

GEOSPATIAL DATA FUSION AND MODELING FOR IMPROVED IRRIGATION OF RICE (*ORYZA SATIVA*) IN THE MWEA IRRIGATION SCHEME, KENYA

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INFO

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ABSTRACT

Water being the most perilous abiotic stress to crop growth, the performance of irrigation systems in the largely arid and semi-arid Kenya is critical in increasing agricultural production. The study aimed at improving the efficiency of irrigation systems for rice in the Mwea Irrigation Scheme during the major growing season from August to December 2022. The study used datasets which include: Vegetation Health Index (VHI), Leaf Area Index (LAI), climate data, crop data, soil data. Random Forest Algorithm was used to fuse VHI and LAI to obtain the crop water content and using the evapotranspiration calculated based on Penman Monteith Algorithm using Climate data, crop coefficient KC values at the different growth stages of rice is obtained. The CROPWAT model was used to integrate the datasets to estimate irrigation water requirements at the different growth stages and develop an irrigation schedule. From the results, the spectral indices ranged from 0-1 with values near zero indicating adequate crop evapotranspiration, good crop condition implying no water stress while higher values close to 1 may indicate crop water stress. The temporal fluctuation in estimated CWC-derived Kc values showed moisture stress events during the season where reduced CWC caused a corresponding drop in Kc values. From the calculation of irrigation water demand, irrigation water increases gradually and reaches its peak at the mid/grain filling stage and decreases in the late stage. From the irrigation schedule developed, schedule based on daily monitoring of soil moisture balance is more robust in contrast with a schedule based on regular time interval period which may lead to over-irrigation or under-irrigation. A validation approach for the applicability of CROPWAT in Mwea Irrigation Scheme should however be developed.

1. Introduction

Irrigated agriculture performance has been hampered by limited soil fertility, erratic rainfall, frequent droughts, ineffective land-use policies, declining arable land, and increasing land fragmentation as a result of population growth (Yarnell, 2008), (OECD/FAO, 2023). Malnutrition, poverty, and unemployment are among the economic repercussions of Kenya's fluctuating and often poor agricultural performance in relation to the country's increasing population growth (Oduol *et al.*, 2006). In light of the foregoing facts, several national macroeconomic strategies aimed at revitalizing Kenya's agriculture and national economy have been developed. These strategies include the National Economic Development Plan (MPI, 2016), Vision 2030, Poverty Reduction Strategy, the Strategy for Revitalizing Agriculture, as well as Economic Recovery Strategy for Employment and Wealth Creation (OECD, 2023). All of these policies prioritize irrigation as a means of achieving their respective goals. Irrigation has the potential to increase agricultural productivity in Kenya. Irrigation, therefore, according to Jones, (2022), is the artificial application of water to land to aid in the growth

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and development of plants. It involves a controlled supply of water to agricultural fields to supplement natural rainfall and soil moisture content to ensure proper moisture levels for plant growth. Irrigation is an important water use sector making irrigated agriculture the largest water use globally accounting for 70% of freshwater withdraws (Ungureanu, Vlăduț and Voicu, 2020) from which 60% is lost in evapotranspiration, runoff and deep percolation. It contributes to 40% of the world's food production from 25% of the world's land area (FAO, 2018). The increased water withdrawals due to intensified agricultural activities, economic growth, population growth, and urbanization have all altered the water balance in watersheds and aquifers. (FAO, 2018). Therefore, the degree to which climatic conditions influence the hydrological cycle and agriculture is dependent on non-climatic factors. Irrigation systems are thus designed to ensure optimized irrigation practices in an era of increasing global warming, shortages of water, and population growth (Countries, 2013).

Irrigated agriculture contributes significantly to global food security by ensuring increased crop yields and multiple growing seasons which enables a stable supply of food for the increasing population. As the world's population grows, so does the demand for food, putting a strain on agricultural systems and making irrigated agriculture a necessity (FAO, 2018). According to World Bank, (2019), the expansion of irrigated agriculture subsequently puts a strain on available water resources worldwide leading to competition for limited supplies among sectors such as domestic use and industrial use. The global extent of irrigated agriculture has environmental impacts as water-intensive crops and inefficient irrigation practices lead to the depletion of aquifers (Tilman *et al.*, 2011) and water pollution through chemical runoff (Zhenci *et al.*, 2020). Consequently, it can be impacted by climate change such as dried aquifers, changes in precipitation patterns, and altered river flows leading to water scarcity, and can also directly impact global warming through the release of greenhouse gases, and excess usage of chemicals and fertilizers (Shuxuan Zhang, Ghulam Rasool, 2020).

Rice has become a highly strategic and priority commodity for food security in Africa (FAO, 2018). Its consumption is influenced by population growth, rapid urbanization and shifts in dietary patterns (Yarnell, 2008). Rice cultivation was introduced in Kenya in 1907 from Asia. According to Mati, (2023); Ndiiri *et al.*, (2013) rice is currently the third most important cereal crop after maize and wheat. Almost 80% of the rice in Kenya is cultivated under irrigation schemes while 20% is cultivated under rain-fed conditions (Ministry of Agriculture, 2008).

Kenya is mostly covered with Arid and Semi-arid regions making it generally dry. Therefore, rice has to be grown in paddy fields with good water-holding capacity and continuously saturated with water (Nyang'au *et al.*, 2014). However, fewer regions have the right soil conditions and few water resources for rice production (Nyang'au *et al.*, 2014) thus limiting the country's ability to meet demands. Consequently, increasing rice growing fields is not advisable due to a lack of water and suitable soils for rice production (Ndiiri *et al.*, 2013). There is however an expansion of growing fields known as out growers in the Mwea Irrigation Scheme of about 4000ha. Rice is cultivated in Mwea (Central Kenya), Bunyala (Western Kenya), Msambweni (Tana Delta in Coast) and Ahero (Nyanza provinces) (Ministry of Agriculture, 2008).

Rice (*Oryza Sativa*) is a grass and highly stipulated cereal crop (Pearsall *et al.*, 1995). Water stress affects metabolic activities, tissue formation, panicle and flower formation, reproduction process, grain filling and seed maturity (Conger, 2018). Rice is grown by seedlings or by direct sowing. The rice paddies are kept in a flooded water condition after transplanting the seedlings to facilitate establishment. The growth and development of rice crop relies on the balance between moisture content in soil and losses through outflows (Smith *et al.*, 2013). Heavy clay soils have a lower percolation and seepage rate as compared to sandy soils. Water losses from the rice paddies are as a result of transpiration (70%) and evaporation (30%) (Bouman *et al.*, 2005). The phenological growth stages of rice are divided into five stages: Establishment after transplanting, vegetative/Tillering, reproductive, grain filling phase and maturity (Kumar Meena *et al.*, 2015). At the establishment stage, seedlings are around 25-30 days old and it marks their transition from the nursery to the main field as they establish root systems. At the vegetative Stage, rice plants start to produce tillers which are additional leaves, stems, and roots to capture sunlight and nutrients for photosynthesis (Thakur *et al.*,

2011). The panicle initiation and flowering stage is when the rice plant begins to transition from the vegetative phase to the reproductive phase and is usually characterized by the formation of the panicle, which is the flowering part of the plant. The booting and heading stage are when the panicle has fully emerged and pollination begins to take place. The grain filling stage is characterized by the milk and dough stage. Just immediately after pollination is the milk stage where the seed is still milky and as rice continues to fill with starch, it becomes firmer hence the dough stage. The maturity stage is when the plants have reached full growth, grains have fully formed and hardened, and are ready for harvesting. The stages may be affected by water stress but are often severe during the reproductive and grain filling stages leading to poor grain filling and thus poor grain quality (Conger, 2018).

There are factors that influenced the scheme's selection. For starters, Mwea is Kenya's oldest and largest public irrigation project, on which other projects such as Ahero, West Kano, and Bunyala are modeled. It is also the most active irrigation area in the Tana basin (Ministry of Agriculture, 2008). More than 90% of the water abstracted in the basin is already used in irrigating just over 40% of its irrigable potential (Obiero, 2010). Further, irrigation is still expanding in the study area. However, such a level of water use threatens the sustainability and expansion of irrigation in MIS. Addressing irrigation water-use efficiency in MIS, therefore has direct benefits to the area, the Tana basin, and a multiplier effect on other basins in the country. This calls for improved water-use efficiency in the basin, which is critical in modeling the sustainable management of finite resource in other basins in the country (Obiero, 2010).

The main aim of this study was to estimate irrigation water requirements of rice crops in Mwea Irrigation Scheme from a fusion of spectral indices and structural parameters and modeling of irrigation schedule using CROPWAT software. The specific objectives were to: estimate the crop water content of rice from a fusion of spectral indices and structural parameters using Random Forest Algorithm; estimate crop water requirements from an integration of climate data, soil data and crop data using CROPWAT; develop an irrigation schedule for rice in Mwea Irrigation Scheme.

2. Materials and Methods

2.1. Study Area

The study area, (**Figure 1**), Mwea Irrigation Scheme is found in Kirinyaga County, Central Kenya in the upper region of the Tana Catchment and is supplied by rivers Thiba and Nyamindi (Obiero, 2010). It lies near the equator within latitudes $0^{\circ} 32'S - 0^{\circ} 46'S$ and longitudes $37^{\circ} 13'E - 37^{\circ} 13'E$ and at an altitude of approximately 1159m above sea level (Ndiiri *et al.*, 2013). The location of MIS near the equator at approximately 1159m above Sea Level ensures high solar radiation and the large day and night temperatures promote rice growth and grain yield. The area experiences an annual mean precipitation of 920mm with long rains between March-May and short rains between October-December. Annual mean air temperature is 23° - 25° with about a 10° difference between minimum temperature in June/July and maximum temperature in October-March.

