Understanding the Interplay of Land Surface Temperature, Soil Moisture and Air Temperature in Diverse Ecosystems

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Abstract

The intricate relationships among land surface temperature (LST), soil moisture, and air temperature are fundamental to understanding the dynamics of Earth's ecosystems. This study delves into these interconnections, focusing on four dam areas in Thailand—Kaeng Krachan, Sirikit, UbolRatana, and Rajjaprabha. Three distinct land cover types—forest, dam water body, and urban areas—are investigated using a combination of satellite data and ground surveys.Research questions address the insights gained from satellite data, the evolution of temperature and moisture variations over time, and the existence of relationships between LST and soil moisture. Hypotheses propose significant influences of land cover type and the province where the dam is located on LST and soil moisture.Thailand's diverse ecosystems offer a unique backdrop for this study, with four dam sites providing distinct geographical characteristics. Data collection involves ground surveys and satellite observations, focusing on temperature, cloud cover, and soil moisture.The analysis utilizes a two-way ANOVA to examine how land use and location impact surface temperature and soil moisture. Results demonstrate significant variations in both daytime and nighttime LST across land cover types and dam locations. Soil moisture exhibits substantial differences influenced by land cover type and dam location, emphasizing the interconnectedness of these environmental factors.Visualization of time series data reveals a reverse correlation between LST and soil moisture, highlighting the dynamic nature of their relationship. The study identifies the role of dam reservoirs in mitigating land surface temperature, making them valuable tools for urban heat management.Discussion encompasses the seasonal patterns observed, emphasizing the impact of dam reservoirs on surrounding temperatures. The study underscores the transformative potential of data science in urban planning, water resource management, and budget allocation, envisioning a future where informed decisions based on environmental data contribute to sustainable and resilient development.In conclusion, this research outlines a data-driven approach to reshape urban planning, optimize water resource management around dams, and foster ecologically responsible development. It envisions cities that are not only aesthetically pleasing but also better equipped to face the challenges of climate change.

Keywords: Land surface temperature (LST), Soil moisture, GLOBE protocol, Data visualization

Introduction

The Earth's ecosystems are dynamic and interconnected systems, where the intricate relationships between various environmental factors play a pivotal role in shaping their functioning and resilience. Among these factors, land surface temperature (LST), soil moisture, and air temperature emerge as key determinants that govern the intricate balance within diverse ecosystems. Understanding land surface temperature is pivotal for climate research, ecosystem functionality, and human well-being. This fundamental variable is intricately woven into Earth's vital systems, playing a crucial role in shaping our understanding of climate dynamics, maintaining the functionality of ecosystems, and influencing the overall well-being of human societies (Wang et al., 2023).

Land surface temperature serves as a crucial indicator of the thermal state of the Earth's surface, reflecting the energy exchanges between the land and the atmosphere. Its variations are not only indicative of local climatic conditions but also intimately linked with the physiological processes of vegetation, the distribution of water, and the overall energy budget of ecosystems. Similarly, soil moisture, representing the water content in the soil, plays a critical role in regulating plant growth, nutrient cycling, and influencing microclimatic conditions. The intricate balance between land surface temperature and soil moisture forms a dynamic nexus that influences the ecological dynamics within the terrestrial ecosystem (Weiland et al. 2023) .

Furthermore, the interdependence of land surface temperature and soil moisture is intricately linked with air temperature, forming a triad of environmental variables that collectively shape the ecological tapestry of diverse landscapes. Air temperature acts as a mediator between the land and atmosphere, influencing the rates of evaporation, transpiration, and thermal radiation (Stewart and Oke, 2012). The complex interactions between these variables give rise to unique patterns and feedback mechanisms that vary across different ecosystems, ranging from arid deserts to lush rainforests.

This study explores the dynamic relationships among land surface temperature, soil moisture, and air temperature in diverse ecosystems, particularly focusing on four dam areas in Thailand. Investigating three distinct land cover types—forest, dam water body, and urban—our approach involves utilizing satellite data and ground surveys. While the primary aim is to comprehend data behavior through data science, the study suggests potential applications in city planning, water management, agriculture, and conflict resolution.

