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การประยุกต์หลักการรับรู้จากระยะไกลและระบบสารสนเทศภูมิศาสตร์ ร่วมกับสมการสมดุลน้ำเพื่อประเมินพื้นที่และขนาดสระที่เหมาะสม ในการผลิตพืชไร่เศรษฐกิจของจังหวัดนครราชสีมา

Application of Remote Sensing and Geographic Information System Incorporated with Water Balance Model to Land Evaluation and Optimum Pond Capacity Analysis for Economic Crops Production in Nakhon Ratchasima Province

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บทคัดย่อ

การศึกษาครั้งนี้เป็นการประยุกต์ใช้หลักการรับรู้จากระยะไกลและระบบสารสนเทศภูมิศาสตร์ ร่วมกับสมการสมดุลน้ำมีวัตถุประสงค์เพื่อ 1) สร้างแผนที่การใช้ประโยชน์ที่ดินและสิ่งปกคลุมดินระดับจังหวัด 2) ประเมินพื้นที่เหมาะสมในการเพาะปลูกมันสำปะหลังโรงงาน อ้อยโรงงาน และข้าวโพดเลี้ยงสัตว์ของจังหวัดนครราชสีมา 3) วิเคราะห์ขนาดความจุของสระที่เหมาะสมสำหรับใช้เป็นแหล่งน้ำชลประทานในการเพาะปลูกมันสำปะหลังโรงงาน อ้อยโรงงาน และข้าวโพดเลี้ยงสัตว์ ในพื้นที่ตัวอย่างที่เลือกมาของจังหวัดนครราชสีมา ผลการศึกษาพบว่า พื้นที่เพาะปลูกพืชไร่ทั้ง 3 ชนิดมีประมาณร้อยละ 27.77 ของพื้นที่จังหวัด แยกเป็นมันสำปะหลังโรงงานร้อยละ 17.70 อ้อยโรงงานร้อยละ 4.14 และข้าวโพดเลี้ยงสัตว์ร้อยละ 5.93 จากการประเมินพื้นที่เหมาะสมพบว่า พื้นที่ที่มีระดับความเหมาะสมที่สุดสำหรับการเพาะปลูกอ้อยโรงงานมีเนื้อที่มากที่สุดร้อยละ 19.94 รองลงมาคือมันสำปะหลังโรงงานมีพื้นที่ที่มีระดับความเหมาะสมที่สุดร้อยละ 15.44 และข้าวโพดเลี้ยงสัตว์มีพื้นที่ที่มีระดับความเหมาะสมที่สุดร้อยละ 7.49 และจากการวิเคราะห์ขนาดความจุของสระที่เหมาะสมในพื้นที่ตัวอย่างที่เลือกมาที่มีขนาด 176,756 ตร.ม. โดยใช้ความรู้เกี่ยวกับความต้องการน้ำสูงสุดของพืชไร่ทั้ง 3 ชนิดข้างต้นพบว่า ขนาดความจุที่เหมาะสมของสระคือ 56,094.60 ลบ.ม. โดยมีพื้นที่หน้าตัดของสระคิดเป็นร้อยละ 10.62 ของพื้นที่ตัวอย่างทั้งหมด ซึ่งสามารถส่งจ่ายน้ำชลประทานได้อย่างเพียงพอต่อความต้องการน้ำสูงสุดของพืชไร่ทั้ง 3 ชนิด

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ABSTRACT

Remote sensing and geographic information system techniques incorporated with water balance model were applied to evaluate suitable area and determine the optimum on-farm pond capacity for economic crops (cassava, sugarcane, and maize) production in an area of interest (representative area) in Nakhon Ratchasima Province, Thailand. This study aimed for 1) formulation of the Landsat-based land use/land cover map; 2) suitable land evaluation; and 3) optimum on-farm pond capacity determination. It was found that 1) the 3 crops had occupied about 27.77% of the entire provincial area including cassava (17.70%), sugarcane (4.14%), and maize (5.93%); 2) sugarcane was found to be the most grown crop with highest percentage of land in highly suitable area (19.94%) and cassava is the second favorite crop with percentage in highly suitable area of 15.44%. Maize is the least grown crop with highly suitable land (7.49%); and 3) the representative area with a total area of 176,756.0 m^2 was delineated and the optimum on-farm pond capacity was determined based on knowledge of full demand for the 3 crops. The optimum on-farm pond capacity was found to be 56094.6 m^3 (with surface area of 10.62% of the representative area) which was sufficient for supplying full irrigation water to all 3 crops.

