# Performance evaluation of sprinkler irrigation system in Matimba irrigation scheme of Rwanda

**Nema Ma-Lyse[a], Mugabe Assiel[b]**

[a] *PhD student in Climate Change and Biodiversity- University of Félix Houphouët Boigny, Ivory Coast*
[b] *Lecturer of irrigation engineering - Rwanda Polytechnic/IPRC Kigali, Civil engineering department*

---***---

***Abstract***

*This study aimed at evaluating the performance of sprinkler irrigation system in Matimba irrigation scheme located in Eastern Province of Rwanda. Catch cans test were performed to assess the system efficiency in the selected zones under maize crop. Distribution parameters such as Distribution Uniformity (DU) Christiansen's Coefficient of uniformity (CU) were calculated. In addition, efficiency parameters such as water application rate, Potential application of the low quarter (PAELQ), delivery performance ratio (DPR), evaporation and wind drifts losses were determined using appropriate formula. The study's findings showed that the distribution uniformity, coefficient of uniformity, and Delivery Performance Ratio of the system were 84%, 86%, and 0.9 respectively. These results guarantee that the sprinkler system's overall performance is satisfactory. However, it is advised to adopt regular maintenance to improve the system performance at its optimum efficiency. Furthermore, there is need to control silting from pumping station in order to prevent frequent malfunction of water delivery network at field level.*

**Keywords:** Sprinkler irrigation, performance indicators, Christiansen's Coefficient of uniformity

## 1. Introduction

In Sub-Saharan Africa, mechanized irrigation systems are increasingly being used to create irrigation systems (Harrison & Mdee, 2018). One explanation for this is the apparent recent failures of numerous substantial canal-based irrigation schemes that depended on furrow irrigation (Harrison & Mdee, 2018; Mutambara, 2016). Another factor is the growing affordability of irrigation pumps powered by gasoline and diesel, as well as the advent of solar irrigation pumps in recent years.

A sprinkler system is a typical irrigation method used by farmers. It is known for being very effective and easy to install and maintain, which has led to its widespread use all over the world. According to (Topak *et al*. 2005), the use of sprinkler irrigation methods encourages system operation and automation by increasing the ability to achieve high uniformity and effective irrigation, which results in water and energy savings that increase farm profitability. Since the first man used water to boost crop production, performance evaluation has been a crucial component of irrigation design and management (Bos *et al*., 1993). In that regard, application consistency and loss serve as the foundation for an irrigation system's efficiency; and these two variables describe the system performance status.

A primary design objective, according to Keller and Bleisner (2000), is sprinkler irrigation uniformity. Whether or not the water is distributed evenly over a specific area is determined by uniformity. It is vital to determine the uniformity of water application in order to evaluate the system's performance because no irrigation system can apply water precisely to every part of the field. According to (Topak *et al*. 2005), environmental factors like wind speed and direction, as well as system network design elements like nozzle diameter and spray spacing, determine the pattern of sprinkler water distribution. In their work on maize yield simulation with regard to sprinkler uniformity variabilities, (Salmerón et al., 2012.) came to the conclusion that maize yield reduction occurred when the irrigation coefficient of uniformity was reduced from 100 to 70%.

The distribution of uniformity (DU) and the coefficient of uniformity (CU) are the two most common ways to express uniformity. According to Keller and Bliesner (1990), if appropriate irrigation is given throughout the entire area, a low DU or CU value indicates that losses due to deep percolation can be considerable.

Although the concept of low values is arbitrary, values of DU <60% (CU <75%) are frequently regarded as being in the low range, particularly for ordinary field and fodder crops. It is advised to use a DU > 75% (CU > 84%) for higher value crops. It is clear that this field is very important because numerous researchers all over the world have published their work on the evaluation of sprinkler system performance (Acar et al., 2010; Ahaneku, 2010; Dechmi et al., n.d.; Maroufpoor et al., 2010; Msibi et al., 2014; Ngasoh et al., 2018; Howell, 2003; Topak et al., 2005)

Numerous studies have been carried out, particularly in Rwanda, to reveal the status of irrigation water management(Geoffrey *et al*., 2015; Kannan *et al*., 2011; Majoro **et al**., 2016; Narayanan, 2014; Urujeni & Chrysostome, 2015) and there are few publications on irrigation systems performance evaluation (Chandra *et al.,* 2020.). In order to assess the current performance of the sprinkler irrigation system at the Matimba irrigation project, this investigation was carried out. Additionally, not just in the research area but also for other irrigation schemes with comparable issues, the findings will be helpful to system operators and decision-makers.

## 2. Study area

The Matimba irrigation scheme is in Nyagatare District of Rwanda. This area of Eastern Province of Rwanda is situated between 1.0584° S and 30.4574° E with an average elevation of 1513.5 meters above sea level. According to Majumdar (2000), the area's soil type is sandy loam, and its infiltration rate of 17.2 mm/hr is regarded to be quick. The research area experiences varying quantities of light precipitation and hot weather, with an average yearly temperature that ranges between 25.3°C and 27.7°C. This region has a critical need for irrigation as the annual rainfall ranges from 700 to 900 mm (Chandra, 2020) and the potential evapotranspiration is 1337 mm (Malesu *et al*., 2010).

