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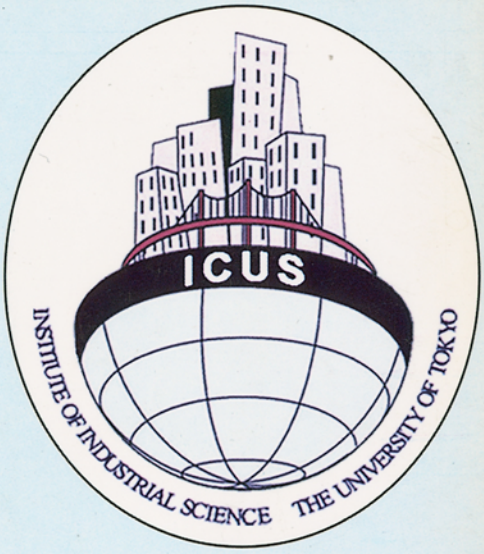

INTERNATIONAL CENTER FOR
URBAN SAFETY ENGINEERING

INSTITUTE OF INDUSTRIAL SCIENCE
THE UNIVERSITY OF TOKYO

REPORT ON MAPPING OF SOIL MOISTURE IN PADDY FIELDS FROM TEMPORAL JERS-1/SAR IMAGES FOR DROUGHT ASSESSMENT IN BURIRAM PROVINCE, THAILAND

Written by

Assistant Professor Junichi Susaki
ICUS, IIS, The University of Tokyo, Japan

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Report on Mapping of soil moisture in paddy fields from temporal JERS-1/SAR images for drought assessment in Buriram province, Thailand

Written by

Junichi Susaki

Visiting Assistant Professor
RS & GIS FoS, School of Engineering and Technology,
Asian Institute of Technology, Thailand

Assistant Professor
International Center for Urban Safety Engineering (ICUS),
Institute of Industrial Science, The University of Tokyo

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MAPPING OF SOIL MOISTURE IN PADDY FIELDS FROM TEMPORAL JERS-1/SAR IMAGES FOR DROUGHT ASSESSMENT IN BURIRAM PROVINCE, THAILAND

JUNICHI SUSAKI
Institute of Industrial Science, the University of Tokyo, Tokyo, Japan
susaki@iis.u-tokyo.ac.jp, susaki@ait.ac.th

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ABSTRACT

Soil moisture is one of the most effective indicators of drought. Active microwave remote sensing can detect backscatter from surface at any weather condition. Based on the backscatter coefficient and other parameters such as surface roughness, soil moisture can be estimated. The current research examined fundamental techniques required to estimate soil moisture from synthetic aperture radar (SAR) data, which is one of active microwave remote sensing data. Authors have measured volumetric soil moisture at 10-cm depth at several points of paddy fields, Buriram province, northeastern part of Thailand from October 2005. Japanese Earth Resources Satellite-1 (JERS-1) / SAR images observed from 1992 to 1998 were available around field measurement sites. Firstly, Integral Equation Method (IEM) model is focused on, which models scattering of microwave between different matters. Several parameters of IEM model were calibrated with the ground measured data and backscatter coefficients obtained from JERS-1/SAR images. In fact, dates of available JERS-1/SAR images are different from dates of field measurements. However, because of the limitation of available JERS-1/SAR data, it was assumed that ground measured data can be applied for the calibration. Then, volumetric soil moisture distribution was mapped from 1992 to 1998. It was found that IEM model is useful to estimate volumetric soil moisture as long as it is well calibrated.

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MAPPING OF SOIL MOISTURE IN PADDY FIELDS FROM TEMPORAL JERS-1/SAR IMAGES FOR DROUGHT ASSESSMENT IN BURIRAM PROVINCE, THAILAND

JUNICHI SUSAKI
Institute of Industrial Science, the University of Tokyo, Tokyo, Japan
susaki@iis.u-tokyo.ac.jp, susaki@ait.ac.th

1. INTRODUCTION

Thai Meteorological Department (TMD) records in 1992 to 1993 demonstrate that many provinces in Northeastern part of Thailand faced the severe drought. North and northeastern parts of Thailand also faced severe drought in 2005, and have suffered from drought periodically. Drought can be defined according to meteorological, hydrological, or agricultural criteria. Meteorological drought is usually based on long-term precipitation departures from normal. Hydrological drought refers to deficiencies in surface and subsurface water supplies. Agricultural drought occurs when there is insufficient soil moisture to meet the needs of a particular crop at a particular time. Agricultural drought is typically evident after meteorological drought but before a hydrological drought.

Especially, it is highly expected to achieve monitoring system of agricultural drought in terms of impact to food security issue. Agriculture drought can be main cause of this water risk is deficient water content in the ground due to a minor amount of precipitation and constant evapotranspiration. Therefore, soil moisture is one of the key variables to detect agricultural drought area. There are different techniques available to observe spatial and temporal patterns of surface soil moisture, and all of them apply remote sensing products as the primary source of information.

Remote sensing is capable of monitoring drought because it enables to simultaneously detect spectral data from the surface of wide area. Microwave sensor is better to detect volumetric soil moisture and water body rather than optical sensor because dielectric constant of water in microwave region can be easily discriminated from dielectric constants of other matter. While active and passive microwave remote sensing approaches are available, active microwave remote sensing has advantage from a viewpoint of spatial resolution. For example, Japanese Earth Resources Satellite-1 (JERS-1) / Synthetic Aperture Radar (SAR) measuring at 1.275 GHz frequency has 12.5-m spatial resolution while Advanced Microwave Scanning Radiometer for EOS (AMSR-E) onboard satellite Aqua, one of the most popular passive microwave sensors, has coarser spatial resolution such as 43x75 km at 6.9 GHz and 3.5x5.9 km at 89.0 GHz.

SAR sensor, one of the most typical active microwave sensors, can detect backscatter scattered on the surface. The backscattering observations are highly dependent on topography, soil texture, surface roughness and soil moisture, meaning that soil moisture inversion from single frequency and polarization SAR observations is difficult. To overcome this limitation, Theoretical backscattering models; the integral equation method (IEM) model (Fung et al., 1992) has been reported to be capable of estimating bare soil moisture from backscattering coefficients. IEM model can retrieve soil moisture and roughness parameters, and it can be applied to wide range of roughness scales (from smooth to rough surfaces).

While drought monitoring, especially agricultural drought monitoring, around Thailand, Laos and Cambodia is getting more and more important, it has not been achieved. In order to mitigate the impact of drought, an early warning system for drought should be developed. In the present research, methodology to map volumetric soil moisture using SAR data with IEM model for drought monitoring is examined.

2. STUDY AREA

Buriram province, located in eastern part of Thailand and affected by drought recently, is selected as study area, shown in Figure 1.The paddy fields area is 6,765 km^2, which cover about 66.8% of total land area 10,128 km2. Its position is between latitude 14.13-15.79oN, longitude 102.36 - 103.50 °E. The average temperature ranges from 22.7 °C in winter to 33.3 °C in summer. Average annual precipitation is 1394.8 mm from 2001-2004 and average annual precipitation day is 100 days.

Authors have installed probes of volumetric soil moisture and soil temperature at 10-cm depth in several rain-fed and irrigated paddy fields in Buriram province since November 2005. One of the sites, named as site 1 (15.636 °N, 102.899 °E), was focused on in the present research.

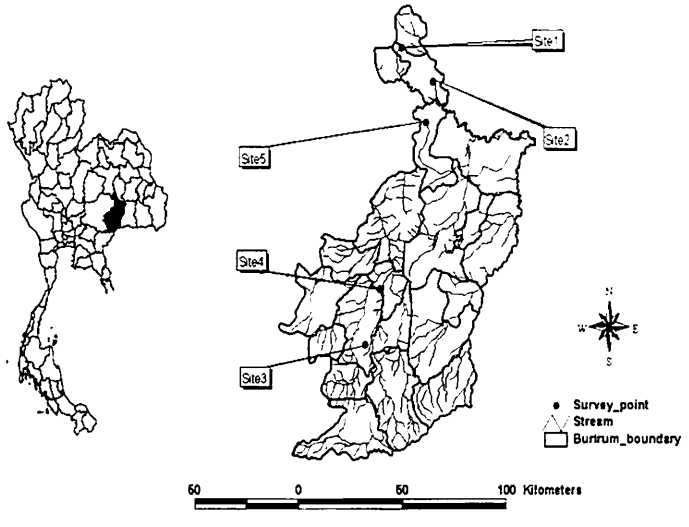


Figure 1: Location of the study area

3. METHODOLOGY

3.1 IEM Model

Radar backscattering response from soil surfaces is widely used to retrieve surface properties as surface roughness or volumetric soil moisture (Loew, et al., 2006). The sensitivity of the active microwave backscatter response to surface parameters has been extensively studies so far. The small perturbation model (SPM) and Kirchhoff approximation (KA) (Ulaby, et al., 1982) (Fung, 1994) are traditional theories of wave scattering from rough surfaces. The SPM is valid for slightly rough surfaces while the KA is applicable for a rough surface with a large surface curvature. They are restricted to a very limited range of surface roughness conditions. Integral equation method (IEM) surface scattering model (Fung, et al., 1994) is valid for a broader range of surface roughness conditions. While several improvements of IEM model have been made, one of which is proposed as advanced IEM (Chen, et al., 2003), IEM model is focused on in the present research because its results are reported to be stable and many knowledge and results to apply the IEM model are available. Hereafter, the brief explanation of the IEM model is described.

In the development of the IEM model, several assumptions were made in order to obtain an explicit mathematical formula that is easy to compute (Chen, et al., 2003). The assumptions undergoing mathematical derivation include the following.

1) Spatial dependence of the local incident angle of the Fresnel reflection coefficient is removed, by either replacing it with the incident angle or the specular angle.
2) For the cross polarization, the reflection coefficient used to compute the Kirchhoff fields is approximately by $(R_{\parallel} - R_{\perp})/2$ where $R_{\parallel}$ and $R_{\perp}$ are the Fresnel reflection coefficients for vertically and horizontally polarized electromagnetic waves, respectively.
3) Edge diffraction terms are excluded.
4) Complementary field coefficients are approximated by simplifying the surface Green's function and its gradient in the phase terms.

Fung, et al. proposed the final integrated scattering results for two cases, that is, $k\sigma < 3$ or not where $k = \omega\sqrt{\varepsilon_1 \mu_1}$, ω is the radian frequency, ε_1 is the permittivity of medium 1, μ_1 is the permeability of medium 1 and σ^2 is the variance of the surface. In the present research, it was found that $k\sigma < 3$. As HH backscattering coefficients are available, following IEM model was used the present research.

$$\sigma_{hh}^{0} = \sigma_{hh}^{1} + \sigma_{hh}^{M}$$

$$\sigma_{hh}^{1} = 8k^4\sigma^4 \left| R_{\perp} \cos^2\theta \right| W(-2k_x, 0)$$

$$\sigma_{hh}^{M} = \frac{8k^4\sigma^4\cos^2\theta}{\pi} \exp(-2k_z^2\sigma^2) \int \frac{u^2 v^2}{q^2} W(u - k_x, v) W(u + k_x, v) du dv$$

where σ^0_{hh} is the total HH-backscattering coefficient, σ^1_{hh} is the single-scattering HH-backscattering coefficient, σ^M_{hh} is the multi-scattering HH-backscattering coefficient, q is the incident angle of radar, $k_x = k\sin\theta$, $k_z = k\cos\theta$, W_n is the Fourier transform of the nth power of the surface correlation function, and $q = (k^2-u^2-v^2)^{1/2}$.

3.2 Measurement of Soil Moisture

Implementation of the IEM model requires tuning of parameters embedded in the model. While some of parameters can be easily obtained from field measurements, e.g. soil component ratio or surface roughness, others are difficult to obtain, e.g. autocorrelation length of surface roughness, which is one of the most important parameters for the IEM model. Such parameters should be optimized through calibration. In order to calibrate such parameters, actual soil moisture should be measured.

Volumetric soil moisture probes were installed in Sites 1 to 5 whose locations are shown in Figure 1. Rain-fed paddy fields (Sites 1, 2 and 5) and irrigated paddy fields (Sites 3 and 4) were selected after the field survey around Buriram province. Soil moisture probes 1, 2, 3, 4 and 5 were installed in Sites 1, 2, 3, 4 and 5, respectively. Figures 2 to 5 show those paddy fields of Sites 1 to 4. After obtaining the permission of farmers, I installed volumetric soil moisture and temperature probes into the soil of paddy fields, and shelves on the pathways of paddy fields. Loggers connected to those probes were set on the shelves, and the shelved were covered by plastic mesh trash box.

Actually, soil temperature was measured in addition to volumetric soil moistures. However, the recorded temperatures are not available because from time to time the values were extremely high or low. As a result of discussion with staff of the manufacturers, it may be caused due to strong sunshine or too much humid condition. As the logger was sealed in the plastic bag, the condition around the logger may not be good. Another important result is that it was found the values measured by probe 5 at Site 5 were not stable. Therefore, soil moisture data measured by the probes 1 to 4.are only reported.

Values measured by the soil moisture probes can be converted into voltage (mV). Calibration requires identifying the relationship between measured voltage and actual volumetric soil moisture. In Site 1, soil samples were taken, and actual volumetric soil moistures were estimated by drying up the samples in oven for 24 hours at 105 °C. The scattergram between measured voltage and actual volumetric soil moisture is shown in Figure 6. It shows that high coefficient of determination even though sample number is limited to 4.

For the cross calibration, the probes 1 to 5 were installed in a site in Asian Institute of Technology (AIT), Thailand. At 10-cm depth, the probes were installed. The cross calibration are shown in Figure 7. Unfortunately,

soil samples taken from Sites 2 to 4 were too limited to estimate regression equation like the one shown in Figure 6. Therefore, calibration of probes 2 to 4 was conducted with consideration of the calibration result of probe 1 and the cross calibration results, such as the cross calibration results between probe 1 and probe 2 (shown in Figure 8), probe 1 and probe 3 (Figure 9), and probe 1 and probe 4 (Figure 10). Finally, regression models to estimate volumetric soil moisture for probes 1 to 4 were obtained. The models are shown in Table 1.

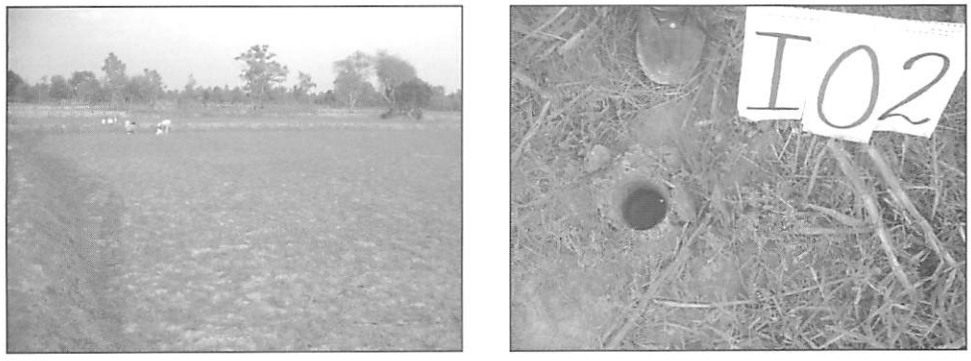
Based on the regression models, volumetric soil moistures in Sites 1 to 4 were estimated, shown in Figures 11 to 14. Especially, as sites 1 and 2 have longer periods of data, the results are shown in Figures 15 and 16, respectively. Figure 17 represents that temporal change of volumetric soil moisture in Sites 1 to 4 from DOY 60 to 260 of year 2006. The period from DOY 60 to DOY 120 shows that soil moisture depends on the site and each condition.

2005/10/31

2005/11/30

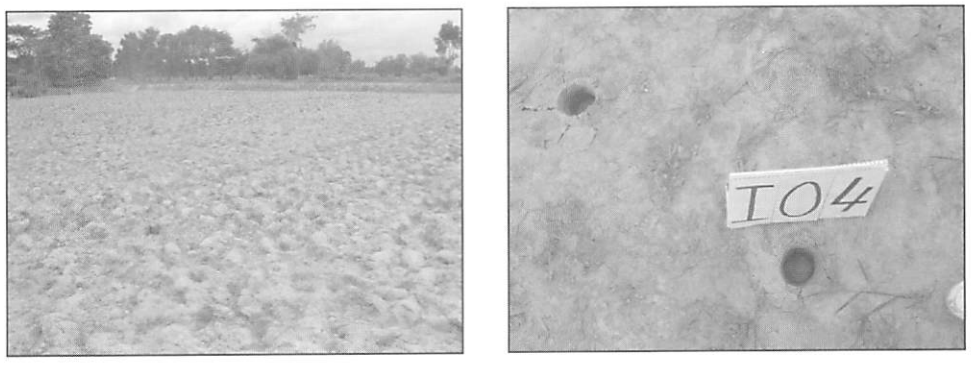
2006/01/22

Figure 2: Rain-fed paddy fields in Site 1



2006/05/02

2006/05/30



2006/06/20

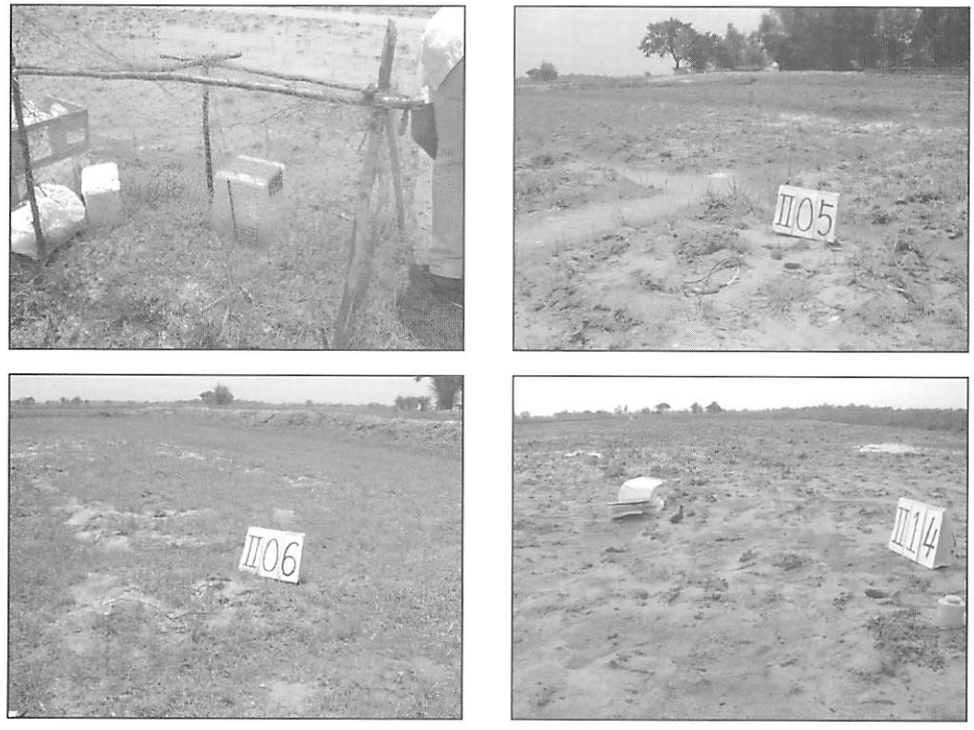
2006/07/25

Figure 2: Rain-fed paddy fields in Site 1 (Cont.)

2006/10/04

2006/11/20

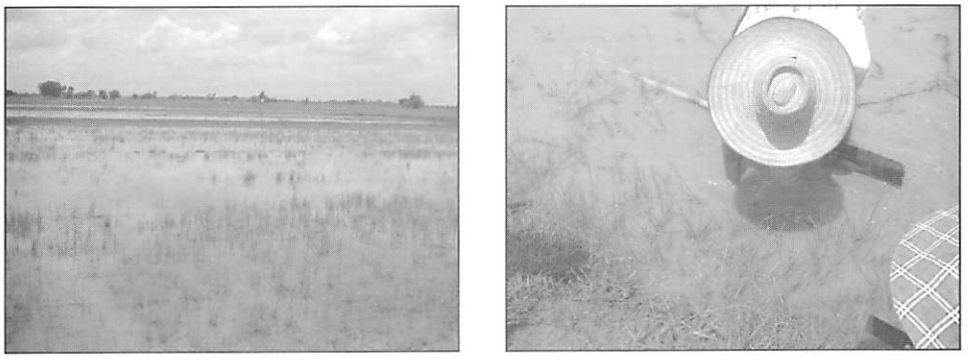
Figure 2: Rain-fed paddy fields in Site 1 (Cont.)



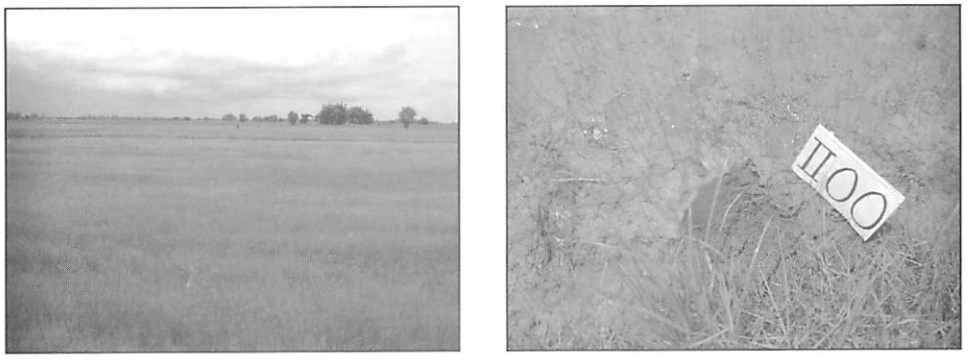
2006/05/02 (Intensive sampling at 26 points in Site 2 was conducted, and following parameters were measured; volumetric soil moisture, thermal conductivity, surface temperature, soil temperature, air temperature, humidity, wind speed.)