คำสำคัญ: การรับรู้จากระยะไกล ระบบสารสนเทศภูมิศาสตร์ ประเมินคุณค่าที่ดิน ขนาดสระ ข้อมูลภาพดาวเทียม

Keywords: Remote sensing, Geographic information system, Land evaluation, Optimum pond capacity, Satellites images

Introduction

Cassava, sugarcane, and maize are the important major economic crops in Nakhon Ratchasima Province. Most of the agricultural areas are rainfed. Irrigation system can serve about 7% of the province (Figure 1). The problem of low annual rainfall causes low economic crops productivity. Furthermore, widespread infertile soil also makes productive planting of the major economic crops within the province less viable (Nakhon Ratchasima Province Office, 2013).

Consequently, to overcome the above problems, this study aims to formulate Landsat-based land use/land cover map, to evaluate suitable land, and to determine optimum on-farm pond capacity in an area of interest (representative area) for economic crops planting by following the New Theory of Agriculture initiated by His Majesty The King of Thailand. In this theory, about 30% of farmland is reserved for water reservoir while another 30% is used for rice planting (for household consumption), another 30% for other crops (for income generation), and the last 10% for residential area (Thammasat University and Community Development Department, 1998; Royal Irrigation Department, 2012).

In addition, various researches related to the formulation of land use/land cover map, land evaluation, and the application of water balance model to determine optimum on-farm pond capacity were carried out. For example, for formulation of the Landsat-based land use/land cover map, Van Niel and McVicar (2004) used data from Landsat 7/ETM+ to classify rice, maize, sorghum and soybeans areas by supervised classification. It was found that overall accuracy was 89.4%. Shalaby and Tateishi (2007) integrated ancillary data and knowledge of the area into supervised classification to refine classification result before being used in the next analysis. Both unsupervised and supervised classification can be used together (hybrid classification), Thammapala (2004) compared overall accuracy of five classification techniques (unsupervised, supervised, hybrid classification, principle component analysis, and expert classification) by classifying forest plantation in Pasak Watershed. It was found that, the maximum overall accuracy (76.36%) was obtained from hybrid classification. For land evaluation, Albab (1995) selected 8 appropriate land characteristics to evaluate suitable land for maize, cassava, sugarcane in Pakchong District, Thailand. The results were found that, the most suitable class for maize, cassava, and sugarcane were 9.08%, 21.23%, and 23.73% respectively. Eiumnoh et al. (1995) used 9 productivity factors for cassava to evaluate land suitability in Nakhon Ratchasima Province. The final suitability map was found to be 14.8 % under most suitable area.

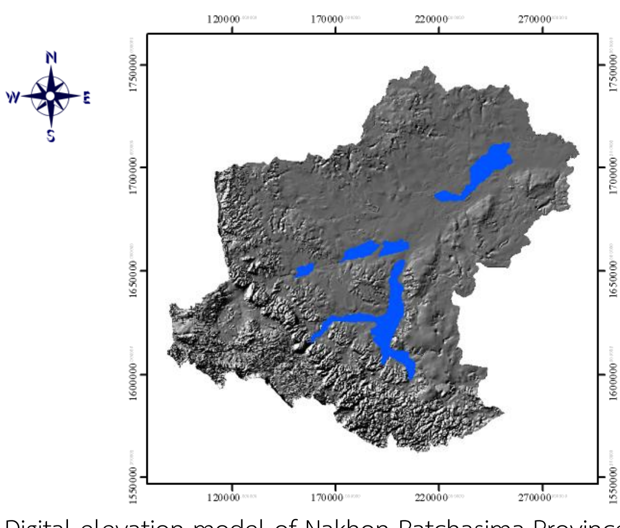


Figure 1 Digital elevation model of Nakhon Ratchasima Province and irrigation area.

Multicriteria evaluation (MCE) was applied to evaluate land suitability for maize in central Mexico. Criterion maps were constructed in form of raster layer and integrated by using a weight linear combination method. In the final suitability map, the area for very high suitability and high suitability were 11,713 ha and 121,067 ha respectively (Ceballos-Silva and López-Blanco, 2003). Charuppat (2002) exploited FAO principle and GIS functions to evaluate suitable land for major crops in Lam Phra Phloeng watershed, Thailand. The multiplication method was used to integrate all criterion maps to obtain the final suitability map. As a result, the land was suitable for six economic crops (maize, cassava, sugarcane, rubber, mango and tamarind). For the application of water balance model to determine optimum on-farm pond capacity, rice and mustard in the eastern India suffered frequent moisture stress due to uncertainty of rainfall and an inadequate field level rainwater conservation structure (on-farm reservoir) leading to severe yield reduction. To increase rice and mustard yield, the optimum capacity of on-farm reservoir was estimated using water balance model to harvest rainwater and surface runoff and provide supplementary irrigation to rice and mustard. The study revealed that the on- farm reservoir of 2 m. depth, requiring 12% of farm area was the optimum size that can substantially increase rice and mustard yield in the study area (Panigrahi et al., 2005). Similarly, Limaye et al. (2004) used water balance equation to estimate optimum farm pond capacity in Henry County, Alabama. As a result, the optimum pond capacity was 40 acres with 10 ft. depth.