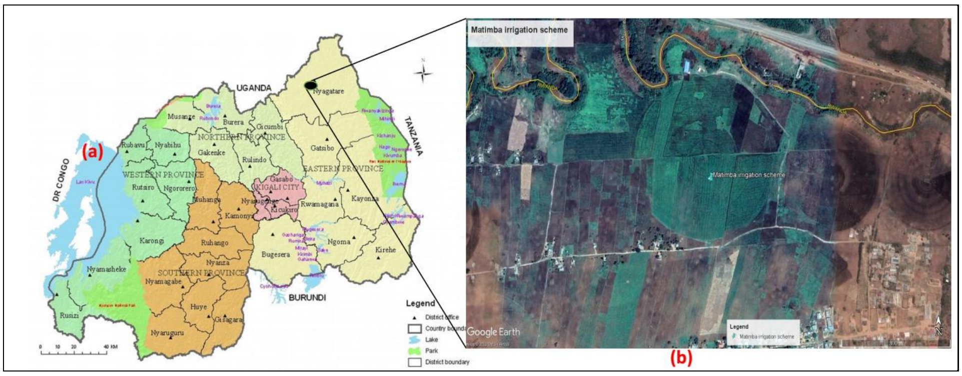


*Figure 1:study location:(a) administrative map of Rwanda and (b) google earth map of the site*

There are three agricultural seasons in the research area, just like in other parts of Rwanda. Every year, Season A runs from September through January. Season B starts in March and runs through July. The C agricultural season, however, runs from June through August. The 460 hectares of land under the Matimba irrigation system are covered. Farmers were given assistance by the government to form water users associations (WUAs) in order to better manage their irrigation systems and agricultural operations as the new community-based irrigation plan was being built. The management and development of irrigation plans have benefited greatly from the contributions of such farmers' organizations (Harrison, 2018).

According to the plan, irrigation water is piped to Matimba from a centralized pumping station on the Umuvumba river. The total irrigated area under Maize is 110ha. The table1 lists the characteristics of irrigation system that was installed at the site.

*Table 1: Features of sprinkler irrigation system of the study area*

| S/N | Features | Values |
|---|---|---|
| 1 | Plots | 22 (5ha/plot) |
| 2 | Net irrigated area per plot | 4.6ha (240mx192m) |
| 3 | Hydrants per plot | 1 |
| 4 | Laterals | 32 |
| 5 | Laterals per hydrants | 2 |
| 6 | Sprinklers per lateral | 10 |

| | | |
|---|---|---|
| **7** | Sprinkler volumetric Flow rate | 1.95m$^3$/hr or 1950L/hr |
| **8** | Sprinkler spacing | 12X12 m |
| **9** | System operating pressure | 3.0 kg/cm$^2$ |
| **10** | Wetted diameter range | 24-36m (30m) |
| **11** | Size of nozzles | 4-4.5mm |
| **12** | Inlet connection: | 3/4" male Threaded(20mm) |
| **13** | Shifts per day | 2 |

## 3. Materials and methods

### 3.1. Experiment at the study area

The Merriam and Keller (1980) technique and the American Society of Agricultural and Biological Engineers (ASABE) standard procedures were used to conduct the field evaluations. The field tests were carried out in 2019 on plots with maize plantations during the dry season (July and August). The field measurements exercise was done throughout the day when farmers were using irrigation techniques. The site was randomly divided into 4 zones for the evaluation, which was conducted as a single-lateral test, and a sprinkler position on a lateral line was selected in each zone. Installing a pattern of comparable metallic catch cans containers was the test protocol.

The Catch cans were roughly distributed in a square grid of 2 meters for the square spacing of 12x12 m inside the area surrounded by four sprinklers (see figure 2.2). Both the discharge rate and the operating pressure of the sprinklers were predetermined prior to the start of each test at the hydrant level as well as the pumping station level of the system. The test involved measuring the sprinkler head flow rate, inlet pressure, and outflow pressure along the lateral. Each sprinkler lateral that was being examined underwent a test that lasted 30 minutes and reading catch cans took 10 to 15 minutes. After the test was finished, a graduated cylinder was used to measure the amount of water that had accumulated in each catch can. For every sprinkler lateral evaluated, same experiment protocols were repeated.