Research questions

1. What insights can satellite data on soil moisture and land surface temperature reveal about our environment?
2. How do variations in surface temperature and soil moisture evolve over time across diverse regions and land cover types in Thailand?
3. Do relationships exist between land surface temperature and soil moisture across different areas and land cover types in Thailand?

Hypothesis

1. Land cover type significantly influences Land Surface Temperature.
2. The province where the dam is located significantly influences Land Surface Temperature.
3. There is a significant interaction between land cover type and province in their influence on Land Surface Temperature.
4. Land cover type significantly influences soil moisture.
5. The province where the dam is located significantly influences soil moisture
6. There is a significant interaction between land cover type and province in their influence on soil moisture.
7. There is a significant correlation between land surface temperature and soil moisture.

Methodology

Study site

Thailand, located in Southeast Asia, is situated on the Indochinese Peninsula, bordered by Myanmar, Laos, Cambodia, and Malaysia. The country's geographic landscape comprises a diverse range of ecosystems, from lush tropical rainforests to coastal plains, providing a unique and dynamic environment for the study of land surface temperature and soil moisture interactions. This geographical diversity, coupled with varying climatic conditions, offers valuable insights into the complex interplay between these environmental factors, making Thailand an intriguing focal point for scientific investigations in this field.

Our research spans four distinct dam sites across various regions of Thailand, each offering unique geographical characteristics. Beginning in Central Thailand's Phetchaburi Province, Kaeng Krachan Dam (latitude 12.916352, longitude 99.631056) serves as our focal point. Heading north to Uttaradit Province, we explore Sirikit Dam (latitude 17.763404, longitude 100.56325). In the northeastern region, our study encompasses UbolRatana Dam in Khon Kaen Province (latitude 16.775432, longitude 102.618414). Lastly, we investigate Rajjaprabha Dam in Southern Thailand's Surat Thani Province (latitude 8.972638, longitude 98.806458).

Within each study area, our analysis extends to three distinct land use categories within a 15-kilometer radius. Firstly, we examine forest land cover in the upper dam vicinity, secondly, water body areas around the dam office, and thirdly, urban and irrigation land downstream of each dam. Our ground investigation exclusively measured environmental parameters at Kaeng Krachan Dam, our main study area.

Figure 1: Geographical Locations of Four Studied Dams in Thailand (pink balloons). Our investigation focuses on four distinct dam sites situated in diverse regions of Thailand. The map highlights the positions of Kaeng Krachan Dam in Central Thailand, Sirikit Dam in Uttaradit Province, UbolRatana Dam in Khon Kaen Province, and Rajjaprabha Dam in Surat Thani Province.

Data collection

In our research, we gathered data in two main ways: through satellite observations and on-the-ground measurements. Satellite data was crucial for testing our hypotheses, while ground data served to validate and cross-check the information obtained from satellites. Our ground data consisted of cloud data, land surface temperature data, and air temperature data.

For cloud data, we employed the GLOBE app, which allowed us to collect accurate information about cloud cover. To measure land surface temperature, we used a temperature gun following the GLOBE protocol. Air temperature and relative humidity data were collected using the Xiaomi MIjia Thermometer and a weather station from the weather link. We gather ground data between 10:00 AM and 11:00 AM as it coincides with the Terra satellite's pass over our study area. The data was collected on November 29, 2023, and November 30, 2023.

We utilized two types of satellite data: land surface temperature and soil moisture. The data were obtained from NASA's AppEEARS application. The soil moisture data, known as SPL4SMGP (Reichle et al., 2020), came from the SMAP satellite and provides global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture. The land surface temperature data, obtained from NASA's MODIS through the MOD11A1 data product (Justice et al., 2002), offers daily values at 1-kilometer spatial resolution. This data is derived from Terra Moderate Resolution Imaging Spectroradiometer (MODIS) observations and is fundamental for studying surface energy balance, land-atmosphere interactions, and hydrological processes.