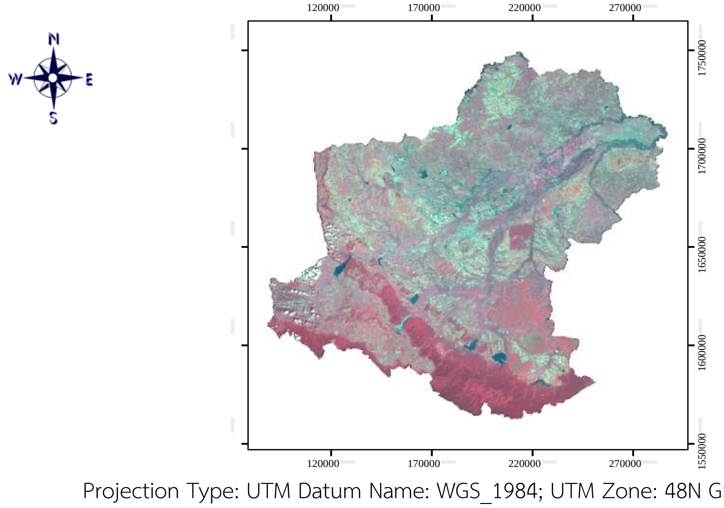
Research Methodology

1. Formulation of Landsat-based land use/land cover map

Landsat-5 TM data in visible and NIR/MIR regions (Band 1, 2, 3, 4, 5, 7) taken in November 2006 over Nakhon Ratchasima Province were acquired from the Geo-informatics and Space Technology Development Agency (GISTDA). Original image was corrected to reduce geometric distortion. The geometric correction was carried out using reference ground control points (GCP) from a topographic map and point data collected from field surveys. The false-color infrared composite image was produced from the combination of TM data in Red (Band 4), Green (Band 3), and Blue (Band 2) (Figure 2) to aid automatic classification and also the visual interpretation for vegetation component. The land use/land cover was classified using hybrid classification method in which the unsupervised classification (Isodata clustering algorithm) was applied first to separate image data into several distinct groups in the spectral space followed by the supervised classification (maximum likelihood algorithm) to group into the corresponding land use/land cover classes based on the unsupervised classification result and training area collected from field surveys. Accuracy of the resulting land use/land cover map was assessed using the reference point data gathered from the field surveys at random locations.

2. Land evaluation for major economic crops

Seven land qualities and their diagnostic factors were selected, land use requirements for cassava, sugarcane, and maize cultivation were determined within FAO principle and previous research. Soil series map derived from Land Development Department was used as the base map. Meteorological data including monthly rainfall and monthly air temperature for the year 1977–2006 were obtained from the Meteorological Department. The evaluation of land suitability was performed based on the principle of geographic information system together with multicriteria decision making (MCDM) and FAO land evaluation guideline for rainfed agriculture (FAO, 1983) and (Malczewski, 1999). The land qualities in terms of diagnostic factors were established in form of raster layer using soil series map as a base map. Matching (comparing) land use requirements to land qualities was conducted, then, factor rating can be assigned to each class of diagnostic factor layers resulted in criterion layers. For each major economic crop, criterion layers were combined using multiplication overlay to obtain the total score of suitability. The total score was grouped into 4 suitability classes namely highly suitable (s1), moderately suitable (s2), marginally suitable (s3) and not suitable (n) to result the suitability map.



Projection Type: UTM Datum Name: WGS_1984; UTM Zone: 48N Grid: 50,000 m.

Figure 2 False-color composite image (RGB = 432) of Nakhon Ratchasima Province.

Note that: Some areas, e.g. forest reserve, urban/built up, salt farm were excluded from the analysis based on the Land Development Department of Thailand guideline.

3. Determination of optimum on-farm pond capacity

Work in this stage was devoted to determine optimum on-farm pond capacity for supplying full irrigation water (100% of net irrigation water requirement) to cassava, sugarcane, and maize cultivation over the selected representative area of interest. The detailed work procedures are as follows.

