Soil Moisture Fluctuation during Severe Flooding Events in Chiang Mai, Thailand Using SMAP Satellite Data

Students (Grade 9): Bunyaorn Orachorn, Haruitchaya Anurathapan, Kantapong payakkachai, Ketsarin Darathavat, Krittawan jarutasroj, Natthakan Saprom, Nirattichai Suksang, Paphatchaya Charattham, Phatchaya Chaichuaypakdee, Ravisara Sornkeaw, Sorawit boontam, Teethat Thosumralt

School: Chonprathanwittaya School

Teacher: Dr. Nittaya Theparunrat, Kaset Bubphapasom

Scientists: Assoc.Prof.Dr.Krisanadej Jaorensutasinee, Assoc.Prof.Dr. Mullica Jaroensutasinee, Dr. Wacharapong Srisang, Center of Excellence for Ecoinformatics, School of Science, Walailak University.

Email: Nayatoix@gmail.com

Abstract

This study investigates the potential of Soil Moisture Active Passive (SMAP) satellite data for monitoring soil moisture changes during severe flooding events in Chiang Mai, Thailand, by exploring the relationship between soil moisture, river water levels, and flood extent. Data were collected from two study sites: a Chiang Mai hydrological measurement station and a Saraburi cornfield for validation. The research integrates field data from the GLOBE Soil Moisture Protocol, GLOBE Data Archive, SMAP satellite data, and water level data from the Upper Northern Region Irrigation Hydrology Center. Data analysis includes time series graphs, box-whisker plots, and linear regression to identify correlations between soil moisture and water levels during flooding. The study analyzed soil moisture data from GLOBE field measurements, GLOBE Retrieved Data (GLOBE-ADAT), and SMAP satellite data. The sample sizes were 5 for GLOBE field measurements, 415 for GLOBE-ADAT, and 324 for SMAP, with no missing data in any dataset. The mean ± standard deviation soil moisture values were 19.6 ± 7.37% g/g for GLOBE field measurements, 9.91 ± 7.19% g/g for GLOBE-ADAT, and 27.4 ± 3.26% m^3/m^3 for SMAP. The results demonstrate significant relationships between soil moisture in the root zone and surface layer and water levels. A linear relationship was observed between the water level in the Ping River and the soil moisture in the root zone, with the equation: Soil Moisture Rootzone = 0.01 × Water Level + 0.21. An ANOVA test confirmed the statistical significance of this relationship. These findings highlight SMAP's potential as a reliable flood monitoring and management tool, suggesting that SMAP data can improve flood prediction and contribute to effective flood management strategies in Thailand.

Research Questions

On October 3, 2024, a severe flooding event occurred in Chiang Mai, an economically significant city in Thailand. This incident presents a valuable opportunity for a case study to analyze how SMAP satellite data can be used to monitor and manage flood conditions. The primary research questions are: 1. How does soil moisture change during a severe flooding event in Chiang Mai, Thailand, as observed from SMAP satellite data? 2. What is the

relationship between soil moisture, river water, and flood extent during a severe flooding event in Chiang Mai? This study investigates whether the SMAP data can detect changes during the flooding event and how these changes manifest. Additionally, the study will identify which specific datasets from SMAP exhibit the most significant variations during the event and which datasets show statistical correlation with river water levels. The knowledge gained from this analysis will be further expanded by creating visual maps using Google Earth Engine to present an overview of the flood situation. The results will be compared with government data sources to evaluate the accuracy and potential of SMAP data for supporting future flood management planning and strategy development.

Introduction

Flooding is one of Thailand's most devastating natural disasters, causing significant loss of life, property damage, and community disruption. Soil moisture is a key factor in understanding flood-prone areas and the interaction between land and water, as it directly influences water absorption, runoff, and flooding. In regions like Chiang Mai, monitoring soil moisture can provide valuable insights into the intensity and spread of flooding, allowing for better prediction and management of flood events. This study uses data from the Soil Moisture Active Passive (SMAP) satellite (Reichle et al., 2018), which provides high-resolution soil moisture information, to examine soil moisture fluctuations during a severe flooding event in Chiang Mai.

The research aims to understand how soil moisture changes during floods, analyze its relationship with river water levels and assess its potential as a tool for flood monitoring and management. The study also compares SMAP data with local government sources to evaluate its accuracy and usefulness in flood management strategies. Fournier et al. (2016) demonstrated that SMAP data could effectively map the progress of flooding in agricultural areas by detecting changes in soil moisture, although some overestimation was noted. Rahman et al. (2017) applied SMAP data to monitor agrarian flood inundation during the 2016 Louisiana flood, utilizing 3-hourly soil moisture data to track flood progression. Using thresholds for soil moisture increase, field capacity, and duration, they identified flooded areas, validating their findings with Federal Emergency Management Agency (FEMA) declared inundated croplands and achieving an accuracy of 60%. However, overestimation was observed due to the coarse spatial resolution of SMAP (9 km).