Figure 3: Rain-fed paddy fields in Site 2

2006/05/02



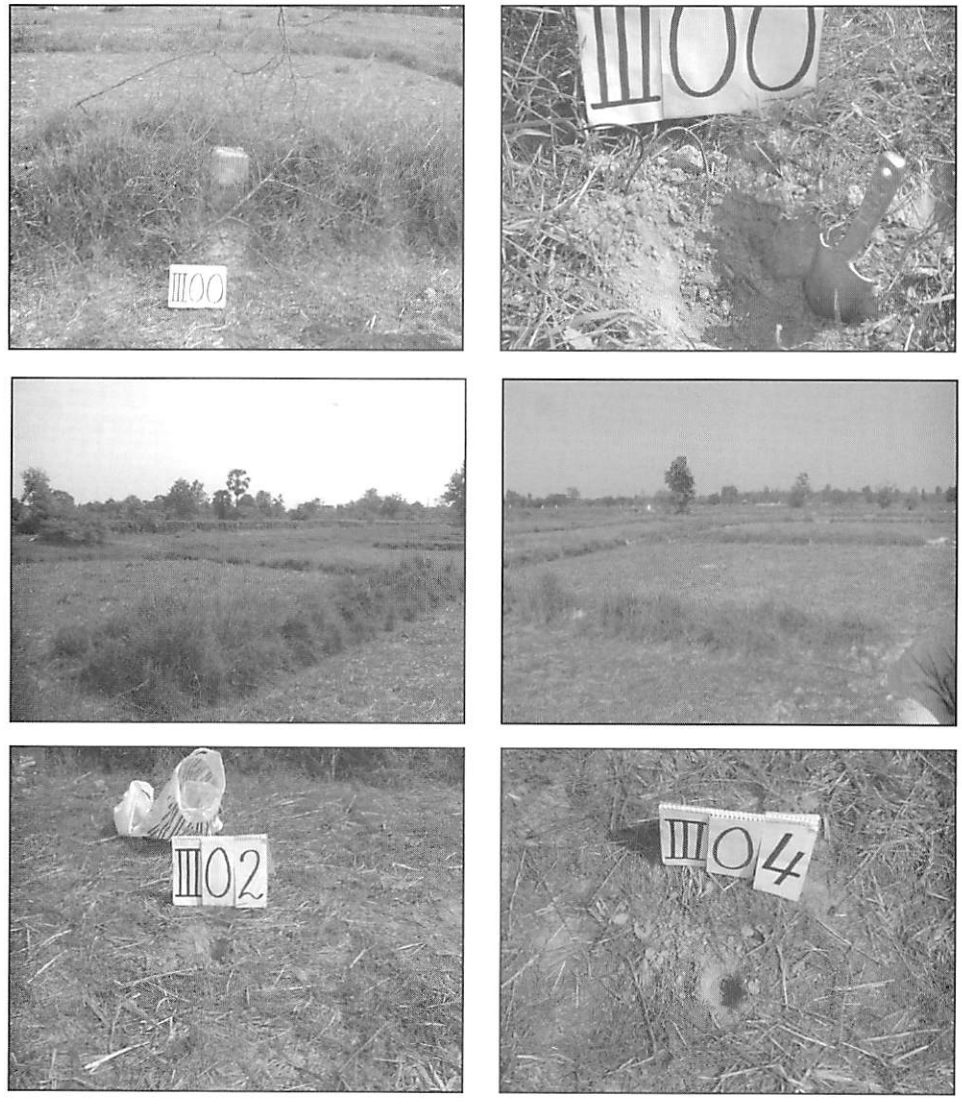
2006/05/30



2006/06/20

2006/10/04 (Farmer kindly set up the above tower, and kept logger on the top of the tower after he found the logger in the high water. However, as the logger was damaged by the water intrusion, the recorded data were not saved.)

Figure 3: Rain-fed paddy fields in Site 2 (Cont.)



2006/05/03

Figure 4: Irrigated paddy fields in Site 3

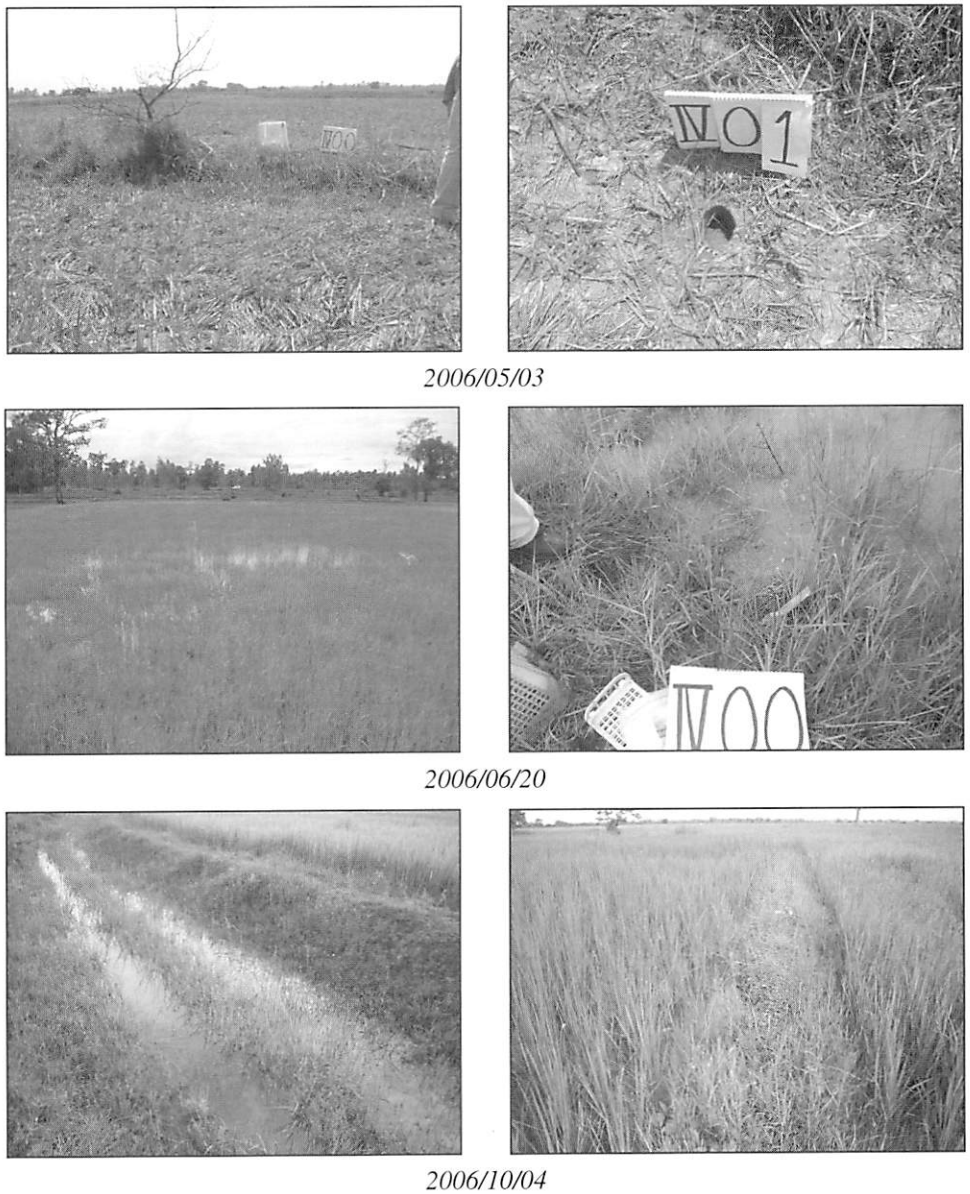
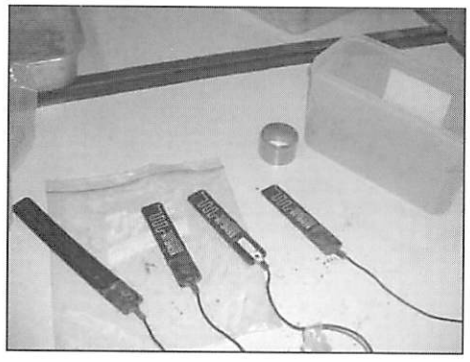


Figure 5: Irrigated paddy fields in Site 4 (As paddy fields around Site 4 were highly inundated, the basket and logger could not be found. Later, it was found that the logger was damaged by the water intrusion, and then the recorded data were lost.)



Soil probes to be calibrated

Site in AIT for calibration (a logger connected to probes was in the basket)

Probes installed at 10 cm depth

Probes installed at 10 cm depth

Hole to take sample to estimate actual volumetric soil moisture

Figure 6: Cross calibration of probes for the measurement of volumetric soil moisture

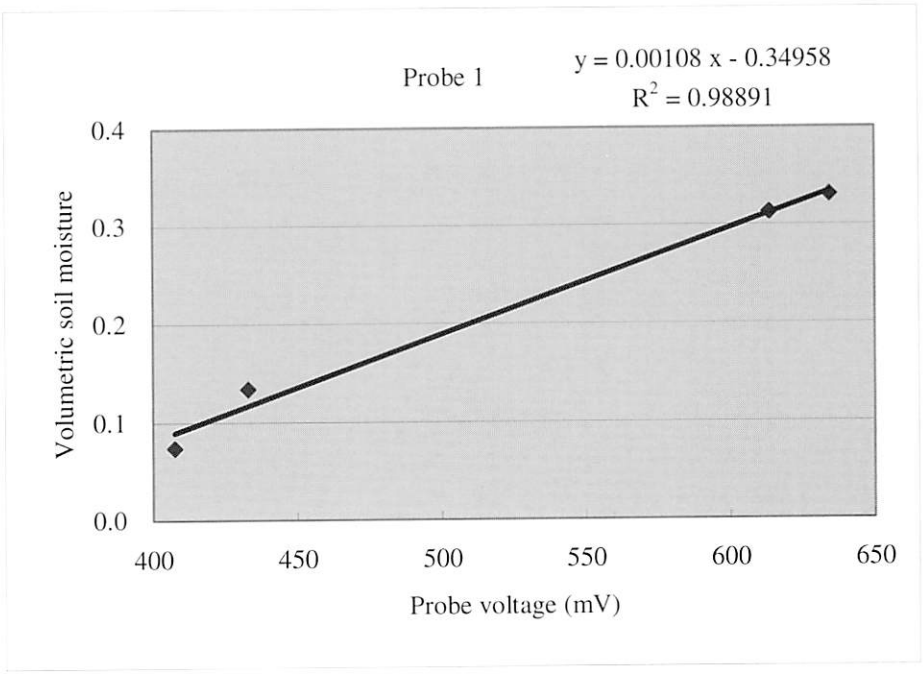


Figure 7: Correlation between probe 1's voltage (mV) and volumetric soil moisture. The soil moisture was estimated from samples taken out of the site

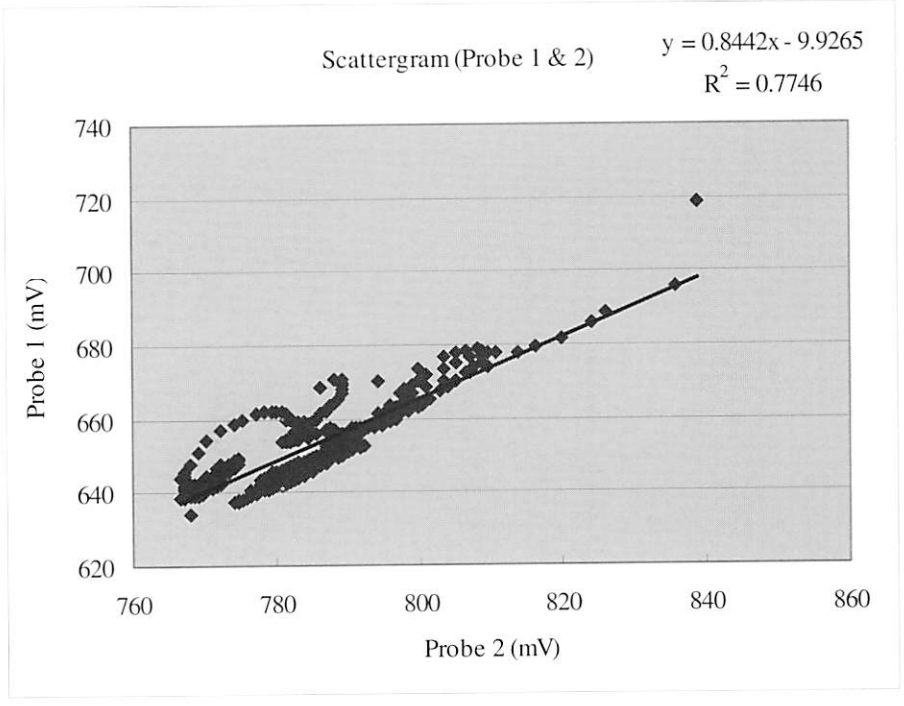


Figure 8: Correlation between probe 1's voltage (mV) and probe 2's voltage (mV)

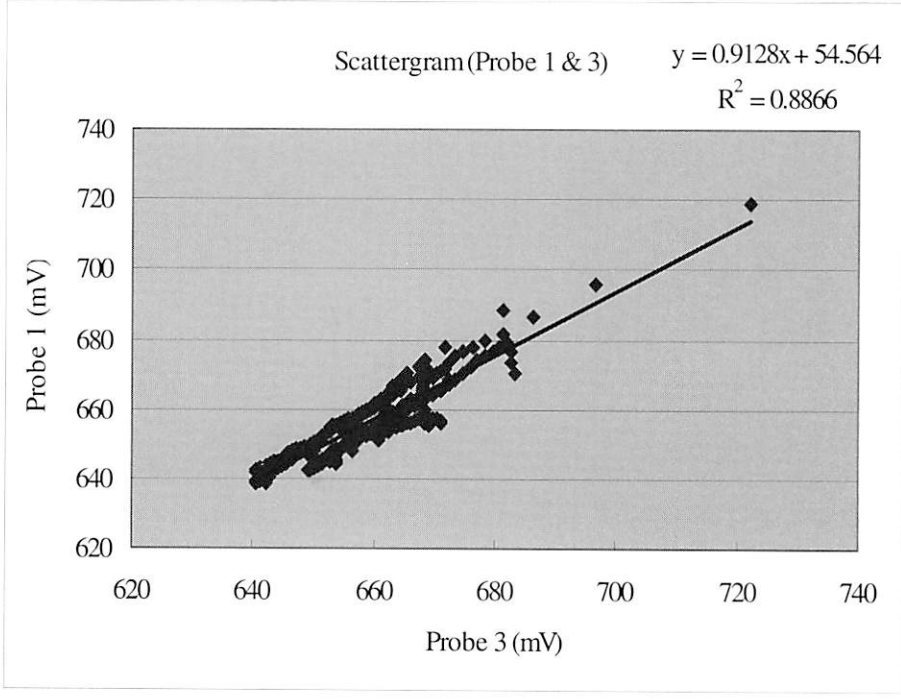


Figure 9: Correlation between probe 1's voltage (mV) and probe 3's voltage (mV)

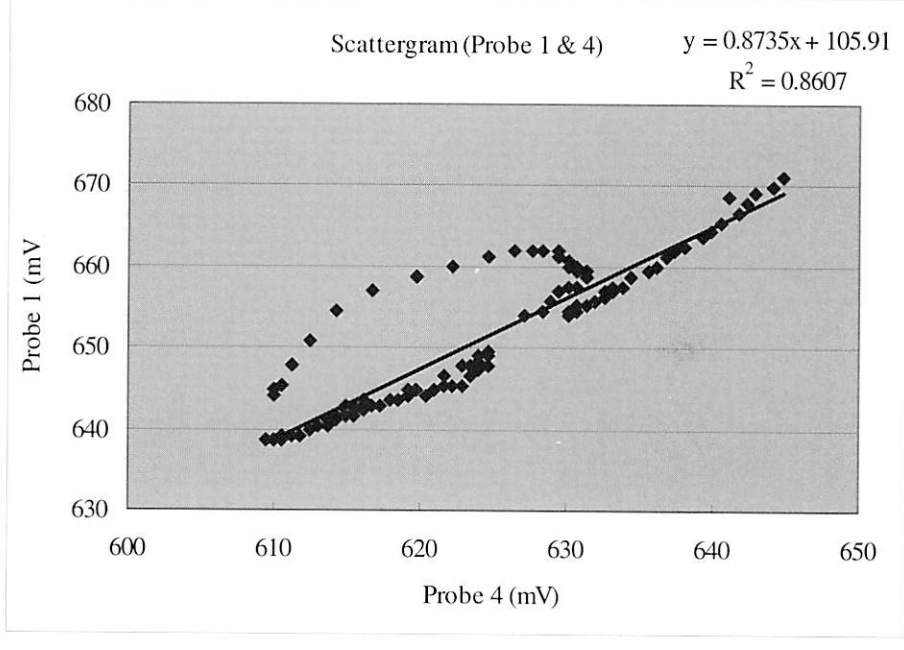


Figure 10: Correlation between probe 1's voltage (mV) and probe 4's voltage (mV)

Table 1: Model to estimate volumetric soil moisture (y) from probe voltage (x: mV)

Probe (Site)	Regression model
1	$y = 0.00108\ x - 0.34958$
2	$y = 0.000912\ x - 0.36030$
3	$y = 0.000986\ x - 0.29065$
4	$y = 0.000943\ x - 0.23520$