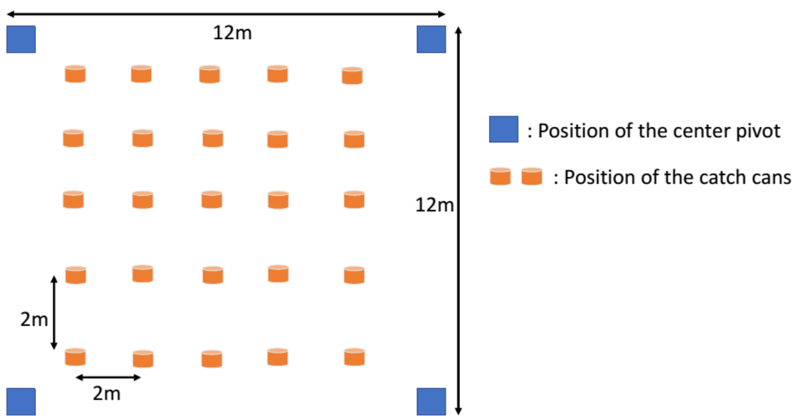


*Figure 2: Catch-can experiment system layout ( not on scale)*

### 3.2. Performance evaluation parameters

The different parameters including coefficient of uniformity (CU), distribution uniformity (DU) and discharge efficiency (DE) were calculated (see table 2) to evaluate the center pivot irrigation system performance according to Merrian and Keller (1978) methods.

*Table 2:Performance evaluation parameters used in the study*

| Parameter | Equation | Notation |
|---|---|---|
| CU (%) | CU= $100\times\left(1.0-\frac{\sum X}{n.m}\right)$<br>CU= $100\times\left(1-\frac{\sum\lvert Z-m\rvert}{\sum Z}\right)$ | CU: Christiansen's Coefficient of Uniformity<br>Z: Amount of water measured in each container while testing uniformity (mm, ml)<br>X= $\lvert Z-m\rvert$: Total absolute value of deviations from average of the amount of water measured in all accumulation container (mm, ml).<br>N: Number of observations<br>m: Mean quantity of water (mm, ml) |
| DU (%) | DU=$\frac{dq}{d}\times 100$ | DU : Distribution uniformity<br>Dq : Lower quartile<br>D: Average depth |
| CUS | $CUS = CU \times \frac{1}{2}\left[1+\sqrt{\frac{P_n}{P_s}}\right]$ | CUS: System uniformity coefficient<br>Pn: The minimum sprinkler pressure (kPa)<br>Ps: The average sprinkler pressure (kPa) |
| DE (%) | DE=$\frac{do}{dd}\times 100$ | DE: Discharge efficiency<br>do: Average water depth observed in catch cans (mm)<br>dd: Average water discharged by sprinkler(mm) |
| PAELQ | $PAELQ = \frac{dc}{d_{lq}}$ | PAELQ : Potential application efficiency at low quarter<br>$dc$ : Average depth of irrigation water contributing to the target(mm)<br>$d_{lq}$ : The low quarter irrigation water target depth(mm) |
| DPR | $DPR = \frac{QA}{QR}$ | DPR : Delivery performance ratio<br>QA : Actual discharge<br>QR : Required discharge |

## 4. Results &Discussions

### Sprinkler system uniformity

The results of uniformity indicators evaluated in the study area for sprinkler irrigation system are presented in the table3. Obviously, Christiansen's coefficient (CU) ranged from 82% to 90% in Zone A; B; C &D with mean value of 86% (see figure3). There was also an increase of CU from zone A to zone D. The distribution uniformity (DU) ranged from 76% to 92 % with an average of 84%. The system coefficient of uniformity (CUS) increased from Zone A to zone D with a mean value of 83% in all study zones.

*Table 3: Uniformity parameters for sprinkler system evaluation*

| Zones | Pressure(bars) | | | CU (%) | | | DU (%) | | | CUS (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Avg. | Max | Min | Avg. | Max | Min | Avg. | Max | Min | Avg. |
| ZoneA | 1.9 | 1.7 | 1.8 | 87 | 81 | 84 | 86 | 75 | 79 | 84 | 78 | 81 |
| ZoneB | 2.1 | 1.9 | 2 | 91 | 79 | 85 | 92 | 81 | 87 | 88 | 77 | 82 |
| ZoneC | 2.4 | 2.2 | 2.3 | 92 | 79 | 87 | 93 | 72 | 83 | 89 | 76 | 84 |
| ZoneD | 2.5 | 2.3 | 2.4 | 90 | 87 | 88 | 97 | 77 | 88 | 87 | 83 | 85 |
| Average | **2.23** | **2.03** | **2.13** | **90** | **82** | **86** | **92** | **76** | **84** | **87** | **78** | **83** |