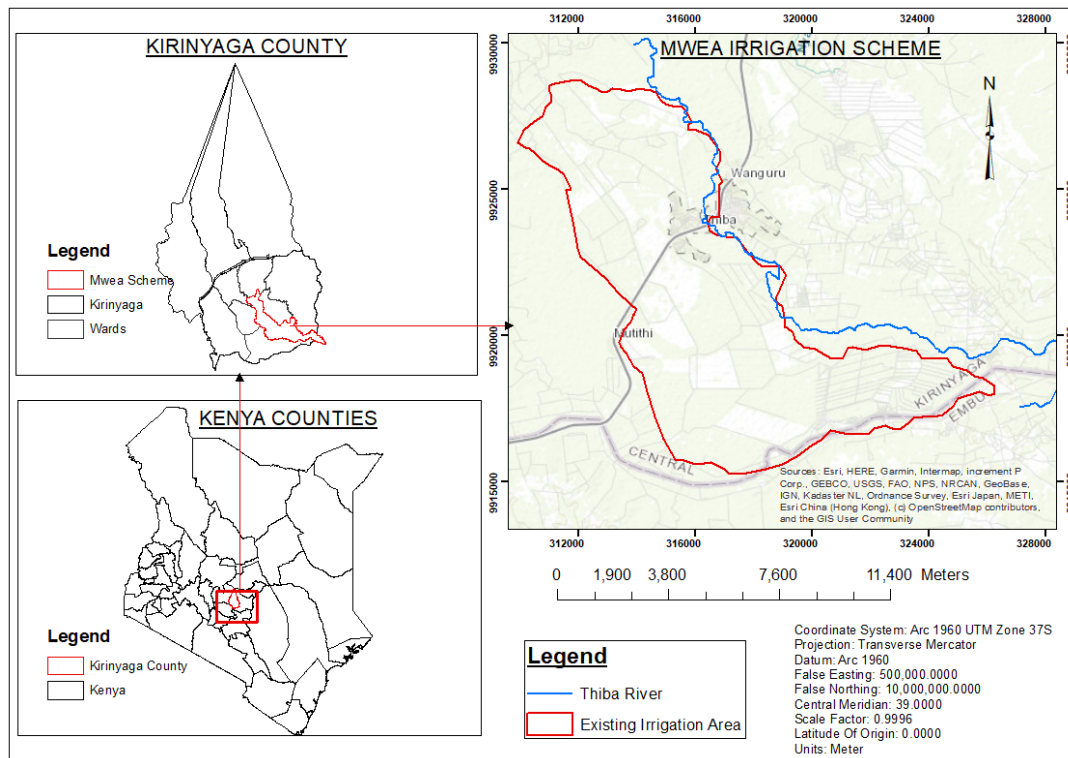


Figure 1. Study Area

The higher areas have shallow reddish-brown lateritic clay loams (red soils), while the low lands are impervious heavy montmorillonite clays (Obiero, 2010). The expansive low-lying marshy areas mainly comprised of vertosols which are characterized by poor drainage, very deep, dark grey to black firm to very firm, cracking clay which is moderately alkaline (Gitonga, Home and Mwangi, 2019). Tana River which is the longest river in Kenya passes across the scheme thus often depositing alluvial deposits which are highly fertile and harnessed for agricultural purposes through irrigation (Ndiiri *et al.*, 2013).

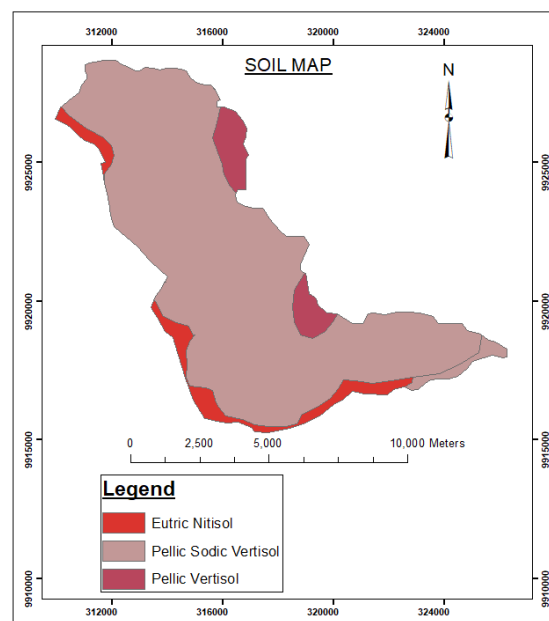


Figure 2. Soil map

In the Mwea Irrigation Scheme, 22000 acres have been assigned for paddy rice cultivation out of 30500 acres and the remaining are for settlement and residentials, public utilities and subsistence crops. The major land-use in the area is commercial water flooded irrigation of rice. MIS is the largest scheme in Kenya under rice cultivation producing 80-88% of rice in the country and is the third most important food grain after maize and wheat (Samejima *et al.*, 2020). Men, women and children participate in rice production where men are involved in land preparation (ploughing, rotavating and leveling) and transportation while women and children carry out transplanting, weed removal, bird scaring, harvesting, threshing and drying. Rice marketing is however undertaken by everyone except women, who largely participate in the local retail rice businesses (Ministry of Agriculture, 2008).

2.2. Methodology

A summary of the methodology is presented in (*Figure 3*). The datasets used are Landsat 8 Imagery 2022, climate data, crop data and soil data. From satellite imagery, spectral and structural indices are derived and then fused using the Random forest regression model to obtain rice crop water content which is essential in determining crop coefficients which describe crop evapotranspiration and irrigation water needs of rice. Climate, crop and soil data are integrated into CROPWAT software and using embedded arithmetic programmes, irrigation water requirements and irrigation schedule for rice crops in Mwea Irrigation Scheme are computed.

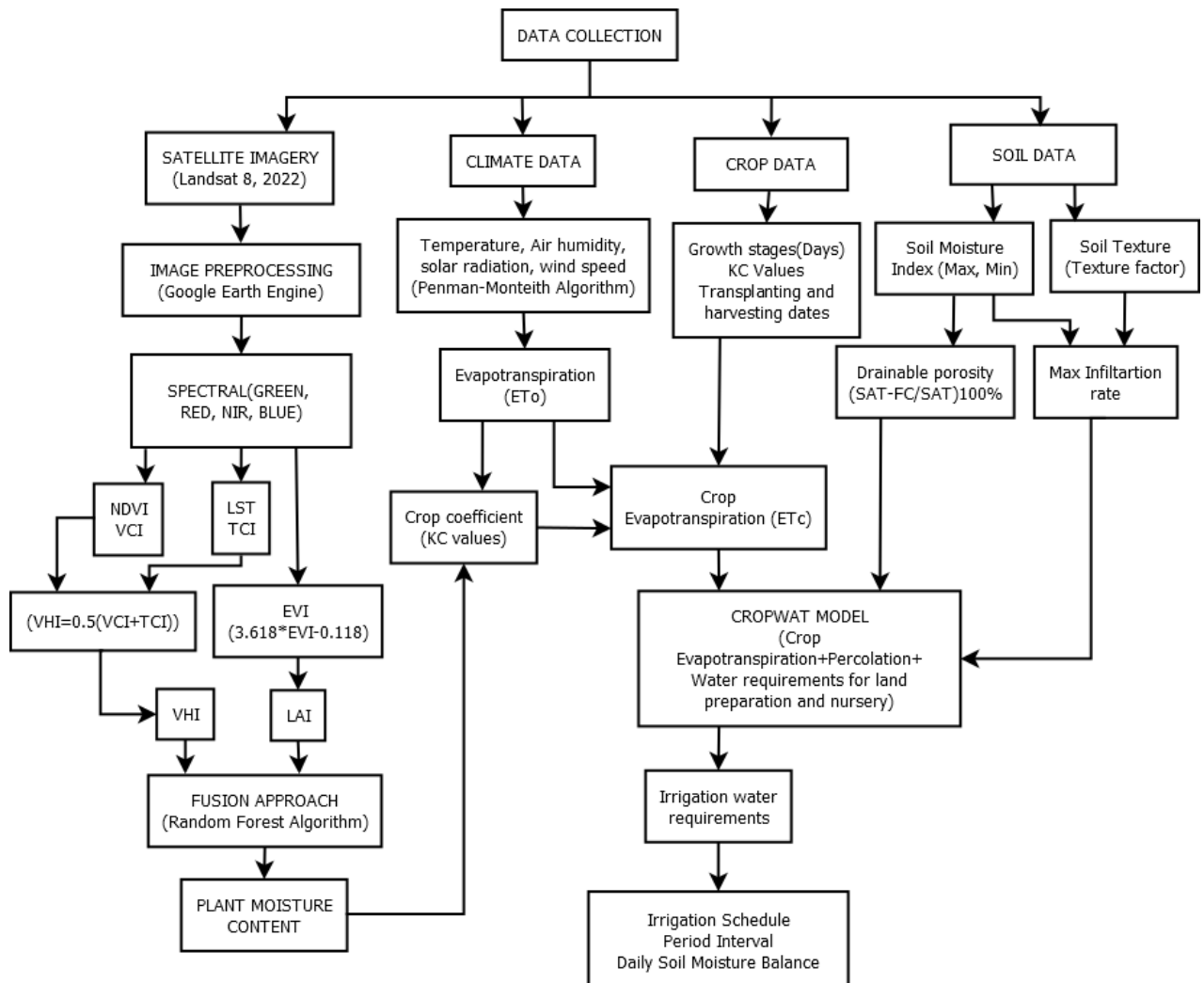


Figure 3. Methodology Flowchart

2.2.1 Estimation of crop water content of rice

To estimate crop water content from a fusion of spectral indices and structural parameters using Random Forest Algorithm, Spectral indices, NDVI, LST and EVI were first derived from Landsat 8 imagery then the structural parameter, LAI, was derived from EVI. VHI was derived from an integration of TCI and VCI.

Vegetation Health Index (VHI) - Assess the condition and health of vegetation. VHI combines both the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). The VCI is obtained from NDVI while TCI is obtained from LST.

