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Surface irrigation and drainage system performance evaluation of MUVUMBA P8-Marshland

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Abstract

The study evaluates the irrigation and drainage performance of an irrigation scheme in MUVUMBA P8 marshland, which has a total area of 1750 ha but only 1500 ha irrigated. The marshland faces water shortages, flooding, and inadequate land and water resource management. The research uses qualitative and quantitative techniques, including Cropwat 8.0 software, to determine crop water requirements and evaluate irrigation system infrastructure. The evaluation of irrigation system infrastructure involves combining physical condition assessment with service delivery performance indicators. Hydraulic checks and flow measurements are also conducted. Current conveyance and application efficiency are determined based on design values and compared to design standards. The results show conveyance losses in the right primary and left secondary canals, attributed to poor drainage and maintenance of primary canals. The average conveyance efficiency for both channels is 63.70%. The agricultural performance varies between 4.001 tons/ha and 6.047 tons/ha per unit of cropped area and 3.052 tons/ha to 5.021 tons/ha per unit of command. The study suggests that the scheme is not performing to its designed capacity, with higher conveyance losses and inadequate maintenance and repair work.

Keywords: University of Rwanda**,** Irrigation System**,** Application Efficiency**,** Conveyance Efficiency**,** Water User Organizations, Water Distribution

Introduction

Perimeter 8 of Muvumba Valley is in Nyagatare District, Eastern Province, at ± 190 km from Kigali. Muvumba 8 is a public land of 1,500 ha that was sometimes used for cattle grazing and growing crops[1]. Irrigation, a drainage network, hydraulic infrastructure, and irrigation dams were needed for farmers to be able to use that land for high-value agriculture production in the two annual seasons.

Rural Sector Support Project II (RSSPII), with the support of the World Bank, has identified for the construction of an irrigation system the Muvumba Perimeter 8 Marshland located in Nyagatare District in the Eastern Province[2]. Three reservoirs and 27 km of irrigation channels will be constructed to facilitate irrigation of 1,500 ha of marshland. The Muvumba Irrigation Scheme consists of surface irrigation (furrow, border strip, basin, spate, and surge irrigation) for the purpose of crop production, and it consists of drainage channels that help in removing excess water from irrigable land for the purpose of providing favorable conditions for agricultural production. The main crops cultivated in marshland are rice, maize, and vegetables.

Food shortages and drought in Rwanda are persistent issues that cannot be solved through rain-fed agricultural production alone. Irrigation technologies can help tap into agricultural potential in arid and semi-arid areas, improving food production and security[3]. However, the MUVUMBA valley faces problems such as lack of water, flooding, and inadequate water management infrastructure. Farmers face problems of lack of water during the dry season, soil salinity, flooding and waterloggingin some parts of the valley during the peak rainy season, and lack of management of available land and water resources; those result in losing 2 ha of land every year[4].

The objectives, such as determining the irrigation water requirement of rice, evaluating the performance of the irrigation system infrastructure, determining the current water conveyance and application efficiency within the scheme in contrast to the recommended design values, and investigating and recommending sustainable strategies for agricultural land use and farm management to mitigate negative impacts of climate change on agricultural water demand, were achieved through the research.

The research achieved the objective due to the main question: What is the irrigation water requirement for rice cultivation in MUVUMBA P8 marshland? How effective and reliable is the current irrigation system infrastructure in supporting rice production? What are the actual water conveyance and application efficiencies in the scheme, and how do they compare with the recommended design values? What sustainable land use and farm management practices can be adopted to reduce the negative impacts of climate change on agricultural water demand in the scheme?

Materials and methods

The study explored Muvumba p8 marshland in Eastern Province, Nyagatare District, focusing on rice cultivation and agricultural productivity since 2011 development. Nyagatare District experiences short rainfall and hot temperatures, with a long dry season and unpredictable annual rainfall, affecting agriculture and livestock needs.

