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Design of Rainwater Harvesting and Sprinkler Irrigation System At the University Of Rwanda Nyagatare Campus Farm

YANKURIJE Agnes[1], Dr. HARERIMANA Leonce [2], Dr. IYAKAREMYE Jean de Dieu [3], NSHIMYUMUREMYI Vincent[4]

[1]MSc candidate in Soil and Water Engineering at the University of Rwanda, currently working in Agro Processing Trust Corporation as an Agronomist.
iyagnes8@gmail.com
[2]Lecturer at University of Rwanda (UR), College of Agriculture and Veterinary Medicine, School of Agriculture Engineering, University of Rwanda.
haleonce01@gmail.com
[3]Lecturer at the University of Rwanda (UR), College of Agriculture and Veterinary Medicine, School of Agriculture Engineering, University of Rwanda.
iyakjdd@gmail.com
[4](MSc.), Agribusiness Expert, currently working in API Ltd as Seed Production Manager.
vincentnshimye@gmail.com

Abstract- Rainwater harvesting is a straightforward technique or technology that collects, conveys, purifies, and stores runoff from rooftops, parks, highways, open spaces, etc. for use in the future. Sprinklers for irrigation can be utilized in residential, commercial, and agricultural settings. Both sandy soil and uneven terrain with insufficient water supply can benefit from it. Water leaks from the revolving nozzles when it is pressured and forced into the main pipe. The crop receives a spray of it. Water is piped to one or more central sites throughout the field for overhead high-pressure sprinklers or guns to disperse during sprinkler or overhead irrigation.

Nyagatare district has an annual rainfall of 827 mm which is less compared to other regions in the country and very unpredictable to satisfy the needs in agriculture and livestock. The annual rainfall of arid-prone regions hurts productivity and production. Therefore, the study is undertaken to design an irrigation system that relies on rainwater harvesting as a source of irrigation. The overall objective of this study is to design a rainwater harvesting and sprinkler irrigation system at UR Nyagatare Campus Farm. The following specific objectives will be accomplished in this study to achieve the main objective 1) To assess irrigation water potential, soil and land characteristics of the study area, 2) To determine irrigation water requirement of the command area concerning various conditions of utilization, 3) To design rainwater harvesting, water storage facility, and suitable sprinkler irrigation system and undertaken its economics and a cost-benefits analysis.

The study was conducted at Nyagatare campus farm. This farm is located in eastern province, Nyagatare district, Nyagatare sector, Rwanda.

Keywords – Weather analysis, Soil characteristics, Design rainwater harvesting, Sprinkler irrigation system, Cost benefits analysis.

I. INTRODUCTION

i. Background of the study

Rwanda's irrigation efforts are pivotal to its development agenda, emphasizing agricultural enhancement through sustainable water management (RAB, 2020). At the UR Nyagatare Campus farm in Nyagatare district, issues of unreliable rainfall significantly affect agricultural output (Nyagatare District, 2018). This study aims to address these challenges through a comprehensive approach focused on three main objectives: understanding farm irrigation needs under varying crop conditions, evaluating potential water sources, soil characteristics, and land suitability, and designing robust rainwater harvesting infrastructure with economic feasibility analysis.

The outcomes of this study intend to offer valuable insights into sustainable water management practices, particularly in semi-arid regions like Nyagatare. By reducing dependency on erratic rainfall and optimizing water use, the proposed rainwater harvesting, and sprinkler irrigation system not only aims to benefit the UR Nyagatare Campus farm but also aims to serve as a replicable model for similar enterprises. Rainwater harvesting, recognized for its environmental benefits and suitability in regions lacking centralized water delivery systems, provides a sustainable water source (UNEP, 2022). Integration of these technologies is expected to strengthen agricultural resilience and enhance productivity in Nyagatare District.

II. RESEARCH METHODOLOGY

2.1. Site description

The study was conducted at Nyagatare campus farm. This farm is located in eastern province, Nyagatare district, Nyagatare sector, Rwanda. The area lies in the low-lying eastern Savannah agro-ecological zone at an average altitude of 1400m absl and lies at latitude 1o 22’51.6’ south of the Equator and longitude 30o 17’07 East. The rainfall ranges from 800-1000mm per annual, to is 25.3o C-27.7oC (http://www.eastern province.gv.rw/index.php).