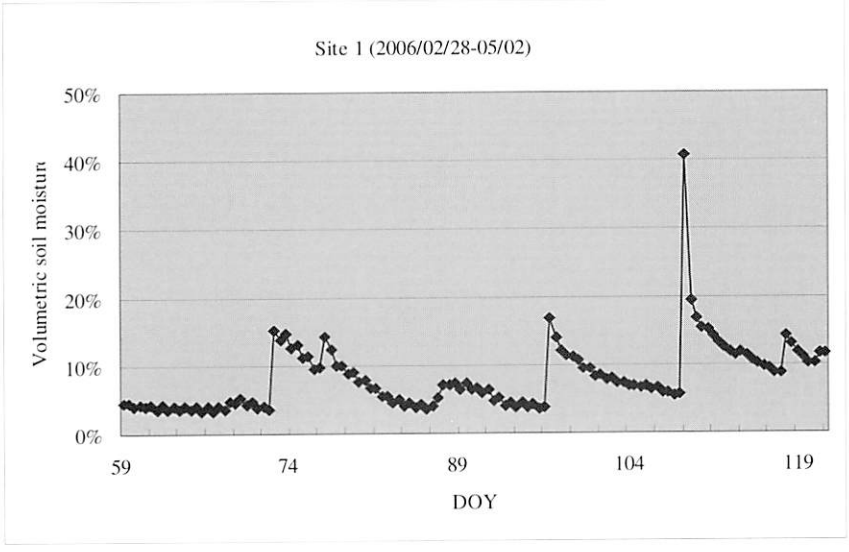


Figure 11: Temporal change of volumetric soil moisture in Site 1

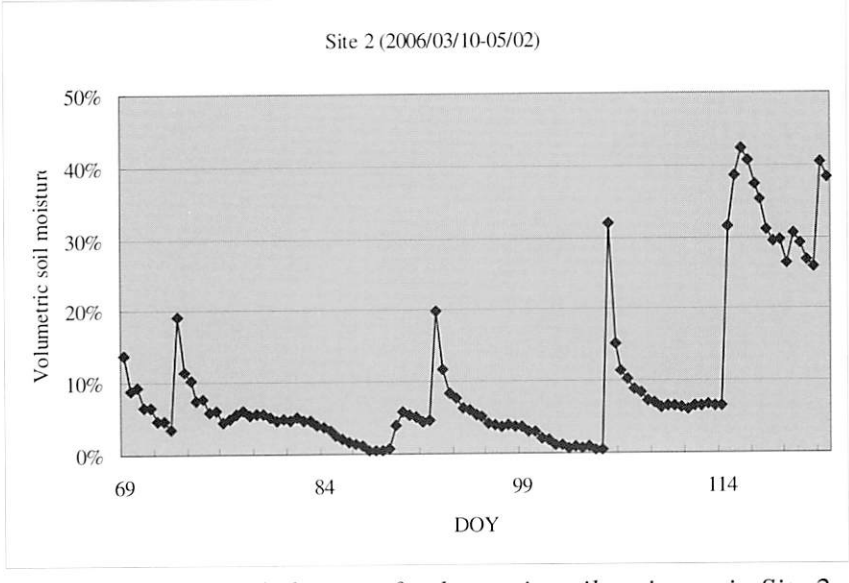


Figure 12: Temporal change of volumetric soil moisture in Site 2

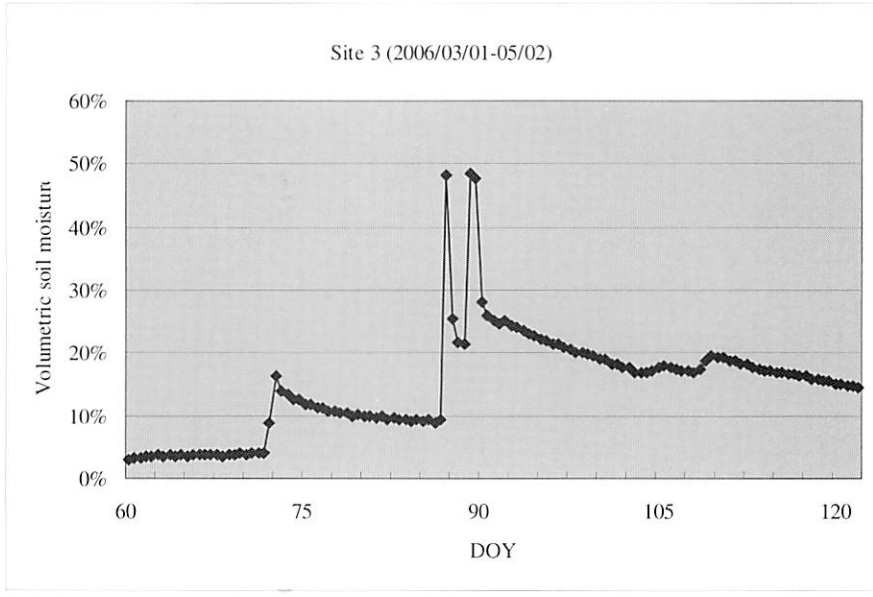


Figure 13: Temporal change of volumetric soil moisture in Site 3

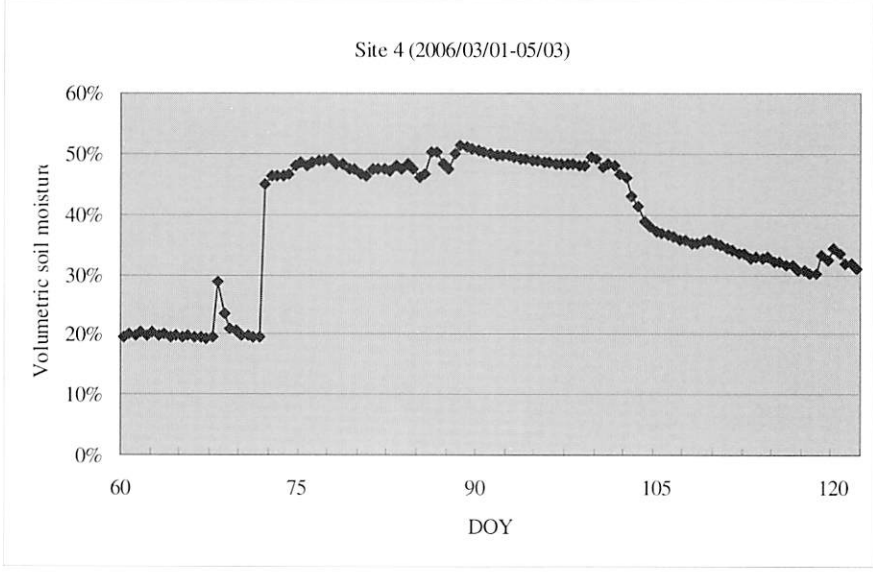


Figure 14: Temporal change of volumetric soil moisture in Site 4

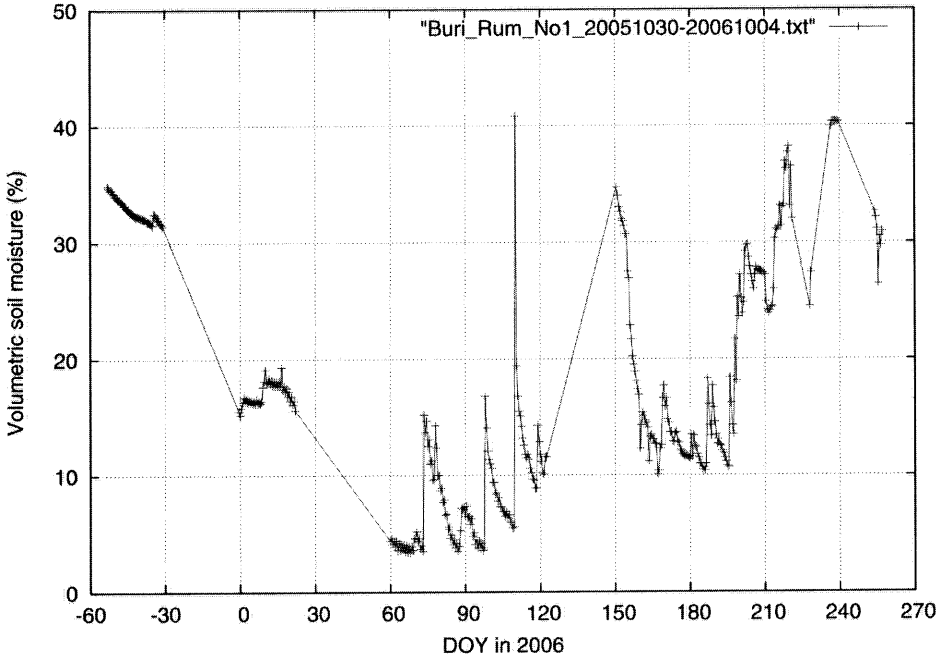


Figure 15: Temporal change of volumetric soil moisture in Site 1 from October 30, 2005to October 4, 2006 (Some periods miss data because of probe problem)

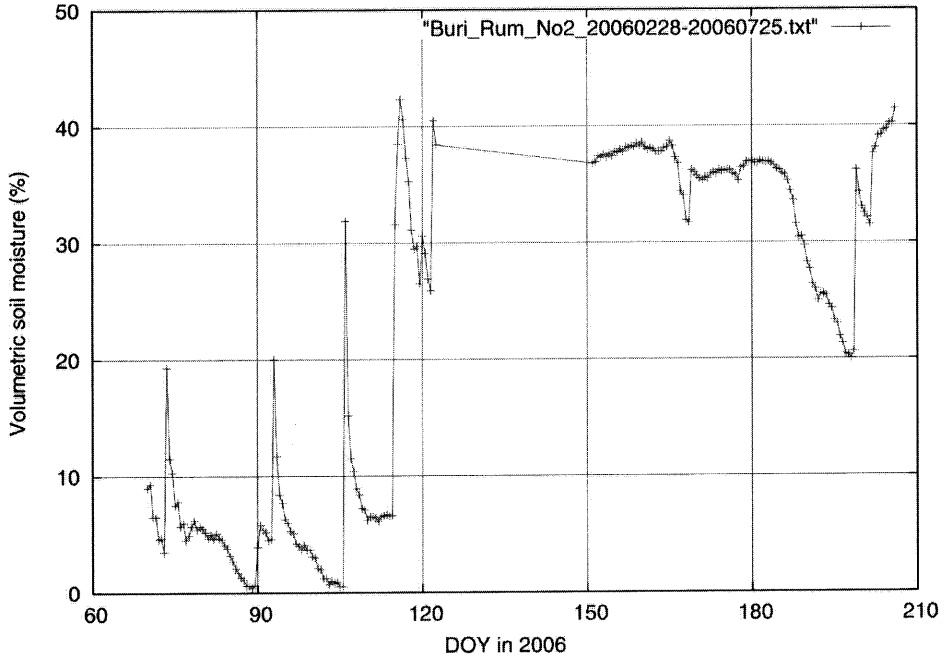


Figure 16: Temporal change of volumetric soil moisture in Site 2 from March 10 to July 25 (Some periods miss data because of probe problem)

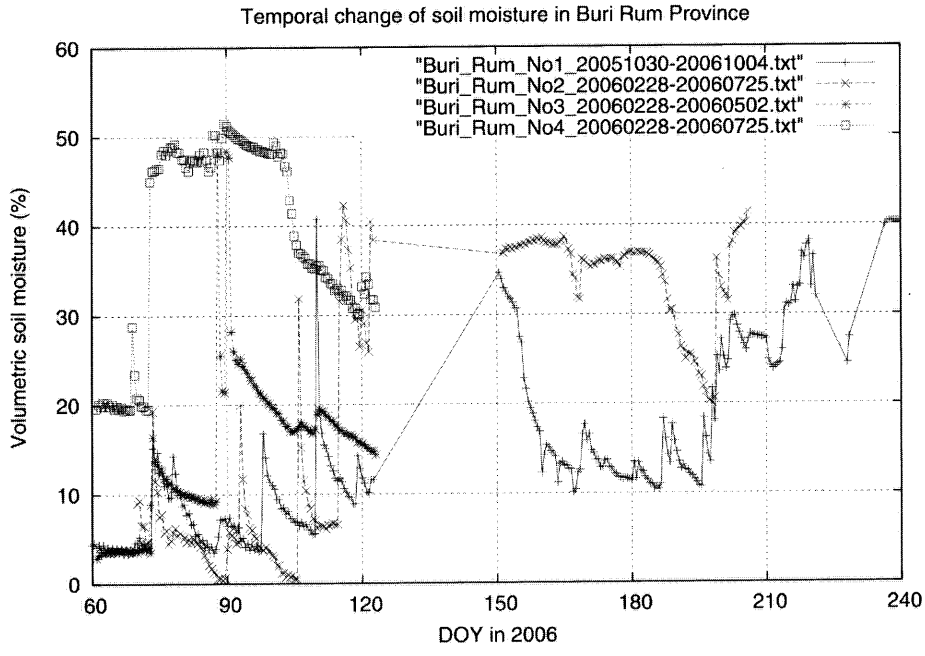


Figure 17: Comparison of volumetric soil moisture in Sites 1 to 4 from February 28 to October 4

3.3 Estimation of Dielectric Constant

As dielectric constant is sensitive to soil moisture, modeling of dielectric constant is one of the most important issues to accurately estimate soil moisture. In the present research, a semiempirical model (Peplinski *et al.*, 1995) was used, which can be applied for simulation in 0.3 – 1.3 GHz range of wavelength. The semiempirical dielectric mixing model used is as follows.

$$\varepsilon_m = \varepsilon'_m - j\varepsilon''_m$$

$$\varepsilon'_m = \left[1 + \frac{\rho_b}{\rho_s}(\varepsilon_s^{\alpha}) + m_v^{\beta'}\varepsilon_{f_w}'^{\alpha} - m_v\right]^{1/\alpha}, \qquad \varepsilon''_m = \left[m_v^{\beta''}\varepsilon_{f_w}''^{\alpha}\right]^{1/\alpha}$$

where ε_m is the relative complex dielectric constant of the soil-water mixture, m_v is the water volume fraction (or volumetric moisture content) of the mixture, ρ_b is the bulk density of the dry soil sample in grams per cubic centimeter, ρ_s = 2.66 g/cm^3 is the specific density of the solid soil particles, ε_s is the complex dielectric constant of soil, $\alpha = 0.65$ is an empirically determined constant, and β' and β'' are empirically determined soil-type dependent constants given by

$$\beta' = 1.2748 - 0.519S - 0.152C$$
$$\beta'' = 1.33797 - 0.603S - 0.166C$$

where S and C represent the mass fractions of sand (0.075 – 2.0 mm) and clay (< 0.002 mm), respectively (i.e. $0 \le S, C \le 1$). The quantities ε'_{f_w}

and ε''_{f_w} are the real and imaginary parts of the relative dielectric constant of free water, given by a Debye-type dispersion equation, with the latter modified to include a term that accounts for the effective conductivity of the soil mixture

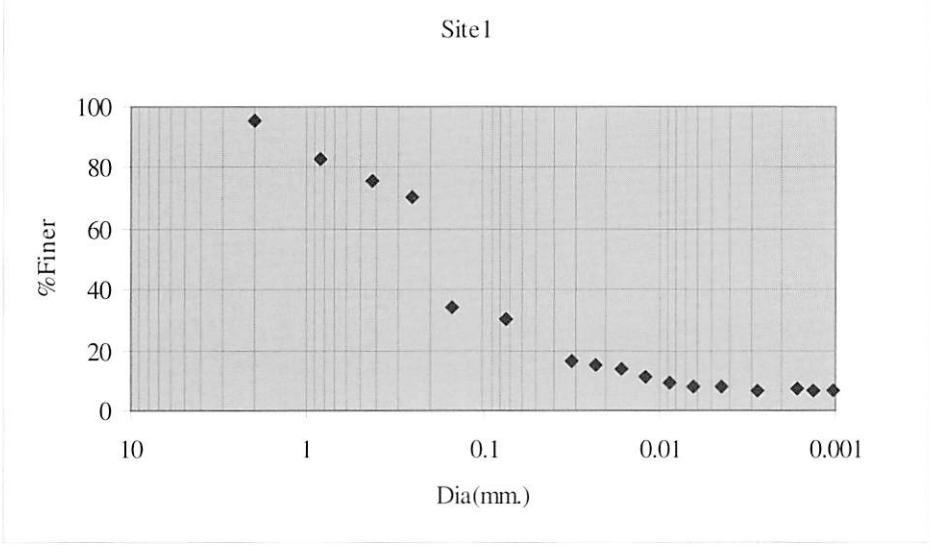
$$\varepsilon'_{f_w} = \varepsilon_{w\infty} + \frac{\varepsilon_{w0} - \varepsilon_{w\infty}}{1 + (2\pi f \tau_w)^2}$$

$$\varepsilon''_{f_w} = \frac{2\pi f \tau_w (\varepsilon_{w0} - \varepsilon_{w\infty})}{1 + (2\pi f \tau_w)^2} + \frac{\sigma_{eff}}{2\pi\varepsilon_0 f} \frac{(\rho_s - \rho_b)}{\rho_s m_v}$$

where $\varepsilon_0 = 8.85\text{x}10^{-12}$ s^2C^2/m^3kg is the permittivity of free space, τ_w is the relaxation time for water, f is the frequency in hertz, ε_{w0} is the static dielectric constant for water, and $\varepsilon_{w\infty} = 4.9$ is the high-frequency limit of ε'_{f_w}. Expressions for are given as a function of temperature. At room temperature (20°C), $2\pi f \tau_w = 0.58\text{x}10^{-10}$ s and $\varepsilon_{w\infty} = 80.1$. A new empirically derived expression was used for the effective conductivity, σ_{eff}, in terms of the textural properties of the soil

$$\sigma_{eff} = 0.0467 + 0.2204\rho_b - 0.41111S + 0.6614C$$

As a result of field measurement conducted on June 20, 2006, it was found that ρ_b = 1.64 when average volumetric soil moisture was 26%. Results of analysis on soil grain size are shown in Figure 18. As a result of these analyses, it was found that $S = 0.651$ and $C = 0.111$ in Site 1.



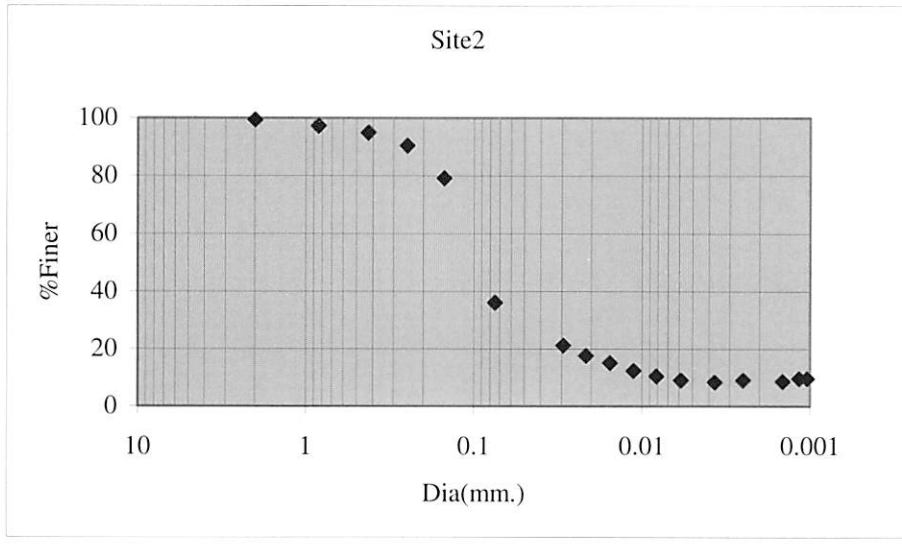


Figure 18: Grain size of soils in site 1 (upper) and site 2 (lower)

3.4 Measurement of Surface Roughness

Surface roughness strongly affects surface scattering, and is a sensitive parameter for the IEM model as well as soil moisture. Surface roughness of rain-fed paddy field was measured, which is located in 15.366°N, 103.012°E. The paddy field is different from site 1 (15.636°N, 102.899°E) because accessibility to Site 1 was limited.

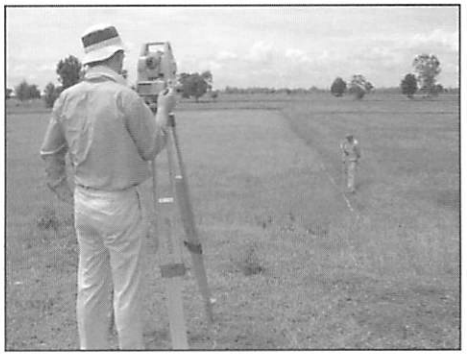
Geolocational data of points along a profile on surface of paddy field were measured using total station GPT-7005 produced by TOPCON, Japan (TOPCON Pulse Total Station GPT-7000 series, 2006). Authors measured data in prism mode, i.e. with prism perpendicular to the target point. The GPT-7005 can measure up to 3,000-m distance in prism mode. The distance accuracy is 3 mm + 2 ppm x (distance).

Surface roughness was measured as root mean square of height difference in different conditions of paddy fields on different dates. On two dates (May 30, 2006 and July 25, 2006), the measurements were conducted. Regarding measurements Sections 1 and 4, measurements were conducted on the same paddy field before and after planting, respectively. The details on measurements are shown in Table 2. The measurements are shown in Figure 19, and profiles of measured relative height difference are represented in Figure 20. Relative height difference means the difference between actual height and mean height of the paddy fields.

Table 2: Measured surface roughness of paddy fields in Buriram province (σ denotes root mean square of height difference)

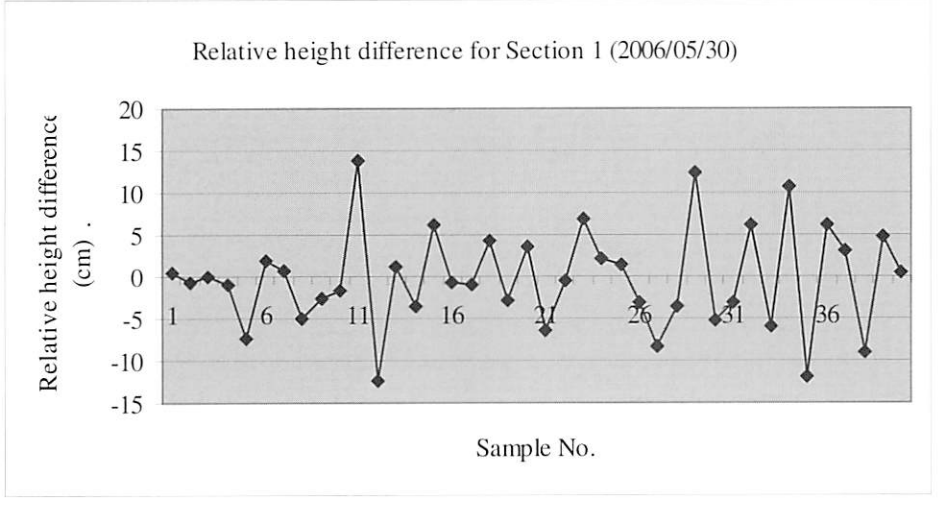
Section	Date (yyyy/mm/dd)	Condition	Interval (Profile)	Samples	σ (cm)
1	2006/05/30	Before planted	50 cm (20 m)	41	5.07
2					5.53
3		After planted			3.17
4	2006/07/25	After planted	5 cm (10 m)	201	3.65

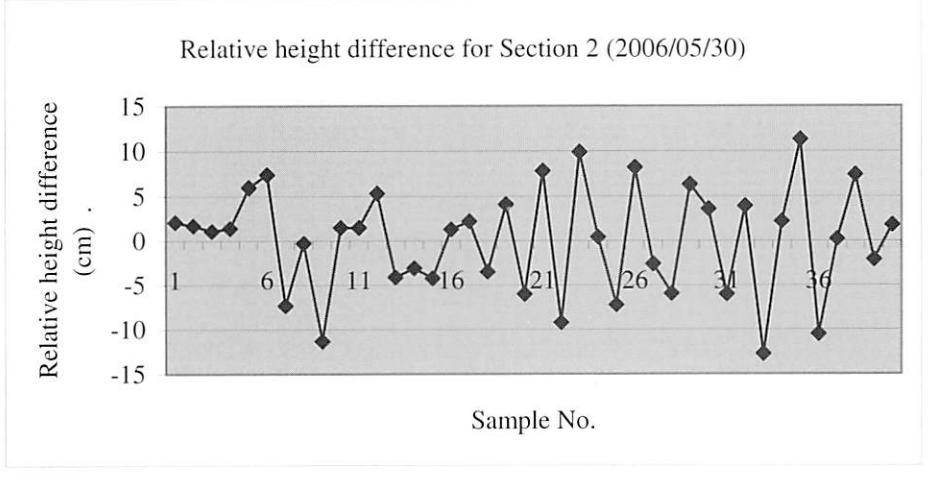
Measurement of Section 1 in Table 2

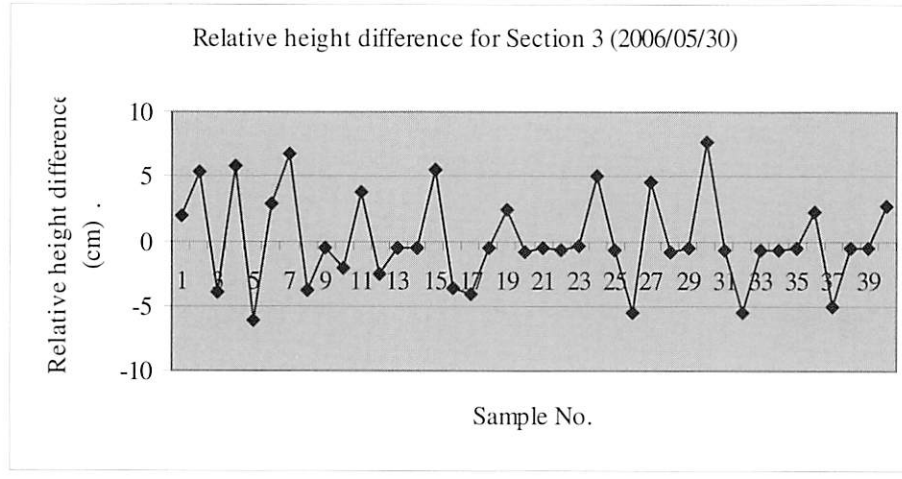


Measurement of Section 4 in Table 2

Figure 19: Measurement of geolocation of points on surface of paddy fields for the estimation of surface roughness using total station







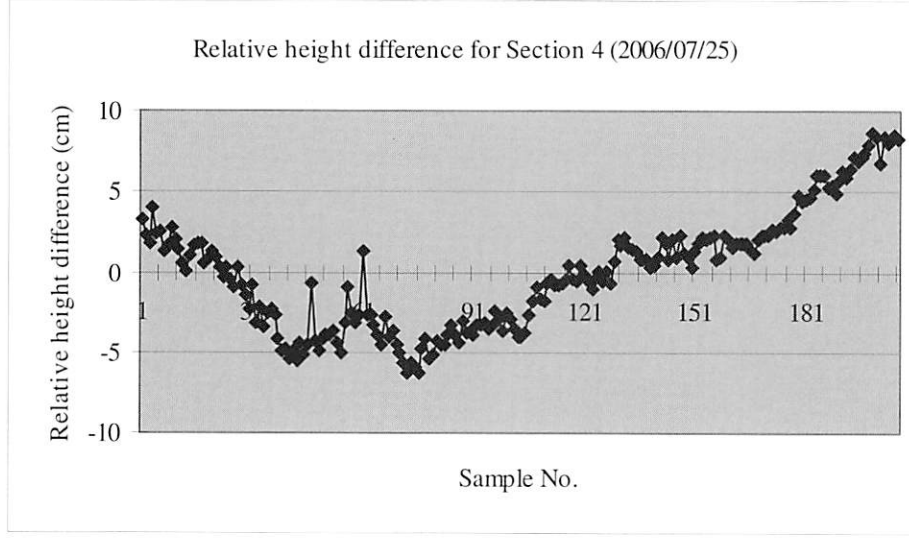


Figure 20: Relative height difference of paddy fields measured by total station

3.5 Estimation of Soil Moisture and Mapping of Soil Moisture Distribution

In order to derive temporal change of soil moisture distribution, temporal JERS-1/SAR images around Buriram province were obtained. Table 3 shows that 17 scenes of JERS-1/SAR Level 2.1 images were available in the present research. These data were geometrically corrected to enable spatial analysis.

