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Spatial and Temporal Distribution of Water Requirement by Major Crops in Chainat Province, Thailand

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Abstract

Water plays an important role in supporting agriculture. Accurate assessment of water requirements in terms of time, quantity, and space is critical for agriculture and food production sustainability. The objective of this study was to assess the spatial and temporal distribution of water requirements for major crops in Chainat Province, Thailand and identify the water shortage hotspots using a geographic information system (GIS). The spatial model was used to identify the crops plantation. Land use is divided into eight categories: rice, sugarcane, cassava, other agriculture, urban and built-up, forest, water bodies, and other lands. The result shows that the main land use in 2019 is for agriculture, accounting for about 85% of the total area. The main crops are rice, sugarcane, and cassava, accounting for 59%, 14%, and 8% of the total area, respectively. The model calculated the water requirements for those three main crops using the crop evapotranspiration, monthly climate data, and the existing water irrigation areas. The results were presented in a grid cell map of monthly crop water demand. The average water requirements of rice, sugarcane, and cassava are 9,675, 10,577 and 7,979 m^3/ha, respectively. The water deficit areas for rice cultivation were Nong Mamong, Wat Sing, Hankha, and Wat Sing districts during February to March. In July, Noen Kham was found as the water deficit area for cassava and sugarcane cultivation. For the irrigation water requirement per year, rice requires around 5,612 m^3/ha/two crop cycles, followed by sugarcane at about 4,322 m^3/ha/crop cycle and cassava around 2,186 m^3/ha/crop cycle. The substitution of rice cultivation by sugarcane or cassava in the water deficit areas could save water resources by about 1,289 and 3,426 m^3/ha, respectively.

Keywords : Spatial data; Water requirement; Agriculture; Water shortage; Geographic Information System

Introduction

Water is a critical resource for agricultural production [1]. Water for agriculture comes from rainwater and irrigation. Rainwater is the primary water source for agriculture, especially in developing countries. However, irrigation is essential for sustainable agriculture because it can help increase agricultural yield and reduce climate change risks. Since rainfall is unevenly distributed, the rainwater may not meet the crop water requirements in some areas and during some periods of crop cultivation. Water deficit has a significant impact on agricultural production. Irrigation needs to be supplemented to ensure that the crops can be grown throughout the year without experiencing a water shortage. In Thailand, several studies have investigated the water requirement of staple crops such as rice, sugarcane, cassava, and maize [2, 3]. Water consumption for rice typically ranges between 10,000-16,000 m^3/ha which is higher than cassava and sugarcane [4, 5]. Water consumption varies depending on various factors, including climatic conditions, crop calendar, and water availability in each area [6, 7], affecting productivity [8].

The Geographic Information System (GIS) is gaining interest as a tool to support water resources management and planning in a specific area. For example, GIS was used to identify the spatial and temporal variation characteristics of water shortage and to support water management under drought risk [9]. The GIS technology is also needed to analyze spatial details such as land use modeling [10] and rainfall estimates [11]. In addition, GIS has also been applied to estimate total crop water use [12] and identify water shortage hotspots [13]. The objective of this study was to assess the spatial and temporal distribution of water requirements for major crops and identify hotspots of water deficits in Chainat Province, Thailand, using a geographic information system.

Material and Methods

1. Study area

Chainat province is located on the flat river plain of Chao Phraya. It covers an area of approximately 250,020 ha (Figure 1). It is a prominent province for agriculture, having the cultivation of both food and energy crops. The primary source of population income is from the agricultural sector, and the major crops grown in the province are rice, sugarcane, and cassava.

2. Land use classification of Chainat Province

The study classified land uses into eight categories, viz., rice, sugarcane, cassava, other agriculture, urban and built-up, forests, water bodies, and other lands. The study obtained land-use map in 2019 from the Land Development Department, Ministry of Agriculture and Cooperatives of Thailand. The map was converted from vector to raster data using the maximum combined area algorithm and a raster resolution of 10 ha with the open-source QGIS 3.14 software.