2.2. Design of Rainwater-Harvesting System

2.2.1. Determination of Runoff Water

The rational formula Q = CIA was employed to estimate peak runoff rate, where Q is the runoff rate, C is the runoff coefficient, I is the rainfall intensity, and A is the watershed area.

2.2.2. Determination of Effective Rainfall

Effective rainfall (Pe) was calculated using empirical formulas based on monthly precipitation (P), adjusted for varying rainfall amounts.

2.2.3. Irrigation Water Requirement (IN)

Using CROPWAT8.0 software, irrigation water requirements were computed by first determining crop evapotranspiration (ETo) based on climatic data. The effective rainfall (Pe) was subtracted from crop water requirements (ET crop) to derive IN.

2.2.4. Input Weather Data

Meteorological data from 2019 to 2021 were collected from Meteo-Rwanda and used to input monthly averages into CROPWAT8.0 for analysis.

2.2.5. Input Soil Characteristics Data

Soil physical properties such as maximum rooting depth, total available soil moisture, and infiltration rates were assessed and inputted into the analysis.

2.2.6. Input Crop Data

Crop-specific data including root depth, sowing and harvesting dates, and crop coefficients (Kc) were entered into CROPWAT8.0.

2.2.7. Calculation of Daily Crop Water Needs (ETc)

Daily crop water requirements were generated from CROPWAT8.0, detailing irrigation needs across different crop stages.

2.3. Design of Rainwater-Harvesting Structures

2.3.1. Determination of Rainwater Quantity

Monthly rainfall data from Nyagatare's Meteo station informed calculations of average rainfall (83.3mm) to be harvested.

2.3.2. Determination of Rainwater Storage Tank Capacity

Reservoir capacity was estimated using the mass curve method based on three years of data (2019-2021), considering monthly rainfall and catchment area.

2.4. Design of Sprinkler Irrigation System

2.4.1. Determination of Net Depth Water Application

Net depth of water application (net) was calculated based on soil moisture characteristics and crop water requirements.

2.4.2. Design of Sprinkler System

Steps included determining irrigation frequency, gross water application depth, layout design, and sprinkler selection based on application rates and spacing.

2.5. Economic and Cost-Benefit Analysis

Investment costs for materials and infrastructure were evaluated against projected crop yields over five years to assess economic viability.

III. DISCUSSION OF THE RESULTS

3.1. Weather Analysis

- **Temperature:** Average monthly maximum temperatures ranged from 26.8°C to 28.9°C, while average minimum temperatures varied from 16.3°C to 17.4°C. The largest temperature fluctuation observed was 2.1°C.
- **Relative Humidity and Rainfall:** Highest rainfall recorded was 146.3 mm in March, with driest months in June and July. Relative humidity ranged from 41% (July/August) to 79% (April).
- **Wind Speed and Sunshine Hours:** Wind speeds varied from 84 to 168 km/day annually, with average sunshine duration of 9.5 hours per day.

3.2. Analysis of soil characteristics

The soil characteristics which were analyzed include soil texture and soil infiltration rate. These soil characteristics play an important role in designing of irrigation system.

3.2.1. Soil texture

The soil sample was collected and analyzed by using methodology which has been described in chapter 2 with facilities at IPRC Musanze. The result of soil analysis are shown the table-1

Table 1: The result of soil analysis

Sieves types in mm	Quantity in gm	Sand diameter(mm)	% of sand
1.18	160.5	0.05-2.0	96.1
0.6	348.5		
0.3	243		
0.15	218		
0.075	114	silt diameter(mm)	% of silt
<0.075	44.5	0.002-0.05	3.9
Total	1128.5		