3.1 A representative area in Nakhon Ratchasima Province was first identified based on four specific requirements: a) having all of the three crops planted, b) evaluated as highly suitable area (S1) for all crops, c) bounded by a small watershed based on a local digital elevation model of 1 meter grid, d) being a rainfed agricultural area outside the irrigation zone.

3.2 Potential location of the farm pond was subsequently placed at the downstream end of the representative area where all (or most) of the direct runoff can be harvested. The proper size of the pond was determined later to suit the required optimum capacity.

3.3 From the location map of rain-gauge stations within Nakhon Ratchasima Province, relevant stations located in the vicinity of the representative area are selected. Monthly rainfall data during 1977 to 2006 for these stations were collected. The data were tested for consistency using the double mass curve method. Areal rainfall for the representative area was calculated as follows (Shaw, 1994):

$$P = \frac{1}{N} * \sum_{i=1}^{N} p_i \tag{1}$$

where P is the areal rainfall (mm), N is the number of rainfall stations in use, and p_i is the rainfall data at the i^{th} station (mm).

3.4. Amount of direct runoff produced from the representative area was calculated using the SCS-CN method, as detailed below (United States Department of Agriculture, 1973; Chaitham, 1999; and Mays, 2005):

$$Q_d = \frac{\left(P - 0.2S\right)^2}{P + 0.8S} \tag{2}$$

where Q_d is the direct runoff, S is potential maximum retention, P is the areal rainfall, all quantities are in mm. Calculation was performed on a monthly basis. The results of experiments suggested that S could be approximated by the following relation:

$$S = 254\left(\frac{100}{CN} - 1\right) \tag{3}$$

where CN is curve number (dimensionless) whose values depended on several factors, e.g., hydrologic soil group and land use/land cover. All direct runoff yielded from the representative area was assumed to flow into the pond.

3.5 The water balance model for the pond was used to calculate successive end-of-month storage as described below (Abdel-Magid et al., 1996; Chaitham, 1999):

$$S_{t+1} = S_t+(Pd_t+Isf_t) - (Osf_t+E_t) \quad (4)$$

where S_{t+1} and S_t are pond storages at the beginning of time $(t+1)^{th}$ and t^{th} , Pd_t is the direct rainfall during time t^{th}, Isf_t is the direct runoff during time t^{th}, Osf_t is the supplementary irrigation (setting at 100% of total net irrigation water requirement) for crops during time t^{th}, E_t is evaporation during time t^{th}, all unit are in m^3. Note that, the ground water and deep percolation were assumed negligible in this study. The pond's horizontal cross-section was assumed to be rectangular and constant at every depth. All components were show in Figure 3.

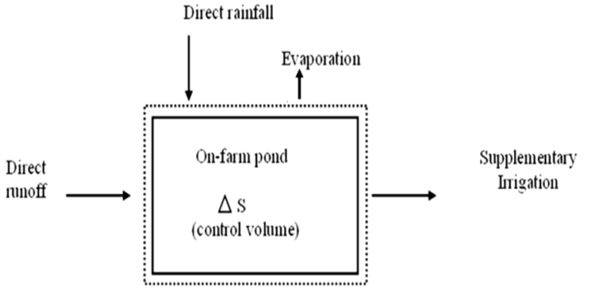


Figure 3 Water balance components of the pond.

Direct rainfall was calculated using:

$$P_t = P*A_p \quad (5)$$

where P_t is the direct rainfall (m^3), P is the areal rainfall (mm), A_p is the pond surface area (m^2). Monthly evaporation was calculated using the following relation (Leewatjanakul, 2006):

$$E_r = C_p*E_p*A_p \quad (6)$$

where E_r is the pond evaporation (m^3), C_p is pan coefficient (dimensionless), E_p is the pan evaporation (mm), and A_p is the pond surface area (m^2).

3.6 Optimum on-farm pond capacity was set as that which hold sufficient amount of water to sustain the driest year data (2001) over the representative area with full irrigation. This was obtained as follows:

The net irrigation water requirement (NIWR) per month for each crop can be calculated as follow (Burton, 2010):

$$NIWR = ET_{crop} - P_{eff} \quad (7)$$

where NIWR is the net irrigation water requirement for a specific month (mm), ET_{crop} is the monthly crop evapotranspiration calculated from modified Penman equation and crop coefficient (Putthakunjarean, 2003; and Rao et al., 2010) and P_{eff} is the effective rainfall of the same month which can be determined as follows (FAO, 1985):

$$P_{eff} = 0.6P_{tot} - 10 \text{ (for } P_{tot} \leq 70 \text{ mm/month)} \quad (8)$$

$$P_{eff} = 0.8P_{tot} - 24 \text{ (for } P_{tot} > 70 \text{ mm/month)} \quad (9)$$

where P_{eff} (effective rainfall) and P_{tot} (areal rainfall) are in mm.

