High-resolution soil moisture estimation using machine learning modelling approach

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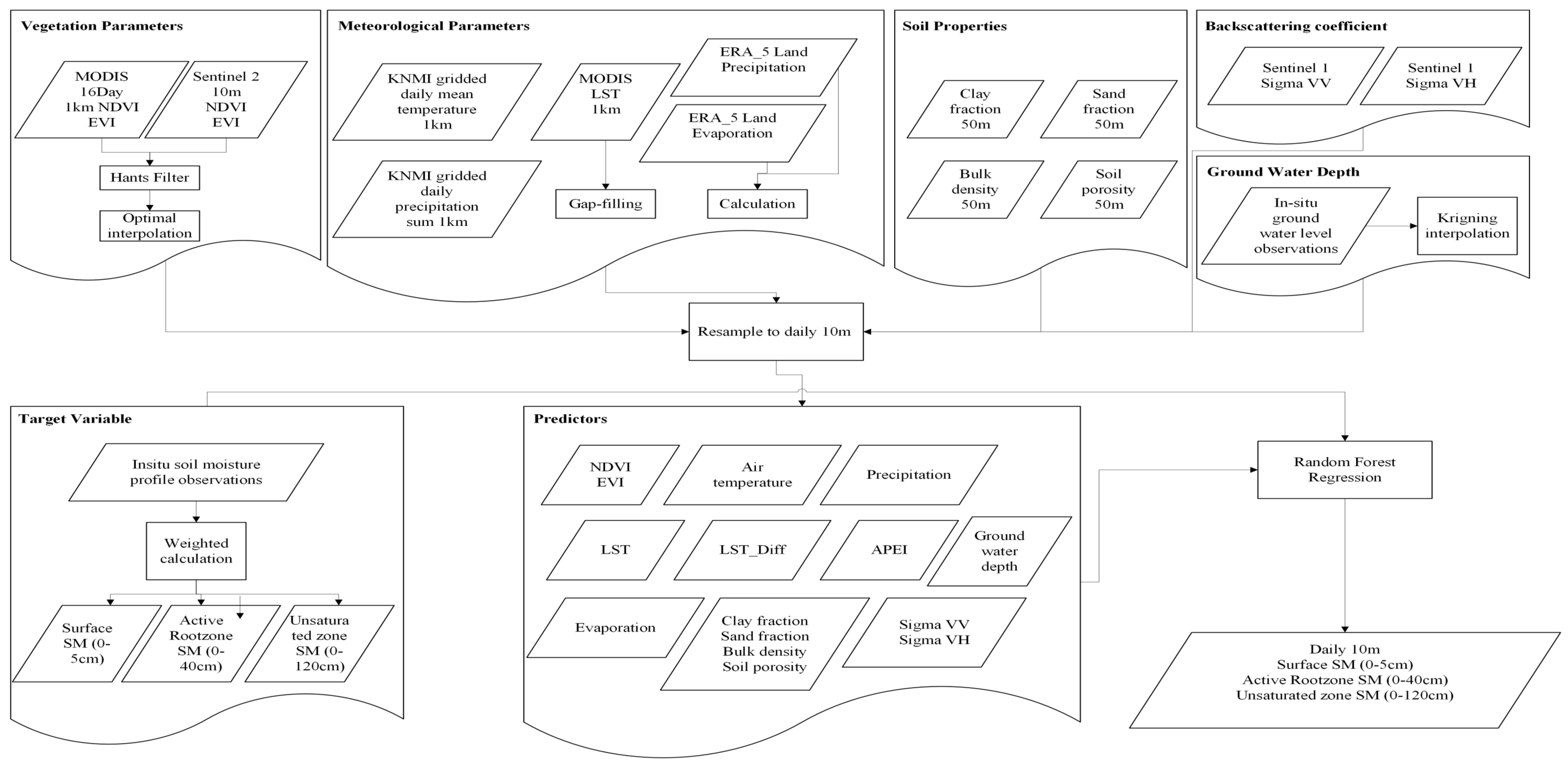
Abstract

The limited availability of high-resolution soil moisture products constrains research at the field scale, which is crucial for agricultural management and informed irrigation decisions. This study addresses this gap by using random forest regression to estimate soil moisture at the surface (0–5 cm), active root zone (0–40 cm), and unsaturated zone (0–120 cm) at a high spatial resolution of 10 meters, focusing on the Twente and Raam regions in the Netherlands over a one-year period (May 18, 2023, to May 18, 2024). Soil moisture measurements from 20 locations, collected from 2016 to 2019, are used to train the model. Predictors include meteorological forcings, soil properties, microwave signals, ground water depth, and vegetation characteristics. Model validation at three stations shows that predictions effectively capture overall soil moisture trends, particularly during winter, though some over- or under-estimations occur in summer.