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad \text{Equation 1 (Bento et al., 2020)}$$

Where:

VCI is Vegetation Condition Index

NDVI is the Maximum and minimum value of the Normalized Difference Vegetation Index

$$TCI = \frac{LST_{max} - LST}{LST_{max} - LST_{min}} \quad \text{Equation 2 (Bento et al., 2020)}$$

Where:

TCI is Thermal Condition Index

LST is the Maximum and minimum value of the Land Surface Temperature

Therefore

$$VHI = 0.5(VCI + TCI) \quad \text{Equation 3 (Bento et al., 2020)}$$

Enhanced Vegetation Index (EVI) – Used to quantify vegetation greenness in dense vegetation areas and corrects for atmospheric conditions and canopy noise. It incorporates the L value to adjust canopy background, the C value as the coefficient for atmospheric resistance and values from the B band.

$$EVI = 2.5 \left(\frac{NIR - RED}{(NIR + 6) * (RED - 7.5) * (BLUE + 1)} \right) \quad \text{Equation 4 (Boegh et al., 2002)}$$

Where:

EVI is Enhanced Vegetation Index

NIR is Near Infrared Band 5

Leaf Area Index (LAI) – This is the structural parameter of rice that was derived from the Enhanced Vegetation Index based on a linear relationship as follows

$$LAI = 3.618 * EVI - 0.118 \quad \text{Equation 5 (Boegh et al., 2002)}$$

Crop Water Content derived from Google Earth Engine was used for training in the Random Forest Algorithm to estimate plant water based on a fusion between VHI and LAI. The estimated crop water content and reference evapotranspiration were then used to calculate Crop Coefficients for each growth stage which was an input in the CROPWAT Model.

2.2.2 Estimation of crop water Requirements

To estimate crop water requirements from an integration of climate data, weather data, soil data and crop data using CROPWAT.

Data that was used for the calculation of Evapotranspiration rate (E_t) are geographical coordinates of the station i.e. latitude, longitude and elevation above mean sea level, maximum and minimum temperature ($^{\circ}\text{C}$), relative humidity (%), wind speed (km/day), sunshine hours and radiation ($\text{MJ m}^{-2} \text{ day}^{-1}$).

Climate data was used to calculate the evapotranspiration rate using the Penman-Monteith Algorithm (Allen *et al.*, 1998).

$$E_{T_o} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.342U_2)} \quad \text{Equation 6 (Allen *et al.*, 1998)}$$

Where:

E_{T_o}	reference crop evapotranspiration (mm day^{-1})
R_n	net radiation at the crop surface ($\text{MJ m}^{-2} \text{ day}^{-1}$)
G	soil heat flux density ($\text{MJ m}^{-2} \text{ day}^{-1}$)
T	mean daily air temperature at 2 m height ($^{\circ}\text{C}$)
u_2	wind speed at 2 m height (km/hour)
e_s	saturation vapor pressure (kPa)
e_a	actual vapor pressure
$e_s - e_a$	saturation vapor pressure deficit (kPa)
Δ	slope vapor pressure curve ($\text{kPa } ^{\circ}\text{C}$)
γ	psychrometric constant ($\text{kPa } (^{\circ}\text{C})$).

Crop coefficient values (K_c) for each of the growth stages of rice which are inputs in the crop data section were calculated from the estimated reference crop evapotranspiration (E_{T_o}) and crop water content. The growth stages are the establishment stage, vegetative/tillering stage, reproductive stage/ panicle initiation to flowering, grain filling and maturity/ ripening and harvesting.

Crop evapotranspiration (E_{T_c}) refers to the aggregate amount of water required by rice under standard conditions for both evaporation from the soil and transpiration from the plant across the different growth stages. Evaporation happens when water is lost from the soil and other free water surfaces, whereas transpiration occurs when water is taken by plant roots, conveyed through the plant and discharged into the atmosphere. E_{T_c} is used to estimate the water requirement of a certain crop throughout its growing season.

$$E_{T_c} = K_c \times E_{T_o} \quad \text{Equation 7 (Allen *et al.*, 1998)}$$

Where

K_c Crop coefficient

E_{T_o} reference crop evapotranspiration (mm/day)

Crop irrigation water requirement (CWR) refers to the amount of water that needs to be supplied. Includes the combined effect of evapotranspiration, percolation and requirements of land preparation and nursery before transplanting. Evapotranspiration occurs immediately after the rice fields are inundated. During the nursery period, evapotranspiration and percolation are accounted for only over the area covered by the nursery. During land preparation, the area increases daily with more land being inundated until the rice fields are fully covered at transplanting.

CWR (mm) was determined as:

$$CWR_i = \sum_{t=0}^T (Kc_i \cdot ETo + \text{Deep percolation} + \text{Runoff} - P_{eff.}) \quad \text{Equation 8 (Division, 1992)}$$

Where:

CWR_i Crop irrigation water requirement for rice

Kc_i — Crop Coefficient of rice at growth stage t

T Final Growth stage

Deep percolation is estimated at 1.9mm/day

Runoff is zero as paddy fields are protected by 30cm dikes.

$P_{eff.}$ — Effective Rainfall which is equal to zero.

2.2.3 Development of an Irrigation Schedule

The calculation of the irrigation schedule is based on soil water balance daily in which all incoming and outgoing water flow in the rootzone of the soil profile is monitored. For calculations, data on crop evapotranspiration, crop and soil are required.

The formula used is:

$$D_{ri} = D_{r,i-1} - (P - RO_i) - I_i - CR_i + ET_{c,i} + DF \quad \text{Equation 9 (Allen et al., 1998)}$$

Where:

D_{ri} Root Zone Depletion/ Soil moisture depletion at the end of the day i (mm)

$D_{r,i-1}$ Water content in the root zone at the end of the previous day (mm)

P_i Precipitation on day i (mm)

RO_i Runoff from soil surface on day i (mm)

I_i Net irrigation depth on day i that infiltrates the soil (mm)

CR_i Capillary rise from the groundwater table on day i (mm)

$ET_{c,i}$ Crop evapotranspiration on day i (mm)

DP_i Water loss out of root zone by deep percolation on day i (mm)

3. Results

3.1. Crop Water Content Estimation

3.1.1 Phenological Spectral Indices

LST is derived from the thermal infrared bands of Landsat 8 Imagery, provides temperature in Celsius and is used to monitor crop water status and health. Cooler crops suggest adequate water supply and crop transpiration while warmer crops may indicate water stress. LST can be used to derive a thermal condition index (TCI) to evaluate rice health and irrigation needs across different growth stages.

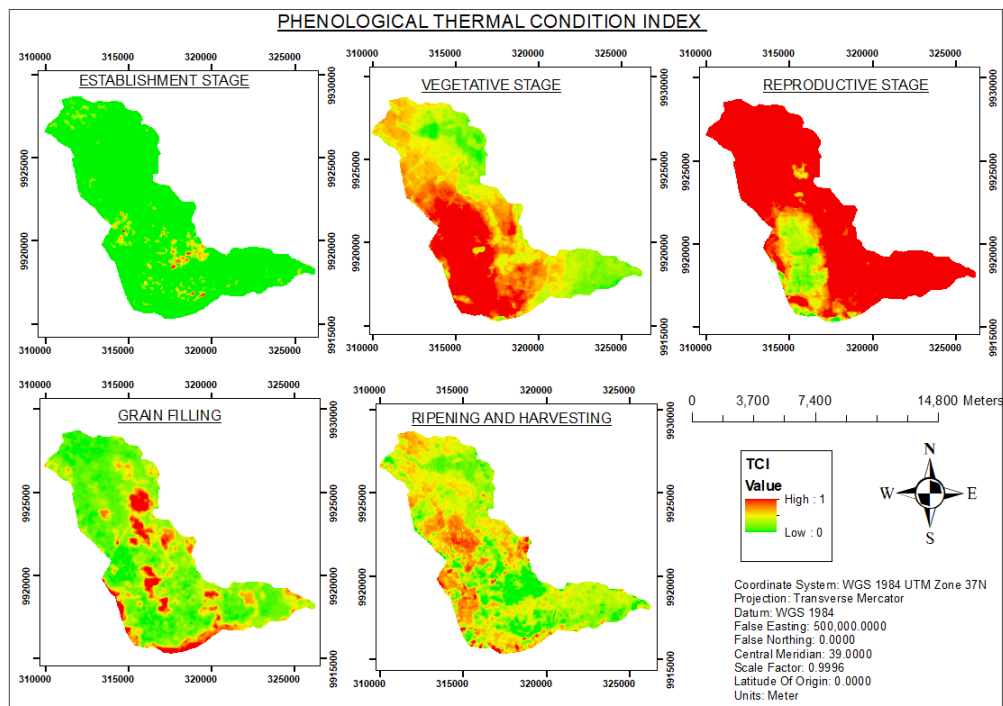


Figure 4. Phenological Thermal Condition Index

TCI ranges from 0-1 according to (Figure 4) with values near zero indicating adequate crop evapotranspiration and water status while higher TCI values close to 1 may indicate crop water stress. The TCI maps provide insights into rice crop thermal dynamics from August to December across different growth phases. During initial flooding and crop establishment in August, TCI is cool around 0.2-0.4 indicating adequate flooded conditions for transplanting. In the vegetative stage in September, TCI remains low around 0.3-0.5 in some areas indicating healthy crop development while other areas have values close to 1 suggesting possible water stress. As rice enters the reproductive phase in October, TCI increases slightly to 0.4-0.6 in some higher elevation blocks, suggesting possible water stress affecting grain formation. November is the grain-filling stage and TCI ranges from 0.3-0.5 indicating mitigation of the water stress in the reproductive stage. Toward harvesting in December, TCI rises across most fields as the crop dries up. But a few fields show cooler TCI around 0.4 likely due to delayed crop senescence.

The normalized difference vegetation index (NDVI) calculated from Landsat 8 imagery provides an indicator of vegetation greenness and vigor it correlates to important crop parameters like leaf area, biomass, yield and plant stress. NDVI values were used to derive a vegetation condition index (VCI) for rice crops in MIS from August to December across the different growth stages as seen in (Figure 5).