In general, SAR images are contaminated by speckle noises that are pixels with high backscatters because of high coherence. Removal of such speckle noises is one of the steps necessary for the spatial analysis. In the present research, author applied median filter and examined different sizes of window of the median filter. Figure 21 shows that original SAR image and images smoothed through median filter. There is no specific approach to determine an optimal window size. Figure 21 shows results of 7x7 and

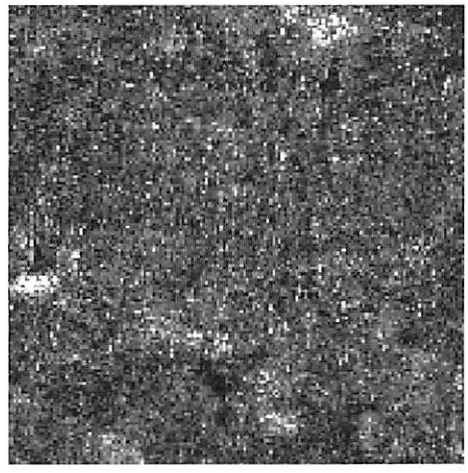
13x13 window size filter. Empirically, 13x13 window was selected to apply to remove speckle noises.

Next, temporal change of backscatter coefficients in paddy field of Site 1 from 1992 to 1998 was obtained from the smoothed images. The extracted backscatter coefficients are shown in Figure 22. Before estimating volumetric soil moisture from backscatter coefficient by the IEM model, calibration of parameters used in the IEM model were conducted. As a result to examine sensitivities of parameters, autocorrelation length of surface roughness was calibrated as 0.5 m with reference to volumetric soil moisture in dry season measured in Site 1. Even though this autocorrelation length of surface roughness might not be optimized because of lack of actual volumetric soil moisture during 1992 to 1998, this tentatively optimized parameter was used in the current research.

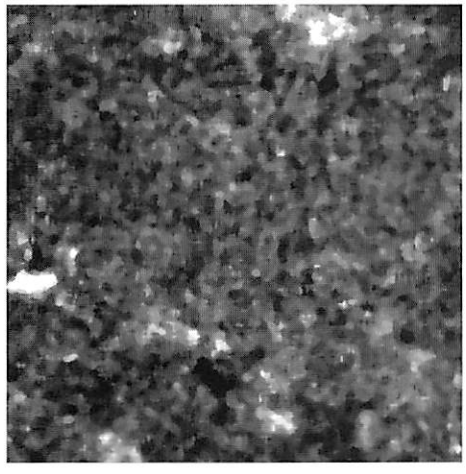
Table 3: Available JERS-1 SAR images around Site 1

No.	Observation date (yyyy/mm/dd)
1	1992/10/31
2	1993/03/12
3	1994/01/14
4	1994/04/12
5	1994/08/22
6	1994/11/18
7	1995/03/30
8	1995/08/09
9	1996/07/26
10	1996/12/05
11	1997/01/18
12	1997/04/16
13	1997/05/30
14	1997/11/22
15	1998/01/05
16	1998/04/03
17	1998/05/17

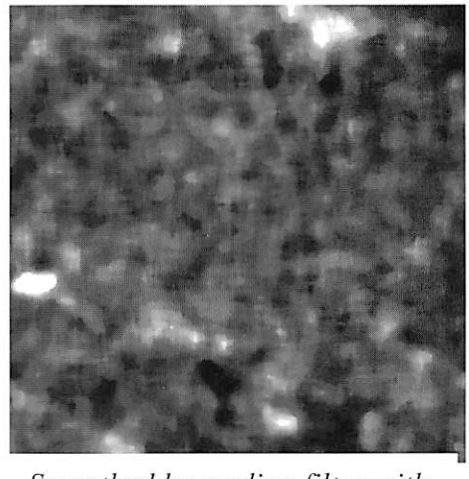
Finally, volumetric soil moisture was estimated from backscatter coefficient by the IEM model. Urban areas show higher backscatter coefficients, the urban areas should be separated from other areas. As it was found that the urban areas could be classified using the image observed on Jan 14, 1994, the mask image for urban areas were produced from the image on Jan 14, 1994 and applied for all SAR images. Figures 23 and 24 show annual change (in 1994) and temporal change (from 1993 to 1998) of soil moisture of Buriram province, respectively.



Original SAR image



Smoothed by median filter with 7x7 window



Smoothed by median filter with 13x13 window

Figure 21: Original and smoothed SAR images. Different windows size of median filter were examined, and two results of 7x7 and 13x13 windows are only shown

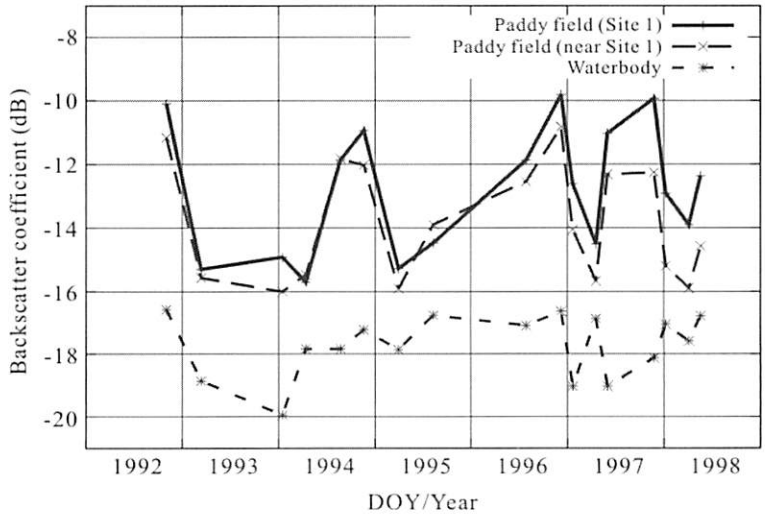


Figure 22: Temporal change of backscatter coefficients in Site 1 from 1992 to 1998 obtained from JERS1/SAR

Mean of soil moisture in dry season (March and April) from 1993 to 1998 except 1996 was also obtained. The image of mean of soil moisture was segmented by an image processing software, "eCognition professional", whose latest name is "Definiens professional" (eCognition Web page, 2006). This software enables segmentation and context-based classification. Our objective in the present research is to map distribution of soil moisture in paddy fields to evaluate vulnerability to drought. Therefore, such segmentation is quite an effective technique to map the distribution.

In the "eCognition professional", segmentation requires two parameters, i.e. compactness and scale factor. In the current research, three different scale parameters, 50, 80 and 120 were selected. "Scale parameter" is used to determine the upper limit for a permitted change of heterogeneity throughout the segmentation process. Larger scale parameter gives a coarse resolution of segmented result. In Figure 25, the mean of soil moisture in dry season (March and April) from 1993 to 1998 except 1996 and the segmented results at different scale parameters (50, 80 and 120) are shown. In the same manner, the mean of soil moisture in rainy season (July and August) of 1994, 1995 and 1998 and the segmented results at different scale parameters (50, 80 and 120) were obtained. The images are shown in Figure 26.

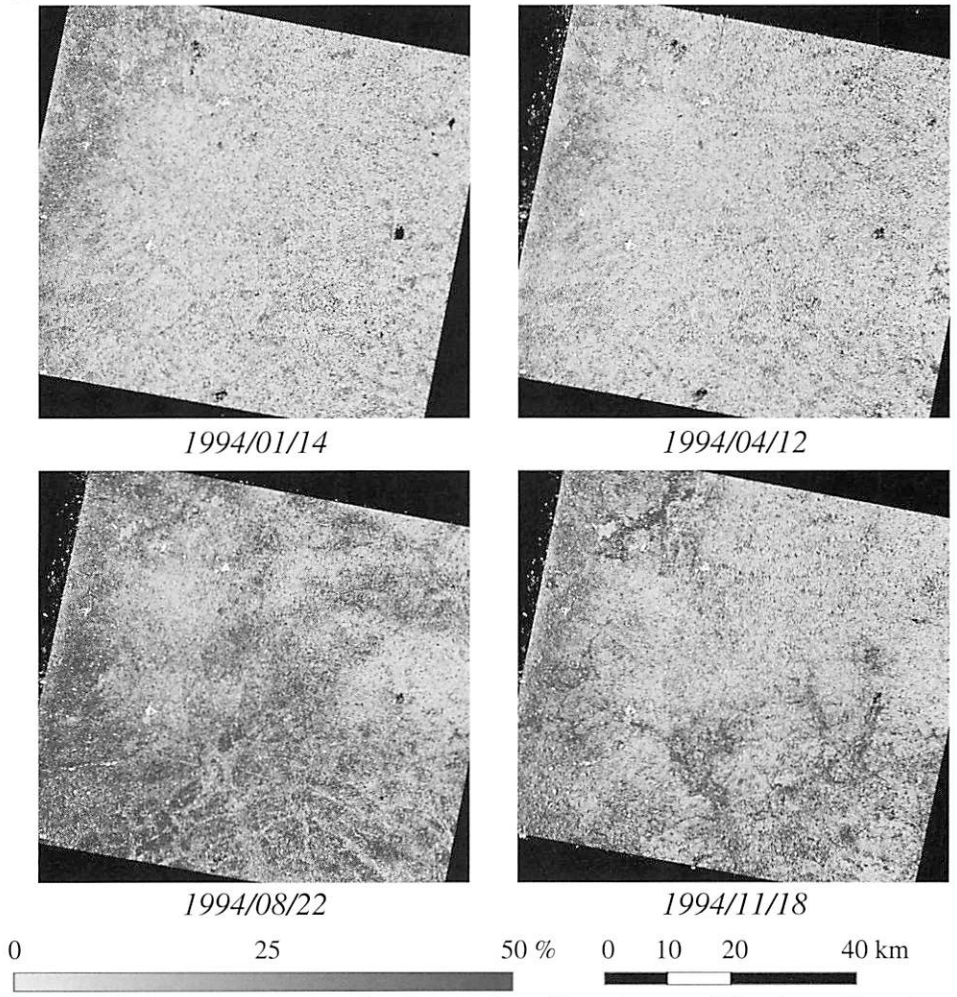


Figure 23: Annual change of volumetric soil moisture of Buriram Province, Thailand in 1994 estimated from JERS-1/SAR with IEM model

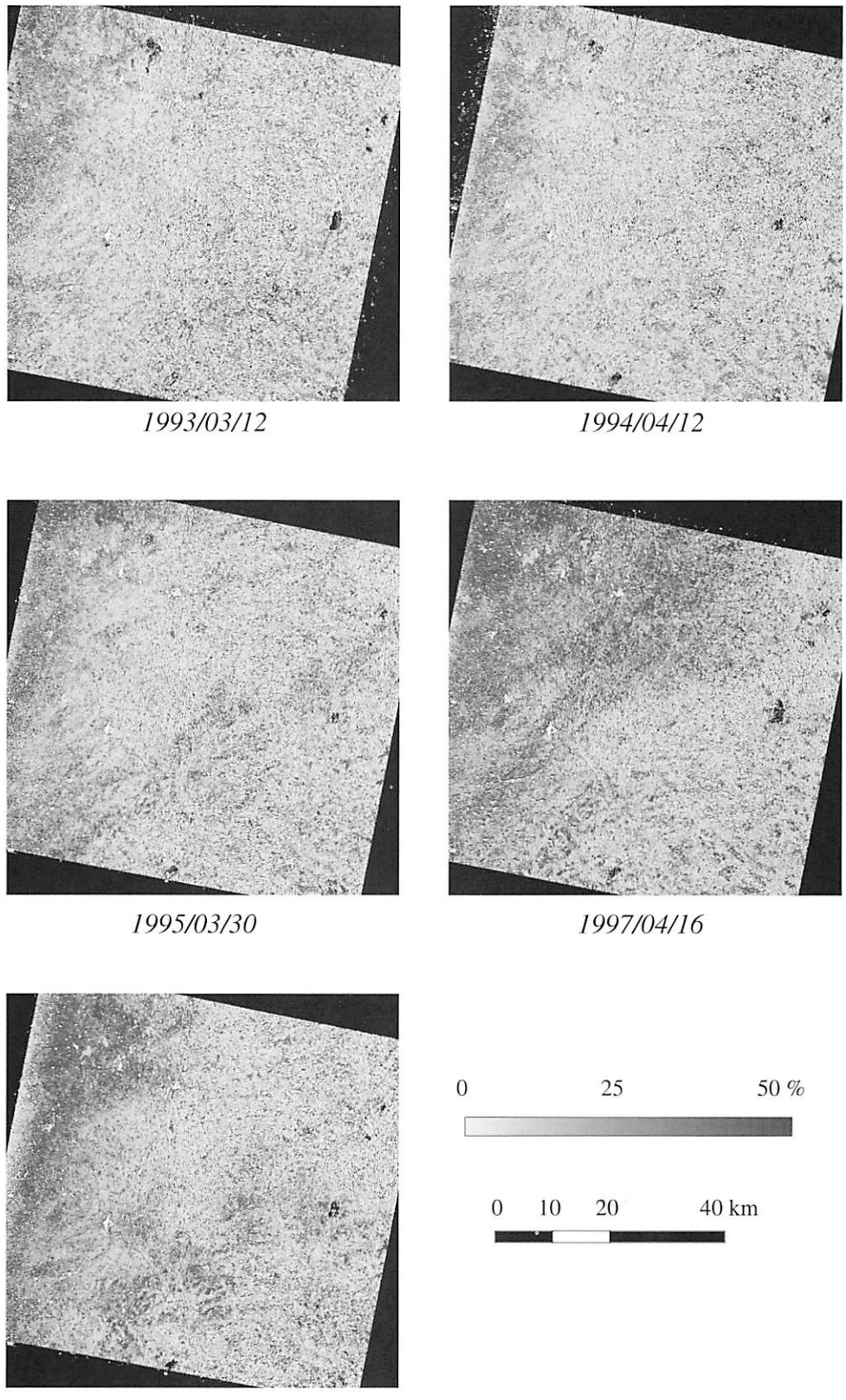


Figure 24: Temporal change of volumetric soil moisture of Burram Province, Thailand from 1994 to 1998 estimated from JERS-1/SAR with IEM model

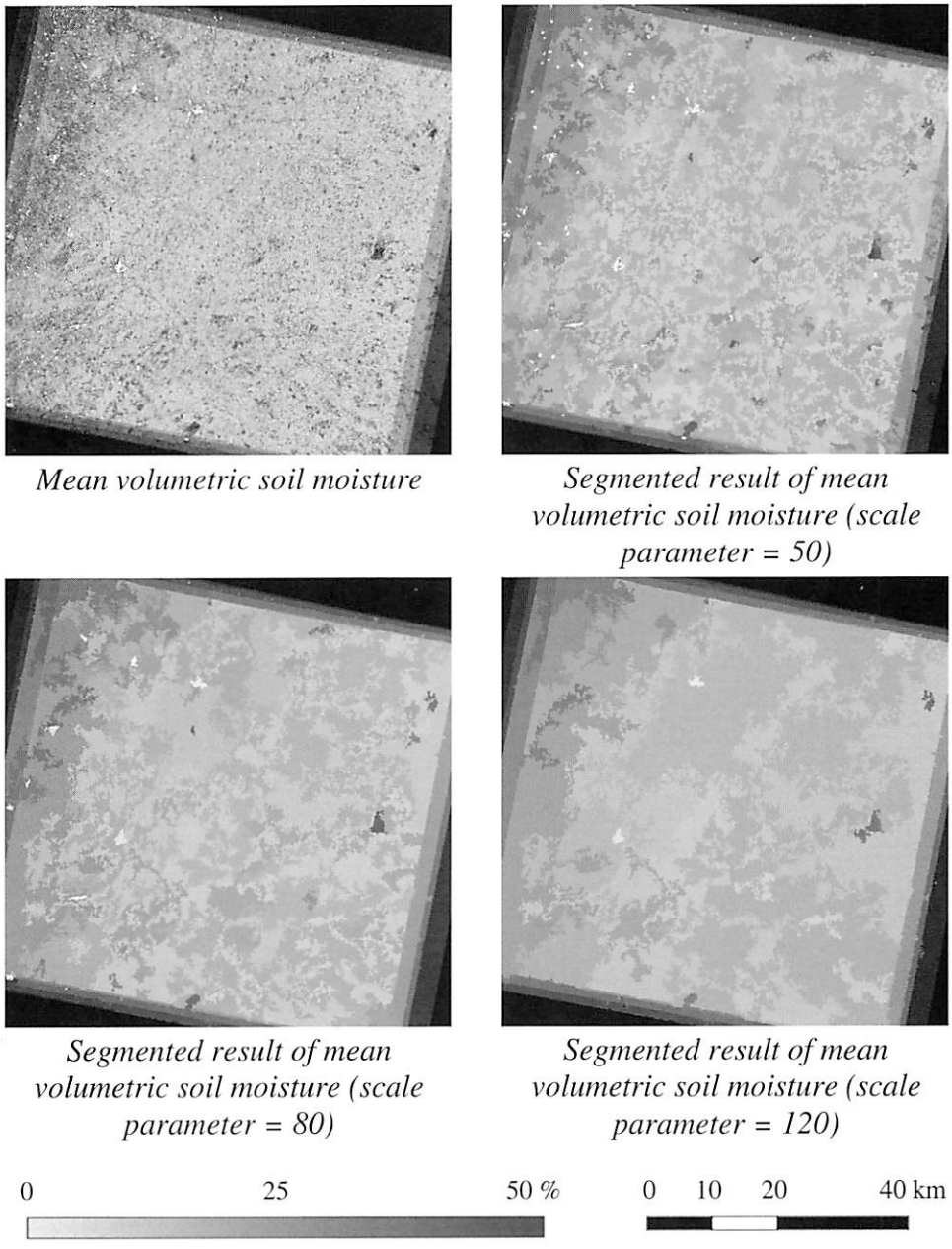


Figure 25: Mean of volumetric soil moisture of Burram Province, Thailand in dry season (March and April) from 1993 to 1998 except 1996. Segmented results are also shown. "Scale parameter" is a parameter required in "eCognition", software for segmentation and classification of images