Rahman et al. (2019) effectively used SMAP data to monitor flood progress in agricultural lands, identifying flooded areas based on soil moisture changes, with results verified using FEMA hazard zones and the Cropland Data Layer (CDL). Li et al. (2022) highlighted the effectiveness of satellite-based soil moisture products, such as SMAP data, in assessing agricultural drought in Mainland Southeast Asia, showing that these products could capture the spatial and temporal patterns of the severe 2016 drought linked to the 2015–2016 super El Niño. We aim to show that SMAP data can help us better understand soil moisture changes and monitor flooding. This will improve how we manage floods, especially in Thailand, by providing helpful information to handle and prevent floods more effectively.

Research Methods

Study site

This study focuses on two key research sites to analyze soil moisture fluctuations during severe flooding events and validate the accuracy of SMAP satellite data. The first site, located in Chiang Mai at coordinates (18.789204 N and 99.002086E), is a hydrological measurement station managed by the Department of Hydrology. This site is the primary location for observing soil moisture changes during flooding. The second site is a cornfield in Saraburi Province at coordinates (14.856744 N and 101.112236E), selected to validate the accuracy of SMAP satellite data through fieldwork (Fig. 1a). Field data were collected using the GLOBE Soil Moisture Protocol and additional data from the GLOBE Data Archive were analyzed (Fig. 1b). These sites were chosen to provide a comprehensive understanding of soil moisture in both hydrological and agricultural contexts, ensuring a thorough analysis of the data.

(a) (b)

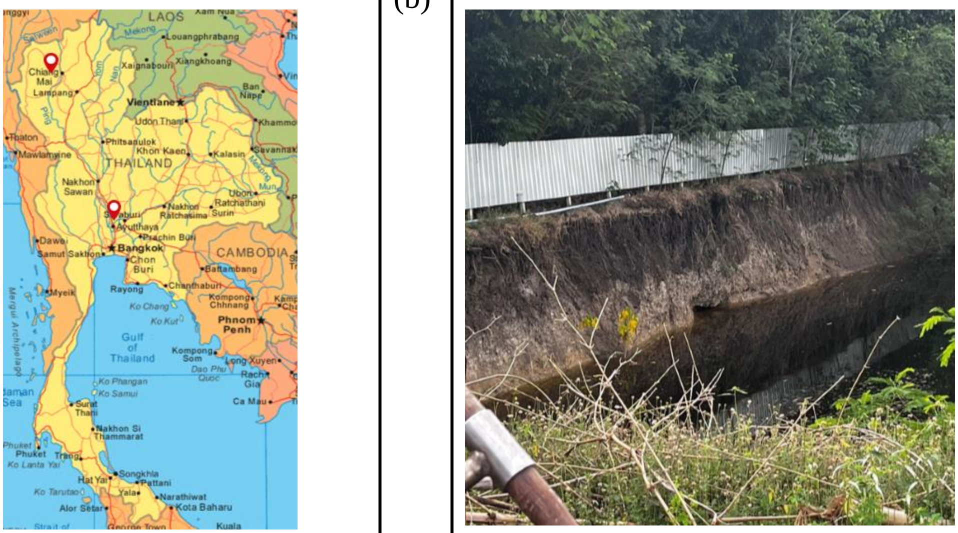

Fig. 1. (a) Map of the study sites: the northern point in Chiang Mai and the midpoint in Saraburi. (b) Soil profile at the water well in the cornfield at the Saraburi study site.

Data collection

This study is divided into two main parts. Part 1 focuses on understanding soil moisture and its relationship with existing datasets, specifically the GLOBE student and SMAP satellite data, to perform a comparative analysis. In Part 2, we studied the SMAP data and then linked it to water level data from Chiang Mai to address the research questions.

The field soil data in Saraburi was collected following the GLOBE protocol, using an auger to gather soil samples at three depth levels: (1) surface soil, (2) 10 cm, and (3) 30 cm. The soil samples were then oven-dried at a temperature of 90°C for 12 hours, and the soil moisture content was calculated according to the GLOBE Soil protocol. The data was subsequently uploaded to the GLOBE server via the website.