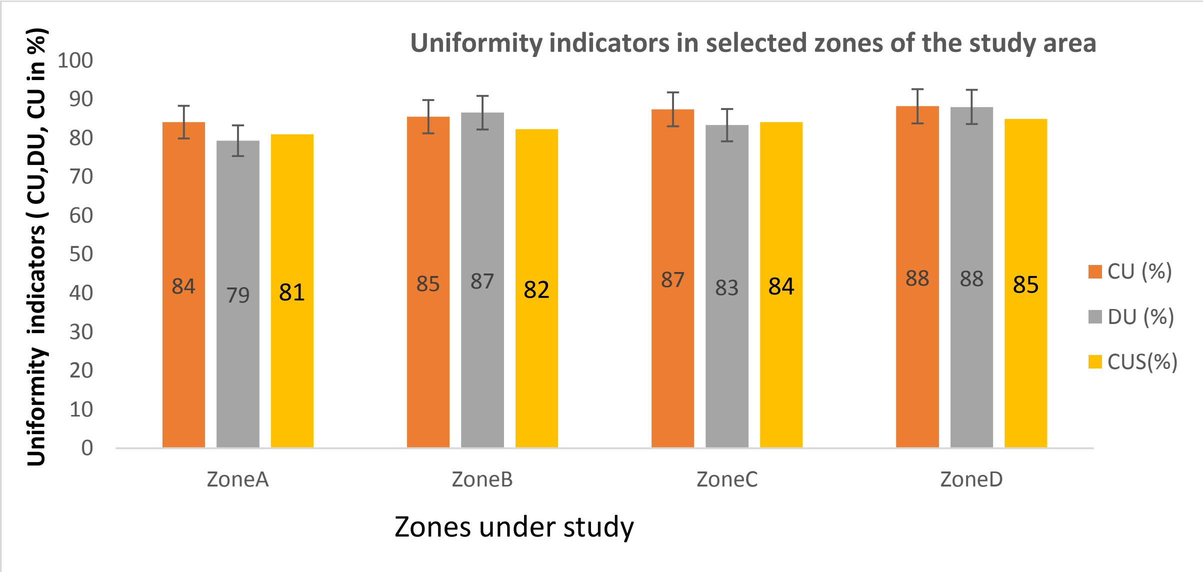


*Figure 3: Uniformity indicators in zones of study area*

It is clear that the results obtained in this study for CU, DU and CUS are in accordance with research findings from Topak et al. (2005) and Keller and Bliesner (1990). As shown in figure3, the CU and DU values of Zone A are lower comparably to other three zones; and the reason may be attributed to the wind direction and its high effect in Zone A. However, the zones B; C and D showed the higher values of CU and DU comparably to the first one and this is justified by least wind effect. Generally, DU and CU values decrease with the increase of wind speed and sprinkler spacing. Furthermore, the low wind speed conditions do not affect the CU significantly (Hills and Barragan, 1998). Referring to the recommendations set by Keller and Bliesner (1990) and (M Burt et al., n.d.)Burt et al. (1997), the mean values of CU (86%) and DU (84%) resulted from the study fall in the desirable category; and that indicates a good performance of the irrigation system evaluated.

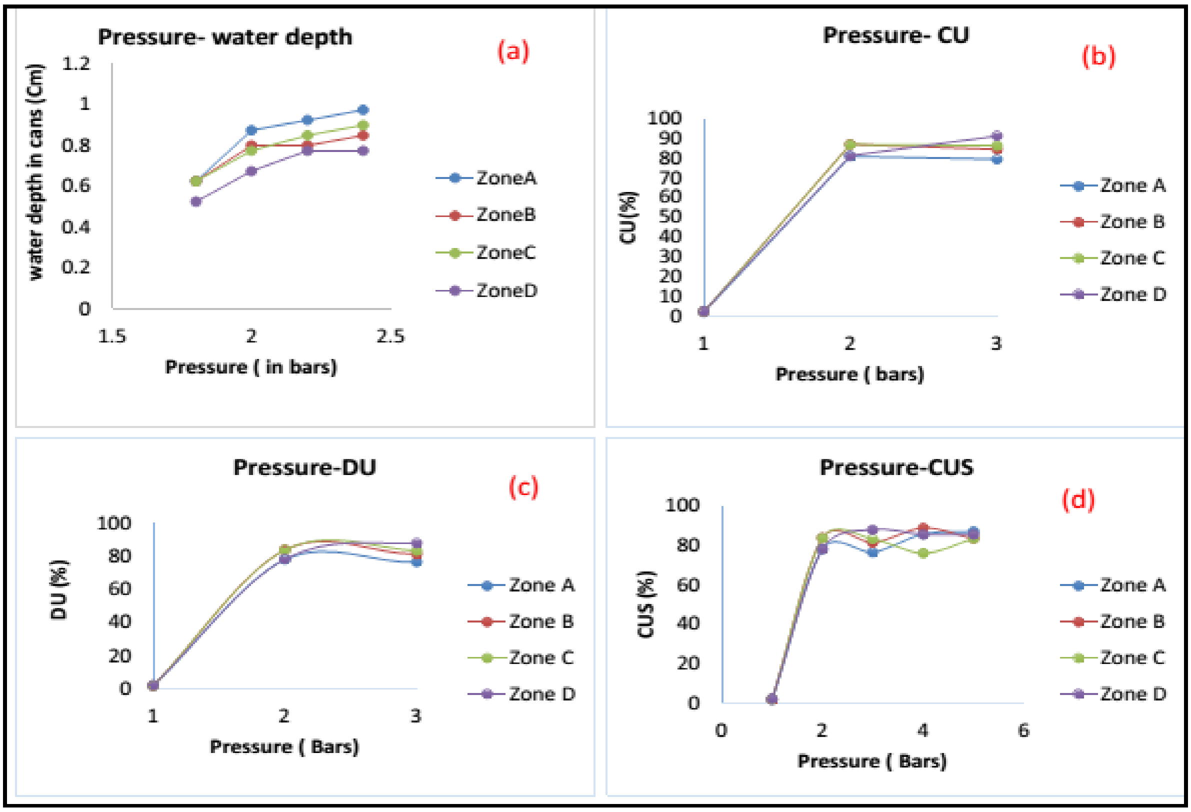


*Figure 4:Pressure versus water depth and uniformity parameters: (a) Pressure-water depth (b) Pressure-CU (c) Pressure-DU (d) Pressure-CUS*

