稲作灌漑用水管理における地理情報学とデータ分析の統合
Integrated Remote Sensing and Data Analytics in Rice Irrigation Water Management

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1. Introduction

Poor irrigation management in Kenya and Sub-Saharan Africa threatens food security due to inadequate infrastructure (Balasubramanian, 2007), climate change, poor water allocation, and accounting impacting rice production. Water usage, charged in m^3, is challenging to track in the Global South. A 2024-2025 study integrates soil and water sensors, remote sensing, and automated Farmo.Inc (Japan) gates into the RiceFarm WebView app (https://rice.powerappsportals.com) to fully implement the water-balance equation and monitor productivity. It leverages Microsoft Power Platform for cloud analytics and Google Earth Engine for water productivity analysis, identifying total water use, excess storage, drainage, and productivity indices per farm per season, as shown in Figure 1.

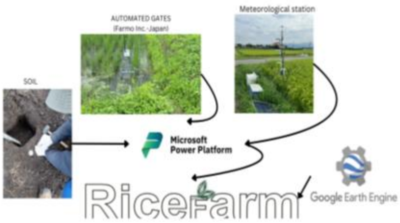

Figure 1 Flowchart

2. Materials and Methods

2.1 Study site

The study examines two 0.23-acre paddy fields owned by Shinshu University, along with a control farm under regular irrigation, located at 35°51'37.66"N, 137°57'39.84"E, 657 m ASL, as shown in Figure 2.

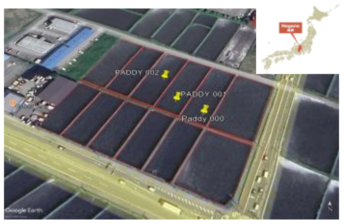

Figure 2 Study Area

2.2 Methods

Soil samples were analyzed for particle density, bulk density, particle size distribution, and water retention using the van Genuchten-Mualem (1980) and pressure plate methods. Infiltration was assessed via the Green-Ampt Method (1911) after 24 hours of ponding. Automated Farmo Inc. (Japan) gates and sensors tracked changes in storage by replacing traditional PVC-fitted lined canals in Paddies 001 (880.89 m^2) and 002 (903.36 m^2). A meteorological station logged evapotranspiration via the Bowen ratio and precipitation by electronic pulse, while remote sensing (Google Earth Engine) generated NDVI, EVI, LAI, and FPAR indices. Productivity was calculated based on water supply and evapotranspiration. Data analyzed on Microsoft Power Platform.

3. Results

Applying eq.1, each farm's effective saturated hydraulic conductivity ($K_{sat\ Eff}$) was calculated, with paddy000 representing the average K_{sat} of Paddy001 and Paddy002, resulting in 0.85 cm/hr.

$$K_{sat\ Eff} = \frac{L_{Topsoil} + L_{Hardpan + L_{subsoil1}} + L_{subsoil2}}{\frac{L_{Topsoil}}{K_{Topsoil}} + \frac{L_{Hardpan}}{K_{Hardpan}} + \frac{L_{subsoil1}}{K_{subsoil1}} + \frac{L_{subsoil2}}{K_{subsoil2}}} \qquad 1$$

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Where: $K_{sat\ Eff}$ is effective saturated hydraulic conductivity, L is the thickness of each layer, and K is the saturated hydraulic conductivity of each layer. Applying eq. 2 and 3, the average infiltration rates were determined to be 11.07 mm/d, resulting in a cumulative infiltration depth of 165.51 mm/ unit of water applied/d. Considering a well-compacted levee, the Runoff was assumed 0, and the excess above capping of 10 cm was accounted for as drainage.

$$f = K\left[\frac{|\varphi|\Delta\theta + F}{F}\right] \quad 2$$

$$F(t) - |\varphi|\Delta\theta \ln\left[1 + \frac{F(t)}{|\varphi|\Delta\theta}\right] = K(t) \quad 3$$

