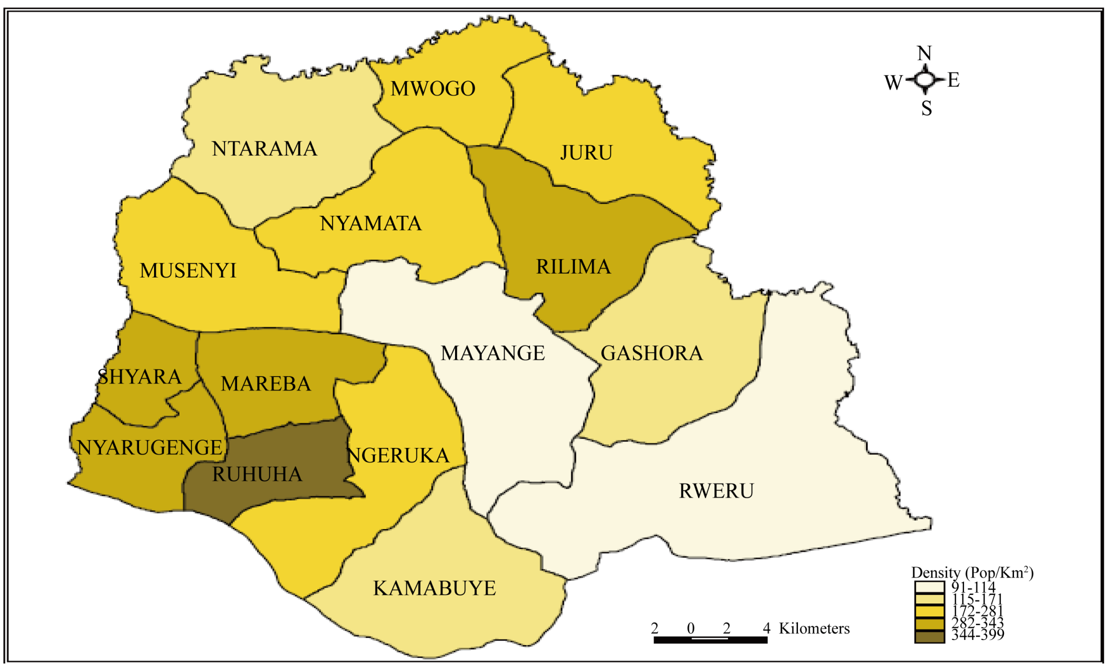

Figure 2. Administrative map of Bugesera District.

the fluvial depositions of Nyabarongo river. Recent erosions superimposed a new drainage system and resulted in a landscape of smaller isolated plateau with deep strongly weathered soils, intersected by dry valleys with very gentle slopes. From a climatic viewpoint, Bugesera District is dry and warm, characterized by an annual rainfall varying between 850 mm and 1000 mm, a dry season lasting for three months and an average temperature of about 21˚C. The best soils for crop cultivation are found on the colluvial deposits bordering the marshes and lakes. Nevertheless, the agricultural potential of this region is generally low and the region mainly has a pastoral vocation.

2.2. Climate

The District of Bugesera experiences small quantity of rainfall and hot temperature. It is characterized by a very hot climate resulting from the absence of mountains and the temperature is varying between 20˚C to 29˚C. The monthly and annually distribution of rainfall in this district varies from one year to another but very weak (850 mm/year) and very unpredictable to satisfy the needs in agriculture and livestock.

The climate of Bugesera District is characterized by four seasons namely:

- Early dry season called Urugaryi from January to mid-March;
- The long rainy season called Itumba from mid-March to mid-June
- The great dry season called Impeshyi covers the mid-June to mid-October
- The short rains called Umuhindo begins and ends mid-October to December

2.3. Hydrographic Description

The hydrographic network is very limited in the Bugesera District. Water system in this District is characterized by three main rivers namely: Akanyaru, Nyabarongo, and Akagera. These three rivers cut across the Western districts of Kamonyi and Ruhangoin the Southern Province and also pass the north of Kicukiro and Nyarugenge Districts of Kigali city, then Rwamagana and Ngoma districts in the Eastern Province. In the south of the district occur two lakes of Rweru and Cyohoha which separate the District with the country of Burundi.

2.4. Soil

The soil of this area is characterized by the tightness of the humus layer of the soil brought about by the grassy savanna and by the vertisoils that are rich in mineral nutrients but lacking organic substances. The land is sandy on the hill and sometimes peaty and generally clay in the valley bottoms. Soils are among the xero-kaolisols and are characterized by a thin layer [7].