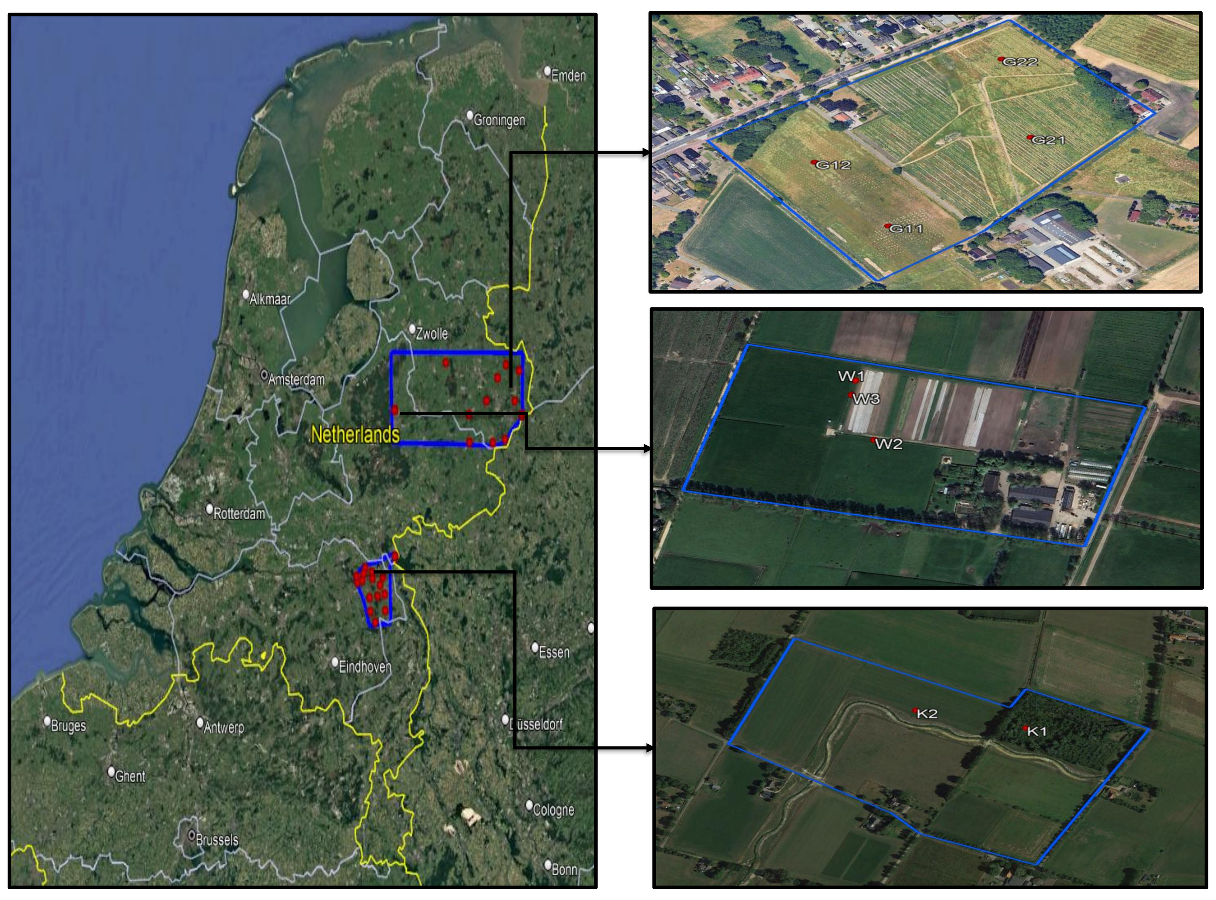
Methods



This research employs a random forest regression model to estimate soil moisture at a high spatial resolution of 10 meters, incorporating various parameters that influence soil moisture variability. The modeling process is organized into three main steps:

(1) Data Preparation – all predictors are collected and resampled to a daily frequency and 10-meter resolution;
(2) Random Forest Model Implementation – the model is configured within the Google Earth Engine (GEE) platform, using data from 2016 to 2019 for training and testing, and data from May 18, 2023, to May 18, 2024, for validation;
(3) Model Prediction and Validation – the model estimates soil moisture at a 10-meter resolution, with results validated against multiple in-situ observations and satellite soil moisture products (SMAP and ESA CCI).