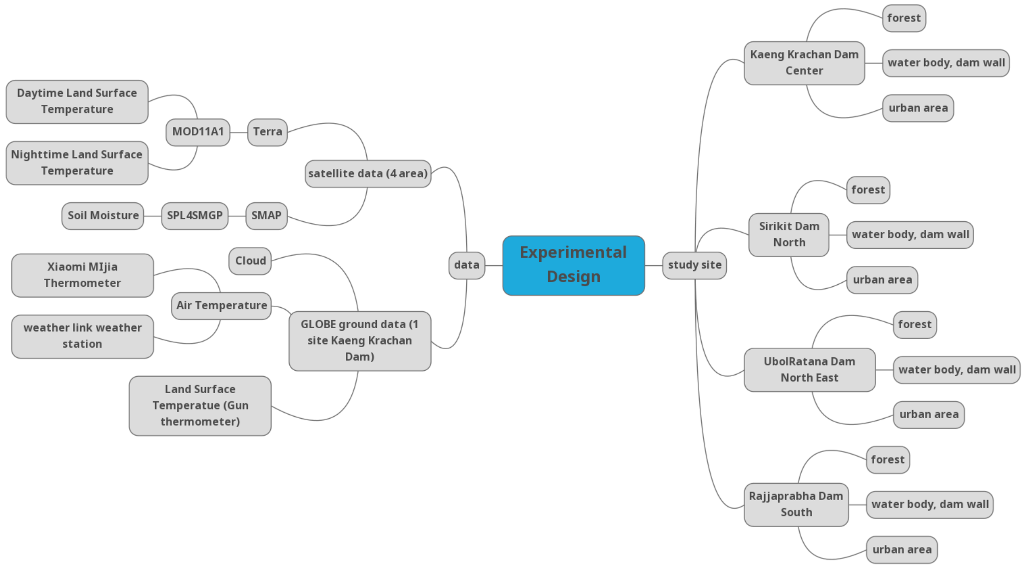


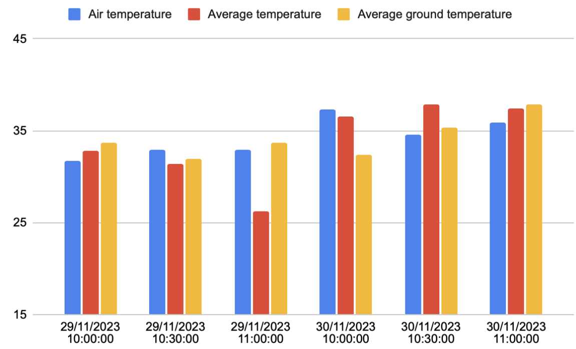
Figure 2: Experimental Design

Data Analysis

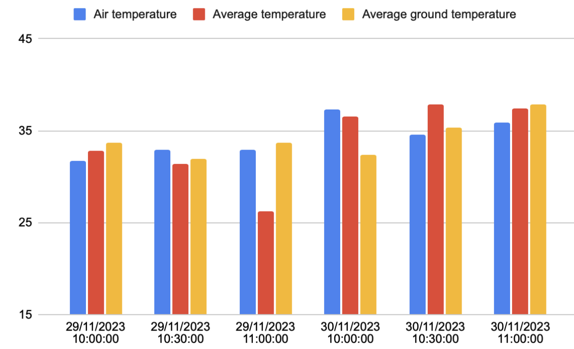
To analyze our data, we employed a two-way ANOVA, a statistical method that allowed us to compare how land use and location influenced surface temperature and soil moisture. We utilized NASA's AppEEARS website, which offers various user-friendly tools for visualizing data, such as maps, charts, and graphs. These visualizations, like Temporal Comparison, Layer Comparison, and Categorical Comparison, helped us see patterns and trends in our data. Additionally, we used Google Data Studio to transform survey data into clear and easy-to-understand visualizations. The data we analyzed included information on land surface temperature and air temperature, providing a comprehensive view of our study parameters.