The second set of soil moisture data consists of GLOBE archive data. We used only data from Thailand, which was downloaded from the website globe.gov. The data was selected based on latitude and longitude coordinates using spreadsheet software. The data was then filtered to remove any anomalies, specifically excluding soil moisture values greater than 0.5. This filtered data was used for comparison in the analysis.

The third data set consists of SMAP satellite data obtained from the Application for Extracting and Exploring Analysis Ready Samples via NASA's AppEEARS data portal (https://appeears.earthdatacloud.nasa.gov/ website. The specific dataset used was "SPL4SMGP.007 SMAP L4 Global 3-hourly 9-km Surface and Root Zone Soil Moisture," the data was retrieved for the year 2024.

The water level data was obtained from the Upper Northern Region Irrigation Hydrology Center (Chiang Mai, Thailand) under the Bureau of Water Management and Hydrology, Royal Irrigation Department of Thailand. The data can be accessed via their website: https://hydro-1.net/.

Data analysis

In the first part of the analysis, we compared the three soil moisture datasets by creating box whisker plots. However, it's important to note that datasets 1 and 2 are measured in % g/g, while dataset 3 from SMAP is in % m^3/m^3. We need to consider this difference in units when comparing the data. To find the flooding date, we compared the water level data with the riverbank level, which is 2.7 meters at the study site. After identifying the flooding date, we set the study period to one month. Therefore, the study period was from September 15, 2024, to October 15, 2024. We made time series graphs to see which SMAP data is related to the water level. Then, we created XY graphs to examine how the variables are connected using linear regression and Jamovi, a free and easy-to-use statistics program. When we found interesting data, we made maps with the Google Earth Engine to see if it was possible to use SMAP data for analysis and evaluation.

Results

The study analyzed soil moisture data from GLOBE field Measurements, GLOBE Retrieved Data (GLOBE-ADAT), and SMAP satellite data. The sample sizes were five for GLOBE field Measurements, 415 for GLOBE-ADAT, and 324 for SMAP, with no missing data in any dataset. The mean ± standard deviation soil moisture values were 19.6 ± 7.37% g/g for GLOBE field Measurements, 9.91 ± 7.19% g/g for GLOBE ADAT, and 27.4 ± 3.26% m^3/m^3 for SMAP. Median values were 17.0% g/g, 7.00% g/g, and 26.8% m^3/m^3 for GLOBE field Measurements, GLOBE-ADAT, and SMAP, respectively. Minimum and maximum values ranged from 10.0% to 28.0% g/g for GLOBE field Measurements, 0.00% to 39.0% g/g for GLOBE-ADAT, and 21.6% to 35.3% m^3/m^3 for SMAP.

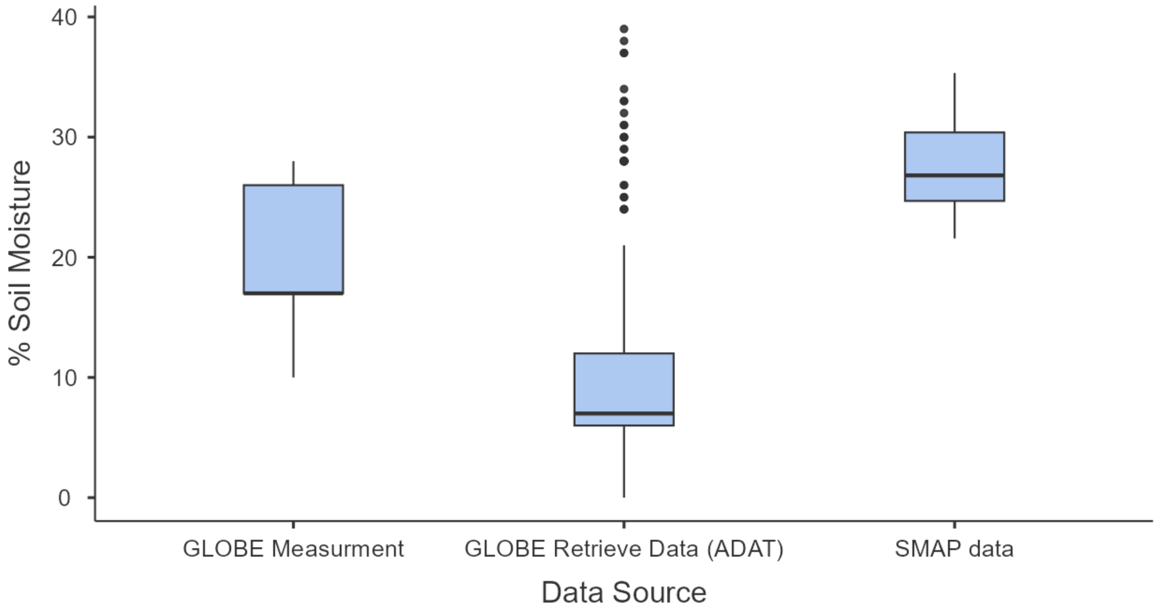

Fig. 2 Soil moisture comparison between field data, GLOBE data, and SMAP sources.