The total net irrigation water requirement for all three crops, is thus:

$$\text{Total NIWR} = \text{NIWR}*A_{cas}+\text{NIWR}*A_{sug}+\text{NIWR}*A_{mai} \quad (10)$$

where A_{cas}, A_{sug}, and A_{mai} are cassava, sugarcane, and maize area respectively, all quantities are in m^2.

Monthly rainfall data in the driest year (2001) over the representative area were used to calculate related variables, then, the successive end-of-month pond storages were calculated from Eq. 4. The maximum storage deficit (negative storage) was taken as the optimum on-farm pond capacity (Patra, 2008) that shall ensure no shortage of water for crop needs in any month even in the driest year.

Results

1. Land use land cover map

The land use land cover (LULC) map was synthesized to have seven classes at spatial resolution of 25 meters as shown in Figure 4. Among these seven LULC types, cassava, sugarcane, and maize, have taken up the area percentage of 17.70%, 4.14%, and 5.93%, respectively. Large portions of the cassava field were clearly found in the southeastern districts. Another 49.58% of the total area was classified as being other agricultural lands, while, water body was found to cover just less than 1% of the total area. The LULC map was then validated for its accuracy by using reference field survey data collected from 1,012 locations spreading throughout the study area. The overall accuracy is 86.36% and Kappa coefficient is 0.83 which were considered fairly satisfactory for further use.

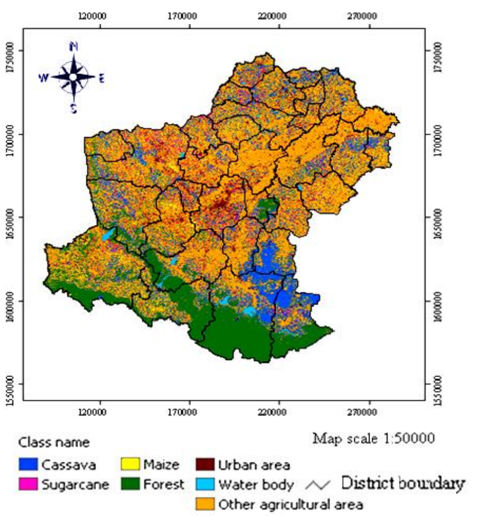


Figure 4 Classified land use land cover map of Nakhon Ratchasima Province.

2. Land suitability map

The land suitability map for cassava, sugarcane, and maize were presented in Figures 5, 6, and 7 respectively. Table 1 provides proportion for each suitability category for each crop at provincial level. It was found that, out of 17,758.19 km^2 of provincial area, sugarcane is the most grown crop with highest percentage of land in both high (S1) and moderate (S2) suitability classes (at 19.94% and 44.23%), and cassava is the second favorite crop with percentage in S1 and S2 classes of 15.44% and 30.87% respectively. Maize is the least grown crop with highly suitable land covers just 7.49% while 51.76% was classified as marginally suitable (S3).

Table 1 Proportion of each suitability category for cassava, sugarcane, and maize.

Suitability class	Cassava		Sugarcane		Maize	
	km^2	%	km^2	%	km^2	%
Highly suitable	2,742.23	15.44	3,540.95	19.94	1,329.98	7.49
Moderately suitable	5,482.24	30.87	7,853.72	44.23	3,271.56	18.42
Marginally suitable	6,406.09	36.07	5,518.04	31.07	9,191.64	51.76
Not suitable	3,127.63	17.62	845.48	4.76	3,965.01	22.33
Total area	17,758.19	100.00	17,758.19	100.00	17,758.19	100.00

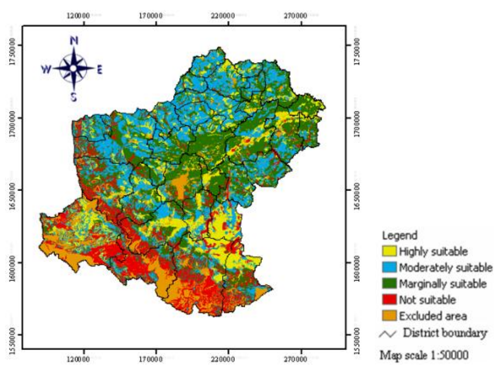


Figure 5 Land suitability map for cassava cultivation.