Results

Based on ground measurements, the mean ± standard deviation of air temperature, soil land surface temperature, and concrete land surface temperature at the urban area are 34.2 ± 2.1, 33.7 ± 4.5, and 34.2 ± 2.2, respectively. Similarly, at the dam wall, the measurements are 27.9 ± 0.2, 34.7 ± 4.3, and 29.2 ± 5.4 (see Figure 3).



(a) Urban Area



(b) Dam Wall (Water Body Area)

Figure 3: Ground Temperature Data Collection - (a) Urban Area, (b) Dam Wall (Water Body Area). The blue bar represents air temperature, the red bar indicates bare soil surface temperature, and the orange bar illustrates concrete surface temperature. In the proximity of the dam wall (water body area), air temperature is noted to be lower than the surface temperature.

The study incorporated satellite data to analyze land surface temperatures across 12 distinct sites, which were categorized into urban (Kaeng Krachan Dam, Rajjaprabha Dam, Sirikit Dam, Ubol Ratana Dam), water body area (Kaeng Krachan Dam, Rajjaprabha Dam, Sirikit Dam, Ubol Ratana Dam), and forested (Kaeng Krachan Dam, Rajjaprabha Dam, Sirikit Dam, Ubol Ratana Dam) settings. The dataset encompassed two types of temperature data: daytime and nighttime land surface temperatures.

For daytime land surface temperatures, the recorded values for each site were as follows: 2036, 1588, 2946, 2577, 3089, 2574, 3631, 3852, 2745, 1812, 2829, and 2739. The mean ± standard deviation values for daytime temperatures were calculated and reported as 308±4.59 kelvin, 304±2.88 kelvin, 306±4.44 kelvin, 306±4.11 kelvin, 301±3.31 kelvin, 301±3.09 kelvin, 302±3.46 kelvin, 302±3.74 kelvin, 303±3.64 kelvin, 299±2.61 kelvin, 299±3.45 kelvin, and 305±4.69 kelvin, respectively.

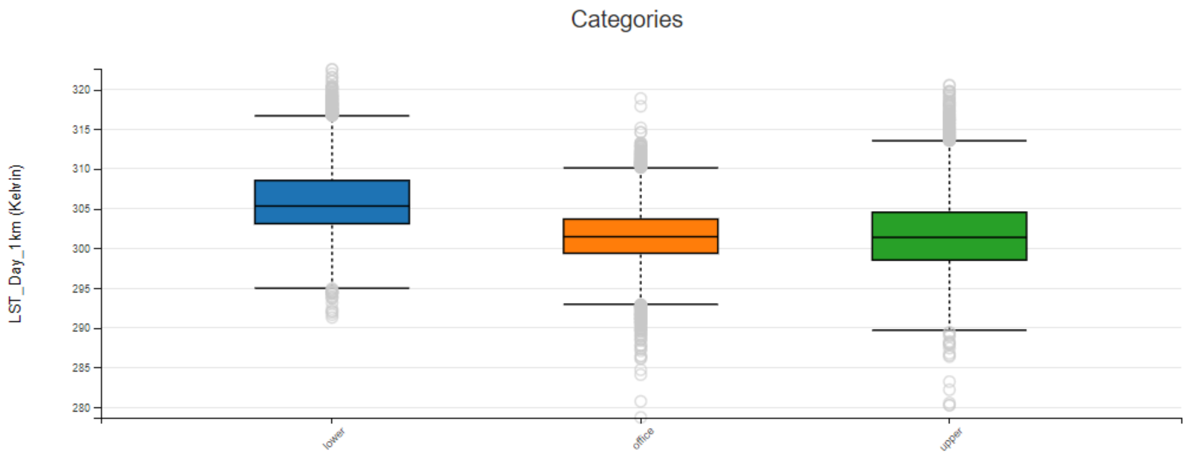


Figure 4: Terra satellite data depicting daytime land surface temperature (blue bars for urban areas, orange bars for dam walls, and green bars for forests above the dam reservoir). During the day, urban areas exhibit higher temperatures than other regions. The narrower orange bars signify that the water body at the dam helps maintain a more stable temperature compared to the soil in the surrounding land.