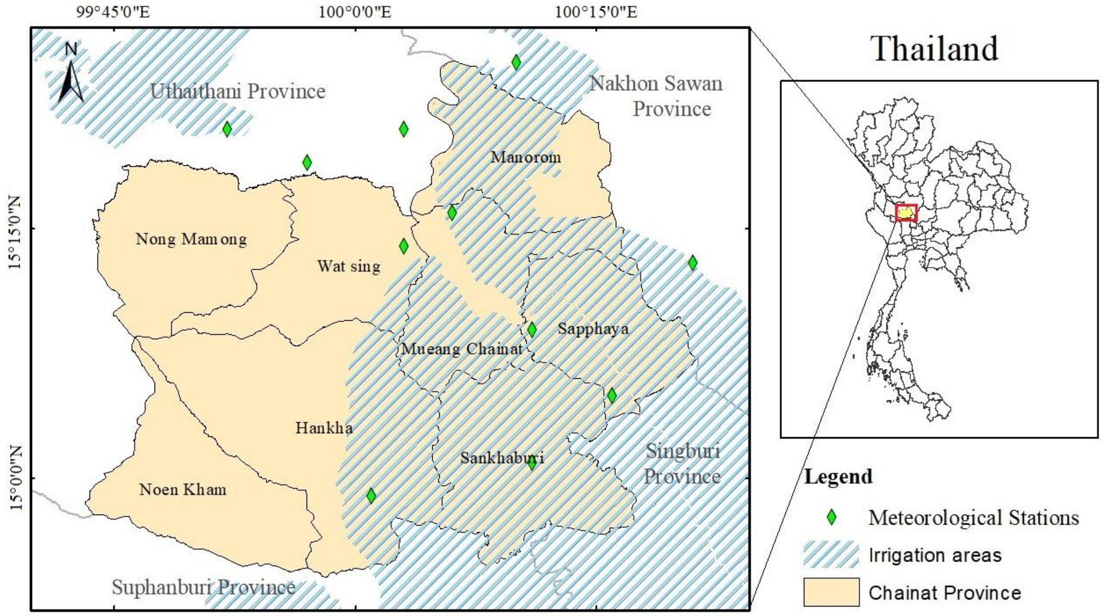

Figure 1 Study area of Chainat Province, Thailand

3. Crop water requirement assessment

The crop evapotranspiration (ET_c) was calculated by Eq. (1), and it was used to indicate the daily crop water requirement for growing rice, sugarcane, and cassava in Chainat. ET_c is the total amount of evaporation and transpiration during the growing period (mm/day) [14].

$$ET_c = k_c \times ET_0 \quad (1)$$

Where k_c represents the crop coefficient, and ET_0 represents the reference crop evapotranspiration (mm/day). The FAO Penman-Monteith method [15] is used to calculate ET_0.

4. Rainwater availability for growing crops

The rainfall data from 1992 to 2001 were used for rainfall distribution pattern analysis. Data were collected from the Thai Meteorological Department (TMD) from six rainfall stations in Chainat and ten rainfall stations in nearby areas. Interpolation of rainfall by Inverse Distance Weighting (IDW) is often used to interpolate rainfall data from rain gauge stations [16]. IDW uses a weighted combination of a set of sample points to determine cell values by using the concept that the nearby data will have a greater influence on the interpolation. This method is used to calculate the optimal values for the weighted average monthly rainfall for ten years. Nevertheless, to determine the rainwater availability for growing crops, the rainfall data are used to calculate effective rainfall which is the usable rainfall for crops. Table 1 shows the factors used to calculate the effective amount of rainfall as the percentage of rainfall that crops suck or extract water from the soil to live and grow. The weighted rainfall is the average monthly rainfall [17].

Table 1 The factors for the assessment of effective rainfall [17]

Weighted rainfall, mm (WRFL)	Effective rainfall, mm
0-10	0
11-100	WRFL × 0.80
101-200	WRFL × 0.70
201-250	WRFL × 0.60
251-300	WRFL × 0.55
301-above	WRFL × 0.50

5. Irrigation areas and water deficits assessment

The irrigation map was obtained from the Digital Government Development Agency. The irrigation area data were converted from vector to raster data using the maximum combined area algorithm and a raster resolution of 10 ha. Raster analysis by overlay was then performed using QGIS software. In the study, crops grown in irrigated areas were assumed to have sufficient water fulfilling the crop water requirement during crop production. Meanwhile, the crops grown in non-irrigated areas would have only the effective rainfall as the water supply source. Eq. (2) was used for determining the amount of irrigation water requirement (for the case of irrigated area) or the water deficits amount (for the case of non-irrigated area) for crop growing [18].

$$IN = ET_c - Pe. \qquad (2)$$

Where IN is the water deficits; ET_c is the crop water requirement; and Pe is the effective rainfall (mm/day).

