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Brief career highlights (less than 250 words):

Siva K Balasundram is a Professor of Precision Agriculture at Universiti Putra Malaysia (UPM) and heads the Department of Agriculture Technology. He serves as the Regional Representative for Asia-Oceania on the International Society of Precision Agriculture Board. His research focuses on modeling spatio-temporal variability in agriculture using geospatial statistics, remote sensing, and artificial intelligence. He teaches two graduate and four undergraduate courses. Over 20 years, he has secured RM1.7 million in research grants as principal investigator, authored over 90 journal articles, and holds two copyrights and one patent. Professor Balasundram is a sought-after speaker, having delivered over fifty (50) keynote/plenary lectures on Precision Agriculture, Smart Agriculture and Digital Agriculture globally.

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ESTIMATION OF CROP COEFFICIENT IN MALAYSIAN DURIAN USING SATELLITE DATA AND MACHINE LEARNING

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ABSTRACT

Durian (*Durio zibethinus*) is a popular fruit and key crop in Southeast Asia, known as the “King of Fruits” for its thorny exterior and distinctive aroma. The crop coefficient (K_c), based on crop evapotranspiration (ET_c) and reference evapotranspiration (ET_o), is crucial for water efficiency. Currently, there is no K_c value for Malaysian durian. This study introduces a machine learning method utilizing remote sensing data from Sentinel-1, Sentinel-3, and MODIS ET, combined with a Random Forest (RF) algorithm, to estimate ET_c . The ET_o was calculated using the FAO 6 Penman-Monteith method. The RF model achieved 97% accuracy during calibration and 94% during validation. Monthly K_c values from January to December 2024 ranged from 0.53 to 0.96. This research fills a significant gap in precision irrigation for Malaysian durian farming, aiding irrigation scheduling, variable-rate irrigation, and sustainable practices amid productipressure from climate change.

Keywords: Precision Agriculture, Irrigation Management, Machine Learning, Remote Sensing, Crop Modeling.

INTRODUCTION

Durian, a high value crop, made a significant contribution to Malaysia’s economy, with export value exceeding RM1.2 billion in 2021 (Eguchi et al., 2025). Traditional K_c estimation methods are time-consuming, labour-intensive, and lack spatial accuracy. Given the widespread cultivation of durian, developing precise K_c at a regional scale is a challenging task. Remote sensing offers a promising solution for regional estimates (Shrestha et al., 2025). Open-source satellites, such as Sentinel, Landsat, and MODIS, combined with machine learning, can enhance accuracy and precision of K_c . Sentinel-1 SAR assesses vegetation and soil, Sentinel-3 SLSTR measures thermal data, and MODIS provides long-term vegetation info. Algorithms like Random Forest (RF), Gradient Boost Machine (GBM), and Support Vector Machine (SVM) handle complex data (Pagano et al., 2025). K_c , derived from ET_c and ET_o , is crucial for irrigation but difficult to measure for trees like durian due to their canopy architecture and long growth cycles. Water requirement data for tropical fruit crops are scarce, with no K_c value available for Malaysian durian. This research utilizes machine learning with remote sensing data from Sentinel-1, Sentinel-3, and MODIS, along with RF, to estimate K_c , ET_c , and ET_o (via the FAO Penman-Monteith method), thereby filling a key gap in sustainable irrigation practices.

MATERIALS AND METHODS

METHODOLOGY

The study workflow is summarized in Figure 1.

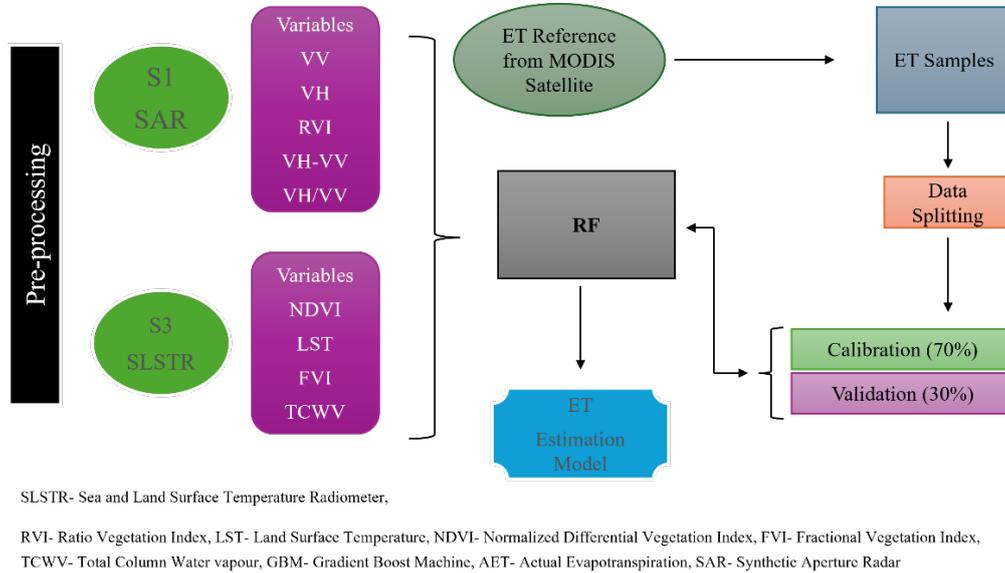


Figure 1. Workflow of the study

The study utilized satellite data, i.e. Sentinel-1 SAR, Sentinel-3 SLSTR, and MODIS ET. These data were downloaded from the Copernicus data ecosystem and the NASA Earth data website, respectively. The downloaded data was preprocessed, and variables were extracted from each of them. The variables, such as Vertical-Vertical Polarizations (VV), Vertical-Horizontal Polarizations (VH), the Ratio (VH/VV), and the Difference (VH-VV), of these polarizations were obtained from the Sentinel-1 SAR. Similarly, Normalized Differential Vegetation Index (NDVI), Land Surface Temperature (LST), Fractional Vegetation Cover (FVC), and Total Column Water Vapor (TCWV) were obtained from Sentinel-3 SLSTR. The ET for calibration of the model was obtained from MODIS ET. Using all these variables, the RF model was developed, and ET_c estimated. The estimated ET_c and ET_o , calculated using the Penman-Monteith equation, were used to determine the K_c of durian. The specifications of remote sensing data are given in Table 1.