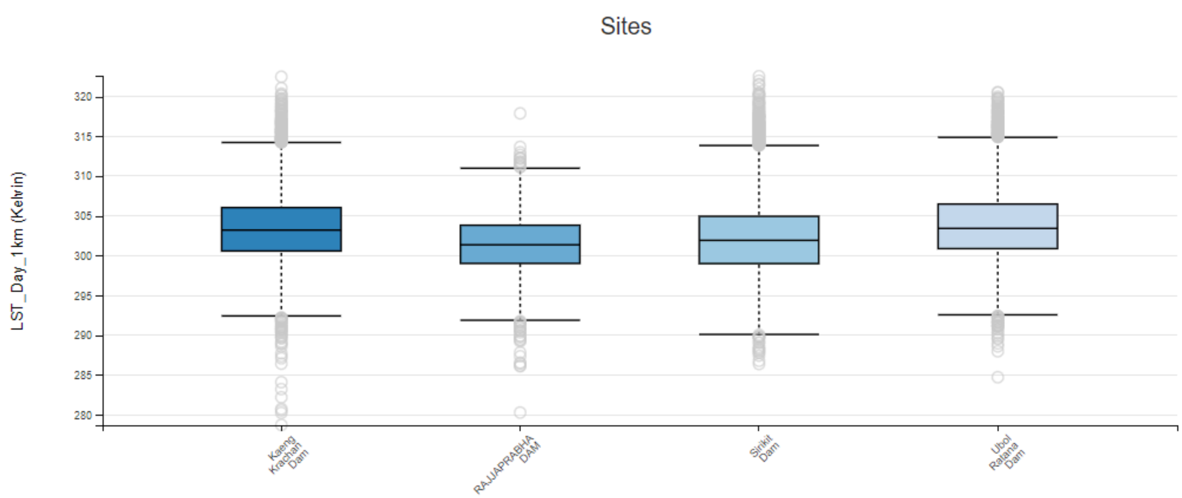


Figure 5: Terra satellite data depicting daytime land surface temperature.

Similarly, nighttime land surface temperature data included values for each site: 1724, 1051, 2709, 2391, 1859, 1265, 2934, 2761, 1696, 1277, 2760, and 2426. The mean ± standard deviation values for nighttime temperatures were reported as: 295±2.72 kelvin, 296±1.68 kelvin, 295±3.06 kelvin, 294±3.54 kelvin, 296±2.11 kelvin, 297±1.98 kelvin, 296±3.01 kelvin, 295±3.49 kelvin, 295±2.42 kelvin, 294±1.57 kelvin, 294±2.74 kelvin, and 294±3.81 kelvin.

A substantial difference in mean daytime Land Surface Temperature was identified, and this variance was attributed to the Land cover type ($F(2,32406) = 4302$, $p < 0.001$). The statistically significant F-value suggests that Land cover type significantly influences the observed variations in daytime temperatures across the study sites. A significant difference in mean daytime Land Surface Temperature was observed, and this variance was attributed to the province where the dam is located ($F(3,32406) = 887$, $p < 0.001$). The obtained F-value indicates a statistically significant influence of the province on the variations in daytime temperatures across the study sites.There is a significant interaction between land cover type and the province where the dam is located in their influence on daytime Land Surface Temperature ($F(6, 32406) = 674$, $p < 0.001$). This indicates that the combined effect of land cover type and province has a noteworthy impact on the variations observed in daytime temperatures across the study sites.

A notable difference in mean nighttime Land Surface Temperature was identified, and this variability was attributed to the Land cover type ($F(2, 24841) = 872.8$, $p < 0.001$). The statistically significant F-value suggests that Land cover type significantly influences the observed variations in nighttime temperatures across the study sites. Additionally, a significant difference in mean nighttime Land Surface Temperature was observed, and this variance was attributed to the province where the dam is located ($F(3, 24841) = 178.7$, $p < 0.001$). The obtained F-value indicates a statistically significant influence of the province on the variations in nighttime temperatures across the study sites.

Moreover, there is a significant interaction between land cover type and the province where the dam is located in their influence on nighttime Land Surface Temperature ($F(6, 24841) = 51.3$, $p < 0.001$). This indicates that the combined effect of land cover type and province has a noteworthy impact on the variations observed in nighttime temperatures across the study sites.