The figure 4 shows the relationship between pressure, water depth and parameters of uniformity. Inlet pressure and outlet pressure of each sprinkler lateral evaluated in different field zones were measured to determine pressure variation along laterals. Within this framework, the results showed a correlation between pressure in sprinkler and water depth (Fig4-a). In addition, the correlation between pressure and uniformity parameters (CU, DU and CUS) was observed (Fig4-b, c & d). It is generally accepted that, in order to maintain sufficient uniformity, the limit of discharge varying in different places of laterals should not be above 10% of average discharge because the sprinkler operating pressure impacts the sprinkler discharge rate and amount applied. The pressure variation restrictions shouldn't go over 20% of the average working pressure for better achievement. Greater pressure variation above this threshold would have an impact on the water distribution uniformity (DU), causing certain areas of the surface to receive more water than others.

**Sprinkler system efficiency**

*Table 4: Assessed efficiency indicators in the study area*

| Zones | Sprinkler discharge rate(mm/hr) | | DPR | Water Application rate (mm/hr) | Water collected in catch cans (mm) | Evaporation and wind drift losses (mm) | DE (%) | PAELQ (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Actual | Required | | | | | | Max | Min | Avg. |
| Zone A | 1580 | 1950 | 0.81 | 10.87 | 9.27 | 1.6 | 80.5 | 88.3 | 73.8 | 79.5 |
| Zone B | 1695 | 1950 | 0.87 | 11.7 | 9.03 | 2.67 | 86.7 | 79.9 | 61.3 | 72.9 |
| Zone C | 1790 | 1950 | 0.92 | 12.04 | 10.62 | 1.42 | 89.2 | 97.2 | 76.3 | 84 |
| Zone D | 1858 | 1950 | 0.95 | 12.4 | 10.03 | 2.37 | 91.8 | 88.1 | 71.7 | 81 |
| Average | 1730.8 | 1950.0 | 0.9 | 11.8 | 9.7 | 2.0 | 87.1 | 88.4 | 70.8 | 79.4 |