Table 1. Specifications of remote sensing data used for ET estimation

Satellite	Spatial Resolution (m)	Spectral Resolution	Temporal Resolution
Sentinel-1 (SAR)	5*20	C band (5.6cm)	5 – 6 days
Sentinel-3 (SLSTR)	500	550 – 12000 nm	14 days
MODIS ET	250	440 – 14400 nm	8 days

Equations, Symbols, and Units

The relationship between Crop Evapotranspiration and Reference Evapotranspiration is

$$ET_c = K_c * ET_o \quad (1)$$

$$\text{Therefore, } K_c = ET_c / ET_o \quad (2)$$

where,

ET_c : Crop Evapotranspiration, ET_o : Reference Evapotranspiration, K_c : Crop Coefficient

RESULTS & DISCUSSION

The ET data were normally distributed with a slight skewness to the left (-0.155). The standard deviation of the data was 0.69, and the variance was 0.48. The correlation analysis between estimated ET_c and all other remotely sensed variables revealed a positive relationship between NDVI and LST. Zeng et al. (2022) opined that higher vegetation greenness, as measured by NDVI, is strongly associated with increased rates of evapotranspiration; essentially, the denser the vegetation, the more water it transpires into the atmosphere. Glenn et al. (2008) demonstrated how NDVI can be used to estimate ET by establishing a strong correlation between NDVI values and vegetation canopy characteristics, which directly influence the amount of water transpired by plants, thus providing a proxy for ET estimations across large areas. Mallick et al. (2022) identified a direct relationship between ET and LST, and another study by Jiang et al. (2023) indicated that when the land surface heats up (higher LST), it provides more energy for water to evaporate from the soil, thereby increasing ET. The developed ET model achieved an accuracy of 99% for calibration and 94% for validation, with RMSE values of 0.0189 and 0.0797, respectively (Figure 2).

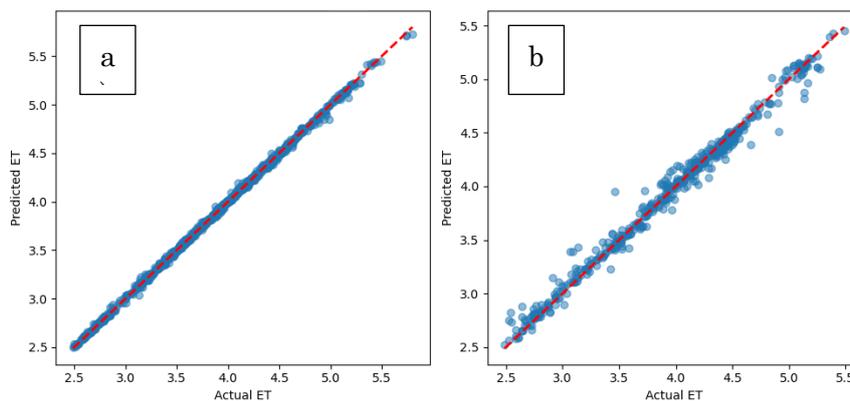


Figure 2. Accuracy of the Random Forest model - (a) calibration with 70% of the dataset, (b) validation with 30% of the dataset

The estimated crop coefficient of Malaysian durian varied from 0.53 to 0.96. The lowest value occurred in July, and the highest value in February. Figure 3 indicates the variation of K_c over the period and compares with the estimated K_c values of Thai durian.

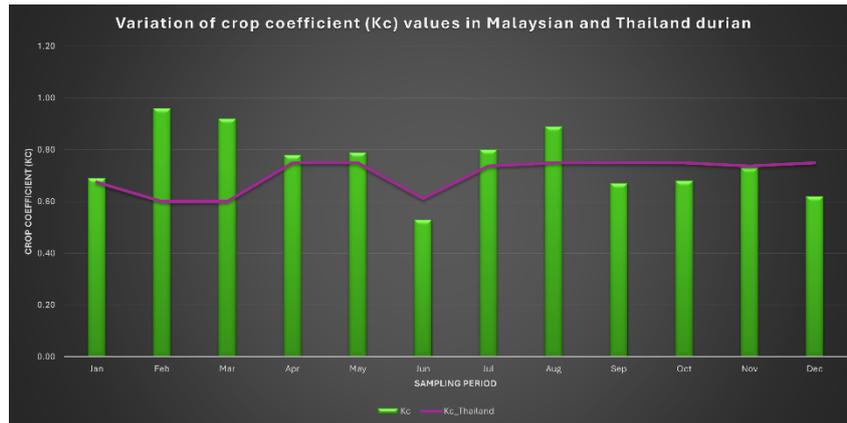


Figure 3. Variation of K_c values in Malaysian and Thai Durian

CONCLUSION

The model demonstrated a strong correlation between observed and estimated ET for both calibration and validation, indicating superiority of the applied method. This study enables timely and consistent monitoring of evapotranspiration, water deficiencies, and agricultural sustainability. This research further enhances our understanding of ET assessment and the potential of using Sentinel-1 and Sentinel-3 data for regional drought monitoring and natural resource management. This study demonstrates a convenient and efficient method for estimating the K_c of Malaysian durian using satellite data.

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