The water level from 9/15/2024 to 10/15/2024 is as follows: sample size 31, missing values 0, mean 2.96 meters, median 2.77 meters, standard deviation 1.14 meters, minimum 1.63 meters, and maximum 5.30 meters. The bank level is 2.70 meters. For the water volume: sample size 31, missing values 0, mean 283, median 259, standard deviation 167, minimum 0.00, and maximum 656. From the data, we can observe that the water level exceeds the bank level two times. Fig. 3 illustrates these data visually.

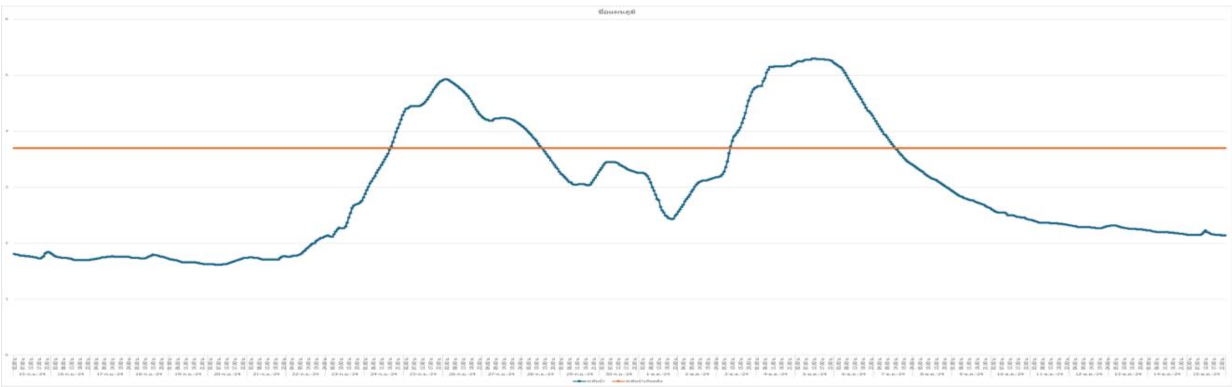

Fig. 3 Water level at the Chiang Mai Water Level Station. The red line shows the bank level, with flooding in Chiang Mai on 3/10/2024, marked by the second peak.

We requested SMAP data from AppEEARS NASA for specific dates. There are 45 SMAP variables, including soil moisture, temperature, water fluxes, and atmospheric conditions. From the data, we identified three variables that correlate with the water level graph: (1) runoff flux (Fig. 4), (2) soil moisture (root zone) (Fig. 5), and (3) soil moisture (surface layer). This analysis was conducted using the AppEEARS exploration tool.