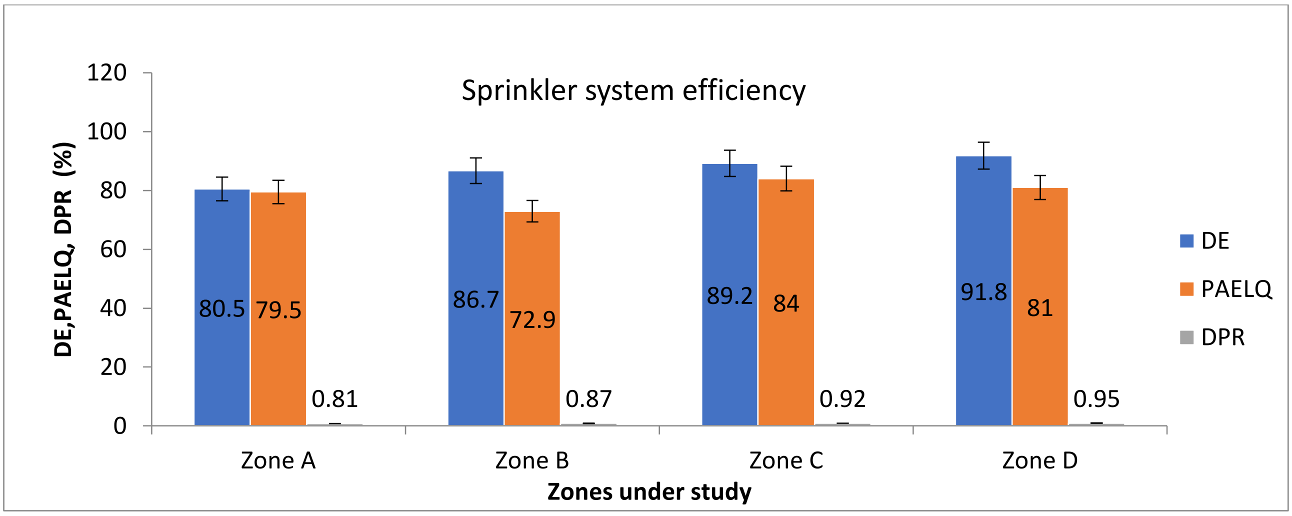


*Figure 5: Efficiency indicators in zones of study area*

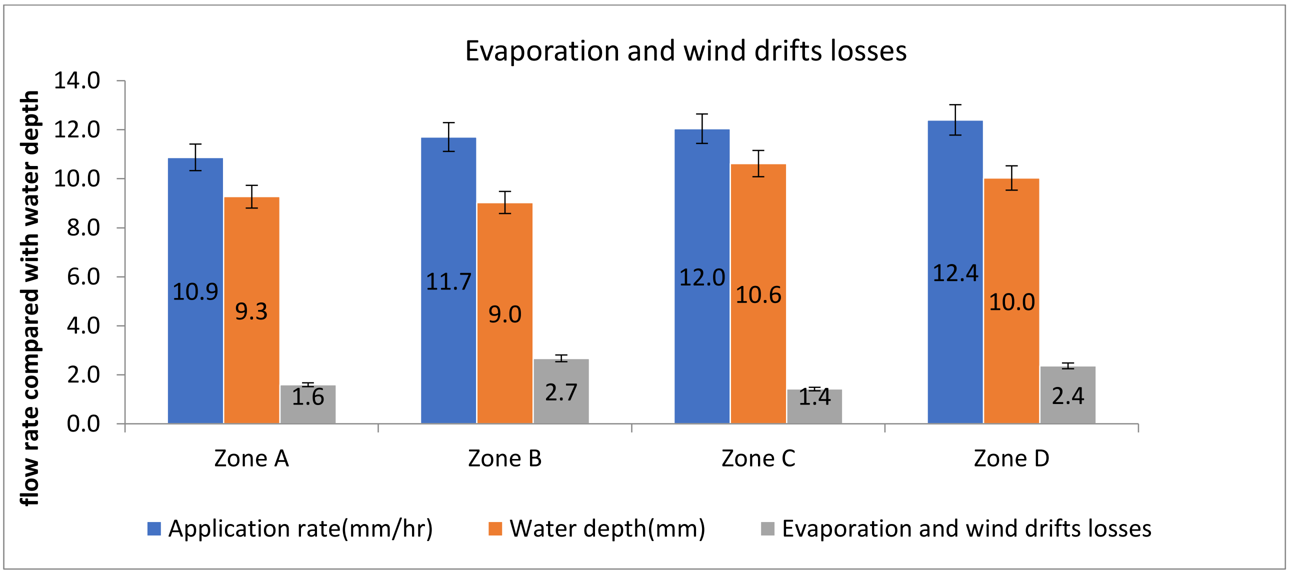


*Figure 6: Evaporation and wind drifts losses*

*Table 5: Results of evaluated variables of the sprinkler system*

| Evaluated indicator | Calculated value | Standard value |
|---|---|---|
| CU of the system (%) | 86 | CU>84% (Keller and Bliesner, 1990) |
| DU of the system (%) | 84 | 75% and above (Burt et al., 1997) |
| Operating pressure (bars) | 2.13 | 3 bars |
| Pressure application efficiency at low quarter (PAELQ) | 79.4 | PAELQ>60% |
| Average discharge of sprinklers (L/hr) | 1730.75 | 1950 |
| Average application rate of sprinklers (mm/hr) | 11.75 | 13.54mm/hr |
| Discharge efficiency (%) | 87.05 | 1 |
| Delivery performance ratio of the system (DPR) | 0.9 | 1 |

The results from figure5 reveal that discharge efficiency (DE) ranges from 80.5% to 91.8% with a mean value of 87.1%. It is notable that the discharge efficiency variance is wide among the four zones when compared to the average. The outcomes also demonstrate that there is only a slight variance in discharge efficiency across the three zones (Zone B, Zone C and Zone D). Zone A, however, showed a significant variance in discharge efficiency, which can be related to the wind effect that prevails there. On the other hand, the results for Potential Application Efficiency of Low Quarter (PAELQ) in the four zones taken into consideration for this study, show the significant variability. In figure 6, it is shown that there is a relationship between the rate of water delivery by sprinkler and the amount of water collected during the catch-can test. Variations between the two measurements show losses due to evaporation and wind drift. This equation also shows how the system's operating pressure affects two efficiency metrics, such as the quantity of water to apply and losses due to evaporation and wind drift.

The highest PAELQ value of 84% was found in Zone C and the lowest Value was observed in Zone B (72.9%) with the system average PAELQ value of 79.4%. Based on standard values for sprinkler irrigation as it was suggested by Keller and Bliesner (1990); it is evident that the results for PAELQ are within the range (see table5).

The Table 4 demonstrates that the computed average sprinkler application rate (11.8 mm/h) was less than the expected value (13.5 mm/h). Additionally, the measured infiltration rate of a sandy loam soil (see table 6) in the study location (17.2mm/hour) was higher than both the calculated and forecasted application rates. A sandy loam soil infiltration rate should be between 20 and 30 millimeters per hour, according to the literature. As a result, water provided to the irrigation system was completely absorbed into the soil profile and free of runoff, confirming the adequacy of sprinkler system's water application intensity in the study area.