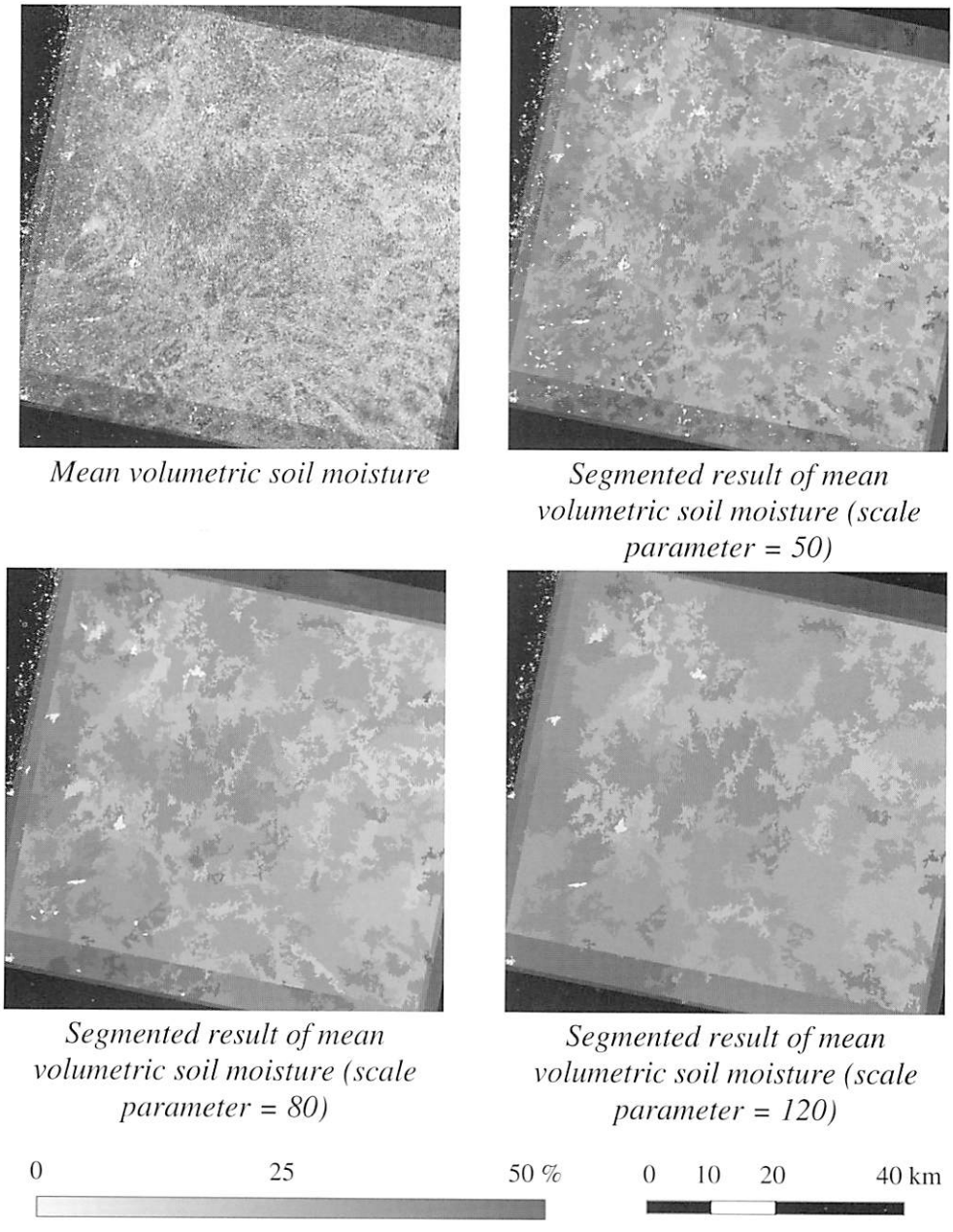


Figure 26: Mean of volumetric soil moisture of Burram Province, Thailand in rainy seasons (July and August) of 1994, 1995 and 1998. Segmented results are also shown. "Scale parameter" is a parameter required in "eCognition", software for segmentation and classification of images

4. DISCUSSIONS

First of all, difficulties in handling with the IEM model should be discussed because the IEM model functions to affect a lot in mapping soil moisture. As a result to apply the IEM model for temporal JERS-1/SAR images, temporal change of soil moisture was estimated. It was found to be easy to calibrate parameters of the IEM model estimating as long as there are not so many sensitive parameters. In the present research, surface roughness was obtained from surveying results. Therefore, autocorrelation length of surface roughness, which is quite difficult to actually measure, was stably calibrated.

However, this calibration technique should be improved even though actual volumetric soil moisture data at the same date are not available. In the current research, author measured and utilized actual volumetric soil moisture measured from October 2005 to October 2006 while JERS-1/SAR images were observed from 1992 to 1998. The lack of actual volumetric soil moisture affects not only calibration but also validation of estimated results. However, precipitation data can be applied for the validation. Least annual precipitation data can be obtained from the Web page of The Meteorological Department of Thailand (TMD Web page, 2006). During 1992 to 1998, Northeastern part of Thailand had 10% less precipitation in 1992 than normal year's precipitation, 17% less precipitation in 1993 and 16% less precipitation in 1998. Authors will collect daily precipitation data in province from TMD. A methodology to validate soil moisture with such existing statistics or other meteorological parameters should be examined in near future.

Next, availability of SAR images is focused on. In the present research, L-band JERS-1/SAR images were utilized. It has been reported that L-band SAR sensor is better to detect soil moisture around root layer because of longer wavelength compared to X-band or C-band SAR sensors. Therefore, L-band SAR sensors are planning to be launched near future for the sake of hydrology. For example, soil moisture and ocean salinity (SMOS) will be developed by European Space Agency (ESA). NASA has a plan to launch Hydros sensor to understand Earth's changing soil moisture and surface freeze conditions (NASA Web page, 2006).

Advanced Land Observing Satellite (ALOS) was successfully launched on January 24, 2006. One of three sensors onboard the ALOS is the Phased Array type L-band Synthetic Aperture Radar (PALSAR), which is L-band (1.27 GHz) SAR sensor (PALSAR Web page, 2006). It is highly expected that users can obtain the PALSAR data for their analysis near future. However, when author started the current research in the late 2005, PALSAR has not been launched nor PALSAR data were not available. In the late 2006, PALSAR data can be ordered through the Internet. However, the archived data are not much so far.

In order to map the distribution of soil moisture, the map should represent the general trend of the specific region. Therefore, long-term observation is quite indispensable for such mapping. JERS-1/SAR was

operated from 1992 to 1998. Even though the data are observed several years ago, lots of archived data enable middle/long-term analysis. As temporal JERS-1/SAR images are quite informative about regional characteristics of soil moisture, author decided to utilize JERS-1/SAR images for the mapping of soil moisture distribution.

Then, the benefits to map distribution of soil moisture are examined. From time to time, high expectations are given to real or near-real time monitoring with use of remote sensing. As for drought monitoring, some expect that early drought warning system should be developed. When it comes to agricultural drought in Thailand, it is quite difficult to obtain cloud-free image, and accordingly difficult to exactly understand the conditions on the surface. Therefore, early drought warning system cannot be achieved without optical remote sensing. While SAR can detect at all-weather conditions and nighttime, the frequency of the observations, e.g. such as dozens of days, is not so high. Due to such a longer recurrent period, SAR cannot be utilized for the real/near-real time monitoring.

However, apart from the real/near-real time monitoring, SAR images are highly capable of mapping distribution of potential soil moisture. As is described above, SAR can detect during rainy season as well as dry season. Author believes that such strategy as utilize temporal SAR images can be fruitful for the preparedness against drought, especially hydrological and agricultural droughts.

Finally, future tasks of the present research should be described. In the present research, actual land cover was ignored, and the IEM model was applied for the whole of area. Basically, the IEM model can be applied for bare soil regions. If there is different type of land cover, scattering on the surface in the microwave region can be easily changed in accordance with surface roughness and three-dimensional shape. In fact, when the IEM model is applied for paddy fields, the accuracy should be examined based on the different growth stages of paddy. More intensive examination should be conducted in terms of different land cover effects.

5. CONCLUSIONS

In the present research, author examined the feasibility to map soil moisture from temporal SAR images with the IEM model. One of the difficulties is that actual in-site soil moisture data were not available, which should be measured synchronously with satellite observation. For the analysis, JERS-1/SAR images observed from 1992 to 1998 were available while actual soil moisture data were measured from October 2005 to October 2006. Even though validation has not been completed, the mapping results may be acceptable.

It was also found that the IEM model is easy to implement as long as there are not so many sensitive parameters. Therefore, field measurements

of several important parameters such as surface roughness or soil component ratio should be obtained in-site.

Sometimes, high expectations are given to real or near-real time monitoring with use of remote sensing. However, in Thailand, it is quite difficult to obtain cloud-free image, and accordingly difficult to exactly understand the conditions on the surface. Therefore, author adopted the approach to utilize SAR images. While SAR can detect at all-weather conditions and nighttime, the frequency of the observations such as dozens of days is not so high. Due to such a longer recurrent period, SAR cannot be utilized for the real/near-real time monitoring. SAR images are highly capable of mapping distribution of potential soil moisture through rainy season as well as dry season. Author believes that such strategy as utilize temporal SAR images can be fruitful for the preparedness against drought, especially hydrological and agricultural droughts.

In the present research, actual land cover was ignored, and the IEM model was applied for the whole of area. In fact, when the IEM model is applied for paddy fields, the accuracy should be examined based on the different growth stages of paddy. One of the approaches to the consideration of actual land cover is data fusion of optical data and microwave data. JERS-1 carried Optical Sensor (OPS) as well as SAR. Such data fusion technique will be examined to help improving mapping of soil moisture distribution from a viewpoint of land cover.

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APPENDIX: FIELD SURVEYS TO PADDY FIELDS

From 2005, author conducted field surveys in three provinces, i.e. Ubon Ratchathani, UdonThani and parts of Nong Khai and Buriram. Detailes on the field surveys are shown in following appendices A.C.

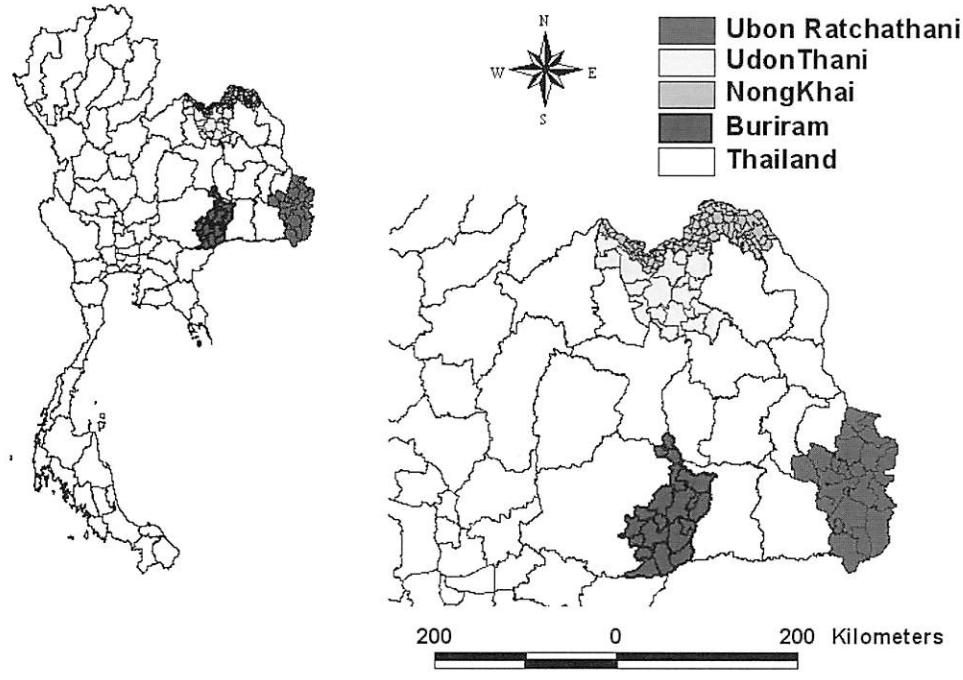


Figure 12: Map of study areas in 4 provinces, Thailand, with districts (Amphoe) boundary

APPENDIX A: FIELD SURVEY TO PADDY FIELDS IN BURIRAM PROVINCE

A.1 INTRODUCTION

Buriram Province is one of the northeastern provinces (*changwat*) of Thailand. Neighboring provinces are Sa Kaeo, Nakhon Ratchasima, Khon Kaen, Maha Sarakham and Surin and near border of Cambodia. Buriram was once part of a great Khmer Empire. Buriram around with many volcanoes and located at the southern of the Khorat Plateau. The biggest of ruin part of Khmer Empire on volcano is protected in the Phanom Rung historical park. 42% of the population can speak Khmer.

In the past it was covered with shady trees and the land was fertile. Approximately 1.75 million Rai of the area is forestland. The main occupation here is rice farming. The average per capita income is 14,343 Baht. The province is subdivided into 21 districts (*Amphoe*) see Figure A-1 and 2 minor districts (*King Amphoe*). The districts are divided into 189 communes (*tambon*) and 2212 villages (*muban*).

Source: http://en.wikipedia.org/wiki/Buri_Ram_province

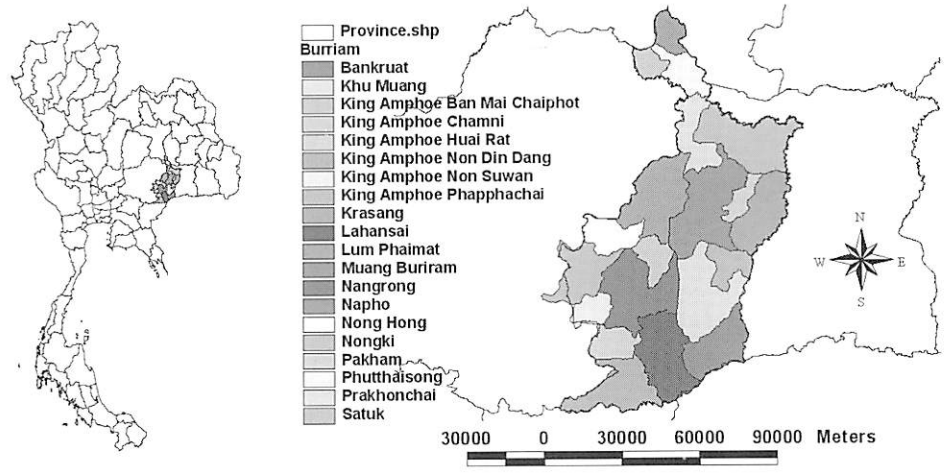


Figure A.1: Map of Buriram province, Thailand, with districts (Amphoe) boundary

Table A.1: Major Rice and Second Rice: Area, production and yield by province, Year 1992/93 -2005

	Planted area (rais)		Harvested area (rais)		Production (tons)		Yield per rai (kgs.)	
	Major Rice	Second Rice	Major Rice	Second Rice	Major Rice	Second Rice	Major Rice	Second Rice
1992/93	2578947	11,051	2,541,945	10,566	606,053	4,573	238	433
1993/94	2,719,697	4,396	2,366,136	4,396	584,735	2,418	247	550
1994/95	2,649,822	388	2,316,489	388	655,767	159	283	410
1995/96	2,830,348	640	2,797,623	640	798,158	218	285	341
1996/97	2,802,660	1,215	2,553,325	1,215	723,862	422	283	347
1997/98	2,853,337	2,050	2,726,098	2,050	709,343	722	260	352
1998/99	2,861,194	2,369	2,829,761	2,018	794,841	617	281	306
1999/00	2,826,907	670	2,808,601	670	811,322	357	289	533
2000/01	2,860,382	670	2,751,062	439	875,986	221	318	503
2001	2,715,822	685	2,603,282	641	807,506	179	310	279
2002	2,665,950	95	2,501,265	82	829,513	28	332	341
2003	2,648,669	350	2,489,749	338	835,441	119	336	352
2004	2,658,557	3157	2,006,208	3151	736,420	1090	367	346
2005	2,752,305	554	2,585,647	554	903,036	184	-	-

(Source: http://www.oae.go.th)

Table A.2: Number of water resources by type of water resources and district in 2005

District/Minor district	Total	Reservoirs			Con crete wire	Dam	Pond	Canal, ditch	Artesian well	Hollow well
		Big	Medium	Small						
	7,867	**1**	**22**	**210**	**117**	-	**7,517**	-	-	-
Mueang Buri Ram	374	–	2	9	5	-	358	-	-	-
Khu Mueang	503	–	1	16	4	-	483	-	-	-
Krasang	191	–	1	14	6	-	170	-	-	-
Nang Rong	608	1	2	13	13	-	579	-	-	-
Nong Ki	799	–	–	4	1	-	794	-	-	-
Lahan Sai	660	–	2	9	5	-	644	-	-	-
Prakhon Chai	248	–	1	13	21	-	213	-	-	-
Ban Kruat	237	–	2	10	0	-	225	-	-	-
Phutthaisong	255	–	1	7	5	-	242	-	-	-
Lam Plai Mat	460	–	4	13	11	-	432	-	-	-
Satuek	783	–	1	16	6	-	760	-	-	-
Pakham	282	–	–	16	3	-	263	-	-	-
Na Pho	196	–	1	8	0	-	187	-	-	-
Nong Hong	586	–	–	14	1	-	571	-	-	-
Phlapphla Chai	73	–	–	2	4	-	67	-	-	-
Huai Rat	98	–	–	2	1	-	95	-	-	-
Non Suwan	383	–	–	3	0	1	380	-	-	-
Chamni	487	–	–	2	5	-	480	-	-	-
Ban Mai Chaiyaphot	208	–	–	6	7	-	195	-	-	-
Non Din Daeng	345	–	2	16	5	-	322	-	-	-
Ban Dan Minor	19	–	–	5	5	-	9	-	-	-
Khaen Dong Minor	25	–	2	7	3	-	15	-	-	-
Chaloem Phra Kiat	44	–	–	5	6	-	33	-	-	-

(Source: http://webhost.nso.go.th)

Table A.3: Monthly rainfall in 2003-2004

	2003				2004			
Buriram (Nang Rong) Meteorological station	Rainfall (mm.)	No. of rainy day	Daily maximum (mm.)	Date of daily highest	Rainfall (mm.)	No. of rainy day	Daily maximum (mm.)	Date of daily highest
Annual	**1,128.6**	**103**	**86.1**	**14 Oct 06**	**1,299.0**	**108**	**95.8**	**9June**
January	-	-	-	-	22.6	2	22.1	16 Jan
February	52.5	6	41.0	18 Feb	18.6	5	8.0	5.8 Feb
March	42.8	6	18.8	27 Mar	2.4	1	12.4	19 Mar
April	37.0	5	17.4	11 Apr	65.7	7	28.6	1 Apr
May	87.9	12	22.6	15 May	190.4	14	78.1	16 May
June	186.8	12	39.2	3 Jun	242.8	15	95.8	9 Jun
July	67.6	16	25.5	28 Sept	215.2	24	78.2	30 Sept
August	243.5	18	42.6	30 Aug	208.4	18	80.4	17 Aug
September	289.0	20	50.4	29 Sept	304.1	20	70.2	18 Sept
October	121.5	8	86.1	14 Oct	1.1	1	1.1	19 Oct
November	-	-	-	-	27.7	1	27.7	20 Nov
December	-	-	-		-	-	-	

(Source: Buri Ram (Nang Rong) Meterological Station)

Table A.4: Monthly Humid in 2004

Relative humidity					
Buriram (Nang Rong) Meteorological station	**Max**	**Mean max**	**Min**	**Mean min**	**Mean**
Annual	**97.25**	**94.97**	**26**	**35.23**	**72.87**
January	97	90.42	30	43.1	70.04
February	98	91.66	26	43.93	69.4
March	95	85.61	26	35.23	59.77
April	97	86.77	27	40.97	67.39
May	97	91.65	42	52.61	75.37
June	98	91.07	47	58.7	77.52
July	98	94.13	47	58.42	79.41
August	98	92.55	52	58.87	78.28
September	99	94.97	50	62.2	82.57
October	96	92.39	41	55.61	76.43
November	96	88.97	35	47	69.69
December	98	91.35	30	40.58	68.59

(Source: Buriram (Nang Rong) Meterological Station)

Table A.5: Monthly Temperature in 2005

	Mean	**Max**	**Date Max**	**Min**	**Date Min**	**Mean atmospheric pressure (HPA)**
Annual	25.99	40.5	17	12.5	25	9.58
January	24.24	35.0	31	12.5	25	12.88
February	24.75	37.2	28	13.3	15	11.92
March	29.55	40.3	27	18.2	10	8.94
April	29.91	40.5	17	21.8	28	8.10
May	28.95	37.8	1	23.2	16,23	6.79
June	28.11	36.3	6	23.0	10	6.55
July	24.94	36.5	2	22.2	15	6.36
August	28.16	35.5	28	23.5	6,10,20	5.71
September	27.13	36.6	23	22.7	28	9.09
October	22.25	32.8	29,30	18.8	27	12.30
November	21.04	36.1	11	16.4	22	12.64
December	22.81	32.7	24	13.8	15	13.68

(Source: Buriram (Nang Rong) Meterological Station)

Table A.6: Land use (Amphoe) in Buriram 2001-2003

Amphoe		**Total area**	**Agriculture land (Rais)**								**Others**
			Paddy field	**Field crops**	**Farm land**					**Total**	
		(Rais)			**Fruit trees**	**Para rubber**	**Flower**	**Vegetable**	**Others**		
Mueang Buri	2001	448896.9	347,668	5,407	20,056	0	13	977	0	374,121	74,776
Ram	2002	448896.9	347,668	5,407	977	20,056	13	0	374,121	74,776	23,036
	2003	448896.9	340,086	3,307	977	22,100	13	0	366,483	82,413,875	23,136
Ban Kruat	2001	364375.0	109,445	45,275	30,106	17,565	547	4,743	23,144	230,825	133,550
	2002	364375.0	114,557	41,432	3,678	50,599	547	18,706	229,519	134,856	10,846
	2003	364375.0	114,557	44,132	3,918	47,899	307	18,706	229,519	134,856,000	9,627
Krasang	2001	407937.5	270,705	1,191	11,096	0	0	1,546	0	284,538	123,400
	2002	407937.5	270,705	1,191	1,546	11,096	0	0	284,538	123,400	16,706