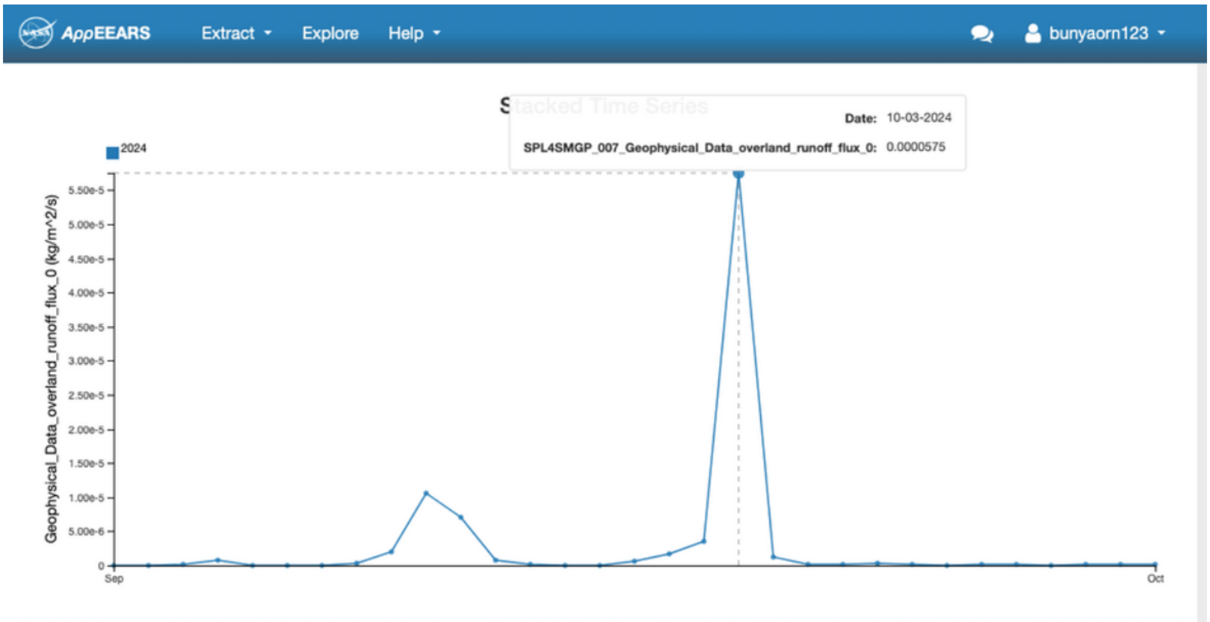

Fig. 4 Runoff flux data from the AppEEARS exploration graph.

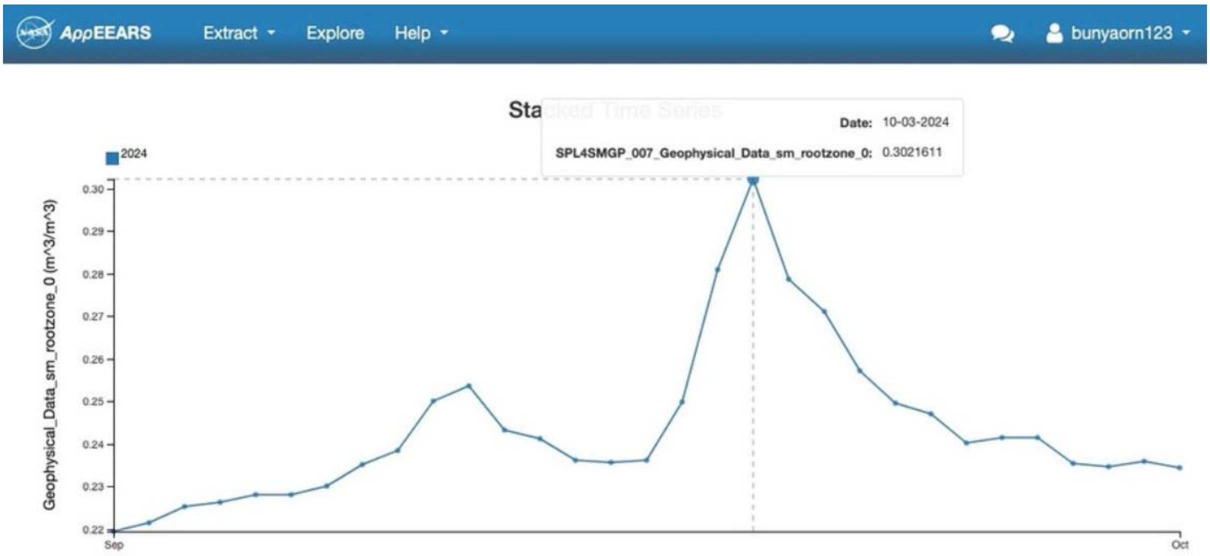

Fig. 5 Soil moisture root zone data from the AppEEARS exploration graph.

There is no linear relationship between the water level in the Ping River and runoff flux. An ANOVA test revealed $F_{(1,29)} = 1.33$ and *ns*, indicating that the relationship is not statistically significant (Fig. 6). There is a linear relationship between the water level in the Ping River and the soil moisture in the root zone, with the equation: Soil moisture = 0.01 × Water level + 0.21. An ANOVA test revealed $F_{(1,29)} = 26.2$ and $P < 0.01$, indicating that the relationship is statistically significant (Fig. 7). There is a linear relationship between the water level in the Ping River and the soil moisture in the root zone with the equation: Soil moisture

= 0.015 × Water level + 0.189. An ANOVA test revealed $F_{(1,29)} = 5.48$ and $P < 0.05$, indicating that the relationship is statistically significant (Fig. 8).