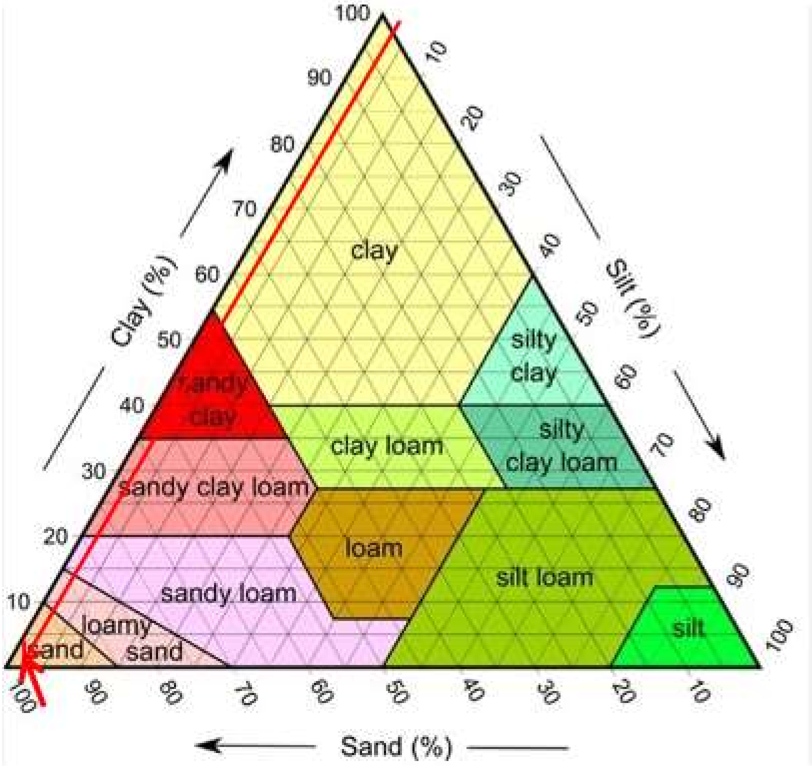


Figure-3.2 Soil texture triangle

Soil analysis indicated the farm predominantly comprises sandy soil (96.1% sand, 3.9% silt), influencing water movement and nutrient flow.

3.2.2. Infiltration rate

High soil infiltration rate (<30 mm/hour) due to sandy soil composition.

3.3. Design Rainwater Harvesting

- **Runoff Calculation:** Total water harvested from different catchments, including rooftops and campus compound, amounted to 36,638.176 m3.
- **Crop Factor (Kc):** Calculated for maize, beans, and radish based on growth stages and sowing dates.

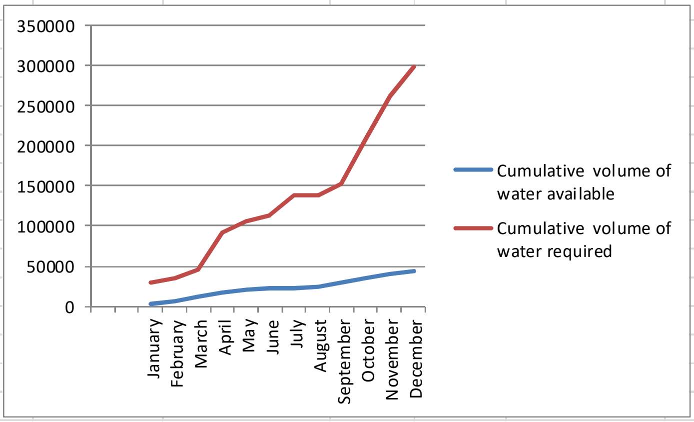
3.4. Crop Evapotranspiration and Irrigation Water Requirement

- **ET and IN Calculation:** Crop evapotranspiration (ETc) and irrigation requirements computed using CROPWAT8.0 software, highlighting peak demand periods and effective rainfall contribution.
- **Reservoir Capacity:** Estimated reservoir capacity based on monthly rainfall data from 2019-2021 to meet irrigation demands.

3.5. Capacity of the reservoir estimated

Table 2 Capacity of the reservoir estimated

Months	Rainfall(mm)	Rainfall in m	Volume of water available(m3	Volume of water required(m3)	difference btn water required and	Positive (+ve)	Negative(-ve)	Cumulative volume of water available	Cumulative volume of water required
January	45	0.045	1999.35	29275	27275.65		27275.7	1999.35	29275
February	83.3	0.0833	3701.02	5500	1798.98		1798.98	5700.37	34775
March	146.3	0.1463	6500.11	11025	4524.89		4524.89	12200.48	45800
April	123.3	0.1233	5478.22	46350	40871.78		40871.8	17678.70	92150
May	77	0.077	3421.11	14900	11478.89		11478.9	21099.81	107050
June	11.3	0.0113	502.059	6650	6147.94		6147.94	21601.87	113700
July	23	0.023	1021.89	24350	23328.11		23328.1	22623.76	138050
August	51.3	0.0513	2279.26	0	-2279.26	2279.3		24903.02	138050
September	84.3	0.0843	3745.45	14625	10879.55		10879.6	28648.46	152675
October	127.3	0.1273	5655.94	55250	49594.06		49594.1	34304.40	207925
November	144	0.144	6397.92	53400	47002.08		47002.1	40702.32	261325
December	89.7	0.0897	3985.37	37750	33764.63		33764.6	44687.69	299075
Volume of water to be stored						2279.3	256667		258946