	2003	407937.5	270.705	1,191	1,546	11,096	0	0	284,538	123,399.500	16,706
Lahan Sai	2001	418125.0	97,569	115,015	12,173	5,890	30	521	0	231,198	186,927
	2002	418125.0	97,569	115,015	521	12,173	30	0	225,308	192,817	9,980
	2003	418125.0	96,575	109,850	520	15,673	20	2,989	225,627	192,498.000	10,244
Lam Plai Mat	2001	501843.8	432,987	21,628	12,920	240	5	677	0	468,457	33,387
	2002	501843.8	432,987	21,628	677	12,920	5	0	468,217	33,627	19,709
	2003	501843.8	430,037	21,579	1,260	11,699	10	0	464,585	37,258.750	17,722
Nang Rong	2001	571250.0	214,715	20,338	9,006	0	20	2,183	4,452	250,714	320,536
	2002	571250.0	214,715	20,338	2,183	9,006	20	4,452	250,714	320,536	15,223
	2003	571250.0	225,878	20,338	2,183	9,006	20	4,452	261,877	309,373.000	15,223
Phutthaisong	2001	205625.0	164,265	4,129	3,744	0	7	320	3,335	175,800	29,825
	2002	205625.0	164,695	3,655	511	3,989	8	2,894	175,752	29,873	8,672
	2003	205625.0	164,695	2,304	294	3,487	8	4,311	175,099	30,526.000	8,393
Satuek	2001	501875.0	364,135	25,760	5,710	2,930	0	321	29,445	428,301	73,574
	2002	501875.0	348,734	28,762	181	4,145	3	8,118	389,943	111,932	15,430
	2003	501875.0	348,734	28,762	181	4,145	3	8,118	389,943	111,932.000	15,430
Prakhon	2001	556325.6	394,486	3,017	3,615	205	51	3,464	0	404,838	151,488
Chai	2002	556325.6	394,486	4,035	3,078	3,700	51	2,143	407,493	148,833	14,026
	2003	556325.6	394,486	3,017	3,015	3,615	50	389	404,572	151,753.625	15,671
Khu Mueang	2001	276250.0	125,151	59,330	13,259	858	0	1,055	0	199,653	76,597
	2002	276250.0	125,151	59,330	1,055	13,259	0	0	198,795	77,455	9,711
	2003	276250.0	125,151	60,030	1,485	13,379	0	0	200,045	76,205.000	9,711
Nong Ki	2001	240625.0	139,182	22,106	7,790	1,454	0	1,706	3,803	176,041	64,584
	2002	240625.0	175,393	28,554	1,587	5,908	0	2,312	213,754	26,871	9,643
	2003	240625.0	175,393	28,554	1,587	5,908	0	2,312	213,754	26,871.000	9,643
Pakham	2001	168143.1	50,234	56,041	1,690	350	0	320	1,095	109,730	58,413
	2002	168143.1	50,234	56,041	320	1,690	0	1,095	109,380	58,763	8,819
	2003	168143.1	50,234	60,941	450	3,270	0	2,180	117,075	51,068.125	8,402
Nong Hong	2001	209375.0	116,304	18,770	833	0	0	2,351	9,306	147,564	61,811
	2002	209375.0	116,304	18,867	2,351	736	0	9,356	147,614	61,761	8,348
	2003	209375.0	116,304	18,867	2,351	736	0	9,356	147,614	61,761.000	8,348
Na Pho	2001	159375.0	109,588	2,095	11,186	0	0	0	0	122,869	36,506
	2002	159375.0	114,850	2,554	60	3,563	0	4,555	125,582	33,793	6,313
	2003	159375.0	114,850	2,554	76	3,563	0	4,555	125,598	33,777.000	6,313
Phlapphla	2001	191668.8	130,462	0	384	0	0	44	0	130,890	60,779
Chai	2002	191668.8	130,582	0	1,102	1,198	0	3,361	136,243	55,426	7,766
	2003	191668.8	130,462	0	1,102	1,198	0	0	132,762	58,906.750	7,766
Huai Rat	2001	109062.5	82,560	2,722	8,217	0	0	216	0	93,715	15,348
	2002	109062.5	82,560	2,722	216	8,217	0	0	93,715	15,348	5,272
	2003	109062.5	82,560	2,722	216	8,217	0	0	93,715	15,347.500	5,272
Non Suwan	2001	118531.3	37,265	72,263	3,836	4,452	0	678	0	118,494	37
	2002	118531.3	37,264	71,869	687	3,123	35	0	112,978	5,553	4,617
	2003	118531.3	37,264	71,869	687	6,855	0	0	116,675	1,856.250	1,180
Chamni	2001	151250.0	94,589	11,110	5,524	0	0	4,930	0	116,153	35,097
	2002	151250.0	93,507	9,862	2,247	5,247	0	0	110,863	40,387	5,785
	2003	151250.0	93,570	9,862	2,247	5,247	0	0	110,926	40,324.000	6,011
Ban Mai	2001	111250.0	87,248	1,191	883	0	0	550	1,027	90,899	20,351
Chaiyaphot	2002	111250.0	87,248	825	1,590	954	0	1,157	91,774	19,476	5,363
	2003	111250.0	87,248	715	1,545	1,084	0	861	91,453	19,797.000	5,333
Non Din	2001	280000.0	23,296	25,522	967	2,055	1	1,248	0	53,089	226,911
Daeng	2002	280000.0	24,558	33,581	1,918	3,495	0	0	63,552	216,448	5,630
	2003	280000.0	23,296	25,522	850	1,365	0	0	51,033	228,967.000	4,896
Chaloem	2001	218750.0	99,497	2,065	3,282	0	0	1,280	0	106,124	112,626

Phra Kiat	2002	218750.0	99,497	2,065	1,280	3,282	0	0	106,124	112,626	7,034
	2003	218750.0	99,497	2,045	1,280	3,282	20	0	106,124	112,626.000	6,761
Ban Dan	2001	99431.3	61,496	15,566	0	0	0	0	0	77,062	22,369
Minor	2002	99431.3	61,496	13,534	430	1,345	0	0	76,805	22,626	3,909
	2003	99431.3	61,496	15,566	430	1,345	0	0	78,837	20,594.250	4,014
Khaen Dong	2001	186250.0	82,380	46,649	11,192	5,214	0	620	14,951	161,006	25,244
Minor	2002	186250.0	82,380	45,199	654	7,141	0	7,153	142,527	43,723	4,831
	2003	186250.0	82,380	25,449	654	26,891	0	7,153	142,527	43,723.000	4,254
23 Amp hoes		**19116146.9**	**10,803,065**	**1,652,184**	**233,864**	**405,083**	**1,837**	**146,128**	**8,871,196**	**8,391,374**	**2,381,775**

(Source: Thailand Agricultural Statistics, crop year 1993-4; Ministry of Agriculture and Cooperatives)

A.2 STUDY AREA

A.2-1 Geography Location

Buriram Province is selected as study area. Located in longitude of 102.36° to 103.50° E and latitude of 14.13° to 15.79° N. It is located in the northeastern part of Thailand. Area 10,312.435 km² and near by

North: Khon Kaen and Maha Sarakham
South: Prachin Buri and Cambodia
East: Surin
West: Nakhon Ratchasima

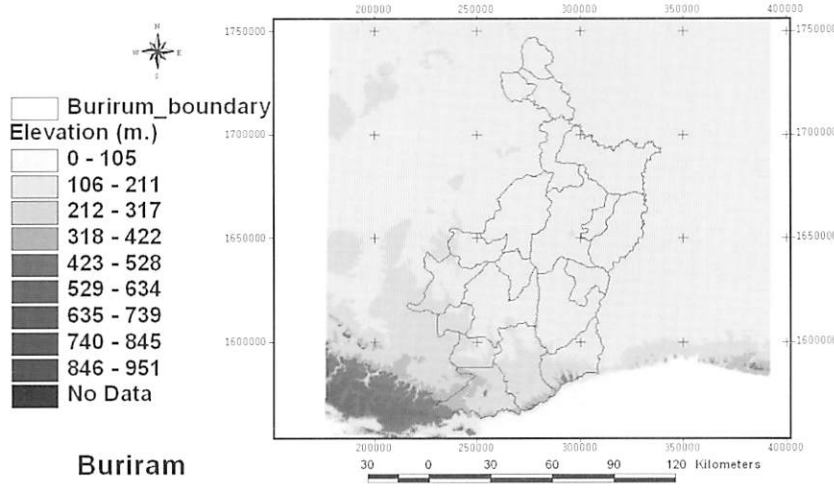


Figure A.2: Map of Elevation of Buriram province.

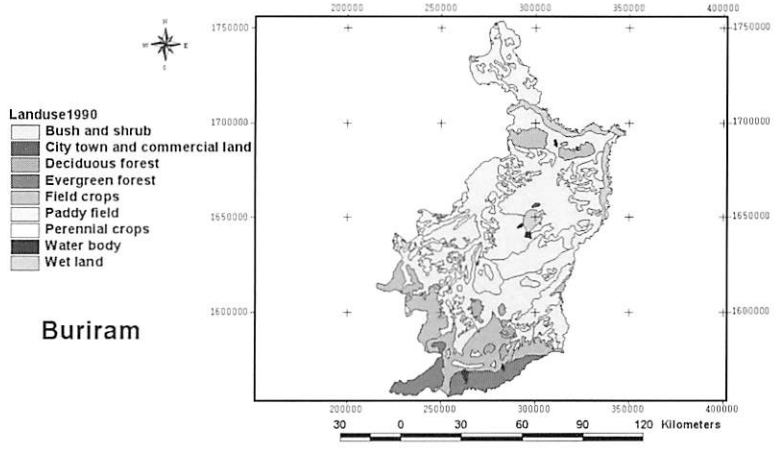
A.2-2 Climates and temperature

Northeastern part of Thailand generally climate is influenced by two seasonal monsoons, the northeast and the southwest comes from two types of monsoon. Buriram Province located in a tropical climate. The southwest monsoon begins in May and lasts until October. It brings the moisture from North Indian Ocean. The northeast monsoon that begins in mid-October and lasts until mid-March is caused by the difference between high pressure over Mongolia and low pressure over the Indian Ocean. The average annual rainfall from 1991 to 2002 in the northeast region is between 1,168.4 to 1,671.7 mm. The minimum temperature is from 21.28°C to 23°C and the

maximum temperature is from 32.0°C to 33.90°C. The relative humidity fluctuates from a minimum of 51 to 55 % to a maximum 88 to 99 %. The average rainfall days are about 100 days (from TMD)

A.2-3 Land Use and Land Cover

According to the data from National Statistical Office in 1989 and 1993, the major land use is paddy fields, which covers almost 49.5% and other field crops, which almost 8 %of the total land area in Buriram province. The detailed land use map is shown in Figure A.3.



Source: Thailand Land development department

Figure A.3: Map of Landuse 1990 of Buriram province.

A.2-4 Hydrology

Buriram has Mun river as main river in Northern part and Lam Plai Mat as minor river in southern part of province.

Source: Royal Irrigation department

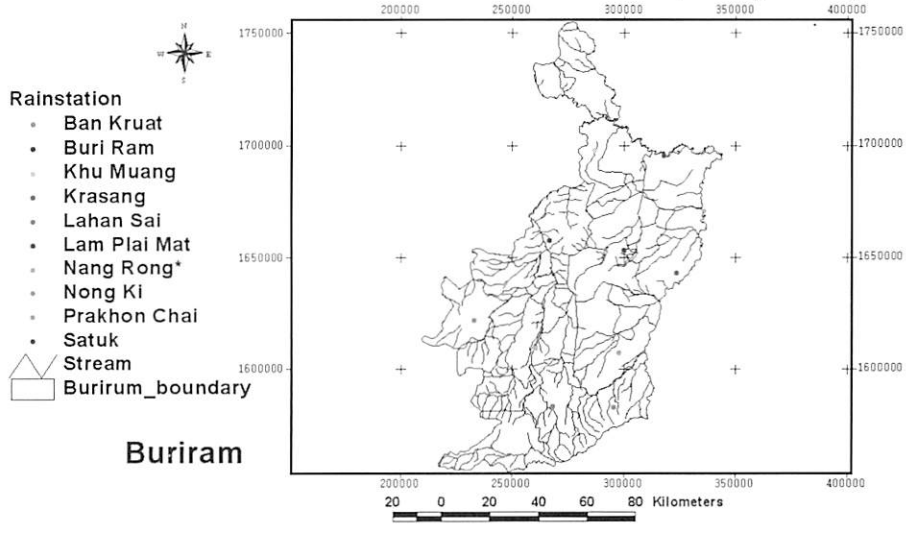


Figure A.4: Streams and Meteorological stations in Buriram province

A.2-5 Soil

Soils in the Buriram province are classified based on physiographic regions, the Korat Plateau most soils are of low fertility. Soils in the northeast are low in clay and therefore of low productivity.

A.3 FIELD SURVEY

Trip to Buriram has been repeated since 31Oct 2005 for more than one year. Author visited at many points mainly in paddy field.

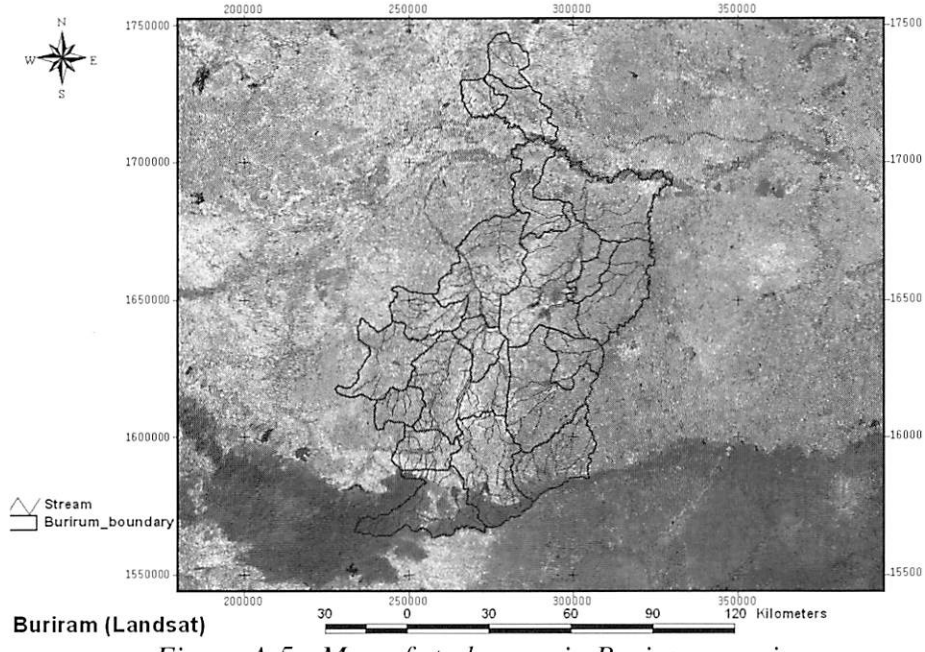


Figure A.5: Map of study area in Buriram province (LANDSAT ETM$^+$: Path 127 row 49 of 4 Nov 2000, Path 127 row 50 of 11 Apr 2001, Path 128 row 49 of 27 Dec 1999, Path 128 row 50 of 18 Feb 2002)

Soil moisture, soil temperature probe and data logger were installed in Site 1, 2, 3, 4 and 5 at 10-cm depth. Humidity, air temperature, wind speed, soil conductivity and albedo were measured on site. In every site, soil samples were collected for volumetric soil moisture calibration. Surface roughness was measure at site 5

Study sites survey sort by date

I. 31 October 2005
II. 30 November 2005
III. 22 January 2006
IV. 3 May 2006
V. 30 May 2006
VI. 20 June 2006
VII. 25 July 2006
VIII. 4 October 2006

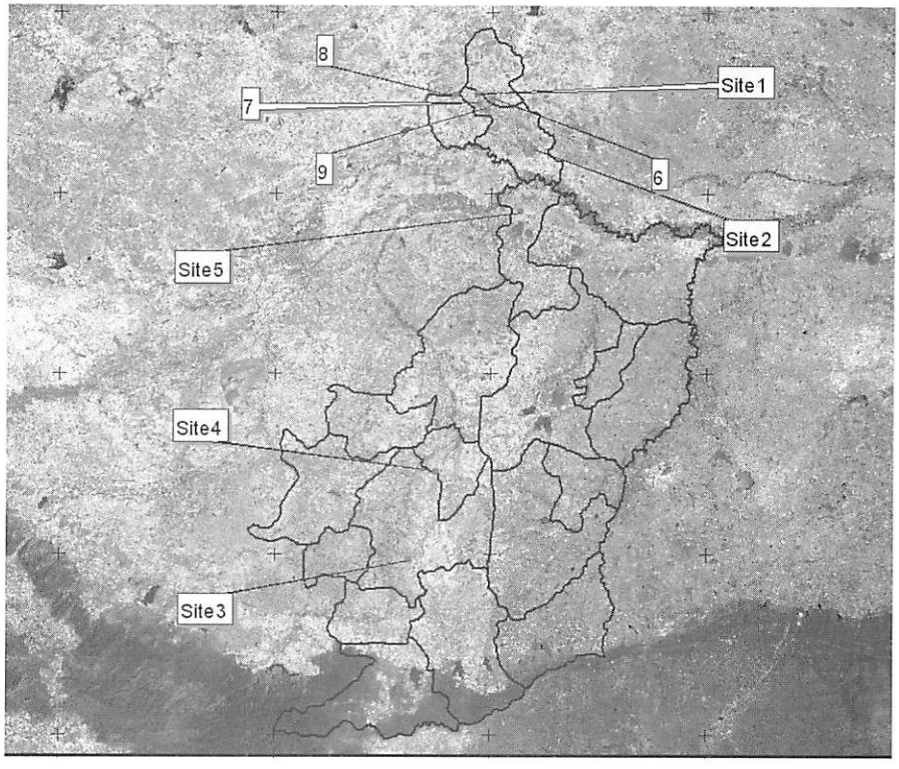


Figure A.6: Map of Sites in study area with LANDSAT ETM+

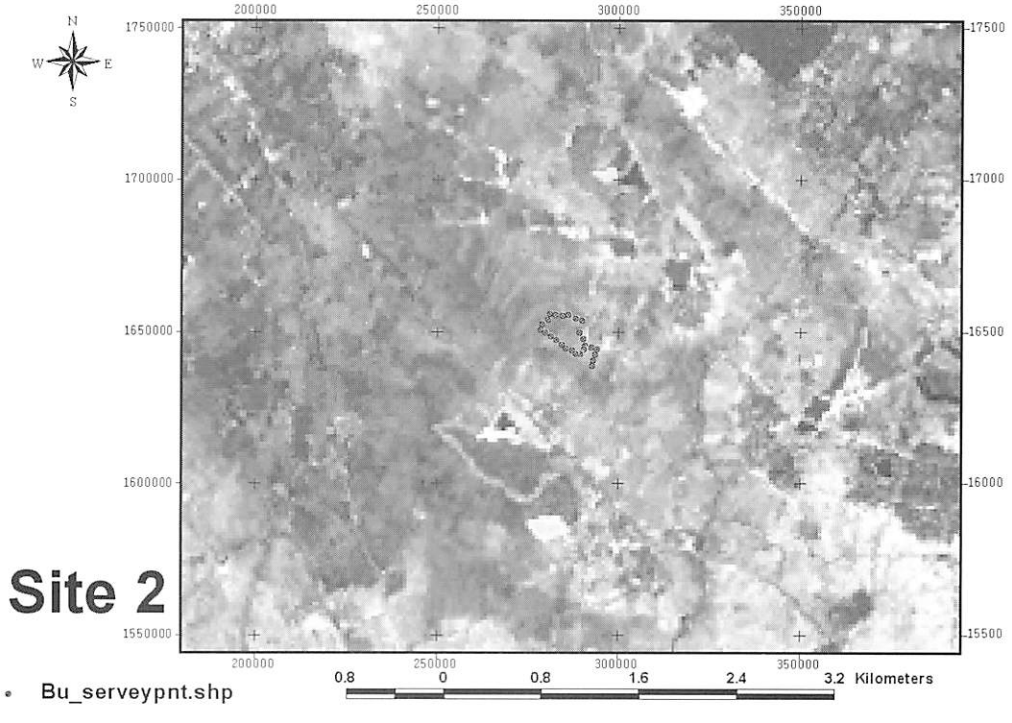


Figure A.7: Map of 26 sample points in study area site 2 with LANDSAT ETM+

Site No.	Site 1	**Date** 31/10/2005	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	(Reproductive)	
	Ripening	Harvesting	
Rice type	(Major rice)	Minor rice	
Drought	Every year in dry season		
Flood	2006		
Notes	Installed soil moisture soil temp. probe and data logger		

Site No.	Site 1	**Date** 31/10/2005	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	(Reproductive)	
	Ripening	Harvesting	
Rice type	(Major rice)	Minor rice	
Drought	Every year in dry season		
Flood	2006		
Notes	Soil samples for moisture calibration		

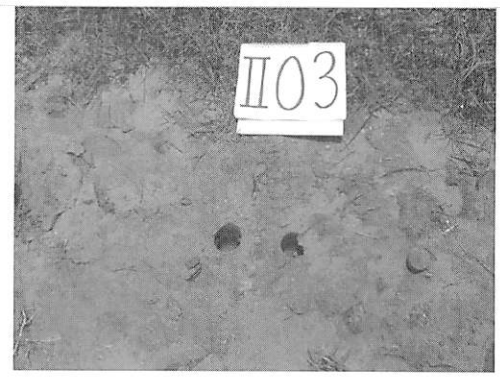
Site No.	Site 1	**Date** 30/11/2005	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.89	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought	Every year in dry season		
Flood	2006		
Notes	Installed soil moisture soil temp. probe and data logger		

Site No.	Site 1	**Date** 30/11/2005	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought	Every year in dry season		
Flood	2006		
Notes	Albedo measurement		