A consistent dataset comprising 2782 records for root zone soil moisture was retrieved for each of the 12 study sites. The mean ± standard deviation values, expressed in cubic meters per cubic meter (m^3/m^3), for root zone soil moisture at each site are as follows: Urban Kaeng Krachan Dam (0.276 ± 0.0419 m^3/m^3), Urban Rajjaprabha Dam (0.326 ± 0.0455 m^3/m^3), Urban Sirikit Dam (0.248 ± 0.0423 m^3/m^3), Urban UbolRatana Dam (0.26 ± 0.0706 m^3/m^3), Water Body Area Kaeng Krachan Dam (0.198 ± 0.0407 m^3/m^3), Water Body Area Rajjaprabha Dam (0.343 ± 0.0594 m^3/m^3), Water Body Area Sirikit Dam (0.327 ± 0.0364 m^3/m^3), Water Body Area UbolRatana Dam (0.285 ± 0.0731 m^3/m^3), Forest Kaeng Krachan Dam (0.266 ± 0.0477 m^3/m^3), Forest Rajjaprabha Dam (0.347 ± 0.0626 m^3/m^3), Forest Sirikit Dam (0.325 ± 0.0361 m^3/m^3), and Forest UbolRatana Dam (0.247 ± 0.0685 m^3/m^3). A significant difference in root zone soil moisture was noted, with Land cover type ($F(2, 3372) = 346$, $p < 0.001$) playing a substantial role in influencing the observed variations across study sites. Similarly, a significant difference in mean root zone soil moisture was associated with the province where the dam is located ($F(3, 3372) = 4799$, $p < 0.001$), highlighting the province's significant impact on these variations. Additionally, the interaction between land cover type and the province ($F(6, 3372) = 1279$, $p < 0.001$) emphasized the combined effect, indicating a noteworthy impact on the variations observed in root zone soil moisture across the study sites.

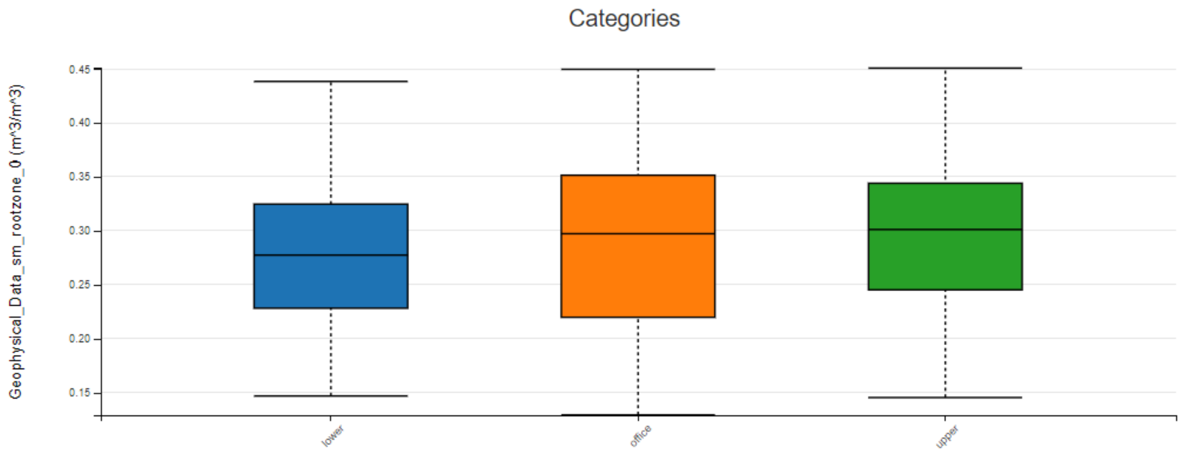


Figure 6: SMAP satellite data on soil moisture (blue bars for urban areas, orange bars for dam walls, and green bars for forests above the dam reservoir). Forest areas exhibit higher soil moisture levels than other regions. The broad orange bars indicate significant fluctuations in soil moisture associated with the water body at the dam.