Nyagatare's hydrographic network is limited, with only a few consistent rivers and a tight humus layer of soil. The district's topography, lowly inclined hills, and mechanized agriculture offer potential for modern agriculture. Annual rainfall ranges from 829 to 900mm, with four seasons. Nyagatare contains half of Akagera National Park, home to a variety of wildlife and thriving flora and fauna.

The following materials were used to collect field data: notebooks, pens, rulers, calculators, and computers; stopwatches and floating bottles for velocity measurements; books for documentation; measuring tapes; the FAO CROPWAT 8.0 software for calculating evapotranspiration and irrigation requirements; digital cameras for site documentation; and various simple floating devices such as sticks or bottles. The test has been carried out on three sites: upstream, middle, and downstream of the marshland.

Primary data was collected from the scheme, which was mainly field measurements of the water levels and balance from the already installed and calibrated structures. Similarly, secondary data was also collected from the meteorological department, the National Irrigation Board, and the scheme offices. Moreover, a participatory approach discussion was conducted with beneficiary farmers and the Muvumba farmers' organizations, especially the Water Users Organizations (WUOs).

Hydraulic conductivity tests were carried out by pumping test that involves removing water from a well and monitoring water level changes to understand aquifer properties[5].

The CROPWAT 8.0 software was used to estimate crop water requirements, including potential evapotranspiration, effective rainfall, and irrigation demand[6]. Calculations considered climatic factors such as minimum and maximum temperatures, humidity, wind speed, and sunshine duration. Crop-specific data and rainfall records were also incorporated.

Stream discharge was measured using the float method[7]. Equipment included measuring tapes, stakes, stopwatches, and floating objects (bottles or sticks). A straight, uniform 10 m section of the stream was selected. Floating objects were released upstream, and their travel times between two points were recorded multiple times to calculate average velocity. Stream cross-sectional area was estimated from measurements of bed width, surface width, and depth. Discharge was calculated using the formula:

$Q=0.85\times A\times V$

Where, Q is discharge (m^3/s), A is cross-sectional area (m^2), and V is flowing velocity (m/s). The correction factor of 0.85 accounted for channel roughness and aquatic vegetation.

Infiltration was measured using a double-ring infiltrometer[8]. The procedure involved inserting concentric rings into the soil, filling them with water, and recording water level changes over time. Measurements were initially taken every 1–2 minutes, then every 20–30 minutes once the infiltration rate stabilized. This method ensured accurate assessment of soil infiltration, which is essential for estimating water losses and surface runoff.

Water Conveyance efficiency was evaluated by measuring discharges at different points along the irrigation canals[9]. The inflow–outflow method was applied to determine water losses in canal segments using the equation:

$S=Qi-Qo$

Where S is conveyance loss (l/s), Qi is inflow, and Qo is outflow. These measurements were carried out in main, secondary, and tertiary canals to estimate system efficiency.

Results and Discussion

The test has been carried out on three sites: upstream, middle, and downstream of the marshland. The hydraulic conductivity K1 (cm/s) at the top 1 m depth of reserves 1, 2, and 3 are 1.108 x 10-8, 1.189 x 10-8, and 1.071 x 10-8, respectively, and the hydraulic conductivity K2 (cm/s) at the bottom 1 m depth of reserves 1, 2, and 3 are 1.92 x 10-8, 1.27 x 10-8, and 1.0358 x 10-8, respectively. According to the previous data, the permeability of the soil was calculated by taking the average hydraulic conductivity of each reserve at the down fields to be irrigated, and the results are 1.514 x 10-8 cm/s, 1.225 x 10-8 cm/s, and 1.0534 x 10-8 cm/s, respectively. Crop water requirements were determined for where rice crops were planted on March 23 and harvested on September 16, with ETc and irrigation requirements determined on a decade-by-decade basis. The peak irrigation requirement varied from 43.1 mm in the 2nd decade of June to 55.1 mm in the 1st decade of August. The highest ETC was observed in the 3rd decade of July, followed by 51.1 mm in the 1st decade of August. The total crop water requirement for the growing season was 772.2 mm, with effective rainfall of 313.3 mm per 180 days. The average water requirement per month was 175.36 mm, and the net irrigation requirement was 1052.2 mm - 313.3 mm = 738.9 mm. The gross irrigation requirement was 7389 m^3/180 days/ha, as 1 mm of water is equivalent to 10 m^3/ha. Hence, the gross irrigation requirement for the whole season of 1500 ha is equal to GIR=7389 m^3 x 1500 ha = 11083500 m^3. The total net irrigation requirement for the rice growing season is 461.2 mm per 180 days, and the gross irrigation requirement for 1500 ha during the month is 6918000 m^3.