Results

1. Land use analysis

Figure 2 shows the eight land use categories in 2019; most land use is for agriculture (about 85%). Major croplands are for rice (accounting for 59% of the total land area), followed by sugarcane (about 14%), and cassava (about 8%). Rice cultivation areas are located in Manorom, Mueang Chainat, Sapphaya, and Sankhaburi districts, while the Hankha, Wat Sing, and Nong Mamong districts have various types of crops including rice, cassava, and sugarcane. For Noen Kham District, there is prominent sugarcane cultivation.

2. Water requirements of main crops

The total crop water requirement is calculated for one cropping cycle (Figure 3) by comparing to the effective rainfall. If the crop water requirement is less than the effective rainfall, the surplus rainwater is considered as the amount of excess water. However, if the crop water requirement exceeds the effective rainfall, the deficits amount is referred as the irrigation water demand. The results revealed that the highest effective rainfall was in September and the lowest was in January. In Chainat, rice is shown for two periods, i.e., May to October for major rice and November to April for second rice. Major rice is grown in the rainy season. In May, farmers prepare the land and sow in June when water demand increases due to insufficient effective rainfall in August. In the off-season (second rice), farmers prepare the land in November, sow in December, and harvest in April, which requires a lot of irrigation water as there is no rainfall during this period.

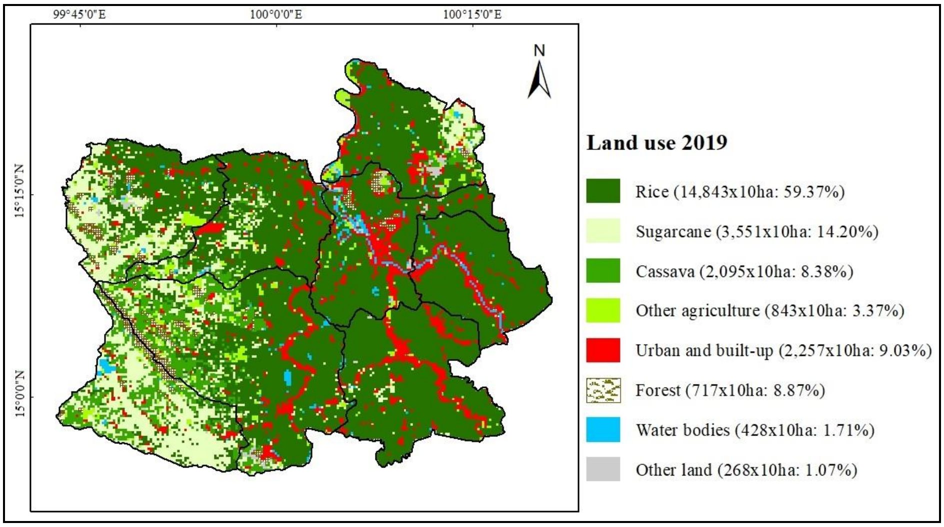

Figure 2 Map of land use classification of Chainat Province in 2019

For sugarcane, the cultivation period is around ten months per cropping cycle, the total crop water requirement for sugarcane per cropping cycle is therefore higher than rice. The results showed that the irrigation water requirement for sugarcane is about 150-160 mm per month from June-August. After that, the total crop water requirement is decreased until harvest. Cassava has a cropping cycle of around 12 months. The maximum irrigation requirement was recorded in July-August. Although this period is the rainy season; however, it is also the same period that crops require a large amount of water. Nevertheless, there were two periods, i.e., during April to May and September to October, when the effective rainfall is higher that the crop water requirement.

Table 2 shows the comparison of total crop water requirement of the three main crops in one cropping cycle comparing between the irrigated and non-irrigated areas in Chainat. The results showed that sugarcane has the highest total crop water requirement at around 10,577 m^3/ha/crop cycle, followed by rice at about 9,674 m^3/ha/two crop cycles and cassava around 7,979 m^3/ha/crop cycle. It is obviously seen that rice has a high irrigation water requirement than sugarcane and cassava. An alternative water-saving measure is thus the replacing rice with sugarcane or cassava. This potentially brings a water-saving of about 1,289 m^3/ha/year and 3,426 m^3/ha/year, respectively.