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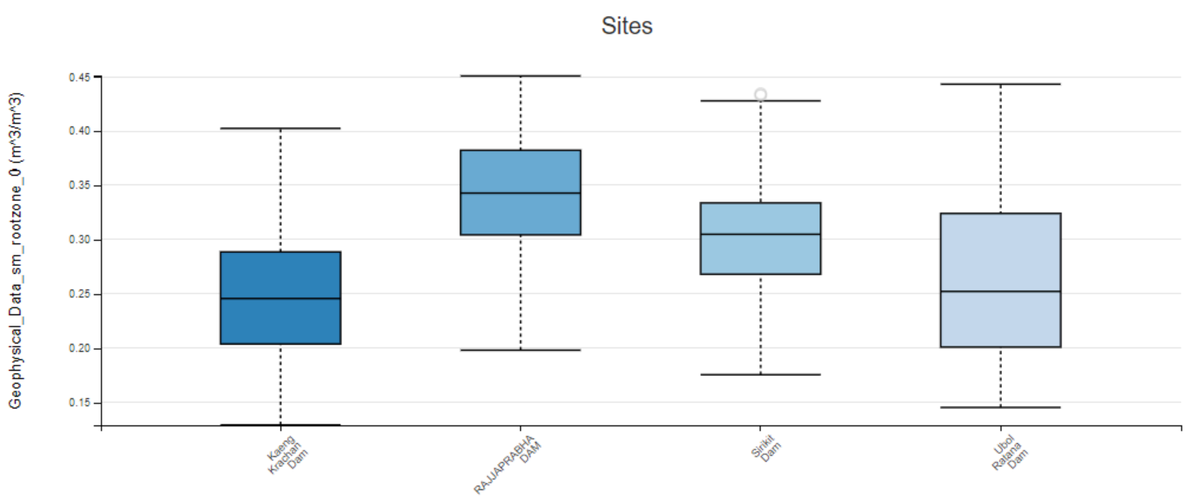

Figure 7: SMAP satellite data on soil moisture for four dams. Rajjaprabha Dam in the south has the highest moisture content, while Ubolratana Dam in the northeast exhibits the broadest bar, suggesting significant fluctuations in soil moisture. This indicates the substantial impact of the dam in that area and underscores the prominent role of dams in influencing moisture levels**.**

In our visualization, as we plot the time series of land surface temperature and soil moisture, we note a reverse correlation between the two parameters, where an increase in temperature corresponds to a decrease in soil moisture.

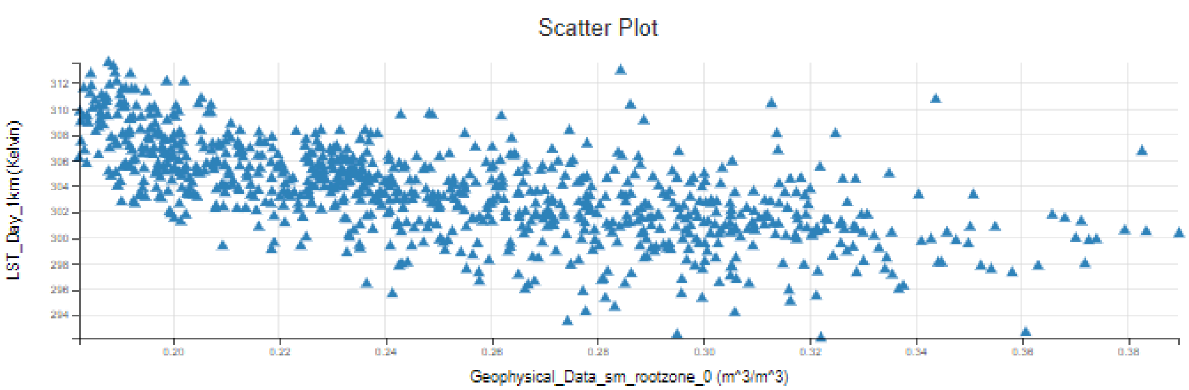

Figure 8: Land surface temperature and soil moisture at Kaeng Krachan Dam. The blue points represent temperature, and the green points represent soil moisture. The graph demonstrates an inverse correlation between the two parameters.