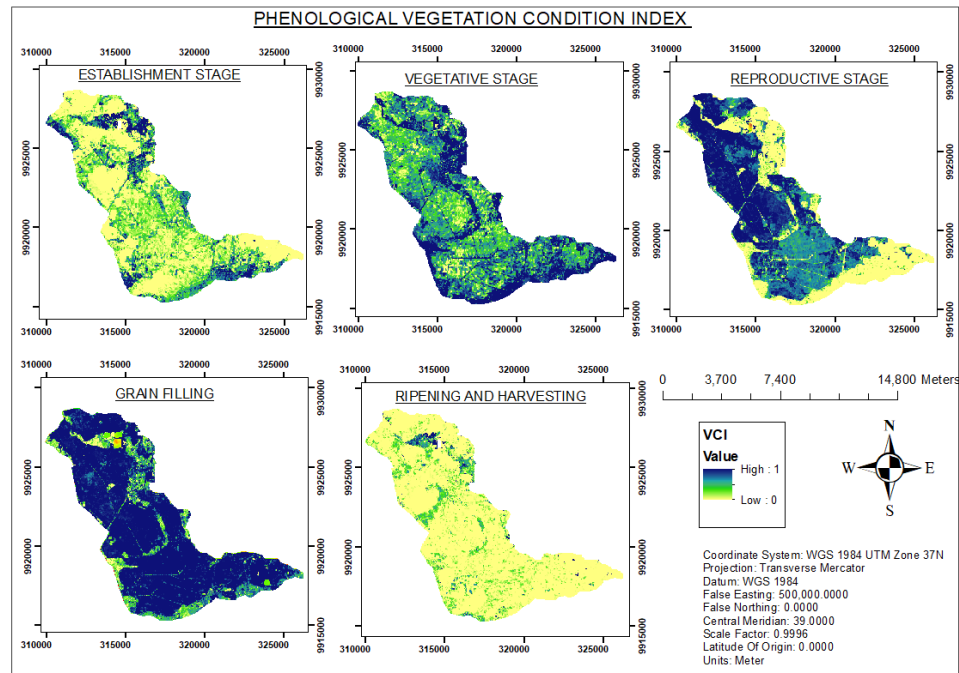


Figure 5. Phenological Vegetation Condition Index maps generated from NDVI maps

VCI provides a normalized indicator of crop performance and stress across the rice fields in the different growth stages. From (**Figure 5**), VCI values range from 0-1. During the initial flooding and crop establishment stage in August, VCI is moderately high around 0.6-0.8 indicating good early season crop establishment across most fields. In the vegetative stage in September, VCI remains high, near 1, as the fields turn green. The consistently high VCI suggests favorable growing conditions at this stage. As the crop enters the reproductive phase in October, VCI dips slightly to 0.8-0.9 in some peripheral fields, potentially signaling some water stress affecting grain formation. November is the grain-filling stage and VCI remains high around 0.9 across most fields, indicating successful grain bulking. Slightly lower values around 0.8 in a few fields suggest variability in grain filling. Toward harvesting in December, VCI declines as leaves start yellowing and drying up suggesting a successful season overall.

VHI maps were then generated for MIS over the major growing season of August to December 2022 using Landsat 8 imagery from a combination of VCI and TCI as depicted in (**Figure 6**). VHI showed distinct seasonal patterns corresponding to rice growth stages.

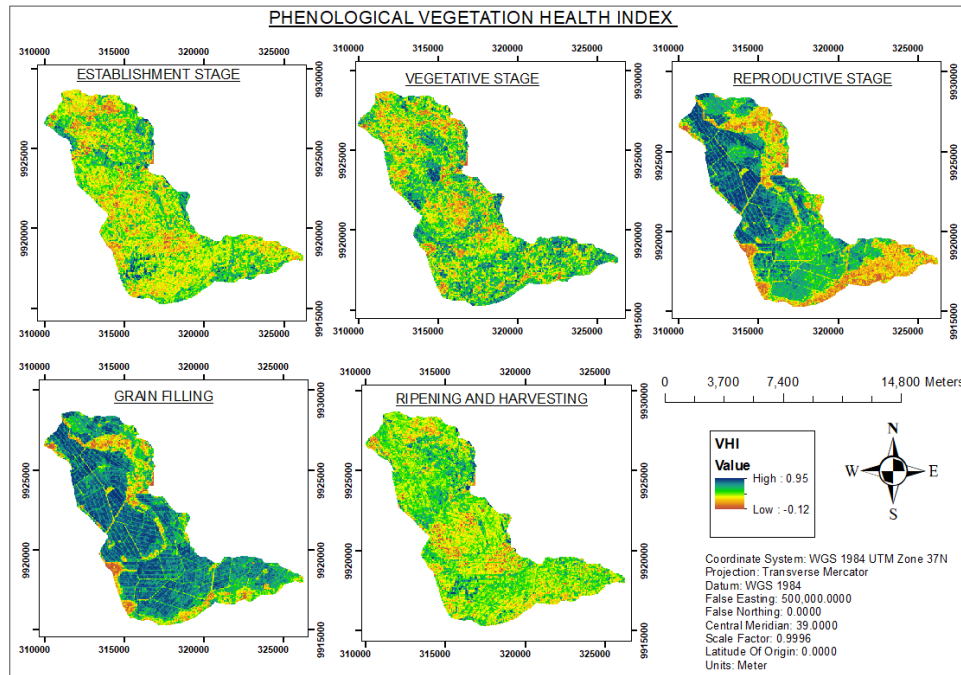


Figure 6. Phenological Vegetation Health Index Maps.

VHI values ranged from -0.12 to 0.95 over the rice fields across the different phenological stages with higher values indicating healthier vegetation. Lower values of below 0.2 indicate built-up and water-flooded rice paddies. During transplanting and early vegetative stages, VHI values are lower, 0.2-0.4, due to the presence of water flooded background and less vegetation biomass. As rice develops, VHI increases reaching a peak value of 0.95 at the reproductive and grain-filling stages. During the maturity and harvesting stage, VHI decreases as the crop senesced ready for harvesting.

From the results, VHI served as a more sensitive indicator of rice growth, vigour and stress as compared to NDVI. The combined information on NDVI and thermal conditions based on LST allowed for the detection of moisture stress. VHI maps can identify areas that require interventions to improve rice crop health and productivity.

3.1.2 Phenological Structural Parameters

The Enhanced Vegetation Index (EVI) calculated from Landsat 8 satellite imagery characterized rice crop growth stages. EVI correlates to canopy cover, biomass accumulation and leaf area index. The research analyzed Landsat 8 EVI of rice from August to December to profile crop development, progression of rice growth stages and canopy characteristics.

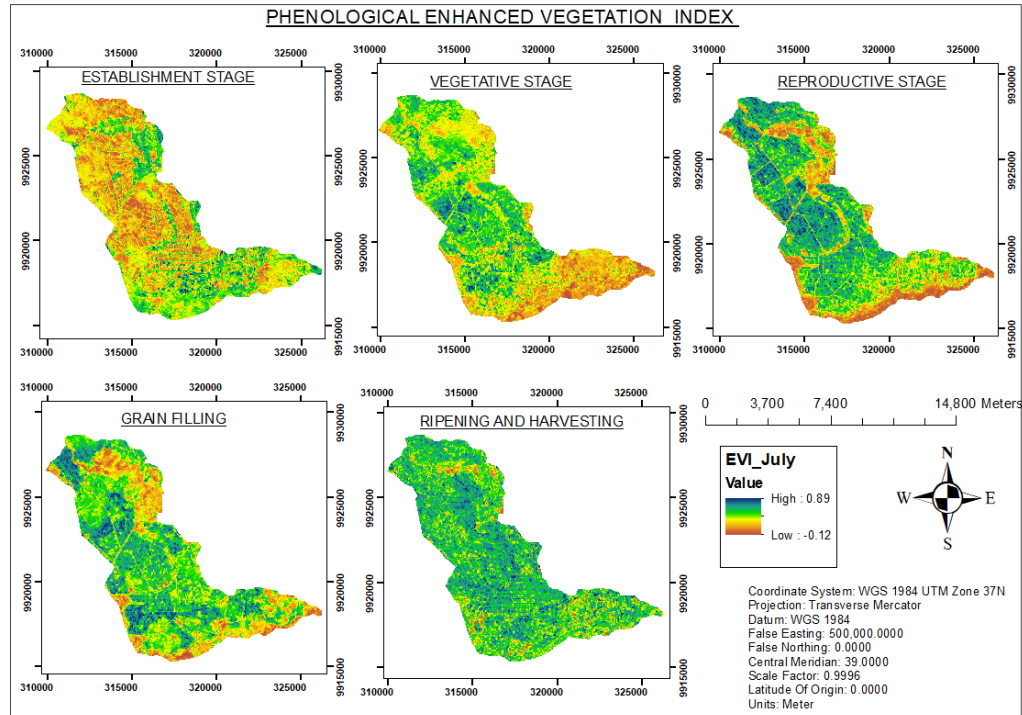


Figure 7. Phenological Enhanced Vegetation Index maps.

The series of EVI maps according to (*Figure 7*) illustrates rice growth progression across the season. In August, during flooding and crop establishment, EVI is low around 0.2 as fields are prepared for transplanting. Through September, EVI rapidly increases to 0.6 as the vegetative phase commences and the canopy develops. October marks the reproductive stage and EVI peaks around 0.8 indicating optimal canopy and biomass. During grain filling in November, EVI remains high around 0.7 but starts declining. By December, EVI drops to 0.5 as leaves senesce and dry down pre-harvest.

The Leaf area index (LAI) indicates the leaf area per unit ground area. For rice crops, LAI is an important indicator of canopy development, medium for light absorption, respiration, photosynthesis and transpiration. The research estimated rice LAI from Landsat 8 EVI to characterize seasonal growth patterns.