2.5. Fauna and Flora

2.5.1. Flora

The Flora in Bugesera District is generally made by afforested savanna vegetation and some forestry gallery.

There are two types of dominant plants in this District which are dense shrub savanna covering the hills, and grasslands covering the dry valleys and plateau of the hills.

2.5.2. Fauna

The great part of the District of Bugesera is occupied by farmers and breeders. The District also accommodates a huge variety of birds occurring in shrubs bushes, tall trees or from burrows. In the lakes, swamps and rivers of Nyabarongo, Akagera and Akanyaru there are hippopotamus, crocodiles, wading birds and some kinds of fishes such as tilapia, catfish, sole, etc. [8].

3. Data and Methods

3.1. Site Visits

During the study period, different site visits were frequently conducted to Ntarama Sector so as to get more information about the level of adoption, performance and the impacts of RWH ponds on the household farm income during both rain and dry seasons.

3.2. Survey Methods

Questionnaire and interviews were both conducted at the site. The interviews were addressed to site engineers in charge of constructing RWH ponds in order to get knowledge about the performance as well as targeted objective during their conception and construction. The interviews were also addressed to local population so as to obtain the level of adoption of RWH ponds by household and their impacts on agricultural income.

The questions of interview included: 1) Do you know the purpose of implementing rainwater harvesting ponds in your daily farming activities? 2) Have you done any kind of training about the use and role of rainwater harvesting technology before putting it into practice? 3) Was this technology voluntary adopted or imposed? 4) How many years of experience do you have in using RWH ponds? 5) What quantity of vegetable and fruits do you get around a farm pond? 6) By comparing the farm yield and the health condition before and after adopting RWH ponds, is there any difference remarked? 7) How is the improvement of your lifestyle after the practice of RWH technology? 8) Do you appreciate the output product? 9) How do you think to be the performance of RWH ponds?

3.3. Data analysis Tools

Microsoft (MS) excel was used for data analysis and helped in getting different bar chats giving an overview of interview and questionnaire results whereas Arc GIS map was used to draw map of the study area and GPS to localize RWH ponds.

3.4. Determination of the Storage Capacity of RWH Pond

Prismoidal formula was used to calculate the storage capacity of the farm ponds.

The storage volume of RWH pond is given by Equation (1):

$$V = \frac{H}{6}\left(Ao + 4A1 + A2\right) \quad (1)$$

where: Ao the bottom surface of the pond, $A1$ middle surface of the pond and $A2$ the top surface of the pond [9].

3.5. Determination of Runoff Volume at the Upstream Side of the Pond

Runoff volume is given by the rational equation:

$$Q = c \times i \times A \quad (2)$$

where Q = peak discharge from the drainage basin runoff in m^3/s, c = Rational method runoff coefficient (dimensionless), i = Rainfall intensity in mm/hour and A = Drainage area in ha.

4. Results and Discussion

4.1. Level of Adoption and Impacts of RHW Ponds on Farmers Income

4.1.1. Level of Adoption of RWH Ponds by Local Population

Table 2 shows the adoption level of RWH ponds by local people after addressing interview at 106 different people. We found that only 45 farmers *i.e*. 42.5% (**Figure 3**) adopted the use of RWH Ponds whereas 61 farmers *i.e*. 57.5% did not adopt. Generally, the level of adoption of RWH Ponds by local households is a failing one due to many reasons identified after a survey. Lack of training about the role and use of RWH Ponds, low level of public involvement during the site selection for RWH Ponds are main reasons of failure.

4.1.2. Impacts of RWH Ponds on Farmers Income

As shown by **Table 3** and **Figure 4**, among 45 farmers who adopted RWH Ponds, 40 farmers *i.e* 88.89% of them testify that their level of living has been both economically and healthily increased after incorporation of RWH Ponds in their daily farming activities whereas the lack in farming prosperity for the remaining 11.11% is mainly due to the inappropriate use of water (irregularities in water application, water which is not uniformly distributed, lack of fertilizers, etc.) for irrigating their crops. After evaluating farm yield from 1/4 ha of land

Table 2. Adoption level of RWHPonds by local households.

Respondents	Frequency	Percentage
Adopted	45	42.5
Non-Adopted	61	57.5
Total	106	100

Table 3. Impacts of RWH ponds on farmers income.