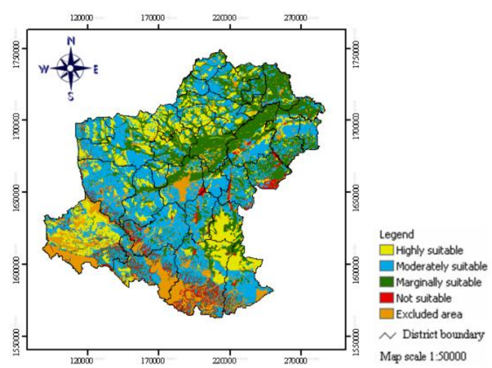


Figure 6 Land suitability map for sugarcane cultivation.

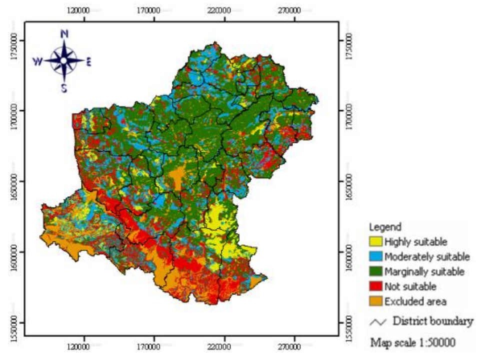


Figure 7 Land suitability map for maize cultivation.

3. Optimum on-farm pond capacity

A representative area was systematically selected. The results are presented in Figures 8 and 9. This area is located in the western part of Mueang Distict, with a total area of 176,756.0 m^2 with sufficient stream network and actual crops planted. The proposed square-shape pond was located at the downstream end of the watershed (representative area) to harvest rainwater and direct runoff originated upstream and supply irrigation water to all three crops grown in the representative area, i.e., cassava = 30,444.30 m^2, sugarcane = 57,706.61 m^2, and maize = 74,205.09 m^2. The initial size of the pond was set as 120*120 m^2. Eight rain-gauge stations in the vicinity of the representative area were selected (Figure 10). Double mass curves of cumulative rainfall data were carried out. The slopes of these curves are the same which means that rainfall data from these stations are consistent.

Areal rainfall in 2001 (the driest year over the representative area during 1977-2006) was calculated using Eq. 1 and, then, direct runoff, direct rainfall, and evaporation for the pond were calculated using Eq. 2, 5, and 6 respectively.

For full irrigation scenario the total net irrigation water requirement for all three crops were calculated from Eq. 10. The successive end-of-month pond storages were calculated using Eq. 4. A maximum storage deficit of 56,094.6 m^3 was obtained which was then taken as the optimum on-farm pond capacity that ensure no shortage of water for full irrigation of all 3 crops in any month even in the driest year.

For the 120m*120m cross-section this capacity requires a depth of 3.9 m. To limit the maximum depth at 3.0 m (Land Development Department, 2005) the cross-section must be increased to 137m*137m (10.62% of total representative area).