*Table 6: Measured soil infiltration rate in the study area*

| | **Depth (cm)** | Infiltration Rate (mm/h) | sand (%) | silt (%) | clay (%) | Texture-textural triangle | FC (%)-Pummia (1990) | WP (%)-Pummia (1990) |
|---|---|---|---|---|---|---|---|---|
| ZA | 0-15 | 17.3 | 70 | 16 | 14 | Sandy loam | 14 | 6 |
| | 15-30 | | 65 | 29 | 15 | Sandy loam | 14 | 6 |
| | 30-45 | | 60 | 21 | 19 | Sandy loam | 14 | 6 |
| ZB | 0-15 | 17.1 | 72 | 13 | 15 | Sandy loam | 14 | 6 |
| | 15-30 | | 68 | 16 | 16 | Sandy loam | 14 | 6 |
| | 30-45 | | 63 | 19 | 18 | Sandy loam | 14 | 6 |
| ZC | 0-15 | 17.1 | 73 | 12 | 15 | Sandy loam | 14 | 6 |
| | 15-30 | | 65 | 20 | 15 | Sandy loam | 14 | 6 |
| | 30-45 | | 60 | 21 | 19 | Sandy loam | 14 | 6 |
| ZD | 0-15 | 17.2 | 72 | 12 | 16 | Sandy loam | 14 | 6 |
| | 15-30 | | 67 | 18 | 15 | Sandy loam | 14 | 6 |
| | 30-45 | | 64 | 19 | 17 | Sandy loam | 14 | 6 |

The pressure variation analysis revealed that as the applied water depth increases proportionally with working pressure, the operating pressure of the system had an impact on the uniformity and quantity of sprinkler application. The system's age and nozzle blockage may have contributed to the drop in the value of the discharge. Looking on the quality of water distributed from the pumping house to the irrigation system, it can be assumed that some parameters such as turbidity are among the contributors of the system efficiency. Therefore, they may have affected the discharge drop through malfunction of some water distribution equipment such as valves, junctions and nozzles in different zones evaluated.

The delivery performance ratio (DPR) was measured and found to be 0.9. This value reflects on system efficiency of 90% with an estimated 10% losses from evaporation and wind drifts.

These findings indicate that the sprinkler system efficiency in the study area is good and effective referring to Molden and Gates (1990) and (Grassini et al., 2011). The efficiency of the system may be increased with proper equipment management and routine maintenance.

## Conclusion

It is essential to carry out assessment in the context of system efficiency for the design and planning of inexpensive and sustainable sprinkler irrigation systems in Rwanda. The effectiveness of the sprinkler irrigation system is assessed primarily based on its efficiency and uniformity. It is clear that low uniformity exhibits poor efficiency. In such conditions, both energy and water are wasted resulting in poor water productivity and revenue at scheme level. The study's findings showed that the distribution uniformity, uniformity coefficient, and system efficiency were 84%, 86%, and 90% respectively. These results guarantee that the sprinkler system's overall performance is rated as satisfactory. However, it is advised to correct system operation and to perform regular maintenance of the system in order to achieve optimal system efficiency. Furthermore, there is need to assess water quality from pumping station for preventing problems in function of water delivery equipment.

## References

Acar, B., Topak, R., & Direk, M. (2010). Impacts of Pressurized Irrigation Technologies on Efficient Water Resources Uses in Semi-Arid Climate of Konya Basin of Turkey. *International Journal of Sustainable Water and Environmental Systems*, *1*(1), 1–4. https://doi.org/10.5383/swes.0101.001

Ahaneku, I. E. (2010). Performance evaluation of portable sprinkler irrigation system in Ilorin, Nigeria. *Indian Journal of Science and Technology*, *3*(7). http://www.indjst.org

Bos, M. G, Methodologies for assessing performance of irrigation and drainage management. Irrigation and Drainage Systems. 7(4): p. 231-261, 1994.

Chandra, A., Heeren, D. M., Odhiambo, L., & Brozović, N. (n.d.). *Water-Energy-Food Linkages in Shared Smallholder Irrigation 2 Schemes 3*. https://ssrn.com/abstract=4224291

Dechmi, F. E., Cavero J M Faci a Martínez-Cob, P. J., Playán Dechmi J Cavero A Martinez-Cob, E. F., & Faci, J. M. (n.d.). *WIND EFFECTS ON SOLID SET SPRINKLER IRRIGATION DEPTH AND CORN YIELD*.