Life condition	Frequency	Percentage
Improved	40	88.89
Not improved	5	11.11
Total	45	100

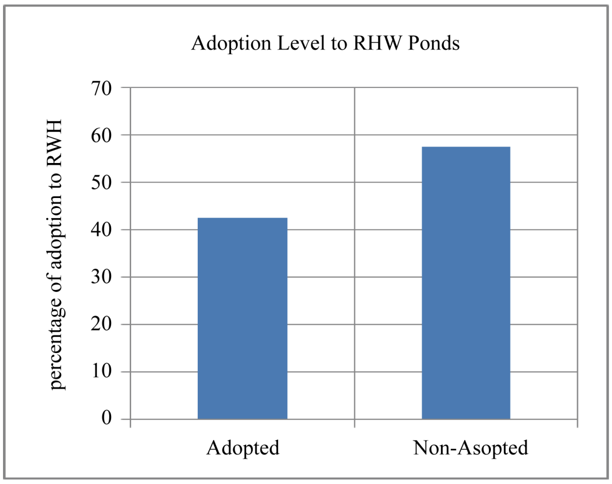

Figure 3. Percentage of RWH adoption by local people.

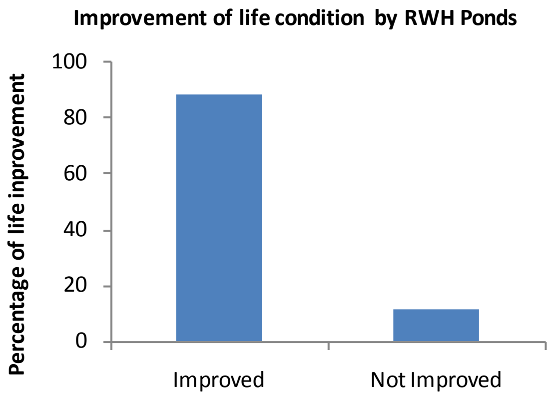

Figure 4. Percentage of improved people through RWH Ponds.

that can be irrigated by a farm pond of 120 m^3, it was found that the average farm income from fruits (mangoes, pawpaws) and vegetables (tomatoes, cabbages) is about 2,325,000 RWF (3,100USD) per year as shown in **Table 4** and **Table 5**.

Table 4. Progressive income from 1st year up to 7th year of around one pond system of 120 m^3.

Crops and their production for 1/4 ha		Income in RWF for1/4ha						
Crops	**Production**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**6th year**	**7th year**
Mango	12,500 fruits	-	-	**500,000** for 200 fruits trees	**875,000** for 350 fruits trees	**1,250,000** for 500 fruits trees	**1,250,000** for 500 fruits trees	**1,250,000** for 500 fruits trees
Pawpaw	2500 fruits	500,000 for 25 fruits per tree	500,000 for 25 fruits per tree	500,000 for 25 fruits per tree	300,000 for 15 fruits per tree	200,000 for 10 fruits per tree	0	0
Cabbage	1.5 tones	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Tomatoes	2 tones	400,000	400,000	400,000	400,000	400,000	400,000	400,000
Total		**1,500,000**	**1,500,000**	**2,000,000**	**2,275,000**	**2,550,000**	**2,250,000**	**2,250,000**

Table 5. Average yield production of vegetables and fruits around pond of 120 m^3.

Crops	Production per 1/4 ha/year	Unit price (RWF)	Income per 1/4 ha/year	Remarks
Mangoes	10250 fruits per 25 trees	100/fruit	1,025,000	One tree of mango gives at least 500 fruits after 5 years. But it begins to produce after 3 years
Pawpaw	2000 fruits per 100 trees	200/fruit	400,000	They begin to produce after 1 year and can produce during 4 years
Tomatoes	4 tones	150/kg	600,000	Tomatoes start to produce after 6 months and this production is for 2 seasons
Cabbages	3 tones	100/kg	300,000	Cabbages start to produce after 6 months and this production is for 2 seasons
Total			**2,325,000**	**The average farm income that a farmer can gain around the pond of 120 m^3 in a year per 1/4 ha is 2,325,000 RWF (3,100USD).**

4.2. Performance of RWH Ponds

4.2.1. Possession of Arable Fields

Table 6 shows the level of land ownership for practicing agriculture. After a survey, we found that 80% of the farmers that adopted the use of RWH ponds have their own land on which they can implement their farming activities whereas only 20% of them depend on farm loaning.