Where: K is the saturated hydraulic conductivities in cm/h, f is the infiltration rate in mm/d, F is the cumulative depth, and φ is the negative suction head in cm of water. The observed water storage changes, measured by sensors, ranged from +178 mm during tillering and panicle formation in summer to 0 mm at harvest in September due to drainage and canal supply cessation. Daily water depth readings were taken for Paddy 000, while 15-minute sensor data were used for Paddies 001 and 002. Adjacent farm inflows and overnight rainfall influenced differences between predicted and actual storage changes. Total inflows reached 51,348.77 m³, with rainfall-adjusted canal supply at 50,637.14 m³ for all three farms (2671.88 m²). The drained water volume was 3,003.83 m³ (Figure 3). Remote sensing analysis (Figure 4) tracked biomass production using key indices: NDVI (plant greenness) increased from 0.5965 (June) to 0.8388 (August), indicating vigorous leaf growth. EVI (vegetation density) followed a similar pattern, reflecting increased photosynthetic activity. LAI (leaf area index) expanded with plant growth but declined as leaves yellowed near maturity. FPAR monitored photosynthetic efficiency throughout the crop cycle, peaking during vegetative growth in July and August and declining with seed development. The total rice yield across the three paddies was 6,179.5 kg/ha, with a total water application of 50,637.14 m³, resulting in an Applied Water Productivity of 122 g/m³. Total evapotranspiration (ET) was 453.2611 mm, leading to a Crop Water Productivity of 1.36 kg/m³.

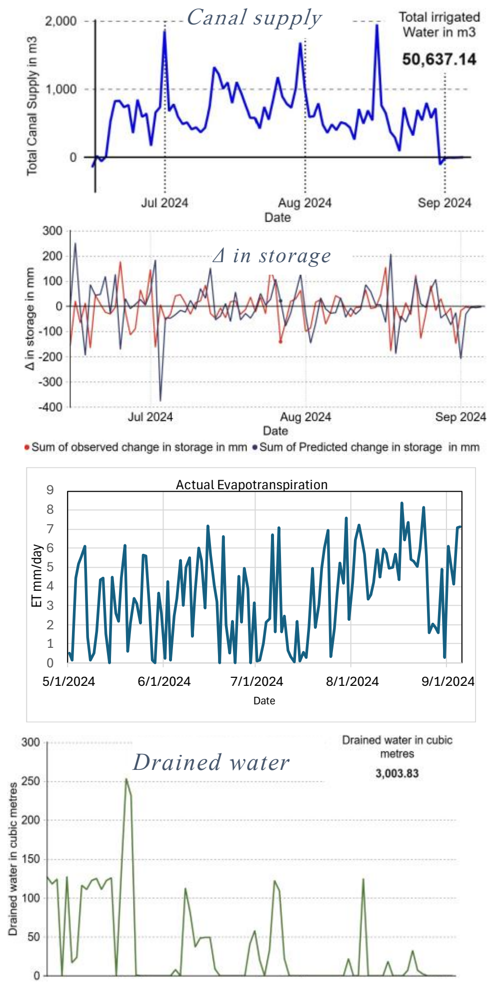

Figure 3 Water usage Analytics

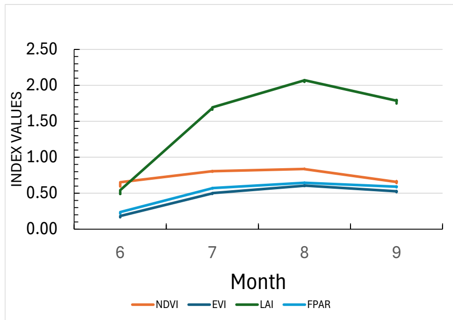

Figure 4 Vegetative indices

4. Conclusion

This study presents a breakthrough in near real-time irrigation water accounting by integrating remote sensing indices, productivity analysis, and farmer-led irrigation control into one application. It provides a practical solution for Kenya and Sub-Saharan Africa, ensuring accurate seasonal tracking with farmer-led rice irrigation water management.