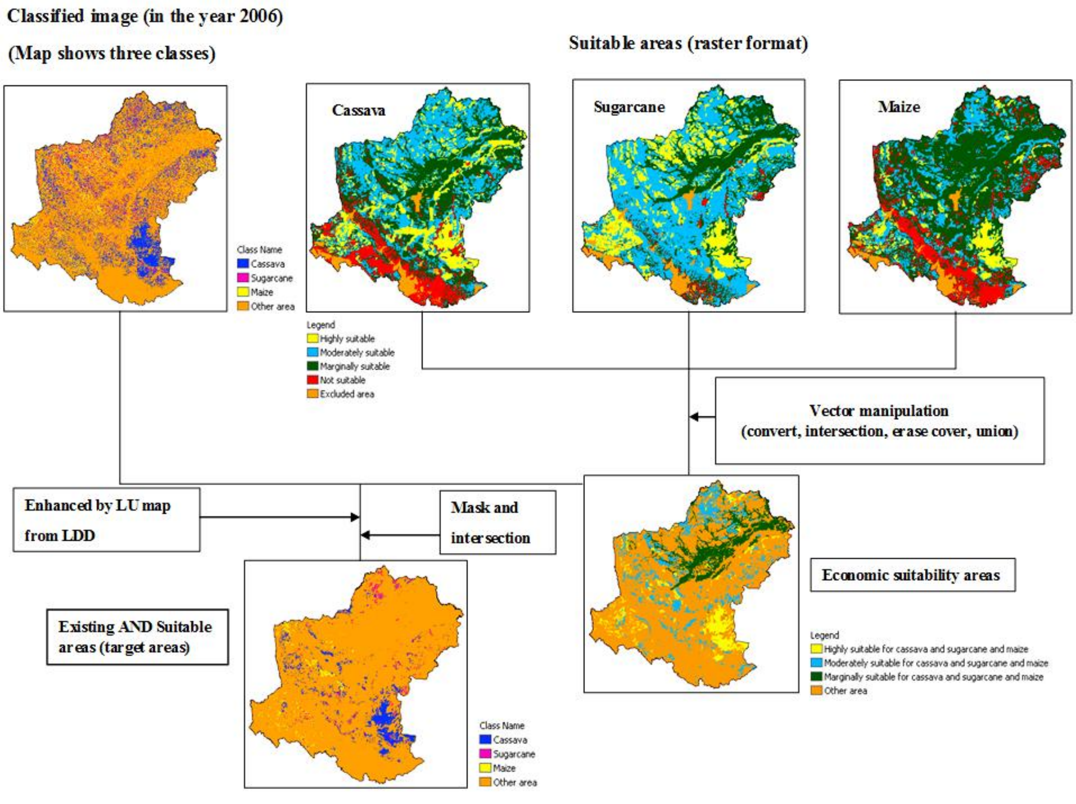


Figure 8 Representative area selection process.

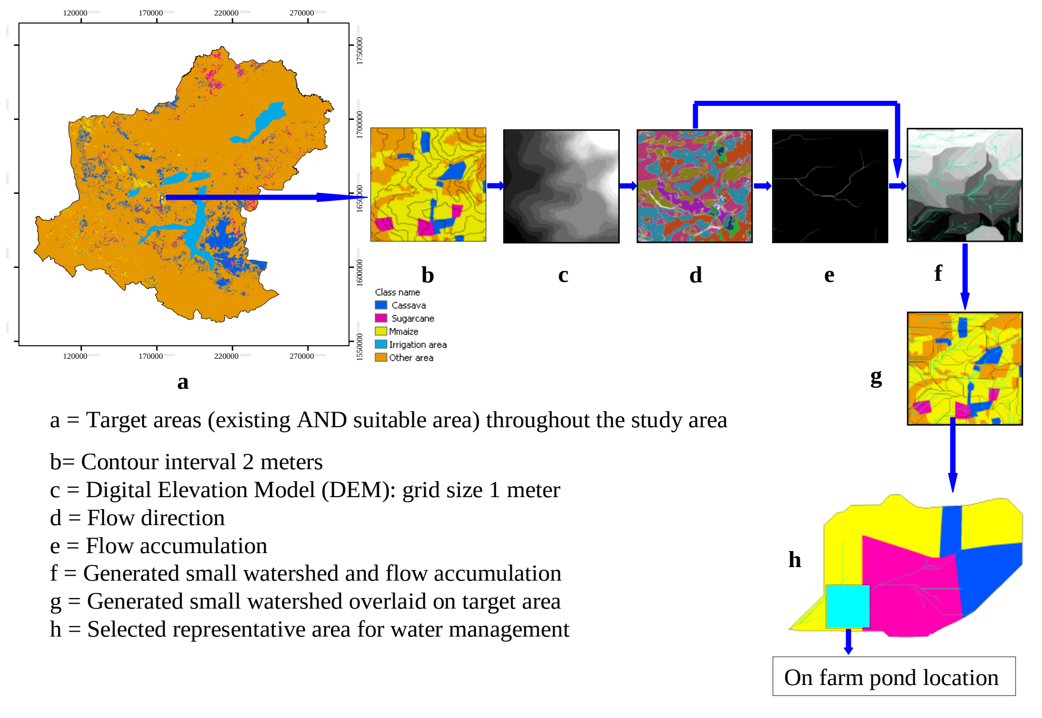


Figure 9 Selection process and detail of the representative area.