Data Collection



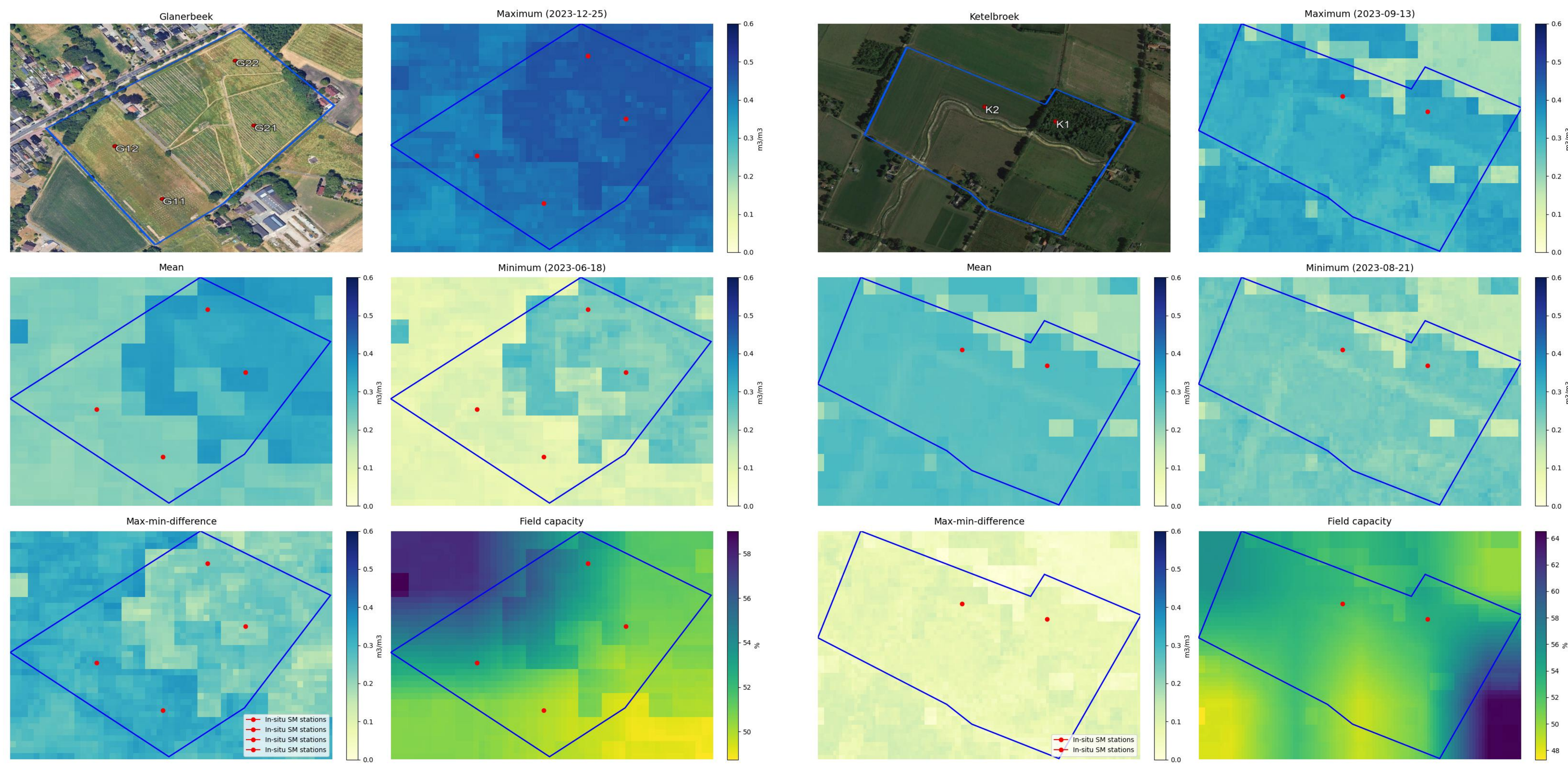
The study focuses on the Twente and Raam regions in the Netherlands, covering 365 km² and 2,318 km², respectively. In these areas, extensive soil moisture monitoring networks have continuously provided in-situ observations since 2016. Key predictors for the model include vegetation characteristics, soil properties, groundwater depth, land surface temperature, air temperature, evaporation, the Antecedent Precipitation Evaporation Index (APEI), and radar backscatter coefficients. All data were collected and resampled to a daily 10-meter resolution.