The discussion revolves around the necessity of irrigation throughout most months except August, highlighting the seasonal demand for water and the consequent need for effective water storage. A key finding is the maximum difference of 258,946 m³ between cumulative inflow and demand, which dictates the required capacity of the reservoir to be constructed. Column 6 in the table represents the difference between demand and adjusted inflow, crucial for determining when water must be withdrawn from storage. The sum of values in column 10 provides the necessary useful storage capacity, confirming it as 258,946 m³ (Smith et al., 2023). This underscores the reservoir's role in managing seasonal water supply variations and ensuring reliable irrigation, necessitating careful consideration of reservoir design and operational strategies to optimize water use efficiency and sustain agricultural productivity.

3.6. Sprinkler irrigation design

3.6.1. Layout

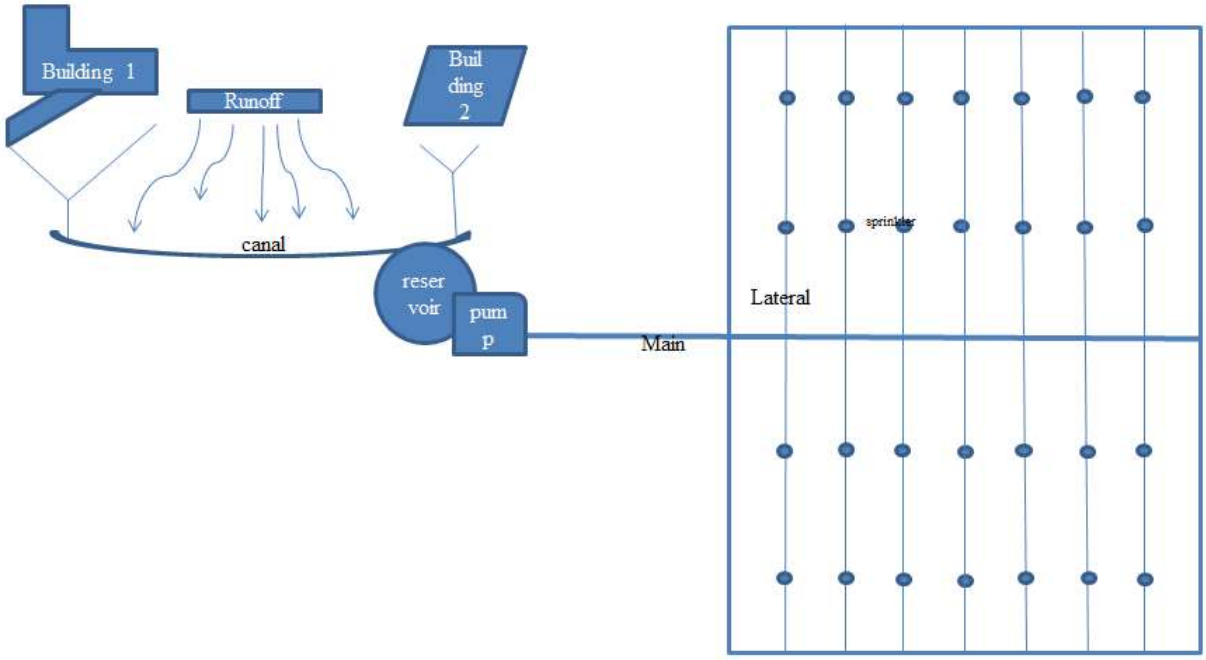


Figure -3.6 Layout (Author's work)

3.6.2. Pipe size selection

1. The discharge

Based on sprinkler capacity, Q is equal to $8m^3/hr$.