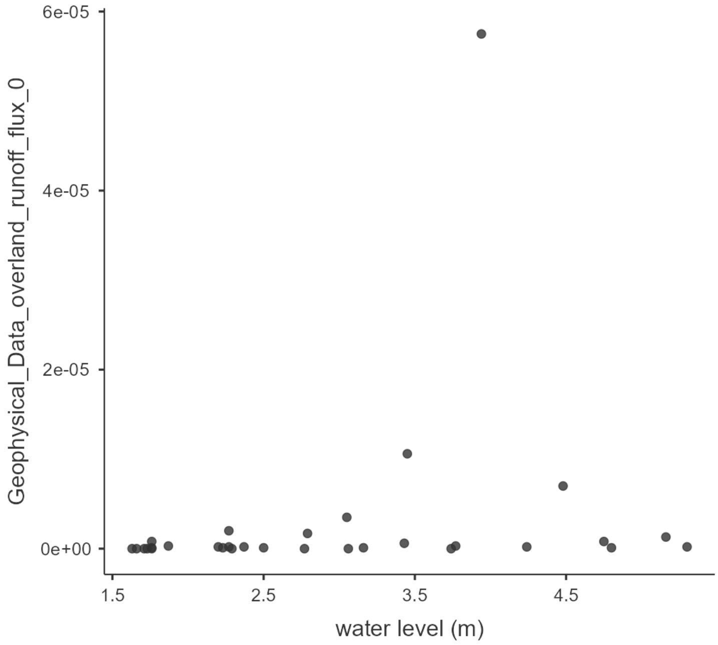

Fig. 6 Scatter plot between water level and runoff flux.

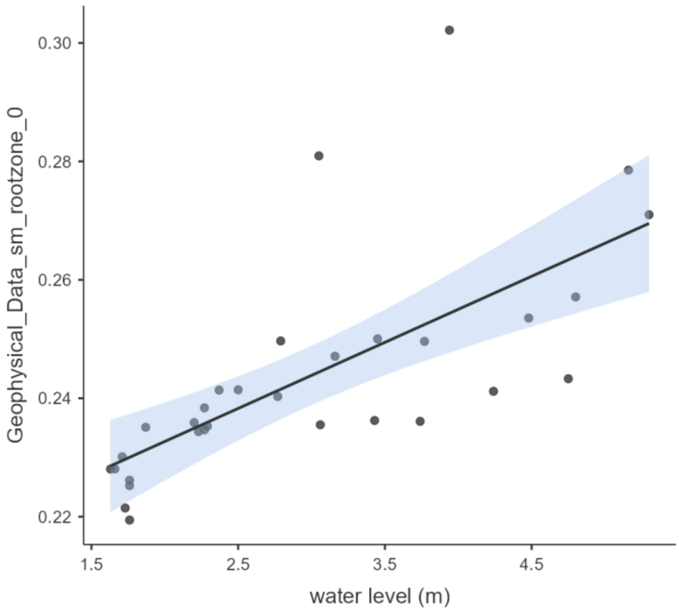

Fig. 7 Scatter plot between water level and soil moisture root zone data.

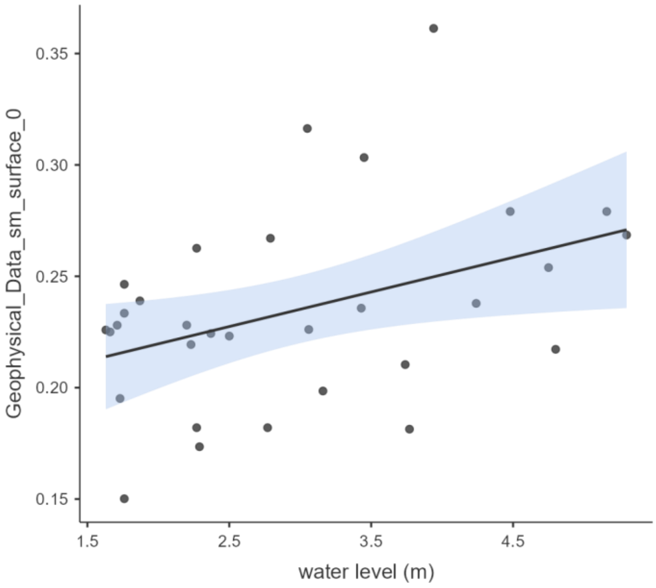

Fig. 8 Scatter plot between water level and soil moisture at the surface.

Discussion

We collected only five data points because the soil was too compact, making it challenging to drill more deeply with the auger. From our data, the study site showed higher soil moisture levels than the overall average for Thailand. This could be because our study was conducted in the central region of Thailand, within the Chao Phraya River Delta. The delta is known for its fertile alluvial soils, which generally retain more moisture than other soil types found across the country, especially compared to mountainous or highland areas (Mikhailov, & Nikitina, 2009). Soil moisture data from Thailand (GLOBE ADAT) exhibited high variability because it was collected from multiple sites nationwide. The mean and standard deviation suggested that most soils in Thailand had relatively low moisture content. Our soil moisture data aligned well with SMAP satellite data, showing around 25% soil moisture. Despite differences in measurement units, both datasets demonstrated a consistent trend, which confirms that SMAP data can be a valuable tool for soil moisture monitoring and can be trusted in this study.