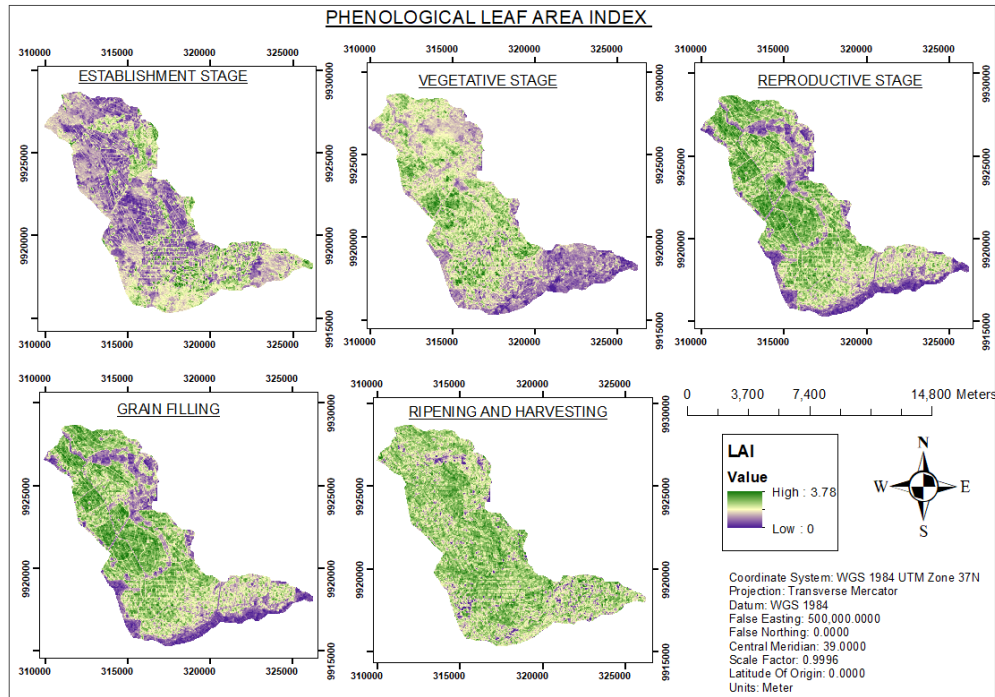


Figure 8. Phenological Leaf Area Index maps

The LAI maps as in (*Figure 8*) derived from EVI show the progression of rice canopy over the season. LAI values ranged from 0-3.78 with zero indicating no vegetation and 3.78 indicating the highest LA per unit ground surface area. LAI at establishment stages was very low as transplanted rice seedlings have been partially submerged in water-flooded rice paddies. LAI increases gradually to its peak value of 3.78 during reproductive and grain-filling stages and declines as it approaches maturity as leaves start senescing.

From the results, LAI provided a robust indicator of rice growth, structural development and yield potential. The LAI signatures follow typical rice growth stage patterns, with the highest leaf area reached during the critical reproductive phase. The peak LAI indicates optimal canopy for interception of light and CO₂ uptake. Therefore, a drop in LAI especially during the reproductive stages is an indication of water stress which affects metabolic activities such as photosynthesis, respiration, transpiration and conversion of sugars to starch. This affects the grain filling process which in turn affects the grain quality and grain yield.

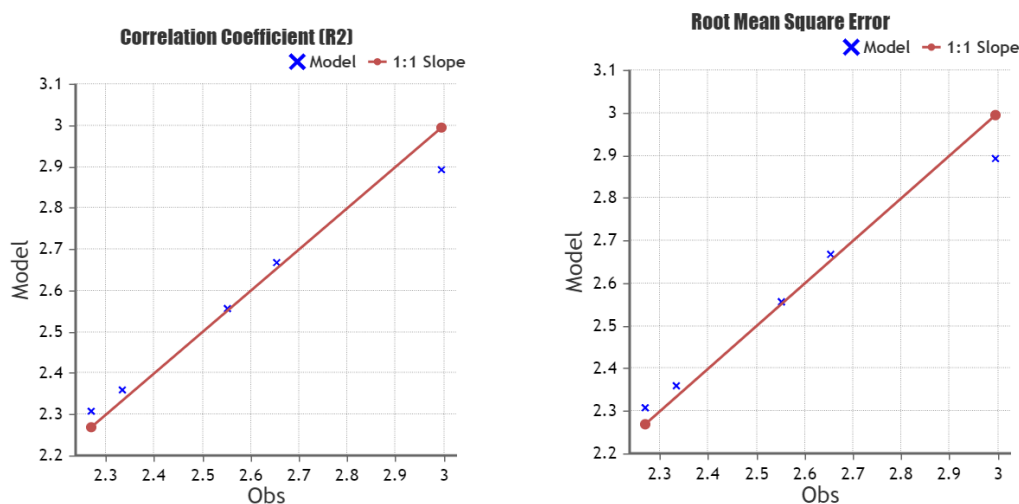
3.1.3 Fusion of VHI and LAI using RFA and Crop Coefficient Estimation

Crop water content (CWC) indicates the total water present in the above-ground biomass. For rice, CWC is related to the crop coefficient (K_c) which helps determine irrigation needs. The Random Forest regression model was used to integrate VHI and LAI to estimate the CWC of rice at different crop growth stages and the obtained results are as shown in (*Table 1*).

Table 1. Results from the Random Forest Regression Model

	Stages	VHI	LAI	Estimated_CWC
0	Establishment	0.572813	1.321004	2.308770
1	Vegetative	0.783422	2.276129	2.360161
2	Reproductive	0.903789	3.521123	2.688487
3	Grain Filling	0.951937	3.782273	2.893429
4	Ripening and Harvesting	0.873461	3.635749	2.557378

A more robust and accurate way of estimating crop water content using the Random Forest Algorithm was achieved with a MSE (R²) of (0.792) and RMSE of (0.051) as seen in (*Figure 9*).

**Figure 9.** Graphs showing the R² and RMSE for the results obtained from the Random Forest Regression Model

In August, during crop establishment, CWC is low as fields are flooded for transplanting. CWC increases through September as the canopy expands in the vegetative phase. CWC peaks in October and November, during the reproductive and grain-filling stage as LAI and vegetation health maximize before declining pre-harvest.

Based on the estimated CWC of rice from a fusion of VHI and LAI, crop coefficients (K_c) values were derived using the FAO-56 approach. This approach relates K_c to CWC and reference evapotranspiration from climate calculated based on Penman-Monteith Algorithm.

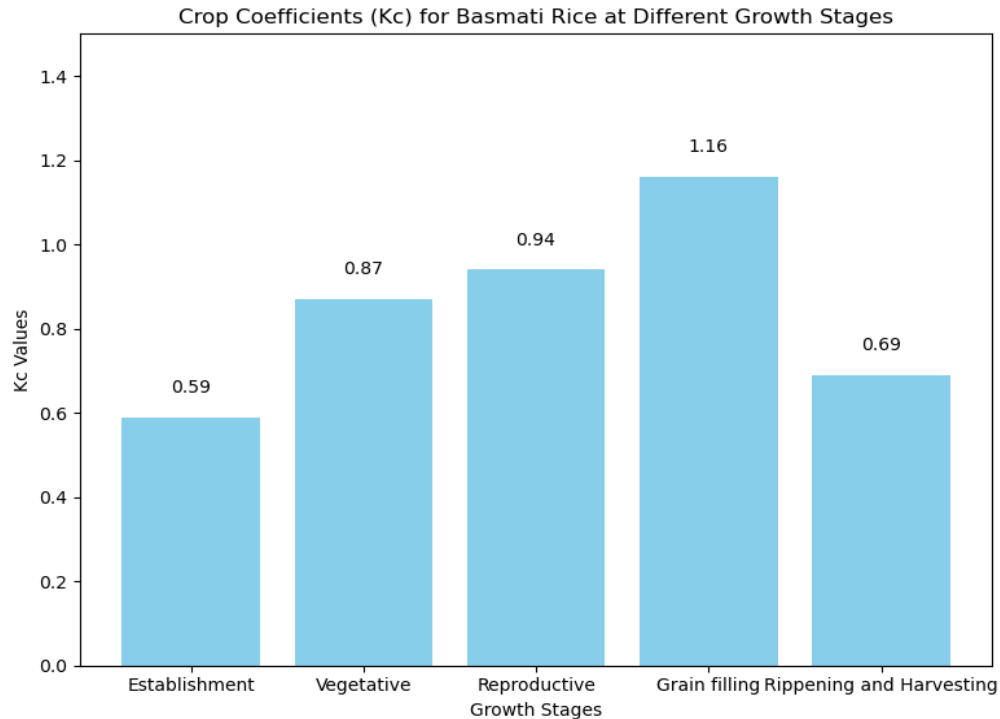


Figure 10. Crop Coefficient values for rice at each phenological stage

From **(Figure 10)**, the CWC-derived Kc values captured characteristic increase with crop development with 0.67 in the initial stage, 0.87 in the vegetative stage, 1.16 in the reproductive/grain filling stage followed by a decline at crop maturity of 0.79.

Temporal fluctuation in estimated Kc values showed moisture stress events during the season where reduced CWC caused a corresponding drop in Kc values. This demonstrates the potential to dynamically update crop water demand based on Remote Sensing of actual crop water status. The use of Remote Sensing based PWC for computing Kc provides an efficient means to capture spatial and temporal variations of crop evapotranspiration.

3.2 Estimation of Crop Water Requirements

3.2.1 Reference evapotranspiration (ET_o)

The model estimated the mean annual reference evapotranspiration of rice crops, which was 1452mm for the Mwea Irrigation Scheme. According to **(Table 2)**, higher ET_o values were recorded between October and March and lower ET_o values between May and September. The highest ET_o value was recorded in March (155.9mm/month) and the lowest in July (97.96mm/month).