3. Spatial and temporal distribution of water deficit by major crops

The total monthly irrigation water demand for each area is determined by subtracting effective rainfall from the total crop water requirements for all three crop cultivations per 10 ha (a grid cell). Figure 4 shows the spatial distribution patterns of water deficits in different months and in different areas (based on grid cell) of Chainat province. The results revealed that the rice cultivation areas have the highest water deficit in February and March, followed by August, January, and July. The water deficit of more than 150 mm is found in Nong Mamong, Wat Sing, and Hankha districts from February to March. Cassava has the water deficit in eight months except for April, May, September, and October. Most of the cassava's water deficit areas are in Noen Kham and Hankha districts and the water deficit is less than 50 mm. Sugarcane has the water deficit for five months, i.e., June, July August, November, and December. The water deficit of about 50-100 mm is found in the Noen Kham, Hankha, and Nong Mamong districts.

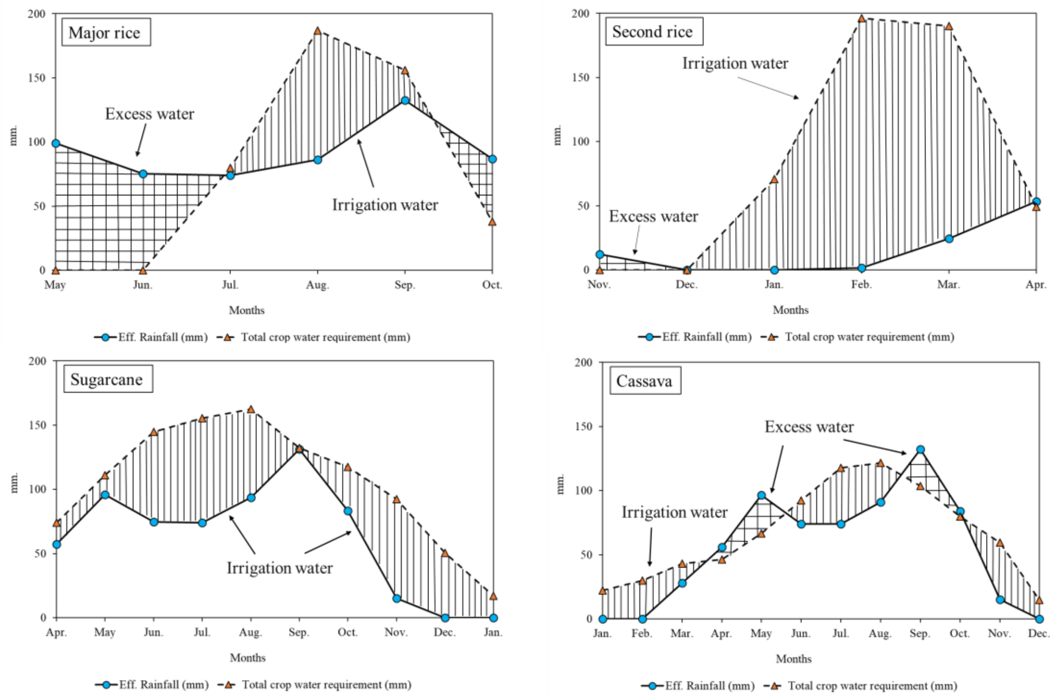

Figure 3 Differences in monthly effective rainfall and total crop water requirement

Table 2 Comparison of water consumption of crops in irrigated and non-irrigated area

Crops	Irrigated		Non-irrigated	Effective Rainfall (m^3/ha/ crop cycle)	Excess water (m^3/ha/ crop cycle)
	Total crop water requirement (m^3/ha/crop cycle)	Irrigation water (m^3/ha/crop cycle)	Total crop water requirement (m^3/ha/crop cycle)		
Major rice (May-Oct.)	4,610.11	1,300.34	3,309.76	5,543.51	2,233.75
Second rice (Nov.-Apr.)	5,064.66	4,311.44	753.22	919.43	166.22
Total rice (Major rice + Second rice)	9,674.76	5,611.78	4,062.98	6,462.94	2,399.97
Sugarcane	10,577.48	4,322.35	6,255.12	6,255.12	-
Cassava	7,978.71	2,185.66	5,793.04	6,513.77	720.70