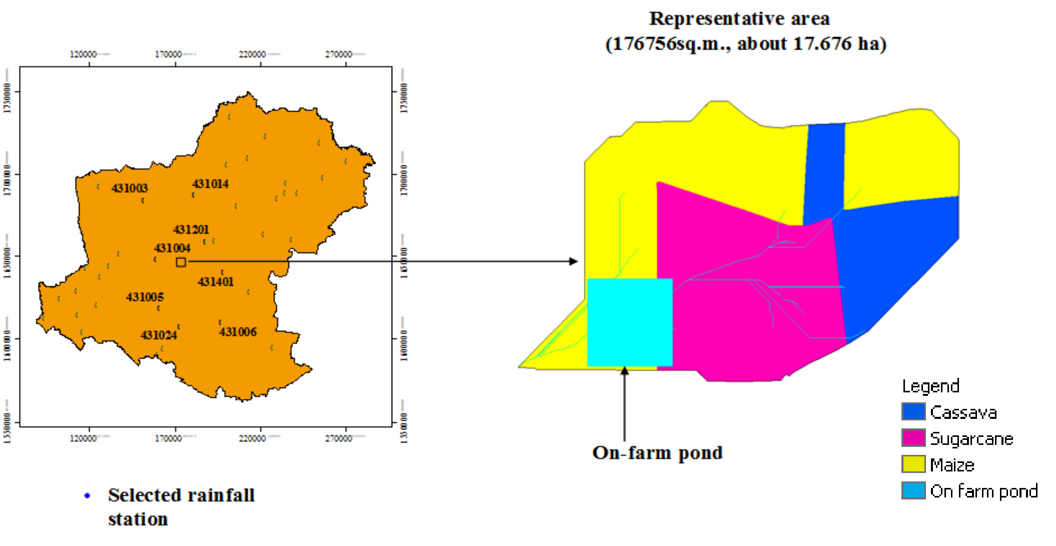


Figure 10 Location of on-farm pond and selected rain-gauge stations.

Conclusions and Discussion

Remote sensing and geographic information system incorporated with water balance model were applied to formulate the Landsat-based land use/land cover map, evaluate suitability area, and determine the optimum on-farm pond capacity for the production of cassava, sugarcane, and maize.

Hybrid classification method was used to classify Landsat-5 TM imagery. It was found that cassava, sugarcane, and maize, have taken up the area percentage of 17.70%, 4.14%, and 5.93%, respectively, while, water body was found to cover just less than 1% of the total area. For land evaluation, the results indicated that sugarcane had the highest percentage of high suitability classes (19.94%) followed by cassava (15.44%). Maize is the least grown crop with highly suitable land covers just 7.49%. Comparing the land use/land cover proportion with the highly suitable area, it was found that the most popular crop was cassava followed by maize and sugarcane, while for an amount of highly suitable area, sugarcane was the most area followed by cassava and then maize. This suggests that sugarcane was the least preferable crop for farmers although more land is suitable for the crop. As a result, in terms of the land quality, implication for policy maker is that sugarcane should be the publicly promoted for this province with the consideration of economic return and trading regulations allowed. In addition, suitability map for each crop can be distributed to agricultural extension agents to advise farmers and land owners in crop selection in conjunction with other economic considerations. This will help to reduce production costs and increase expected yields. However, in some areas of Nakhon Ratchasima Province, there are problems of soil salinity. Therefore, exclusion from the suitability map should be applied for the Level 1 and Level 2 of soil salinity areas before determining the cultivation areas.

The determination of optimum on-farm pond capacity, a representative area was identified based on digital elevation model (DEM), having a total area of 176,756.0 m^2. The on-farm pond was placed at the downstream end of the representative area where all (or most) of the direct runoff can be harvested. The optimum capacity of on-farm pond was found to be 56,094.6 m^3 (with surface area of 10.62% of representative area) which is sufficient to supply full irrigation for production of the three crops in this area without shortage of water. The surface area of the on-farm pond is still rather low compared to one suggested in the New Theory of Agriculture initiated by His Majesty the King of Thailand (about 30%). This is because the latter number was introduced to enable the pond to provide sufficient water to all activities, especially rice cultivation and household use, not only for economic crop planting like one assumed in this study. However, if the amount of total water demanded (for all activities) for each month is known, similar process can be carried out to identify the appropriate volume and size of pond as demonstrated in this work. For practicability, there should be cooperation among farmers in the form of cooperatives. The number of farmers of each co-op depends on land ownership in the watershed, about 7-8 members should be sufficient, where a small pond can be planned and constructed for cooperative crop production. Once the pond is in place other uses can be introduced such as vegetables production and aquaculture for household and co-op consumption. If the farmers may not be able to carry out the planning and construction of such a collective pond. The government agencies should take initiative to promote the activity.

For future study: The suitability map at sub-district level should be prepared for better coverage and the suitability levels (S1, S2, and S3) for each crop should be verified with the observed crop yield. The study of this nature should include the economic analysis of rate of return and costs of water investment.

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