Table 2. Reference Evapotranspiration based on Penman-Monteith Algorithm

Month	MinTemp	MaxTemp	Humidity	Wind	Sunshine	Radiation	Eto	Eto
	°C	°C	%	Km/day	hours	MJ/m ² /day	mm/da	mm/month
January	14.5	27.9	67	130	8.9	22.6	4.52	140.12
February	16	29.5	64	138	9	23.4	4.96	138.88

March	16.1	30.3	61	147	8.1	22.2	5.03	155.93
April	16.5	28.8	70	138	6.7	19.4	4.26	127.8
May	15.8	27.9	72	121	6.5	18	3.82	118.42
June	14	26.8	69	130	4.6	14.7	3.35	100.5
July	13.3	25.6	71	138	4	14.1	3.16	97.96
August	13.5	25.7	70	147	4.3	15.3	3.4	119.35
September	13.9	26.4	72	147	6	18.6	3.85	115.5
October	14.5	28.8	65	138	7.5	21	4.54	140.74
November	15.7	25.9	80	147	6.7	19.3	3.78	113.4
December	15.2	26.3	76	130	7.3	19.9	3.89	120.59
Average	14.9	27.5	70	138	6.6	19	4.05	124.09917
Total								1489.1904

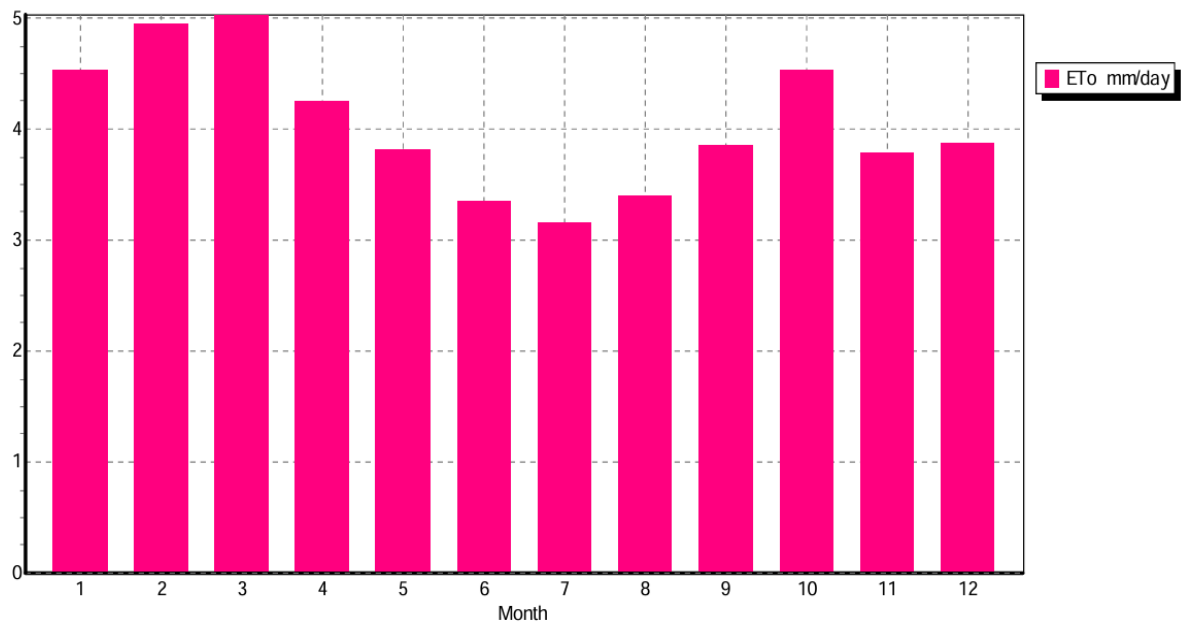


Figure 11. Graph showing Monthly Evapotranspiration rates

From (**Figure 11**), increased evapotranspiration rates in the periods between October and April are characterized by low humidity, higher temperatures and longer sunshine hours leading to increased radiation. This is because of the short rains experienced during this season. Decreased evapotranspiration rate between May and September is characterized by lower temperatures, higher humidity and shorter sunshine hours. Windspeed is usually higher before the beginning of rains and this results in higher evapotranspiration rates in March-April before beginning of long rains and in September before the beginning of short rains. From the results, it is noted that temperatures are too low to start rice cultivation during long rains in March – June as supported by (Ndiiri *et al.*, 2013; Samejima *et al.*, 2020). Due to lower temperatures and lower solar radiation, sowing between March

and June had poor grain yield due to cold-induced sterility. Therefore, maximum and minimum temperatures alone are insufficient as an indication of the degree of cold stress. Based on the findings, the best growing season for rice is between August and December and or October to February. This is due to higher temperatures, longer sun hours thus longer solar radiation reducing cold stress sterility of rice grains at the grain filling stage hence improving yields.

3.2.2 Rice ET_c Patterns Across the Growth Stages

Table 3. Crop Evapotranspiration of Rice Across the Growth Stages

Growth Stages	Duration (Days)	KC Values	ET_c mm/day	ET_c mm/dec
Nursery/ Land preparation	21days	0.44	2.57	25.8
AFTER TRANSPLANTING				
Initial/Establishment	0-60	0.69	5.85	58.5
Development/Reproductive	60-90	0.94	14.97	149.7
Mid/Grain Filling	90-120	1.16	20.02	200.2
Late/Ripening& harvesting	120 th	0.79	10.34	103.4
Total	150		53.76	537.6

According to (Table 3), the ET_c values showed distinct patterns across the different growth stages. In the early stages, Initial/ Establishment stage, ET_c values are relatively low. The smaller size of rice plants together with the small leaf area reduce transpiration rates. Additionally, less sunlight, lower temperatures and wind speed in early stages reduce loss through evaporation hence the lower ET_c values. From the literature review, too much water is not recommended for early growth stages. ET_c values further increase in the development/ reproductive stage. Increased growth of branches, Leaf area and reproductive structures such as panicles provide a greater surface area for transpiration hence increasing transpiration process. Higher metabolic activity to support panicle initiation to flowering process requires more water to facilitate pollination and fertilization. Active nutrient uptake occurs at the reproductive stage and water is the medium for transporting the nutrients to different plant parts to facilitate growth. ET_c values are at maximum during the mid/ Grain filling stage. This stage influences the final yield and quality of the rice crop. Water stress in this stage leads to incomplete grain filling resulting in decreased grain quality and yields. ET_c values are higher because of increased metabolic activities such as photosynthesis, respiration and conversion of sugars to starch which demand a significant amount of water to facilitate grain filling and development. Consequently, an adequate amount of water is essential to facilitate nutrient uptake to developing grains and the already increased biomass of the rice crop. In the late/ ripening and harvesting stage, ET_c value decreases. At this stage, there is no active growth of new leaves or stems as rice plants have reached maturity. As rice crop senesce and loose leaves, reduced leaf area results in less surface area available for transpiration hence reduced transpiration.

3.2.3 Irrigation Water Requirements

Irrigation water requirements are the aggregate amount of water supplied to rice fields that accounts for evapotranspiration, deep percolation, surface runoff and requirements of land preparation and nursery before transplanting.

Based on the results in (*Table 4*) from the calculation of irrigation water demand, irrigation water increases gradually and reaches its peak at the mid/grain filling stage and decreases in the late stage.

Table 4. Irrigation Water Requirements for rice crops across the phenological stages.

Growth Stages	Duration (Days)	KC Values	ET _c mm/dec	Percolation (mm/day)	Irrig. Requirement mm/dec
Nursery/ Land preparation	21days	0.59	25.8	3.56	209.4
Initial/Establishment	0-60	0.69	58.5	1.9	58.5
Development/Reproductive	60-90	0.94	149.7	1.9	149.79
Mid/Grain Filling	90-120	1.16	200.2	1.9	205.2
Late/Ripening& harvesting	120 th	0.79	103.4	1.9	103.4
Total	150		537.6	11.16	719.89

The crop evapotranspiration and the corresponding irrigation water requirements across the different phenological stages in the growing season are depicted in (*Figure 12*) in form of a graph.

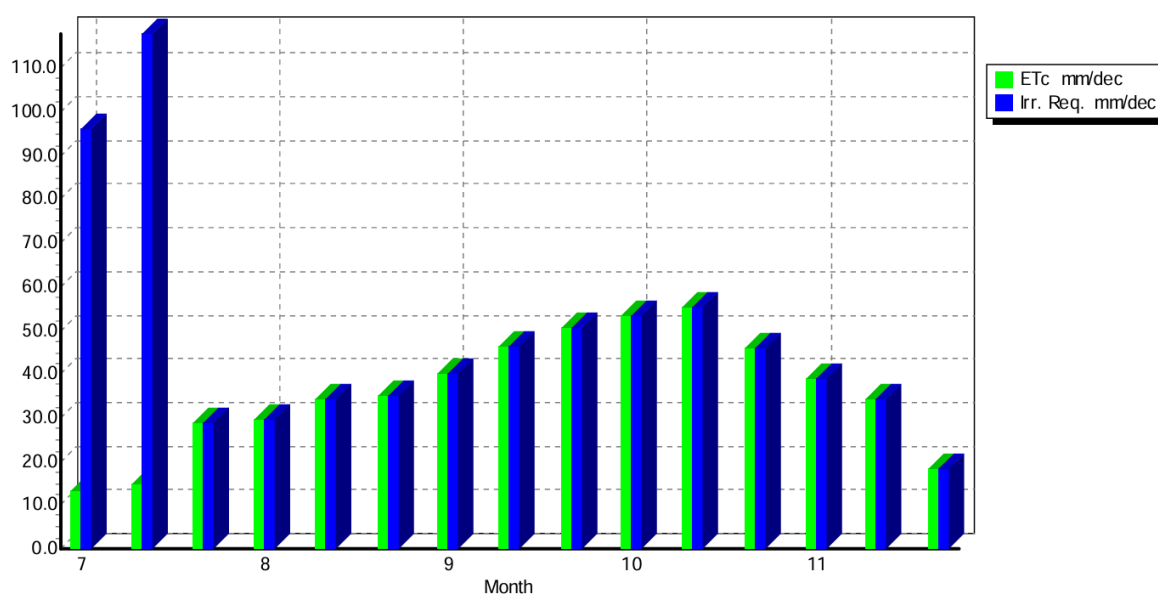


Figure 12. Graph showing irrigation water requirements and crop evapotranspiration in the growing season

The green bars indicate the crop evapotranspiration while the blue bars show irrigation water requirements in the different growth stages of rice. From (*Figure 12*), in the month of July, which is the land preparation and puddling stage, irrigation water requirements are higher than crop evapotranspiration as irrigation water is needed to flood the rice fields before transplanting the rice seedlings. After transplanting in August, irrigation water requirements and crop evapotranspiration are almost equal to maintain a balance to meet the transpiration demand of rice crops. The trend increases and reaches its peak in October during the reproductive stage and slowly declines as it approaches harvest.