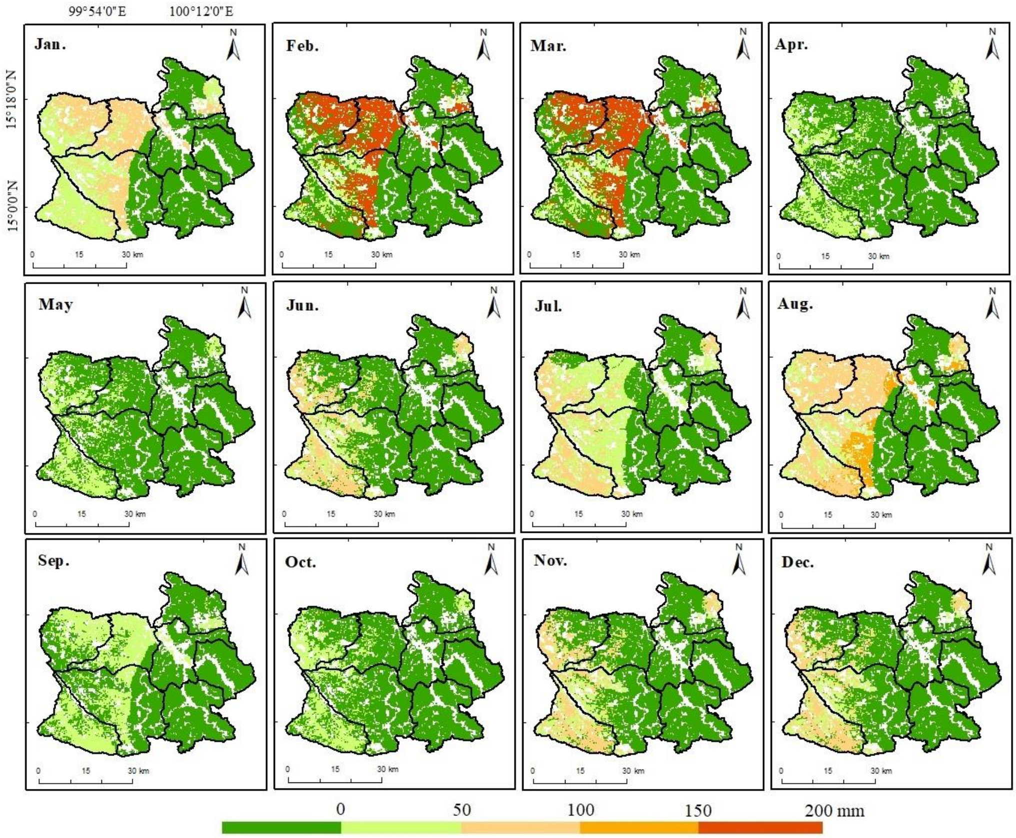

Figure 4 The spatial distribution of water deficit for each grid cell

Discussion

For a year of crop cultivation, the results indicated that sugarcane has the highest water requirement per hectare, more than the two cropping cycles of rice (i.e. major rice and second rice) and cassava. Nevertheless, it must be noted that some varieties of rice can have a higher water requirement than sugarcane and cassava [2]. The spatial tool was applied to assess water demand in terms of time, quantity, and space, which are critical for agricultural sustainability. In terms of irrigation areas, replacing rice with sugarcane or cassava can save water at around 1,289 m^3/ha and 3,426 m^3/ha, respectively. This could potentially reduce water shortage in some districts of Chainat. According to [5], replacing rice with sugarcane or cassava could reduce the water scarcity footprint by more than half.

Crop production in Chainat is predominantly rain-fed. The water availability for the crops thus depends on the cultivation calendar. Shifting the cropping period to when average rainfall is high can reduce overall water requirements [5]. However, the shifting the cropping period must be relevant to the other factors especially the climatic conditions (not only for the water saving purpose). For example, the future changes in rainfall patterns may potentially cause severe effects to crop production leading to food insecurity [19]. The effects to yield and the total amount of water requirements over the entire crop cycle should be considered. Some measures such as developing small water sources in the farmers' fields [20], growing crops suited to the region's climate [21], and restoring forest cover in the watershed [22] can help reduce the risk of water shortage and those measures can be applied to farmers in Chainat.

Understanding the spatial dimensions, timing, and quantity of agricultural water requirements is necessary and important for crop zoning promotion by policymakers to identify areas where food production could be affected.

Conclusions

GIS technology was used to analyze the spatial and temporal distribution of the total irrigation water requirements and the potential water deficits areas of rice, sugarcane and cassava grown in Chainat province. Sugarcane has the highest total water requirement over a year of cultivation. It is more than rice and cassava. Nevertheless, in terms of the irrigation demand, rice is found to have the highest irrigation water requirements. The spatial and temporal distribution of water requirement by major crops revealed that the potential crop water deficits area is located in the western part of the province. Rice cultivation in Nong Mamong, Wat Sing, and Hankha districts potentially has the water deficit in January, February, March and August. Noen Kham, Hankha and Nong Mamong districts are found as the water deficit areas for sugarcane and cassava cultivation.

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