4.2.2. Total Area of Arable Land Available for Households

Table 7 shows the area of arable land available for RWH Ponds users to do their farming activities. We found that 64% of RWH ponds users possess arable land whose area is ranging from 1 to 2 ha, whereas 20% of them have the land whose area is greater than 2 ha and finally 16% have parcels ranging from 0.5 to 1ha.

4.2.3. Irrigated Crops

Table 8 shows the irrigated crops through the use of RWH Ponds. We found that 60% of farmers use water from the ponds to irrigate the mixture of vegetables and fruits. Vegetables themselves are irrigated at 20% and fruits at 5%. Other crops (like green beans, pumpkins, cucumbers, etc.) than fruits and vegetables are irrigated at 15%.

4.2.4. Frequency of Irrigation

Table 9 shows that 45% of farmers affirm that they irrigate their fields twice per day whereas the irrigations done once per day and once in three days are 35% and 20% respectively. The high percentage of farmers who irrigate their fields twice per day is justified by high hydraulic conductivity of the soil and daily insolation rate which drives high rate of evapotranspiration.

4.2.5. Irrigated Area

After conducting the survey on the surface area covered during irrigation through RWH technology, we found that 60% of RWH Ponds users irrigate the land whose area is less than 0.5 ha, whereas 40% of them irrigate area of

Table 6. Ownership of farming land.

Designation	Effective	Percentage
Land owner	36	80
Land loaning	9	20
Total	**45**	**100**

Table 7. Total area available for RWH ponds users to perform agriculture.

Designation	Effective	Percentage
<0.5 ha	0	0
0.5 to 1 ha	7	16
1 to 2 ha	29	64
>2 ha	9	20
Total	**45**	**100**

Table 8. Irrigated crops through RWH ponds technology.

Designation	Effective	Percentage
Vegetables	**9**	**20**
Fruits	2	5
Vegetables+ fruits	27	60
Others	7	15
Total	**45**	**100**

Table 9. Irrigation frequencies.

Designation	Effective	Percentage
Once per day	16	35
Twice per day	20	45
Once in 3 days	9	20
Once per week	0	0
Once in 10 days	0	0
Total	**45**	**100**

land ranging from 0.5 to 1 ha as shown in **Table 10**. By combining the obtained data with those found in **Table 6**, we found that irrigated area remains small for a great deal of people practicing irrigation due to both weak storage capacity and limited number of RWH Ponds.

4.2.6. Determination of the Storage Capacity of the Pond

According to the constructor, RWH Ponds located in Ntarama Sector have been constructed with storage capacity of 120 m^3. At the site, we divided the ponds location into three zones according to the side slope of the basin and its area as shown by **Figure 5**.

$Ao = 3\ \text{m} \times 3\ \text{m} = 9\ \text{m}^2$ (Bottom surface of the pond),

$A1 = 6\ \text{m} \times 6\ \text{m} = 36\ \text{m}^2$ (Middle surface of the pond),

$A2 = 8\ \text{m} \times 8\ \text{m} = 64\ \text{m}^2$ (Top surface of the ponds), and

Table 10. Area of irrigated land by RWH ponds users.

Designation	Effective	Percentage
<0.5 ha	27	60
0.5 to 1 ha	18	40
1 to 2 ha	0	0
>2 ha	0	0
Total	**45**	**100**

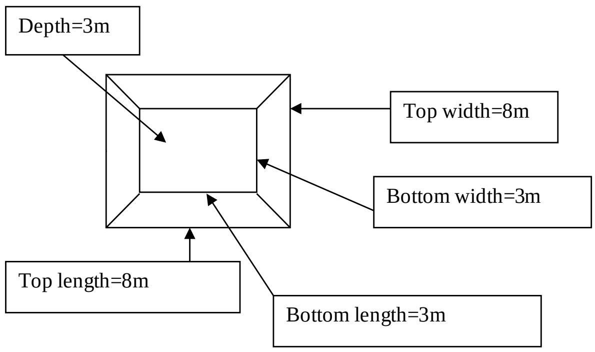

Figure 5. RWH pond geometry.

$H = 3\text{ m}$ (The height of the pond).

By applying prismoidal formula [9], the storage capacity of RWH pond was determined using Equation (1):

$$V = \frac{H}{6}\left(Ao + 4A1 + A2\right), V = \frac{3}{6}\left(9 + 4\times 36 + 64\right)\text{ m}^3 = 109.5\text{ m}^3$$

Comparing this calculated volume (109.5 m^3) to the constructed volume (120 m^3); the small difference is reserved as freeboard for preventing the pond from being damaged by excess water.