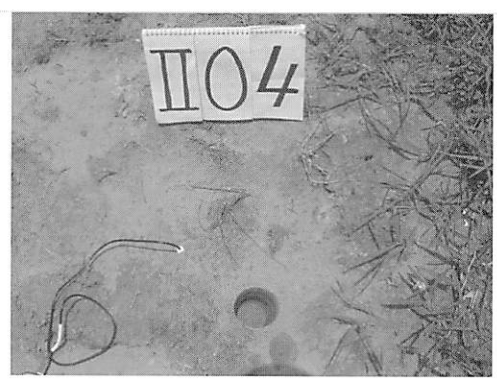
Site No.	Site 2-01	**Date** 3/05/2006	
Name	Amphoe: Phutthaisong		
Location	Lat: 15.512	Lon: 103.041	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	Site 2-02	**Date** 3/05/2006	
Name	Amphoe: Phutthaisong		
Location	Lat: 15.512	Lon: 103.041	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	Site 2-03	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

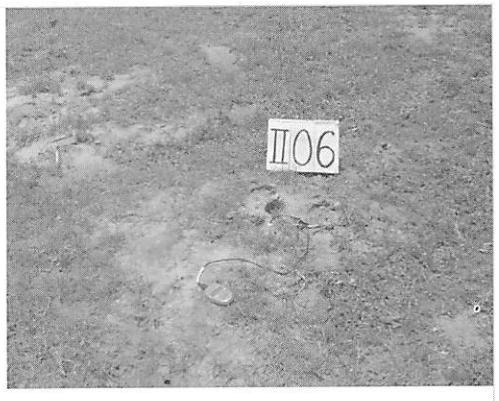


Site No.	Site 2-04	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 2-05	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-06	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



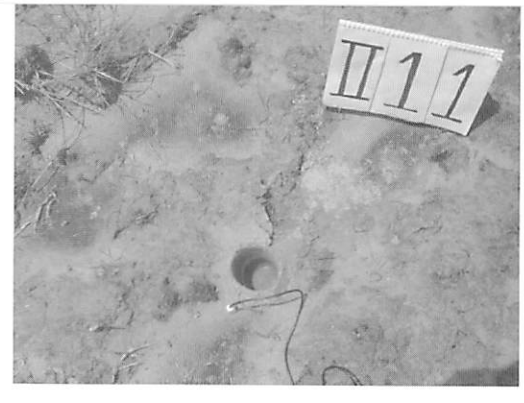
Site No.	Site 2-07	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-08	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-09	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-10	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

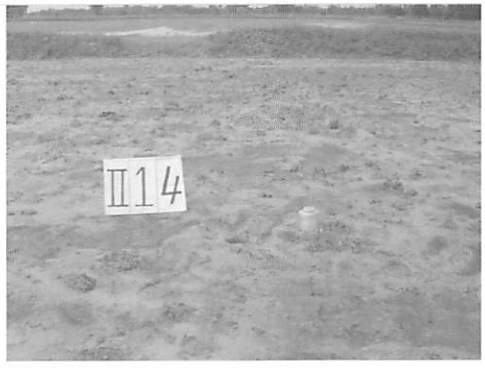
Site No.	Site 2-11	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



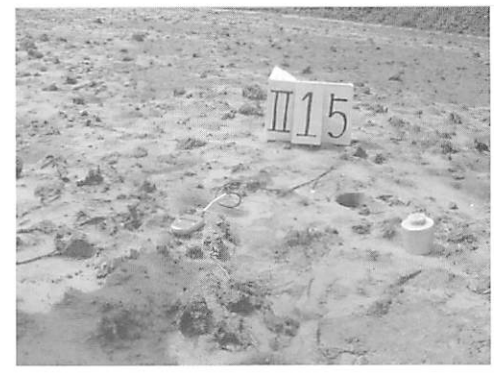
Site No.	Site 2-12	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-13	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

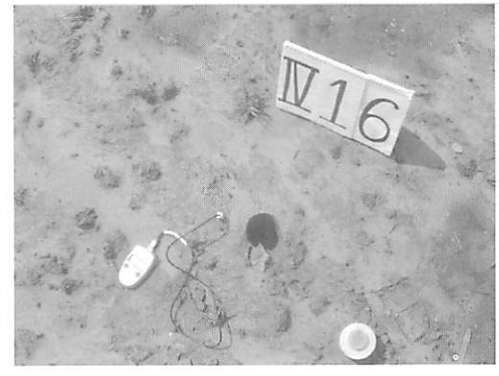
Site No.	Site 2-14	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 2-15	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 2-16	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

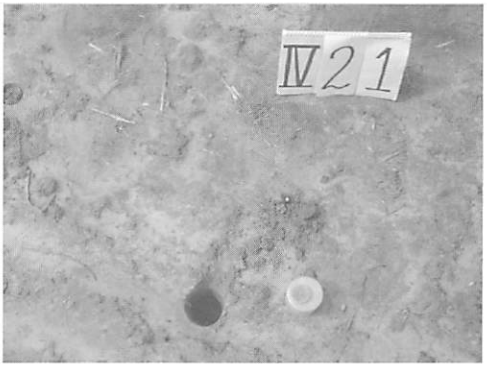


Site No.	Site 2-17	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

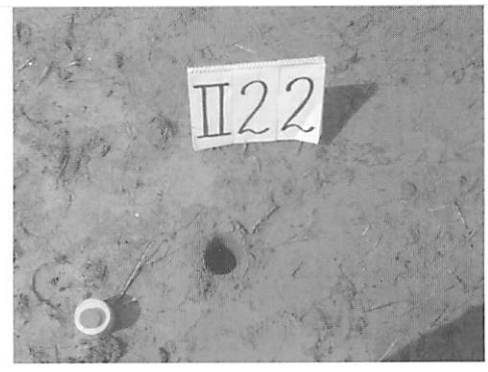
Site No.	Site 2-18	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-20	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-21	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



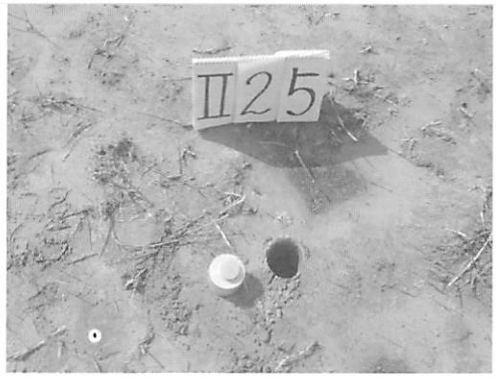
Site No.	Site 2-22	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 2-23	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-24	Date 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-25	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 2-26	**Date** 3/05/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 4	**Date** 3/05/2006
Name	Amphoe: King Amphoe Chamni	
Location	Lat: 14.755	Lon: 102.810
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes	Even though there is canal near the paddy field, the water didn't come to paddy field	

Site No.	Site 4-01	**Date** 3/05/2006
Name	Amphoe: King Amphoe Chamni	
Location	Lat: 14.755	Lon: 102.810
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 4-02	**Date** 3/05/2006
Name	Amphoe: King Amphoe Chamni	
Location	Lat: 14.755	Lon: 102.810
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 4-03	**Date** 3/05/2006
Name	Amphoe: King Amphoe Chamni	
Location	Lat: 14.755	Lon: 102.810
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 4-04	**Date** 3/05/2006	
Name	Amphoe: King Amphoe Chamni		
Location	Lat: 14.755	Lon: 102.810	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

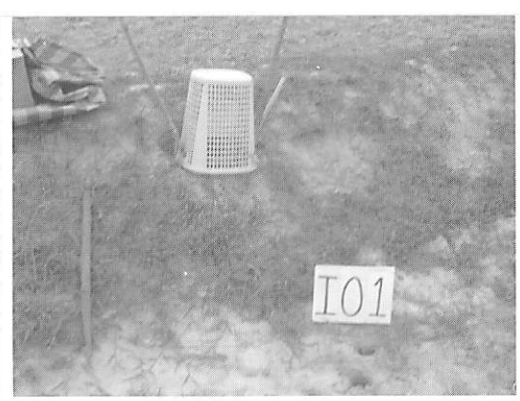
Site No.	Site 4-05	**Date** 3/05/2006	
Name	Amphoe: King Amphoe Chamni		
Location	Lat: 14.755	Lon: 102.810	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	Site 1	**Date** 30/05/2006	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes	It has water only around this small area		

Site No.	Site 5	**Date** 30/05/2006	
Name	Amphoe: Khu Muang		
Location	Lat: 15.365	Lon: 103.012	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Installed soil moisture and soil temperature at 10 cm from surface.		

Site No.	Site 5	**Date** 30/05/2006	
Name	Amphoe: Khu Muang		
Location	Lat: 15.365	Lon: 103.012	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Measure surface roughness by Topcon equipment		

Site No.	Site 1	**Date** 20/06/2006	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			



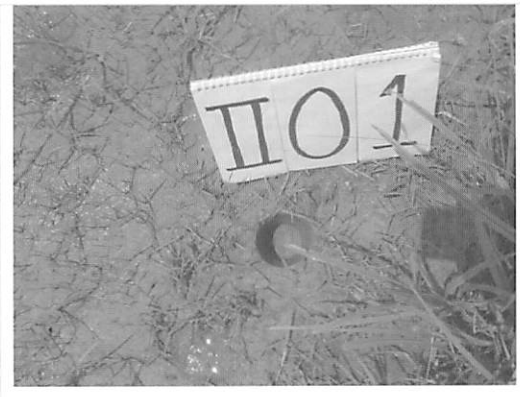
Site No.	Site 1	**Date** 20/06/2006	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	Site 1	**Date** 31/10/2005	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	Site 1	**Date** 31/10/2005	
Name	Amphoe: King Amphoe Ban Mai Chai Phot		
Location	Lat: 15.636	Lon: 102.899	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	Site 1	**Date** 31/10/2005
Name	Amphoe: King Amphoe Ban Mai Chai Phot	
Location	Lat: 15.636	Lon: 102.899
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-01	**Date** 20/06/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 2-02	**Date** 20/06/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

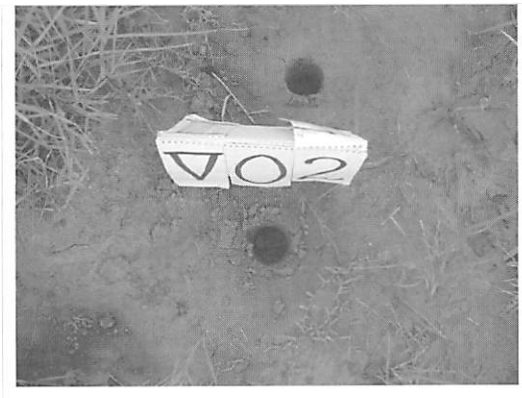
Site No.	Site 2-03	Date 20/06/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-04	Date 20/06/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2-05	Date 20/06/2006
Name	Amphoe: Phutthaisong	
Location	Lat: 15.512	Lon: 103.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 5-01	**Date** 20/06/2006
Name	Amphoe: Khu Muang	
Location	Lat: 15.365	Lon: 103.012
Irrigation	Irrigated	(Rain-fed)
Growth stage	(Vegetative)	Reproductive
	Ripening	Harvested
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 5-02	**Date** 20/06/2006
Name	Amphoe: Khu Muang	
Location	Lat: 15.365	Lon: 103.012
Irrigation	Irrigated	(Rain-fed)
Growth stage	(Vegetative)	Reproductive
	Ripening	Harvested
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		



Site No.	Site 5-03	**Date** 20/06/2006
Name	Amphoe: Khu Muang	
Location	Lat: 15.365	Lon: 103.012
Irrigation	Irrigated	(Rain-fed)
Growth stage	(Vegetative)	Reproductive
	Ripening	Harvested
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 1	**Date** 25/07/2006
Name	Amphoe: King Amphoe Ban Mai Chai Phot	
Location	Lat: 15.636	Lon: 102.899
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes	It is flooded after it rained two nights	

Site No.	Site 5-03	**Date** 25/07/2006
Name	Amphoe: Khu Muang	
Location	Lat: 15.365	Lon: 103.012
Irrigation	Irrigated	(Rain-fed)
Growth stage	(Vegetative)	Reproductive
	Ripening	Harvested
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes	Measuring surface roughness	

Site No.	Site 1	**Date** 25/07/2006
Name	Amphoe: King Amphoe Ban Mai Chai Phot	
Location	Lat: 15.636	Lon: 102.899
Irrigation	Irrigated	(Rain-fed)
Growth stage	(Vegetative)	Reproductive
	Ripening	Harvested
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes		

Site No.	Site 2	**Date** 04/10/2006	
Name	Amphoe: Phutthaisong		
Location	Lat: 15.512	Lon: 103.041	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	(Vegetative)	Reproductive	
	Ripening	Harvested	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes	Because of heavy flood, equipments were broken		

Site No.	Site 5	**Date** 04/10/2006	
Name	Amphoe: Khu Muang		
Location	Lat: 15.365	Lon: 103.012	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	(Vegetative)	Reproductive	
	Ripening	Harvested	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes	It was flooded and the basket was broken. It seemed to be damaged by human being.		

Site No.	Site 4	**Date** 3/05/2006	
Name	Amphoe: King Amphoe Chamni		
Location	Lat: 14.755	Lon: 102.810	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	(Vegetative)	Reproductive	
	Ripening	Harvested	
Rice type	(Major rice)	Minor rice	
Drought	N/A		
Flood	2006		
Notes	Because of heavy flooding, equipments could not be found		

A.4 REMARKS

After surveyed paddy fields in Buriram province, we found that

- Southern parts of Buriram province have irrigation system from Lam Nang Rong Dam, but farmers almost plant only major rice.
- Droughts repeatedly occurred in March until May and flood also happened in July until August because of two seasonal monsoons in this area.
- In 2006, as Buriram had rainstorm, some areas were suffered by flooding after they transplanted rice in August. But many areas had much less rain before flooding.
- Many unpredictable situation of human and equipments always happen in our study sites.

APPENDIX B: FIELD SURVEY TO PADDY FIELDS IN UBON RATCHATHANI PROVINCE

B.1 INTRODUCTION

Ubon Ratchathani provinces (*changwat*) is the country's easternmost in north-eastern of Thailand. Distance is about 500 km away from Bangkok. Neighboring Provinces are Sisaket, Yasothon and Amnat Charoen. To the north and east it borders Salavan and Champasak of Laos, to the south Preah Vihear of Cambodia. Area is around 15,744.8 km².

From history this area was a part of Khmer Empire until King Ramathibodi of Ayutthaya defeated it and take this part. In 1767, many tribes settled in this area call Kha and Suai. In next 20 years, King Rama I period, Thao Khamphong established Ubon Ratchathani then in 1792 it became a province. Ubon Ratchathani became the administrative center of north-eastern region of Thailand. Until 1972 the Ubon Ratchathani province was the largest province of Thailand areawise. In the same year Yasothon was split off also in 1993 Amnat Charoen, after which it now holds the 5th rank.

The province is subdivided into 20 districts (*Amphoe*) and 5 minor districts (*King Amphoe*). The districts are divided into 219 communes (*tambon*) and 2469 villages (*muban*).

Source: http://en.wikipedia.org/wiki/Ubon_Ratchathani_Province

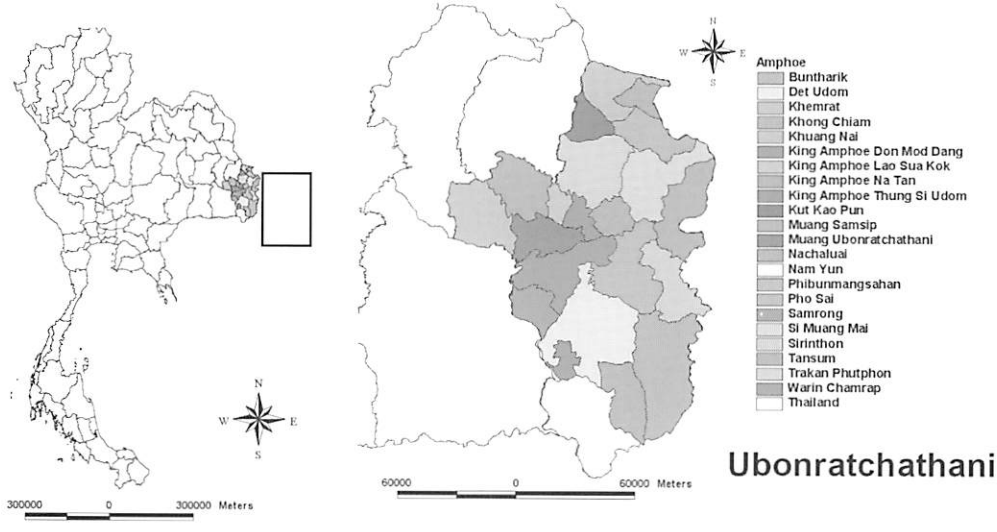


Figure B.1: Map of Ubon Ratchathani province, Thailand, with districts (Amphoe) boundary

Table B. 1: Major Rice and Second Rice: Area, production and yield by province, Year 1992/93 –2005

	Planted area (rais)		Harvested area (rais)		Production (tons)		Yield per rai (kgs.)	
	Major Rice	*Second Rice*	Major Rice	Second Rice	Major Rice	Second Rice	Major Rice	Second Rice
1992/93	3508727	30,188	3,441,368	29,930	821,042	11,049	239	369
1993/94	3,432,199	44,322	3,212,881	44,322	713,897	12,962	222	292
1994/95	2,945,927	31,319	2,858,190	30,502	741,530	10,210	259	335
1995/96	2,946,448	24,029	2,723,991	23,501	748,398	8,105	275	345
1996/97	2,891,807	25,916	2,818,081	24,675	686,035	7,848	243	318
1997/98	2,979,330	31,639	2,910,286	30,416	746,471	10,589	256	348
1998/99	3,042,863	49,582	2,999,651	48,197	743,247	12,845	248	267
1999/00	3,097,624	59,875	3,061,557	59,875	796,490	17,942	260	300
2000/01	3,160,726	65344	3,018,089	64985	857,491	18452	284	284
2001	3,363,915	62816	3,316,356	61504	896,904	17721	270	288
2002	3,224,240	46,543	3,042,148	45,476	799,877	14,138	263	311
2003	3,180,431	57,978	3,116,822	57,978	808,041	16,660	259	287
2004	3,285,062	59,606	3,019,583	59,606	689,863	18,751	228	315
2005	3,207,788	44,540	3,062,557	44,466	959,606	13,140	-	-

(Source: http://www.oae.go.th)

Table B. 2: Number of water resources by type of water resources and district: 2005

District/Minor district	Total	Type of water resources							
		Reservior		Concrete wire	Dam	Pond	Canal, ditch	Artesian well	Hollow well
		Medium	Small						
	64,038	**86**	**868**	**1,878**	**7**	**19,041**	**1,442**	**14,163**	**26,553**
Muang Ubon Ratchathani	11,896	8	25	83	3	718	86	2,069	8,904
Kut Khaopun	1,638	-	17	141	1	627	50	412	390
Khemarat	2,007	-	88	117	-	658	48	517	579
Khuang Nai	2,828	8	69	40	1	1,222	161	408	919
Khong Chiam	1,379	2	19	107	-	480	20	364	387
Don Mot Daeng	766	1	2	17	-	426	22	95	203
Det Udom	4,589	-	19	237	-	2,010	205	1,204	914
Trakan Phutphon	2,877	6	86	106	-	1,091	84	680	824
Tan Sum	1,226	-	28	122	-	397	53	174	452
Thung Si Udom	1,269	1	1	24	-	728	35	115	365
Na Chaluai	2,402	3	73	53	-	988	34	470	781
Nam Yun	3,047	22	39	143	-	647	46	433	1,717
Buntharik	2,574	9	87	101	-	858	66	813	640
Phibunmangsahan	4,957	8	40	92	1	970	47	2,643	1,156
Pho Sai	922	1	37	79	-	311	28	252	214
Muang Samsip	4,042	1	55	76	-	1,250	83	828	1,749
Warin Chamrap	5,397	6	33	108	1	935	68	866	3,380
Si Muang Mai	2,157	-	34	75	-	892	44	431	681
Samrong	3,705	-	27	70	-	1765	115	483	1,245
Sirindhorn	1,311	5	41	25	-	671	28	280	261
King amphoe Na Year	645	-	9	13	-	332	27	133	131
King amphoe Lao Sua Kok	992	5	-	17	-	385	28	106	451
King amphoe Na Tan	553	-	15	19	-	246	23	169	81
King amphoe Swang Wirawong	579	-	12	2	-	272	31	148	114
King amphoe Nam khun	280	-	12	11	-	162	10	70	15

(Source: http://webhost.nso.go.th)

Table B.3: Temperature, Humid and rainfall 1993-2005

Temperature (o C)	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Average								-	-	-	-	27.3	27.5
Max Avg.	36.7	34.6	35.4	39.9	37.9	42.0	35.2	39.1	36.3	36.3	33.4	33.5	33.7
Min Avg.	19.1	20.2	18.3	11.1	13.2	15.0	19.1	11.7	19.6	19.7	22.7	22.3	22
Max								-	-	-	-	40.4	41.2
Min								-	-	-	-	12.2	11.2
Avg. Air pressure								-	-	-	-	1,009.7	1,009.30
Humidity (%)	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Average								-	-	-	-	70	72
Max Avg.								89.4	88.8	87.5	89.0	87	88
Min Avg.								59.9	53.9	52.0	53.0	51	53
Min								-	-	-	-	25	25
Rainfall	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Rainfall (mm.)	1,028.7	1,980.7	1,264.5	1,469.4	1,544.9	1,318.3	1,582.5	1,844.6	1,720.0	1,677.3	1,560.4	1,471.1	1,323.0
No. Of rainy day	97	146	101	128	110	112	128	123	125	118	118	105	120
Highest rainfall (mm.)								-	-	-	93.8	110.5	66.5