Geoffrey, G., Dieu, M. J. de, Pierre, N. J., & Aimable, T. (2015). Design of Automatic Irrigation System for Small Farmers in Rwanda. *Agricultural Sciences*, *06*(03), 291–294. https://doi.org/10.4236/as.2015.63029

Grassini, P., Yang, H., Irmak, S., Thorburn, J., Burr, C., & Cassman, K. G. (2011). High-yield irrigated maize in the Western U.S. Corn Belt: II. Irrigation management and crop water productivity. *Field Crops Research*, *120*(1), 133–141. https://doi.org/10.1016/j.fcr.2010.09.013

Harrison, E., & Mdee, A. (2018). Entrepreneurs, investors, and the state: the public and the private in sub-Saharan African irrigation development. *Third World Quarterly*, *39*(11), 2126–2141. https://doi.org/10.1080/01436597.2018.1458299

Howell, C.R. (2003) Mechanisms Employed by Trichoderma Species in the Biological Control of Plant Diseases: The History and Evolution of Current Concepts. Plant disease, 87, 4-10. https://doi.org/10.1094/PDIS.2003.87.1.4

Kannan, N., Jeong, J., & Srinivasan, R. (2011). Hydrologic Modeling of a Canal-Irrigated Agricultural Watershed with Irrigation Best Management Practices: Case Study. *Journal of Hydrologic Engineering*, *16*(9), 746–757. https://doi.org/10.1061/(asce)he.1943-5584.0000364

Keller J and Bleisner RD (2000) Sprinkler and trickle irrigation. The black burn press, Caldwell, NJ. p:652.

Keller, J., & Bliesner, R. (1990). Sprinkler and Trickle Irrigation Von Nostrand-Reinhold New York: NY

M Burt, B. C., Clemmens, A. J., StrelkotT, T. S., Solomon, K. H., Bliesner, R. D., Hardy, L. A., Howell, T. A., & Eisenhauer, D. E. (1997.). *Irrigation Performance Measures: Efficiency and Uniformity*.

Majoro, F., Mukamwambali, C., Shumbusho, J. D. U., & Hagenimana, E. (2016). Environmental Impacts Investigation of Irrigation Projects: Case Study of Kanyonyomba Rice Perimeter in Rwanda. *Journal of Water Resource and Protection*, *08*(07), 687–696. https://doi.org/10.4236/jwarp.2016.87056

Majumdar S.P., Meena R.L., Baghel G.D.S.Effect of levels of compaction and potassium on yield and quality of tomato and chilli crops grown on highly permeable soils

Malesu, M.M., Raymonds, O.A., Cherogony, K., Douglas, N., Charles, G., Kipngetich, B.E., Mogoi, J., et al. (2010) Rwanda Irrigation Master Plan. Report, Ministry of Agriculture and Animal Resources, Kigali.

Maroufpoor, E., Faryabi, A., Ghamarnia, H., & Yamin Moshrefi, G. (2010). Evaluation of Uniformity Coefficients for Sprinkler Irrigation Systems under Different Field Conditions in Kurdistan Province (Northwest of Iran). In *Soil & Water Res* (Vol. 5, Issue 4).

Merriam, J., Shearer, M., & Burt, C. (1980). Evaluating irrigation systems and practices. *Evaluating irrigation systems and practices.*, 721-760.

Merriam, J.L. and Keller, J. (1978) Farm Irrigation System Evaluation: A Guide to Management. Utah State University, Logan, Utah.

Molden D.J. and Gates, T.K. (1990) Performances measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage, 116, 804-823. dx.doi.org/10.1061/(ASCE)0733-9437(1990)116:6(804).

Msibi, T., Kihupi, N., Tarimo, A., & Manyatsi, A. (2014). *Climate-smart Agriculture View project Constrains, Production Systems and Roles of Phosphorus in Rice Production in Tanzania View project*. http://www.ijasber.com

Mutambara, S. (2016). Smallholder irrigation farmers' financial exclusion in Zimbabwe: A resilience threat. *International Journal of Agricultural Policy and Research*, *4*(8), 256–270. https://doi.org/10.15739/IJAPR.16.027

Narayanan, K. (2014). Impact of Participatory Irrigation Management - Case Study: Cocurirwa Cooperative, Rwamagana Rice Project, Rwanda. *Advances in Plants & Agriculture Research*, *1*(3). https://doi.org/10.15406/apar.2014.01.00013

Ngasoh, F. G., Anyadike, C. C., Mbajiorgu, C. C., & Usman, M. N. (2018). Performance evaluation of sprinkler irrigation system at Mambilla beverage limited, Kakara-Gembu, Taraba state-Nigeria. *Nigerian Journal of Technology*, *37*(1), 268. https://doi.org/10.4314/njt.v37i1.35

Noreldin T, Ouda S, Mounzer O, Abdelhamid MT. Crop System model for wheat under deficit irrigation using sprinkler and drip irrigation in sandy soil. Journal of Water and Land Development. 2015; 26:57-64)

Salmerón, M., Urrego, Y. F., Isla, R., & Cavero, J. (n.d.). *Effect of non-uniform sprinkler irrigation and plant density on simulated maize yield 1 2*.

*Topak et al. (2005*). Performance evaluation of sprinkler irrigation in a semi-arid area. *Pakistan Journal of Biological Sciences (8) 1:97-103, 2005*

Urujeni, S., & Chrysostome, J. (2015). Economic Valuation of Irrigation Water in Smallholder Farming System in Rwanda: The Case of Kibaya-Cyunuzi Scheme. In *International Journal of Agriculture Innovations and Research* (Vol. 4, Issue 1).