3.3 Demonstration of Irrigation Schedule

3.3.1 Irrigation Scheduling Options

Figure 13 is the CROPWAT Software interface used in the study to define the irrigation schedule criteria for rice in Mwea Irrigation Scheme. In rice irrigation, the goal is to maintain a balance between the amount of irrigation water applied and the amount of water used by the crop. Irrigation scheduling involves determining when and how much to apply irrigation water based on crop needs. Scheduling options based on timing and application were selected to fit the study area. Irrigation water is to be applied when critical depletion 100% is reached also when RAW has been depleted. According to (*Figure 13*), irrigation timing was set to below 90% indicating irrigation before RAW is completely depleted. Irrigating at above 100% allows a certain level of water stress before next irrigation application and it may impact negatively on water stress especially during the reproductive and grain filling stages.

The amount of irrigation water is also defined by application options. The study, according to (*Figure 13*) set its irrigation application to refill soil to (100%) or below field capacity which is water held by gravitational forces after deep percolation. The application below field capacity (<100%) allows for rainfall while above field capacity (>100%) allows a certain level of deep percolation useful for leaching for salinity control. The ratio of irrigation water utilized by crops plus the amount of water to maintain a favorable soil balance to the total irrigation water supplied calculates the efficiency of the irrigation system used. Water supplied by irrigation systems and not being made available to be taken up by plant roots is wasted through storage losses, conveyance losses and field application losses such as deep percolation, surface runoff reducing the irrigation efficiency. There is therefore need for effective land preparation and puddling to reduce field application losses. The study set its irrigation efficiency at 65 %.

CROPWAT options

Climate / ETo | Rainfall | Non-rice crop scheduling | **Rice scheduling** | Land Preparation (rice)

Scheduling criteria for rice

Irrigation timing

Irrigate at fixed % of critical depletion

Irrigation at 90 % critical depletion

Irrigation application

Refill to or below field capacity

Refill soil moisture content to 100 % of field capacity

Irrigation efficiency

Irrigation efficiency: 65 %

Save as default | Reset to FAO defaults | OK | Cancel | Help

Figure 13. Irrigation Scheduling Options for Rice

Irrigation schedule based on regular interval period.

This irrigation schedule relies on a predetermined schedule and does not take into account actual soil moisture conditions. The time interval can be days or weeks and for the project, the interval is taken to be every 10-20 days.

Table 5. Irrigation Schedule based on Regular Time Interval Period

Date	Day	Stage	Rain mm	Ks Fract	Eta %	Puddle State	Percol. mm	Depla. SM	Net Gift mm	Loss	Depl. SAT
11 th July	-20	PrePud	0.0	1.00	100	Prep	0.0	11	82.9	0.0	66.0
22 nd July	-9	Pudd	0.0	1.00	100	Prep	1.7	0	102.8	0.0	52.8
1 st Aug	1	Initial	0.0	1.00	100	OK	1.9	0	99.1	0.0	-0.9
23 rd Aug	23	Initial	1.9	1.00	100	OK	19	0	98.1	0.0	-1.9
11 th Sep	42	Dev	0.0	1.00	100	OK	1.9	0	97.4	0.0	-2.6
29 th Sep	60	Mid	0.0	1.00	100	OK	1.9	0	101.3	0.0	1.3
22 nd Oct	83	Mid	0.0	1.00	100	OK	1.9	0	97.6	0.0	-2.4
6 th Dec	120	Late	0.0	1.00	100	OK	0	0			

Based on the results from (**Table 5**), the day column represents the day count relative to the start of the irrigation schedule. Negative values indicate days before the start of the schedule while positive values indicate days after the schedule began. The stage column represents the irrigation stage for the growth cycle of rice. The rainfall column is zero as rice cultivation in MIS is not rain-fed but irrigation fed. Ks is the water stress coefficient and equals one when planting conditions are close to standard and below under nonstandard conditions thus indicating stress levels. Eta is adjusted ETc values under non-standard conditions such as low soil fertility, soil water logging, pests and diseases. The puddle

state describes the condition of the soil during and after preparation and whether it is okay for each irrigation stage while the puddle (mm) column shows the amount of water applied during the puddling process. Percolation is the amount of water that sips below the root zone while loss is the amount of water lost through runoff. The value of surface runoff is 0.0mm as irrigation water is contained in paddy fields restricting runoff. Depleted soil moisture shows how much the soil moisture content has decreased while depleted soil moisture SAT shows soil moisture depletion below saturation point. The negative values suggest the soil is not completely depleted, zero value indicates refill to Field Capacity while positive values indicate under irrigation or amount needed to refill rootzone to Field Capacity.

During land preparation, Net Gift of 82.9mm is supplied to ensure adequate soil moisture levels for seedbed preparation and subsequent transplanting, weed control, fertilizer application and temperature regulation. During the puddling stage, a net gift of 102.8mm is supplied to ensure soil is at the desired flood condition for rice transplanting, crop establishment, nutrient management and disease management. Puddling is the tillage of rice fields while flooded and involves mechanical or manual mixing of soil with water and compaction to create a saturated, muddy and anaerobic environment to reduce percolation rates of irrigation water. At the initial stage, net irrigation is relatively lower at 99.1mm and development stage at 98.1mm as a lot of water is not recommended due to the need for development of a strong root system, increased nutrient leaching and disease risks. At the Mid stage, net gift of irrigation is highest at 198.9mm during which panicle initiation, booting, flowering and grain filling occur. This ensures the facilitation of increased metabolic processes such as pollination, photosynthesis, respiration and grain filling. Soil moisture deficit at the last phase of the mid stage is used through to the late stage. At the late stage, ripening and harvesting stage, there is no net gift of irrigation water as crop growth and development have stopped and rice ripens and dries ready for harvesting.

Irrigation Schedule based on Daily Soil Moisture Balance.

A more precise method of calculating irrigation needs is based on daily monitoring of soil moisture content and determining how much water is needed to refill to a desired level. It optimizes water use as irrigation is based on actual soil moisture conditions, maintains consistent soil moisture levels and promotes healthier crop growth by reducing the risk of water stress. From (**Table 6**) in the Appendix, the negative values suggest the soil is not completely depleted/soil deficit, the zero value indicates refill to Field Capacity while positive values indicate under irrigation or amount needed to refill rootzone to Field Capacity.

During land preparation, positive values indicate the amount of water to be supplied to the rice fields to increase moisture levels in the rice fields and facilitate flood conditions. At the puddling stage, negative values indicate a soil moisture deficit showing the soil is not completely depleted. Consequently, puddling reduced the percolation rate hence reducing the soil water deficit. The negative values increase steadily until the next Net gift of irrigation water and this shows a decrease in daily soil moisture balance. Negative values at the end of the season provide a check if the last irrigation gift was required, and whether it should be suppressed or reduced.

4. Discussion

Using VHI as the spectral indices was more effective as compared to NDVI and the results from this study agreed with results from Bento et al., (2020) in vegetation water stress detection. Leaves are the main medium for plant light absorption, respiration, photosynthesis hence better suited for irrigation water requirements estimation. The results from the fusion of VHI and LAI using Random Forest Algorithm agreed with results from a study by Xu et al., (2021) who concluded random forest could detect the nonlinear correlation between variables and was effective in the predicting missing data. Similarly fusion of spectral indices and structural parameters agreed with a research by Banerjee et al., (2020) who concluded the technique surpassed the generally used VI for biomass estimate. Results for the irrigation water requirements of rice agreed with a study by Akoko et al., (2020) who estimated the irrigation water requirements from 2013-2016 and predicted IWR in 2020-2060 using CROPWAT and modelled the availability of water resources using SWAT model. Irrigation scheduling practice using CROPWAT that incorporates weather variables, crop evapotranspiration,

crop coefficient and soil water balance has not however been adopted in the MIS. However, from the research study that was conducted in MIS, it was discovered a lot of water could be saved when the irrigation scheduling using CROPWAT is adopted. This research agrees with a research study by Okuku, (2020) conducted in Pekerra Irrigation Scheme which concluded that when planting date is shifted from November to September, less irrigation water will be required as it is supplemented by the rain that are available from September all the way to December. From the research, transplanting was done in August and growth and development proceeded in the rainy season in October November hence less irrigation water demand in the critical growth stages of reproduction and grain filling.

5. Conclusion

An effective phenology-based demonstration of precisely estimating irrigation water requirements and irrigation schedule for rice cultivation was achieved and this will ensure improved irrigation activities in MIS. The study focussed on the major growing season from July- December 2022. The rice-producing area was under the Thiba System with an approximate area of 20613 acres.

Through the integration of data sets and modeling techniques, a more holistic understanding of plant-water dynamics was achieved. VHI was the most suitable spectral indices as it combines VCI and TCI for vegetation drought detection and is highly correlated with crop yields at critical growth stages. Consequently, LAI was best suited as the structural parameter as it is the main medium for light absorption, photosynthesis, respiration and transpiration. With the integration of VHI and LAI, a more robust and accurate way of estimating crop water content using the Random Forest Algorithm was achieved with a MSE of (0.792) and RMSE of (0.051)

Integration of climate data, crop data and soil data using CROPWAT modelled the Irrigation water requirements and irrigation schedule for rice cultivation in MIS. From the outputs, as K_c values increase gradually from the initial/establishment stage, so do crop evapotranspiration and irrigation water requirements. This reaches its peak at the reproductive/development stage and gradually drops as it approaches the maturity stage. Therefore, crop coefficients, K_c , are a major factor in evaluating the crop evapotranspiration and irrigation water requirements.

The irrigation schedule was developed based on regular time interval periods and daily soil moisture balance. The study concluded that an irrigation schedule based on daily monitoring of soil moisture balance is more robust as it determines how much water is needed to refill to a desired level. Irrigation schedules based on regular time interval period may however lead to over-irrigation or under-irrigation as it does not account for the soil moisture balance.

Some recommendations included a need for continuous data collection by installing sensors to monitor daily soil moisture conditions, and UAVs to monitor crop growth and health to develop an irrigation schedule based on current scenarios in order to predict future scenarios with adequate and accurate availability of data. Consequently, a validation approach for the applicability of CROPWAT in Mwea Irrigation Scheme should be developed.