The studied zone of Ntarama Sector was composed by three ponds. The area which can drain water towards one pond is estimated to be 11 ha. Thus, we can calculate the volume of water that can be collected by one pond throughout the year.

This runoff volume is given by the rational Equation (2):

$$Q = c \times i \times A$$

where:

Q = volume of water that can be collected by one pond throughout the year from drainage basin in m^3/year,

c = 0.2 (runoff coefficient),

i = 850 mm/year (rainfall intensity) ,

A = 11 ha (drainage area).

Then, Equation (2) gives:

$$Q = c \times i \times A = 0.2 \times 0.850\text{ m} \times 110000\text{ m}^2 = 18,700\text{ m}^3/\text{year}$$

The ratio $\frac{Q}{V}$ gives the total number of the ponds that can be used to store water during rainy season to be used during dry period. So, we can estimate that the studied area can bear 18,700/109.5 = 171 ponds of 120 m^3 if all rainfall is harvested throughout the year. The zone S1 which only possesses 3 RWH ponds has the potentiality of having other many ponds, which can be, therefore, used to increase the irrigated area.

4.3. Factors That Influence Loss of Storage Volume in the Ponds

Among the factors which deplete water from the ponds, infiltration comes on the first place and represents 24%

due to the facts that animals fall in the ponds and tear the plastic sheeting which makes the pond inactive. Other factors which lead to the depletion of the stored water in the ponds include domestic usage, sedimentation, evapotranspiration, construction activities and others with 20%, 12%, 8%, 16% and 20% respectively as shown in **Table 11**.

4.4. Negative Effects of Rainwater Harvesting Ponds

Although RWH ponds have remarkable role in the development of human being, they can cause dangerous effects such as social conflicts, breeding site for mosquitoes, water related diseases, accidents and others with a level of severity of 32%, 24%, 20%, 16% and 8% respectively as shown in **Table 12**. At social life point, we found that the conflicts which result among RWH ponds users are mainly related to those who wish to use water in other activities rather than farming. Also, some people who made their lands available for the construction of ponds do not want to share water with their neighbors which results in social conflicts among water users. So, there must be an intervention of local authority, people and agronomists in charge of maintenance of those ponds to eradicate those problems.

5. Concluding Remarks

The study assessed the adoption level and the impacts of RWH ponds on farm income in Ntarama Sector, Bugesera District Southern Province of Rwanda. It is found that only 42.5% of households have adopted RWH ponds. The adoption level of RWH ponds is failing due to many reasons: Lack of training about the role and use RWH ponds before their implementation, low level of public involvement during the site selection for ponds associated with social conflicts among water users. It is further revealed that the use of RWH ponds positively impacts agricultural income on 1/4 hectare per year by about 2,325,000 RWF (3100 USD) as shown in **Table 4**.

The implication of these findings is that the adoption of rainwater harvesting ponds presents a pathway for reducing rural poverty. Therefore, policies that target promotion of farmer development should be pursued together with the promotion of RWH ponds. In addition, there is a need for policies and strategies that target on various ways of reducing the cost of adopting RWH technology so as to include the poorer farmers alongside the

Table 11. Various factors affecting the storage of water in the pond.

Designation	Effective	Percentage
Sedimentation	5	12
Domestic usage	9	20
Evapotranspiration	4	8
Construction	7	16
Infiltration	11	24
Others	9	20
Total	45	100

Table 12. Negative impacts of RWH ponds on local population.

Designation	Effective	Percentage
Breeding site for mosquitoes	11	24
Accidents	9	20
Water related diseases	7	16
Social conflicts	14	32
Others	4	8
Total	45	100

public involvement during ponds implementation in order to avoid the social conflicts arising among water users. So, access and the right to land can be the first step toward implementation of rainwater harvesting by putting special measures in place so that rainwater harvesting benefits the land-poor and the landless communities.

Finally, RWH pond is a technology coping strategy in variable rainfall areas like our studied area. In the future, climate change will increase rainfall variability and evaporation, and population growth will increase demand on ecosystem services, particularly for water. Due to this, rainwater harvesting will become a key intervention in adaptation and in reducing vulnerabilities. Thus, there is a need to consider rainfall as an important, manageable resource in water management policies, strategies and plans so that rainwater harvesting interventions can be considered as potential options in land and water resource management activities for human well-being and ecosystem productivity [10].

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