More details about the field experiment, you can visit: https://youtu.be/1RsWyUQUHRg?si=M3wCOFzdTJY6k3iR

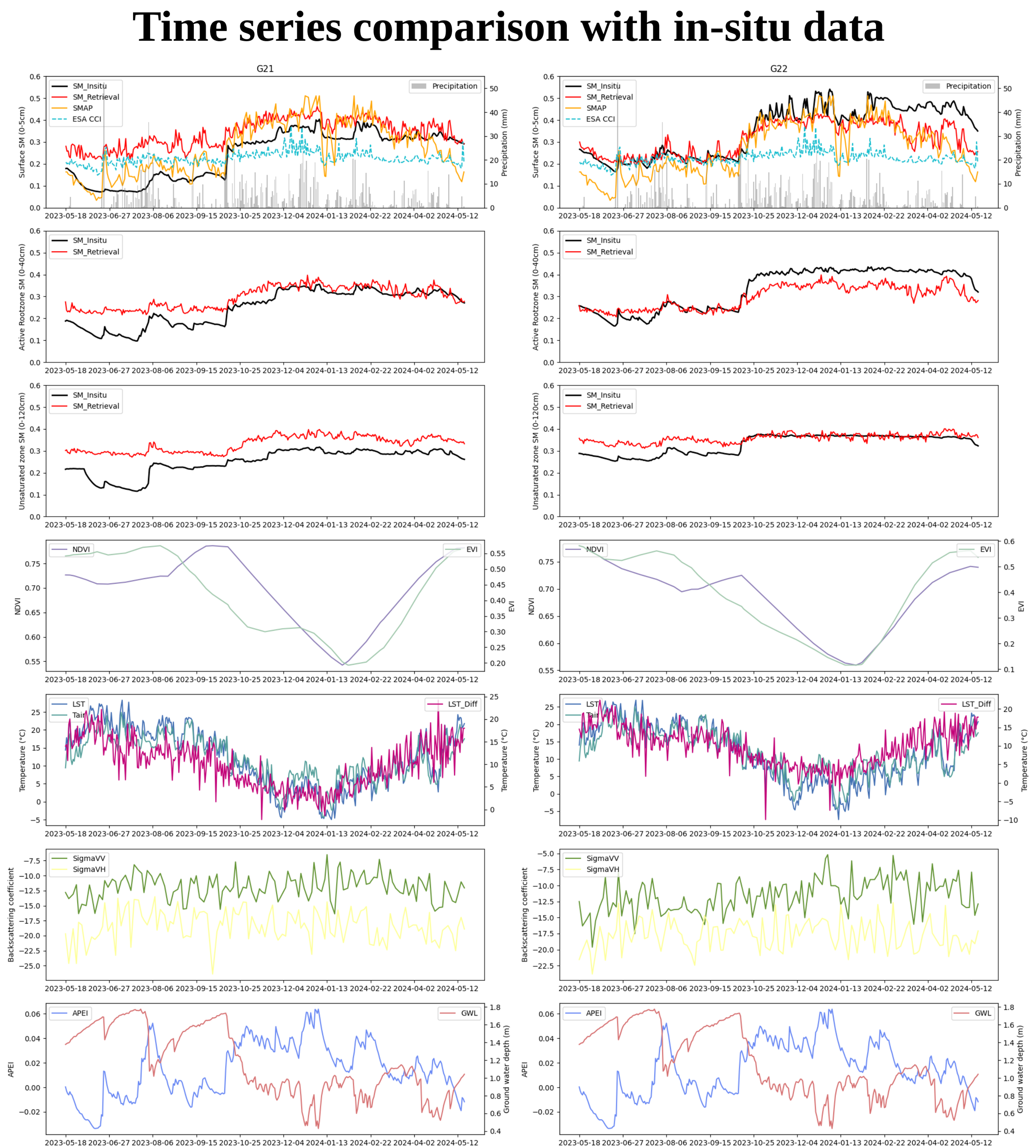
Results

The study presents maps of soil moisture (SM) for maximum, minimum, mean, and max-min difference values across multiple in-situ stations. Additionally, time series comparisons are shown between model estimates, in-situ observations, SMAP 9 km SM, and ESA CCI SM products. Soil moisture maps for the Twente and Raam regions clearly illustrate seasonal variations, highlighting the model's ability to capture temporal changes in soil moisture.

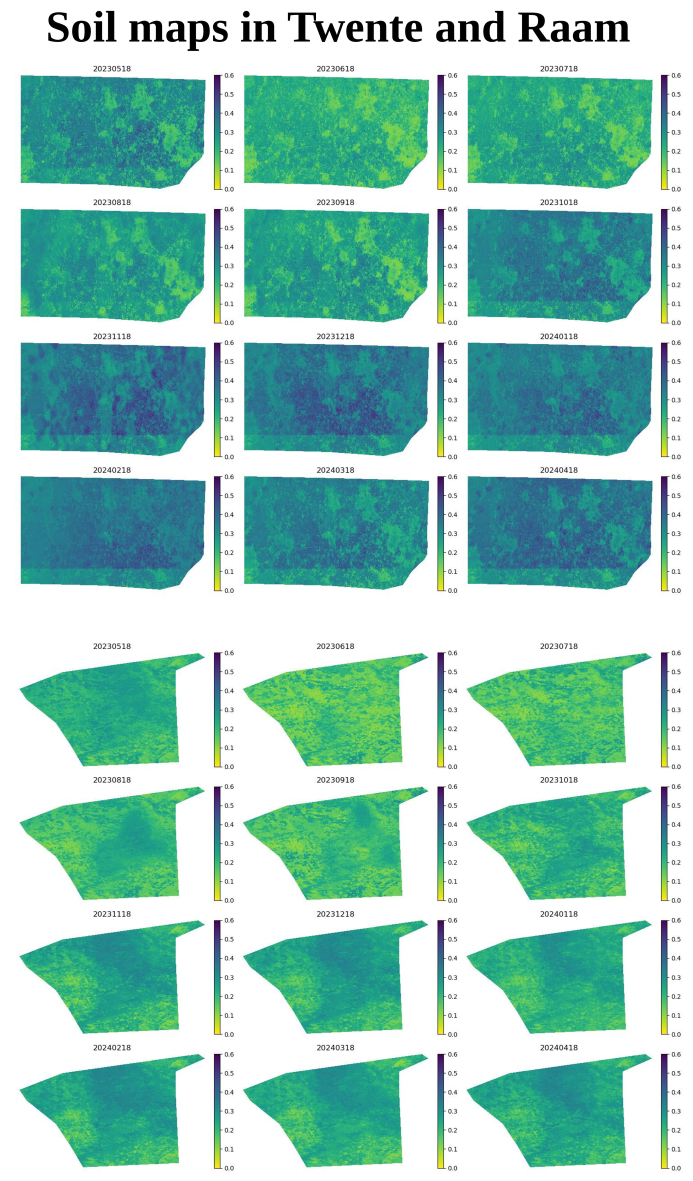
Soil maps in Glanerbeek and Ketelbroek stations



Time series comparison with in-situ data



Soil maps in Twente and Raam



Conclusion

This research introduces a machine learning approach to estimate soil moisture at a high spatial resolution of 10 meters and daily temporal resolution for two regions in the Netherlands, covering the period from May 18, 2023, to May 18, 2024. The model reveals a strong correlation between soil moisture, groundwater depth, and vegetation parameters, effectively capturing seasonal soil moisture trends over the year. By providing high-resolution soil moisture data at the field scale, this approach supports more precise insights into soil moisture variability, aiding in informed agricultural decision-making.

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