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Appendix A: Table

Table 6: Irrigation Schedule based on Daily Soil Moisture Balance

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl. SAT
			mm	fract.	mm	state	mm	mm	mm	mm	mm
11 Jul	-20	Land Pre	0.0	1.00	1.3	Prep	0.0	11	82.9	0.0	66.0
12 Jul	-19	Land Pre	0.0	1.00	1.3	Prep	7.0	0	0.0	0.0	2.6
13 Jul	-18	Land Pre	0.7	1.00	1.3	Prep	6.8	0	0.0	0.0	10.0
14 Jul	-17	Land Pre	0.0	1.00	1.3	Prep	5.9	0	0.0	0.0	17.2
15 Jul	-16	Land Pre	0.0	1.00	1.3	Prep	5.2	0	0.0	0.0	23.6
16 Jul	-15	Land Pre	0.0	1.00	1.3	Prep	4.5	0	0.0	0.0	29.4
17 Jul	-14	Land Pre	0.7	1.00	1.3	Prep	4.0	0	0.0	0.0	33.9
18 Jul	-13	Land Pre	0.0	1.00	1.3	Prep	3.4	0	0.0	0.0	38.6
19 Jul	-12	Land Pre	0.0	1.00	1.3	Prep	2.9	0	0.0	0.0	42.7
20 Jul	-11	Land Pre	0.0	1.00	1.3	Prep	2.5	0	0.0	0.0	46.5
21 Jul	-10	Land Pre	0.0	1.00	1.3	Prep	2.1	0	0.0	0.0	49.8
22 Jul	-9	Puddl	0.0	1.00	1.3	Prep	1.7	0	102.8	0.0	52.8
23 Jul	-8	Puddl	1.1	1.00	1.3	OK	6.1	0	0.0	0.0	-43.6
24 Jul	-7	Puddl	0.0	1.00	1.3	OK	5.4	0	0.0	0.0	-36.9
25 Jul	-6	Puddl	0.0	1.00	1.3	OK	4.7	0	0.0	0.0	-30.9
26 Jul	-5	Puddl	0.0	1.00	1.3	OK	4.2	0	0.0	0.0	-25.4
27 Jul	-4	Puddl	1.1	1.00	1.3	OK	3.7	0	0.0	0.0	-21.6
28 Jul	-3	Puddl	0.0	1.00	1.3	OK	3.2	0	0.0	0.0	-17.1
29 Jul	-2	Puddl	0.0	1.00	1.3	OK	2.8	0	0.0	0.0	-12.9
30 Jul	-1	Puddl	0.0	1.00	1.3	OK	2.5	0	0.0	0.0	-9.2
31 Jul	0	Puddl	0.0	1.00	1.3	OK	2.2	0	0.0	0.0	-5.7
1 Aug	1	Init	0.0	1.00	2.9	OK	1.9	0	99.1	0.0	-0.9
2 Aug	2	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-95.2
3 Aug	3	Init	1.6	1.00	2.9	OK	1.9	0	0.0	0.0	-92.0
4 Aug	4	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-87.2
5 Aug	5	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-82.4
6 Aug	6	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-77.6
7 Aug	7	Init	1.6	1.00	2.9	OK	1.9	0	0.0	0.0	-74.5
8 Aug	8	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-69.7
9 Aug	9	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-64.9
10 Aug	10	Init	0.0	1.00	2.9	OK	1.9	0	0.0	0.0	-60.1
11 Aug	11	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-55.2
12 Aug	12	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-50.3
13 Aug	13	Init	1.9	1.00	3.0	OK	1.9	0	0.0	0.0	-47.3
14 Aug	14	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-42.4
15 Aug	15	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-37.6
16 Aug	16	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-32.7
17 Aug	17	Init	1.9	1.00	3.0	OK	1.9	0	0.0	0.0	-29.7
18 Aug	18	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-24.8
19 Aug	19	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-20.0
20 Aug	20	Init	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-15.1
21 Aug	21	Init	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-10.1
22 Aug	22	Init	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-5.0
23 Aug	23	Init	1.9	1.00	3.1	OK	1.9	0	98.1	0.0	-1.9
24 Aug	24	Init	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-95.0
25 Aug	25	Init	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-90.0
26 Aug	26	Init	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-84.9
27 Aug	27	Init	1.9	1.00	3.1	OK	1.9	0	0.0	0.0	-81.8

28 Aug	28	Init	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-76.8
29 Aug	29	Dev	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-71.8
30 Aug	30	Dev	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-66.8
31 Aug	31	Dev	0.0	1.00	3.1	OK	1.9	0	0.0	0.0	-61.7
1 Sep	32	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-56.3
2 Sep	33	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-50.9
3 Sep	34	Dev	0.6	1.00	3.5	OK	1.9	0	0.0	0.0	-46.0
4 Sep	35	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-40.6
5 Sep	36	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-35.1
6 Sep	37	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-29.7
7 Sep	38	Dev	0.6	1.00	3.5	OK	1.9	0	0.0	0.0	-24.8
8 Sep	39	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-19.4
9 Sep	40	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-14.0
10 Sep	41	Dev	0.0	1.00	3.5	OK	1.9	0	0.0	0.0	-8.5
11 Sep	42	Dev	0.0	1.00	4.0	OK	1.9	0	97.4	0.0	-2.6
12 Sep	43	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-94.1
13 Sep	44	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-88.1
14 Sep	45	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-82.2
15 Sep	46	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-76.3
16 Sep	47	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-70.3
17 Sep	48	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-64.4
18 Sep	49	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-58.4
19 Sep	50	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-52.5
20 Sep	51	Dev	0.0	1.00	4.0	OK	1.9	0	0.0	0.0	-46.6
21 Sep	52	Dev	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-40.0
22 Sep	53	Dev	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-33.5
23 Sep	54	Dev	5.5	1.00	4.6	OK	1.9	0	0.0	0.0	-32.5
24 Sep	55	Dev	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-25.9
25 Sep	56	Dev	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-19.4
26 Sep	57	Dev	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-12.9
27 Sep	58	Dev	5.5	1.00	4.6	OK	1.9	0	0.0	0.0	-11.8
28 Sep	59	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-5.3
29 Sep	60	Mid	0.0	1.00	4.6	OK	1.9	0	101.3	0.0	1.3
30 Sep	61	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-93.5
1 Oct	62	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-86.5
2 Oct	63	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-79.6
3 Oct	64	Mid	13.4	1.00	5.0	OK	1.9	0	0.0	0.0	-86.0
4 Oct	65	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-79.0
5 Oct	66	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-72.1
6 Oct	67	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-65.1
7 Oct	68	Mid	13.4	1.00	5.0	OK	1.9	0	0.0	0.0	-71.5
8 Oct	69	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-64.6
9 Oct	70	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-57.6
10 Oct	71	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-50.7
11 Oct	72	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-43.4
12 Oct	73	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-36.2
13 Oct	74	Mid	19.1	1.00	5.3	OK	1.9	0	0.0	0.0	-48.0
14 Oct	75	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-40.7
15 Oct	76	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-33.5
16 Oct	77	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-26.2
17 Oct	78	Mid	19.1	1.00	5.3	OK	1.9	0	0.0	0.0	-38.0
18 Oct	79	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-30.8
19 Oct	80	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-23.5
20 Oct	81	Mid	0.0	1.00	5.3	OK	1.9	0	0.0	0.0	-16.3
21 Oct	82	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-9.3
22 Oct	83	Mid	0.0	1.00	5.0	OK	1.9	0	97.6	0.0	-2.4

23 Oct	84	Mid	21.5	1.00	5.0	OK	1.9	0	0.0	0.0	-114.6
24 Oct	85	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-107.6
25 Oct	86	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-100.7
26 Oct	87	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-93.8
27 Oct	88	Mid	21.5	1.00	5.0	OK	1.9	0	0.0	0.0	-108.3
28 Oct	89	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-101.4
29 Oct	90	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-94.5
30 Oct	91	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-87.6
31 Oct	92	Mid	0.0	1.00	5.0	OK	1.9	0	0.0	0.0	-80.6
1 Nov	93	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-74.1
2 Nov	94	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-67.6
3 Nov	95	Mid	25.9	1.00	4.6	OK	1.9	0	0.0	0.0	-87.0
4 Nov	96	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-80.5
5 Nov	97	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-74.0
6 Nov	98	Mid	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-67.5
7 Nov	99	End	25.9	1.00	4.6	OK	1.9	0	0.0	0.0	-86.9
8 Nov	100	End	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-80.4
9 Nov	101	End	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-73.9
10 Nov	102	End	0.0	1.00	4.6	OK	1.9	0	0.0	0.0	-67.4
11 Nov	103	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-61.6
12 Nov	104	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-55.8
13 Nov	105	End	29.9	1.00	3.9	OK	1.9	0	0.0	0.0	-79.8
14 Nov	106	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-74.0
15 Nov	107	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-68.2
16 Nov	108	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-62.4
17 Nov	109	End	29.9	1.00	3.9	OK	1.9	0	0.0	0.0	-86.5
18 Nov	110	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-80.7
19 Nov	111	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-74.9
20 Nov	112	End	0.0	1.00	3.9	OK	1.9	0	0.0	0.0	-69.1
21 Nov	113	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-63.8
22 Nov	114	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-58.4
23 Nov	115	End	23.2	1.00	3.4	OK	1.9	0	0.0	0.0	-76.3
24 Nov	116	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-71.0
25 Nov	117	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-65.6
26 Nov	118	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-60.3
27 Nov	119	End	23.2	1.00	3.4	OK	1.9	0	0.0	0.0	-78.2
28 Nov	120	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-72.8
29 Nov	121	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-67.5
30 Nov	122	End	0.0	1.00	3.4	OK	1.9	0	0.0	0.0	-62.2
1 Dec	123	End	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-57.2
2 Dec	124	End	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-52.3
3 Dec	125	End	14.5	1.00	3.0	OK	1.9	0	0.0	0.0	-61.8
4 Dec	126	End	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-56.9
5 Dec	127	End	0.0	1.00	3.0	OK	1.9	0	0.0	0.0	-51.9
6 Dec	End	End	0.0	1.00	0.0	OK	0.0	0			