Based on the research question of whether SMAP data can be used to study flooding, our analysis demonstrates that SMAP can indeed be utilized for flood studies. We observed significant correlations between variables, such as soil moisture and river water levels, which were statistically significant (Fig. 7 and 8). Specifically, the relationship between soil moisture in the root zone and the surface layer with water levels showed a linear pattern. Moreover, ANOVA tests confirmed the statistical significance of these relationships. Therefore, SMAP data can effectively be applied to analyze and predict flood events.

Our study found that runoff does not have a linear relationship with soil moisture, which may be because flooding events in the study area typically occur over a short period. Using linear regression may not be appropriate for analyzing the effects of flooding in this case. A more suitable approach could involve statistical methods that can handle data with variability or instability over short intervals, such as non-linear regression or time series analysis. These methods can better account for the rapid changes in data and provide a more accurate understanding of the impact of flooding.

Our study found that soil moisture in the root zone demonstrates a stronger correlation with the water level in the Ping River compared to soil moisture in the surface layer. This result is noteworthy, suggesting that the root zone could play a more significant role in hydrological processes related to flooding, which has important implications for future research. This finding could improve water management strategies and enhance flood prediction models, particularly in regions with agricultural systems or ecosystems by better understanding how the root zone contributes to flood dynamics.

The stronger correlation observed in the root zone may be attributed to the fact that the root zone extends to a depth of 90 cm, while the surface layer only reaches 0-15 cm. This depth difference likely accounts for the increased variability in surface layer soil moisture measurements, which may be more susceptible to rapid changes due to short-term precipitation and evaporation. In contrast, the root zone has a more stable moisture retention capacity, which could make it a more reliable indicator for flood forecasting.

The potential of root zone soil moisture as an indicator for flood management is supported by the work of Gao et al. (2021), who emphasize the critical role of the root zone in regulating soil moisture and its direct impact on flooding events. Their research suggests that saturated soils in the root zone contribute to surface runoff, which can exacerbate flood events. As such, managing soil moisture at the root zone level could be a key strategy for improving flood prediction and mitigation efforts.

By enhancing our understanding of how the root zone interacts with hydrological processes, this study contributes to developing more accurate models for predicting flood events. Additionally, it underscores the importance of soil moisture management in flood risk reduction, especially in areas prone to seasonal flooding or agricultural runoff. In conclusion, our research reinforces that root zone soil moisture is a critical factor in flood dynamics, offering valuable insights for flood monitoring, forecasting, and risk management.

From this study, we can use the knowledge gained to create maps using Google Earth Engine to study flooding in a spatial context, opening up opportunities for future research. However, this research helps define the scope, indicating that future studies should focus on runoff and soil moisture in the root zone (Fig 9), representing an initial attempt at creating the image. At this stage, we cannot analyze it comprehensively, as more events and time are needed for future work.