Discharge measurements in the primary and secondary channels show flows of about 0.21 m^3/s in the primary canals and 0.13 m^3/s in the secondary canals, indicating relatively modest conveyance capacity.

The scheme covers about 1,750 ha, but the irrigated area fluctuated between 969 ha and 1,543 ha from 2011 to 2017, rarely achieving full potential.

Production performance varies across seasons. Output per cropped area ranged between 4.0 and 6.0 t/ha, while output per command area ranged from 3.1 to 5.0 t/ha. These variations reflect impacts of water shortages and floods, with significant drops in 2012/13, 2014/15, and 2016/17 due to drought and excessive water levels that damaged crops. For example, in 2014/15 yields fell by 1.54 t/ha per unit cropped area compared to the previous year.

Water productivity analysis revealed production per unit of water consumed increased from 1,700 t/m³/s in 2011/12 to 2,781 t/m³/s in 2015/16, before slightly declining to 2,332 t/m³/s in 2016/17. This indicates gradual improvements in water use efficiency, though challenges in crop management and climate variability limited consistent gains.

Conclusion and Recommendations

The evaluation of the Muvumba P8 marshland irrigation scheme shows that although the command area is about 1,750 ha, actual irrigated land fluctuated between 969 and 1,543 ha, demonstrating underutilization of its potential. Conveyance efficiency averaged only 63.7%, with significant water losses caused by poor drainage, inadequate maintenance, and canal deterioration. Agricultural performance varied seasonally, with rice yields per cropped area ranging from 4.0 to 6.0 t/ha and per command area from 3.1 to 5.0 t/ha. Yield fluctuations were strongly linked to droughts and flooding, highlighting the vulnerability of the scheme to climatic extremes. Water productivity showed gradual improvement from 1,700 to 2,780 t/m³/s between 2011 and 2016, before declining slightly, reflecting inconsistent crop management and water distribution. Overall, the scheme is not performing to its design capacity, with inefficiencies in water conveyance, variable crop yields, and challenges of climate change affecting sustainability.

To enhance the performance and sustainability of the Muvumba P8 scheme, there is a need to rehabilitate and modernize the irrigation infrastructure[10]. This includes lining critical sections of primary and secondary canals, repairing damaged hydraulic structures, and installing reliable flow measurement devices to reduce water losses and improve conveyance efficiency. Equally, drainage channels should be upgraded to minimize flooding and waterlogging, thereby creating favorable conditions for crop growth. At the farm level, climate-smart agricultural practices such as Alternate Wetting and Drying (AWD) for rice, the introduction of drought-tolerant varieties, and the use of well-aligned planting calendars should be promoted to improve water use efficiency and crop resilience. Land management interventions such as proper leveling, organic matter enhancement, and integrated soil fertility management will further increase application efficiency and yields. The role of Water User Organizations (WUOs) should be strengthened through capacity building in irrigation scheduling, system maintenance, and equitable water allocation to ensure reliable and fair distribution. Finally, institutional and policy support is necessary to improve monitoring of water use, provide financial assistance for modernization, and promote strategies that adapt to the impacts of climate change, ensuring that the marshland contributes effectively to food security and livelihoods in the Nyagatare district.

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