Discussion

Our study reveals a consistent and interconnected relationship between land surface temperature (LST) and soil moisture across all study areas. Additionally, distinctive seasonal patterns are observed in both LST and soil moisture datasets, demonstrating synchronous changes. Notably, this aligns with previous research findings, such as those by Colliander et al. (2017) and Gomez-Casanovas et al. (2013), which also highlight similar correlations between LST, soil moisture, and seasonal patterns.

Furthermore, our investigation identifies the influence of water bodies in dam reservoirs on the land surface temperature of surrounding areas. This insight is particularly valuable for addressing heat-related challenges in urban environments. Our research emphasizes the role of dam reservoirs as effective temperature buffers, reducing heat in adjacent regions and presenting a valuable tool for developing cooler and more resilient cities. These findings resonate with existing studies by Scott & Huff (1996) and Thiery et al. (2015), which underscore the significant impact of large water bodies, such as dam reservoirs, on land surface temperature.

Analyzing the boxplot in Figure 7, we note significantly higher soil moisture levels around Rajjaprabha Dam in southern Thailand compared to the fluctuating levels near Ubonrat Dam in the northeast. This implies that dams in the northeast, characterized by more stable soil moisture patterns, hold greater potential for optimizing water resources in urban development, agricultural strategies, and efficient budget allocation.

Our research emphasizes the transformative potential of data science in reshaping urban planning and environmental management. Utilizing satellite data and the GLOBE protocol, we showcase the ability to empower individuals by providing accessible tools, such as mobile apps, for understanding local LST and soil moisture levels. This knowledge facilitates informed decision-making, such as optimizing water usage and selecting cooler commuting routes.

Additionally, the integration of LST and soil moisture data into urban planning models allows us to envision cities that are naturally cooler and less vulnerable to heat stress. This includes strategic placement of green spaces and water bodies, optimal building orientations, and the promotion of sustainable construction materials.

Our findings also impact dam decisions, suggesting that dams in the northeast region, with their consistent soil moisture patterns, offer greater potential for sustainable water resource management. Data science enables precise dam placement and operation, minimizing conflicts and maximizing benefits for surrounding communities.

In terms of budget management, data science-driven predictions of water availability and demand inform efficient allocation for water infrastructure projects, promoting responsible resource management and minimizing unnecessary expenditure.

In conclusion, our research envisions a future where data science plays a pivotal role in steering sustainable and resilient urban development. By integrating LST, soil moisture, and other environmental data into well-informed planning, we can construct cities that are aesthetically pleasing, livable, ecologically responsible, and better prepared to confront the challenges of climate change.

I would like to claim IVSS badges

1. **I make an impact**

My research reveals the intricate relationship between land surface temperature and soil moisture in Thailand, providing valuable insights for a sustainable future. The negative correlation discovered serves as a key for optimizing agriculture, balancing high yields with drought resilience. This knowledge informs development plans, promoting harmony between progress and environmental balance. As a researcher, I contribute to shaping a prosperous Thailand with a focus on environmental stewardship**.**

2. **I am a STEM professional**

I explore our world using science, technology, engineering, and mathematics. In this study, NASA's satellite data served as our telescope, revealing the intricate relationship between land surface temperature and soil moisture in Thailand. Through statistical analysis and field measurements using temperature guns and various thermometers, we uncovered a significant finding: a negative correlation, indicating that increasing temperatures signify drier land. This discovery, observed across four dam ecosystems, highlights a vital connection for water resource management, showcasing the impact of STEM collaboration in unraveling the land-water relationship.

3. **I am a data scientist**

I wield NASA's satellite data, statistics, and visualization as my brush, unveiling the intricate canvas of Thailand's land. Our study paints a clear picture: a negative tango between surface temperature and soil moisture. As temperatures rise, the land thirsts, revealing a crucial link for water resource management and a testament to the power of data-driven discovery.

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