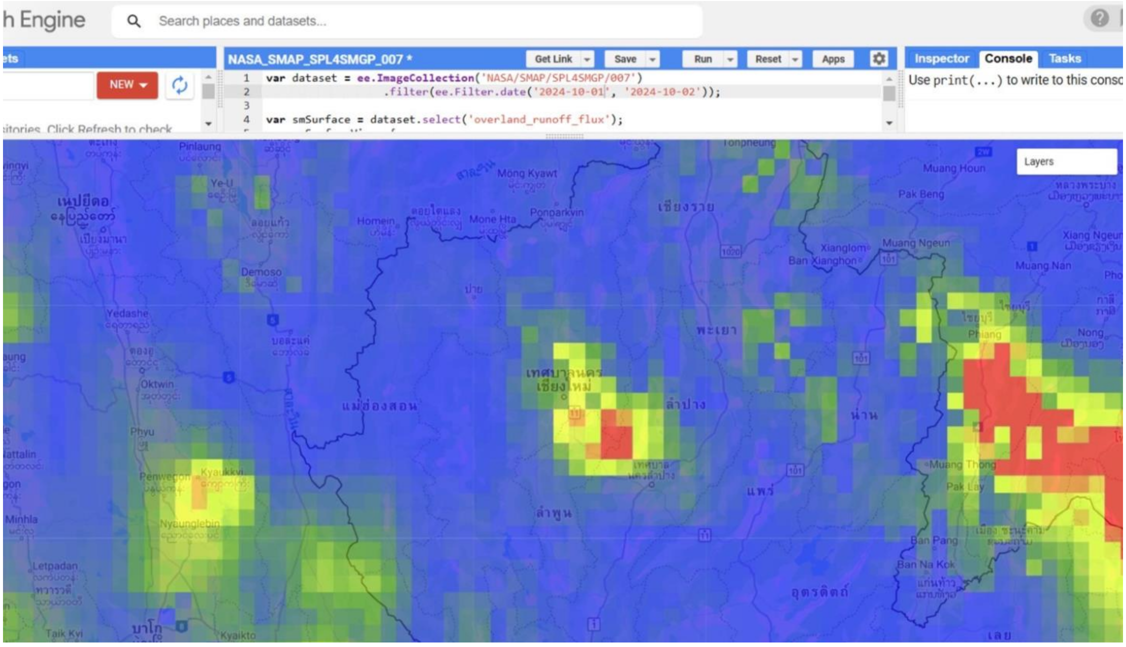

Fig. 9 Visualization map displaying runoff flux from SMAP data in Google Earth Engine from 10/01/2024 to 10/02/2024 during the severe flooding event in Chiang Mai.

Conclusion

This study has demonstrated that SMAP satellite data can effectively monitor and manage severe flooding events, particularly in Chiang Mai, Thailand, by tracking soil moisture changes. The analysis of soil moisture data from SMAP revealed significant changes during the flooding event in Chiang Mai. The data showed that soil moisture levels, both in the surface layer and the root zone, increased during the flood, aligning with the expected flooding impacts as water infiltrates the soil. A statistical correlation between soil moisture and river water levels confirmed that SMAP satellite data can detect soil moisture changes during flooding events.

The analysis also revealed a linear relationship between river water levels and soil moisture in both the root zone and surface layer. Regression analysis showed that soil moisture levels also directly correlated with river water levels increased during the flood. This relationship was statistically significant, suggesting that SMAP data can provide valuable insights into soil moisture behavior during floods and can be used to predict or monitor flood dynamics. However, the runoff flux did not show a significant relationship with water levels, indicating that it might not be a reliable indicator for flood monitoring in this case, which still requires further validation.

In conclusion, SMAP data proves to be a valuable tool for flood monitoring in Chiang Mai. The observed relationship between soil moisture and water levels supports using this data in flood management and planning. However, this study still requires further research with more comprehensive data and more accurate methodologies, such as time-series analysis or non-linear regression, to improve the accuracy of flood predictions.

I would like to claim IVSS badges

1. I AM A DATA SCIENTIST

This study imported data from the cloud and analyzed it using Jamovi, an easy-to-use, free software. Jamovi helped us use simple statistical methods like time series graphs, box-whisker plots, and linear regression to understand the relationship between soil moisture, river water levels, and flood extent. This software made analyzing the data easier and getting clear, reliable results. We imported data from the GLOBE Soil Moisture Protocol, GLOBE Data Archive, SMAP satellite data, and water level data from the Upper Northern Region Irrigation Hydrology Center.

2. I WORK WITH A STEM PROFESSIONAL

In this study, we conducted soil sampling using an auger following the protocol. We applied scientific principles related to soil moisture, utilized engineering tools for soil analysis, and performed calculations using mathematics. The collected data was then uploaded to the GLOBE system. We also used NASA data to support our research. By combining the knowledge and tools from different STEM fields, we could better understand the relationship between soil moisture and flooding. This collaboration with various STEM professionals helped improve the accuracy and reliability of our findings.

3. I AM AN EARTH SYSTEM SCIENTIST.

This study looks at water (hydrology) and soil moisture, which work together in a system. To understand floods, we need to look at rain, water flowing on the ground, and water underground. These parts all affect each other and help us understand how floods happen. By studying these together, we can learn how to predict and manage floods better**.**

4. I AM A PROBLEM SOLVER

This study found that in the future, flooding could be reduced or managed better by improving the soil in the root zone. This could help the soil handle rainfall for extended periods, making flooding less likely. Additionally, we can plan and respond more effectively if we genuinely understand flooding.

5. I AM A COLLABORATOR

This study involves data from four different sources: data that we collected ourselves, data from students at other schools through the GLOBE program, data from the Department of Hydrology, and data from NASA. We worked with these groups to gather and analyze the information needed for this study. Additionally, we shared our collected data with the GLOBE database to contribute to the global community of researchers. By collaborating with others and sharing our findings, we aim to improve our understanding of soil moisture, flooding, and environmental issues. Our efforts should be recognized because of our teamwork and data sharing.

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