2. Cross section

$$Q = AV$$

$$A = \frac{Q}{V} = \frac{0.0022\text{m}^3/\text{s}}{3\text{m/s}} = 0.00073\text{m}^2$$

3. Main line pipe diameter

$$A = \pi r^2$$

$$r = \sqrt{A}/\pi = \sqrt{0.00073}/3.14 = 0.015\text{m}$$

$$D = 2r = 2 * 0.015 = 0.030\text{m} = 30\text{mm}$$

4. Laterals diameter=30mm/14=2.14mm Means that the number of laterals are 14
5. Riser diameter=2.14mm/125=0.017mm

$$Number\ of\ sprinkler = \frac{\text{Designed area}}{\text{Caverage area of one sprinkler}} = \frac{50000\text{m}^2}{(20 * 20)\text{m}^2} = 125$$

3.6.3. Pump selection

1. Total head loss(TH)

$$\text{TH} = OP + \text{EL} + \text{R} + \text{Hf} = 5000m + 125\text{m} + 357\text{m} + 0.006m = 5482.006m = 548.2\ bar$$

Where OP is operating pressure, El is elevation, R is riser and Hf is friction loss

2. Power required

$P = \text{Qst} * 9.81 * \text{TH}= 0.0022*9.81*548.2= 12\text{Kw}$

The required pump should meet the power of 12Kw

Table 3 Sprinkler system design parameters

S/N	Parameters	Formula
1	Net irrigation requirement	24.6m^3/ha/day
2	Gross irrigation requirement	34.2mm
3	Irrigation frequency	4days
4	Depth of application	24mm
5	Time required per irrigation	1.34hrs
6	Discharge of individual sprinkler	0.0022m^3/s
7	Discharge capacity of sprinkler system	0.24m^3/s
10	Total head loss	5482m
11	Power required	12kw
12	Application rate	83mm/hr

Each parameter in the table is interconnected and essential for designing an efficient sprinkler irrigation system that meets crop water requirements effectively while minimizing water and energy usage.

3.6.4. Specifications

Table 41 Specifications

S/N	Item	Type	Size	Flow	Radius	Pressure
1	**Pump**	QP-105	425x318x465,mm	2.4~2.8 PSI		
2	**Main**	MDPE PN12.5	30mm of diameter	20mm/day	15mm	
3	**Laterals**	PVC	126 m long			
4	**Sprinkler**	30py	1.5”	8m^3/hr.	20m	4 bar
5	**Nozzles**	rotary	2.5 to 3mm in diameter	0.59m^3/hr.	1.2m	2.1bar

Table 4 shows the specifications for the parameters used in designing water harvesting and sprinkler irrigation systems.

3.7. Economic and Cost-Benefit Analysis

- **Investment Costs:** Breakdown of costs for rainwater collection, storage infrastructure, and distribution system, totaling 13,733,040 RWF.
- **Crop Yield and Benefits:** Expected crop yield and revenue generated over five years, showing a net benefit of 75,766,960 RWF after deducting investment costs.

IV. CONCLUSION AND RECOMMENDATION

The research was conducted in Nyagatare district in Eastern province in UR Nyagtare Campus Farm. The title of the research is the design of rainwater harvesting and sprinkler irrigation system. To accomplish the proposed objectives, a set of activities were performed, and the results found were illustrated and discussed in previous chapters. Based on the findings of the research work, the following conclusion may be drawn.

4.1. CONCLUSION

The study conducted at the Nyagatare campus farm focused on weather analysis, soil characteristics, and rainwater harvesting design, sprinkler irrigation system design, and economic analysis. Key findings include the predominance of sandy soil with high infiltration rates, peak irrigation demands during dry periods despite effective rainfall contributions, and a feasible economic return on investment over five years.

4.2. RECOMMENDATION FOR THE FUTURE STUDIES

- **Promotion of Rainwater Harvesting**: Rainwater harvesting should be promoted as a viable and reliable water supply option in Rwanda, given the country's abundant rainfall potential. The study demonstrates its feasibility and effectiveness in meeting agricultural water demands.
- **Policy Integration**: The government should integrate rainwater-harvesting technology into national water policies. This integration should involve policy initiatives and frameworks that facilitate the widespread adoption and implementation of rainwater harvesting systems across the country. Similar initiatives in other developing countries can serve as models.

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CONFLICT OF INTEREST

The author of this article declares that there is no conflict of interest related to this publication manuscript.

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