(Source: http://ubonstatistic.ubpoc.in.th)

Table B.4: Monthly rainfall in 2004-2005

	2004				2005			
	Rainfall (mm.)	No. of rainy day	Daily maximum (mm.)	Date of daily highest	Rainfall (mm.)	No. of rainy day	Daily maximum (mm.)	Date of daily highest
Ubonratchathani Meteorological sta. (Annual)	**1471.1**	**105**	**110.50**	**13-Jun**	**1,323.00**	**120**	**66.50**	**17-Aug**
January	7.70	3	6.40	18	-	-	-	-
February	18.80	4	14.00	2	-	-	-	-
March	2.60	2	1.90	21	9.50	5	3.80	3
April	65.00	8	32.00	22	45.20	7	14.30	19
May	130.20	11	44.70	4	137.30	14	40.60	8
June	458.10	20	110.50	13	1,254.50	17	36.00	21
July	334.90	21	72.10	26	263.00	18	51.60	12
August	190.80	18	86.00	7	313.60	24	66.50	17
September	261.50	16	66.20	19	246.20	19	57.90	8
October	1.10	1	1.10	2	37.10	10	10.60	7
November	0.40	1	0.40	25	15.70	5	7.30	7
December	-	-	-	-	0.90	1	0.90	20

Table B.5: Monthly Humid in 2005

Monthly	Relative humidity(%)				
	Mean	Mean maximum	Mean minimum	Min	Date min
Ubonratchathani Meteorological station (Annual)	**72**	**88**	**53**	**25**	**18-Feb**
January	64	86	40	32	9.28
February	60	80	37	25	18
March	61	79	42	29	8
April	68	84	47	34	21
May	73	90	49	31	6
June	77	92	59	46	13
July	82	94	65	50	15
August	83	94	66	55	22
September	84	95	68	48	2
October	74	89	56	45	22
November	73	88	55	40	30
December	66	82	48	36	18

(Source: Ubon ratchathani Meteorological Station)

Table B.6: Monthly Temperature in 2005

	Temperature (° C)							Mean atmospheric pressure (HPA)
	Mean	Mean max	Mean min	Max	Date Max	Min	Date Min	
Ubonratchathani Meteorological station								
Annual	**27.5**	**33.7**	**22**	**41.2**	**3-Jan**	**11**	**2-Jan**	**1,009.30**
January	24.7	33.6	17.9	37	30	11	2	1,012.90
February	28.7	36.6	21.7	39.2	26	17	21	1,011.00
March	28	35.5	21.3	40.3	31	13.1	6	1,011.70
April	30	37.4	23.9	40.6	11	20	4	1,009.60
May	29.9	36.3	24.7	41.2	3	22	9	1,006.40
June	28.7	34.1	24	36.6	7,13	22	22	1,005.30
July	27.9	32.7	23.2	36.2	15	20	3	1,006.20
August	27.4	31.9	22.9	35.2	24,25	20	18	1,006.20
September	27.4	31.7	23.5	34.4	25	21	19	1,007.30
October	27.5	33.1	22.1	35	3,4	20.0	31	1,010.40
November	26.3	32.4	21.2	35.3	12	16	22	1,011.30
December	23.4	30	17.5	34.5	3,4	13	19	1,013.10

(Source: Ubon ratchathani Meteorological Station)

B.2 STUDY AREA

B.2-1 Geography Location

Ubon Ratchathani Province is selected as study area. Located in latitude 15° 13' 59N and longitude 104° 51' 47E. It is located in the northeastern part of Thailand. Area 15,744.8 km² which about 9.5% of North-east region of Thailand and near by

North : Amnat chareon, Yasothon Province and Laos
East : Laos
South : Srisaket Province and Cambodia
West : Srisaket and Yasothon Province

Average height above mean sea level is 68 meters. Major landform is plateau. Mae Khong river is border of Thailand and Loas. Chi river come to Mun river at Amphoe Muang and flow to Mae Khong river at amphoe Klong Chiam.

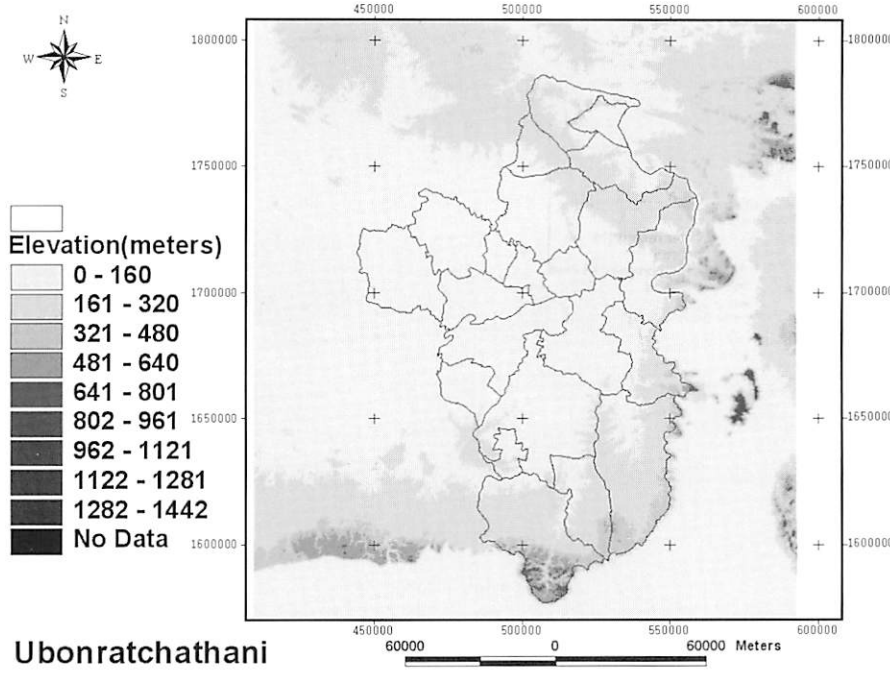


Figure B.2: Map of Elevation of Ubon Ratchathani province

B.2-2 Climates and temperature

Ubon Ratchathani Province located in a tropical climate. There are usually three seasons one year. Summer or dry season start from March to June and rainy season usually start from July and ends by October and winter start from November and ends in February. Normally climate is same as neighbor provinces. Highly rainfall in May till September in 2005 have 120 rainy days. (Rainfall 1323 mm.)

B.2-3 Land Use and Land Cover

According to the data from Thailand Land Development Department in 1990, the major land use is paddy fields, which covers almost 60% and field crop, which almost 27%of the total land area in Ubon Ratchathani province. The detailed land use map is shown in Figure B.3.

Source: Thailand Land development department

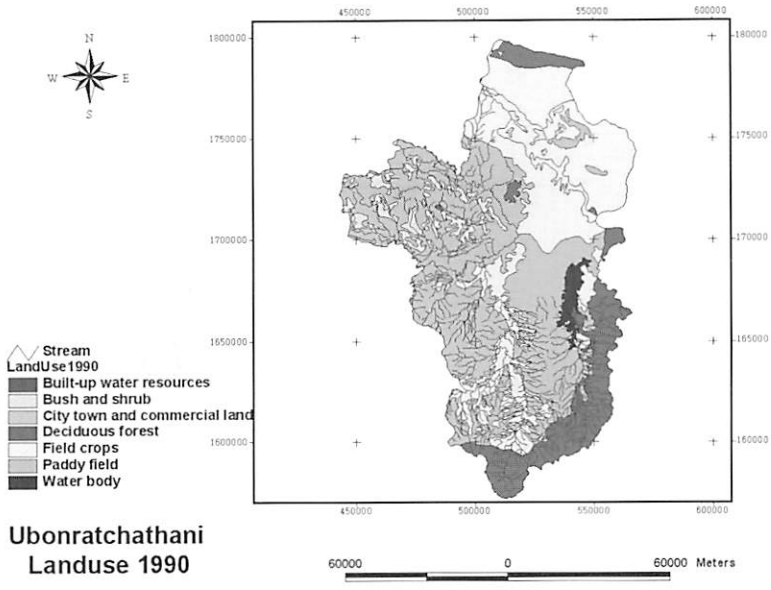
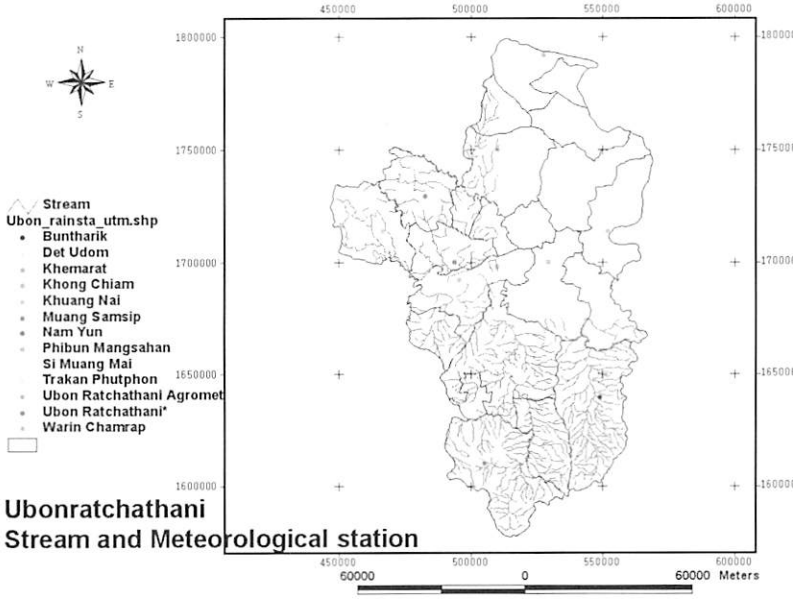


Figure B.3: Landuse map in Ubon Ratchathani province

B.2-4 Hydrology

In Ubon Ratchathani have main river for example Mun and Chi river. Minor rivers such as Lam Sebok, Lam Domyai, Lam Domnoi and hilly area at south part that have Bantat and Phanomdongrak mountain as the border of Loas and Cambodia. The northern bank of the Mun River, which down to its confluence with the Mekong River, known as "the Two-Colored River at Amphoe Klong Chiam (most eastern part of Thailand). This province has 2 water resources underground water resources and natural waer resources. Dam for electric plant are Sirinthon dam and Pak mun dam.



Source: Royal Irrigation department

Figure B.4: Streams and Meteorological stations in Ubon Ratchathani province

B.2-5 Soil

General Ubon Ratchathani soil has 4 categories

1. **Silt** found near river dalta, about 25.5% of total area
2. **Sandy loam** found in plateau area less nutrient, about 38.5% of total area
3. **Sandy clay loam** in flat plain moderately nutrient, about 7.5% of total area
4. **Loamy sand** near mountain and steep area low to moderately nutrient about 28.5% of total area

B.3 FIELD SURVEY

Trip to Ubon Ratchahani start from 30Oct -1 Nov. Within 3 days, we surveys 65 points in various type of land use mainly in paddy field (Figure B.5).

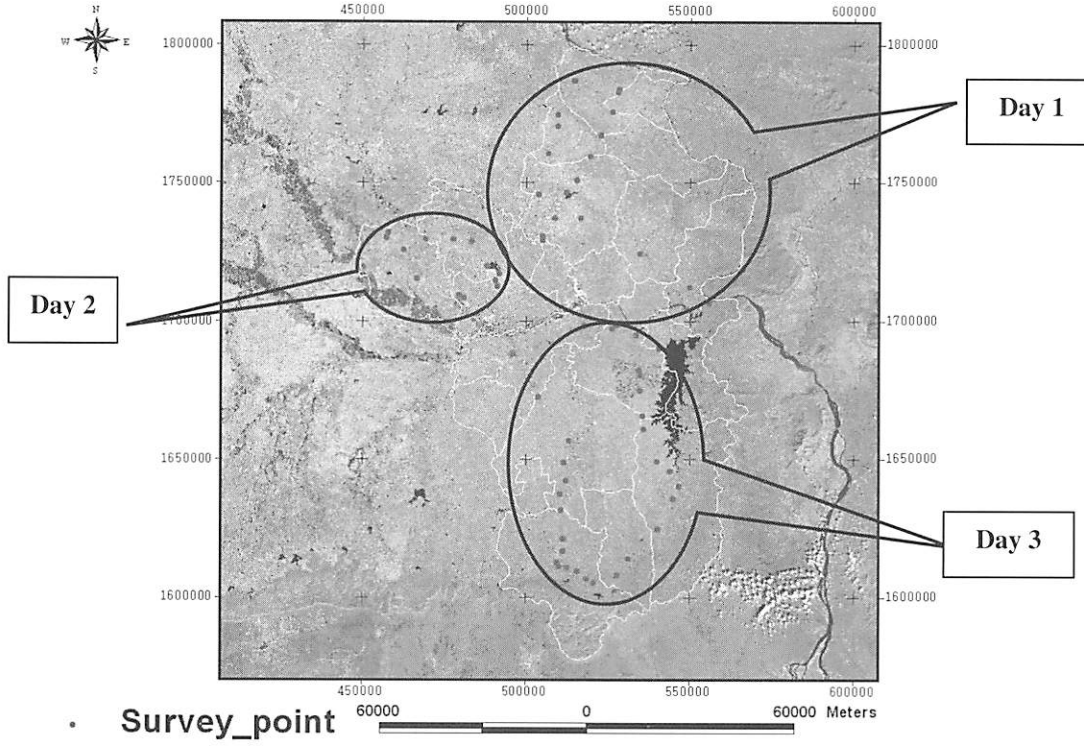
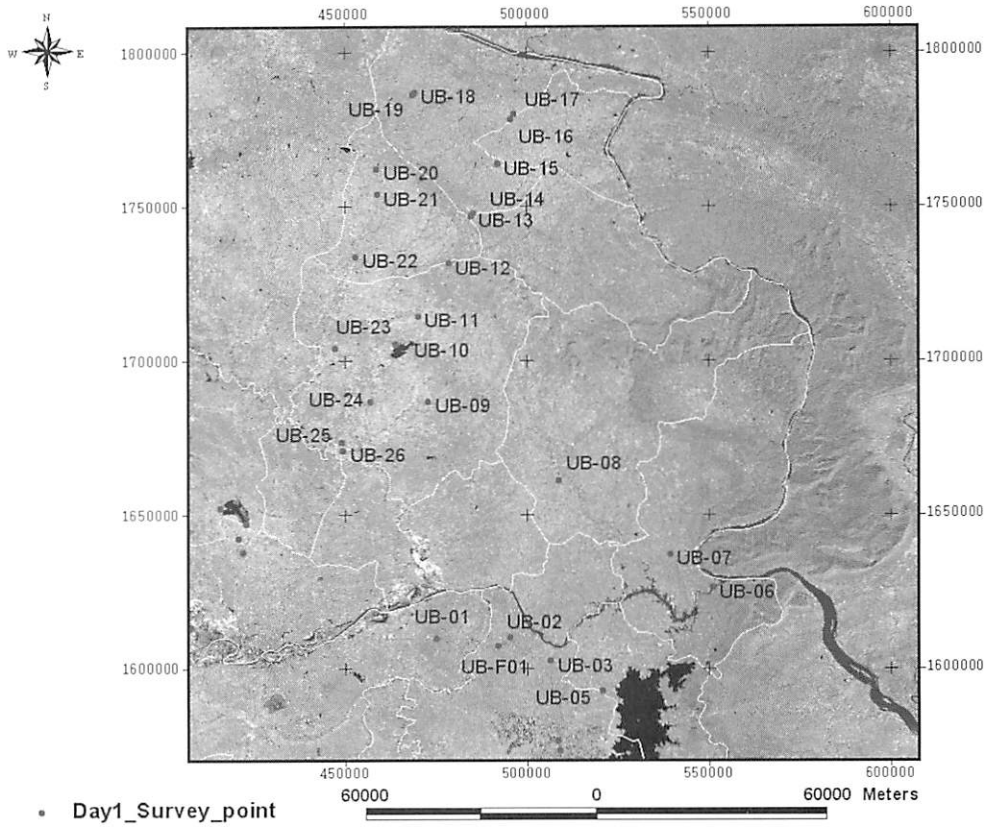


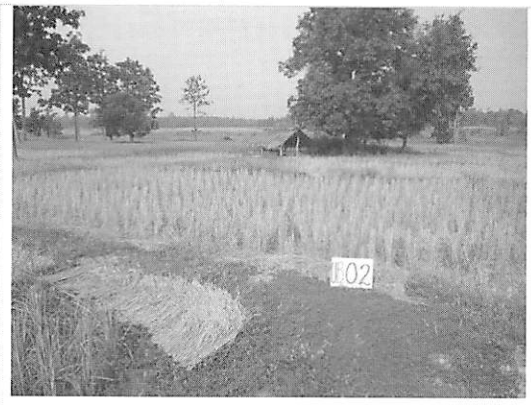
Figure B.5: Survey points in Ubon Ratchathani province

3.1 Day 1: Site UB 01 to UB 26 (27 points)



Site No.	UB-01	**Date** 30/10/2006	
Name	Amphoe: Kingsawangweerawong		
Location	Lat: 15.239	Lon: 105.099	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought	No drought before 2006 In 2006, Rain period came late		
Flood	Never flood		
Notes	Production 500 Ton/Rai		

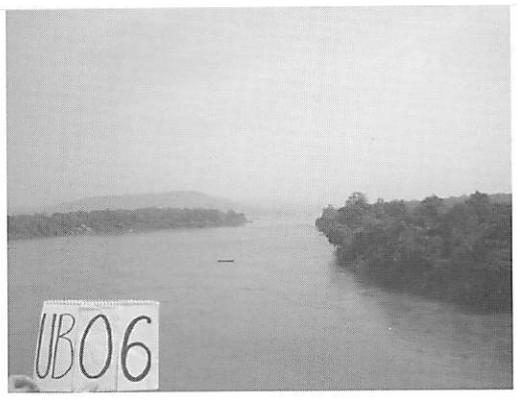
Site No.	UB-02	**Date** 30/10/2006
Name	Amphoe: Phibunmangsahan	
Location	Lat: 15.241	Lon: 105.204
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		



Site No.	UB-03	**Date** 30/10/2006
Name	Amphoe: Phibunmangsahan	
Location	Lat: 15.207	Lon: 105.261
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	It has a canal from Mun river	

Site No.	UB-05	**Date** 30/10/2006
Name	Amphoe: Sirinthon	
Location	Lat: 15.239	Lon: 105.099
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-06	**Date** 30/10/2006
Name	Amphoe: Khong Chiam	
Location	Lat: 15.309	Lon: 105.493
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Mun river, the biggest river of the Khorat Plateau, joins the Mekong river	



Site No.	UB-07	**Date** 30/10/2006
Name	Amphoe: Khong Chiam	
Location	Lat: 15.355	Lon: 105.432
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	(Major rice)	Minor rice
Drought		
Flood		
Notes	Rock soil, high land	

Site No.	UB-08	**Date** 30/10/2006
Name	Amphoe: Si Muang Mai	
Location	Lat: 15.458	Lon: 105.274
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	(Major rice)	Minor rice
Drought	In 2005, it had less rain	
Flood	No flood	
Notes		

Site No.	UB-09	**Date** 30/10/2006	
Name	Amphoe: Trakan Phutphon		
Location	Lat: 15.567	Lon: 105.087	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	It has a canal		

Site No.	UB-10	**Date** 30/10/2006	
Name	Amphoe: Phutphon	Trakan	
Location	Lat: 15.647	Lon: 105.042	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Near reservoir		

Site No.	UB-11	**Date** 30/10/2006	
Name	Amphoe: Trakan Phutphon		
Location	Lat: 15.685	Lon: 105.073	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-12	**Date** 30/10/2006
Name	Amphoe: Trakan Phutphon	
Location	Lat: 15.757	Lon: 105.117
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-13	**Date** 30/10/2006
Name	Amphoe: Khemrat	
Location	Lat: 15.823	Lon: 105.150
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-14	**Date** 30/10/2006
Name	Amphoe: Khemrat	
Location	Lat: 15.826	Lon: 105.152
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	In 2006, it had less rain than 2005.	

Site No.	UB-15	**Date** 30/10/2006	
Name	Amphoe: Khemrat		
Location	Lat: 15.896	Lon: 105.187	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvesting)	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-16	**Date** 30/10/2006	
Name	Amphoe: Khemrat		
Location	Lat: 15.958	Lon: 105.206	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvesting)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-17	**Date** 30/10/2006	
Name	Amphoe: Khemrat		
Location	Lat: 15.965	Lon: 105.210	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	(Ripening)	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-18 **Date** 30/10/2006	
Name	Amphoe: Khemrat	
Location	Lat: 15.995	Lon: 105.069
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	(Ripening)	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-19 **Date** 30/10/2006	
Name	Amphoe: Khemrat	
Location	Lat: 15.992	Lon: 105.066
Irrigation	Irrigated	(Rain-fed)
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	(Major rice)	Minor rice
Drought	No drought	
Flood	No flood	
Notes	Near mountain	

Site No.	UB-20 **Date** 30/10/2006	
Name	Amphoe: Kut Kao Pun	
Location	Lat: 15.889	Lon: 105.015
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	(Ripening)	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-21	**Date** 30/10/2006	
Name	Amphoe: Kut Kao Pun		
Location	Lat: 15.853	Lon: 105.015	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvesting)	
Rice type	(Major rice)	Minor rice	
Drought	No drought		
Flood	No flood		
Notes	In 2006, it had less rain than 2005 Seeding starts in Aug., and harvest starts in Nov.		

Site No.	UB-22	**Date** 30/10/2006	
Name	Amphoe: Kut Kao Pun		
Location	Lat: 15.767	Lon: 104.984	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	(Ripening)	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

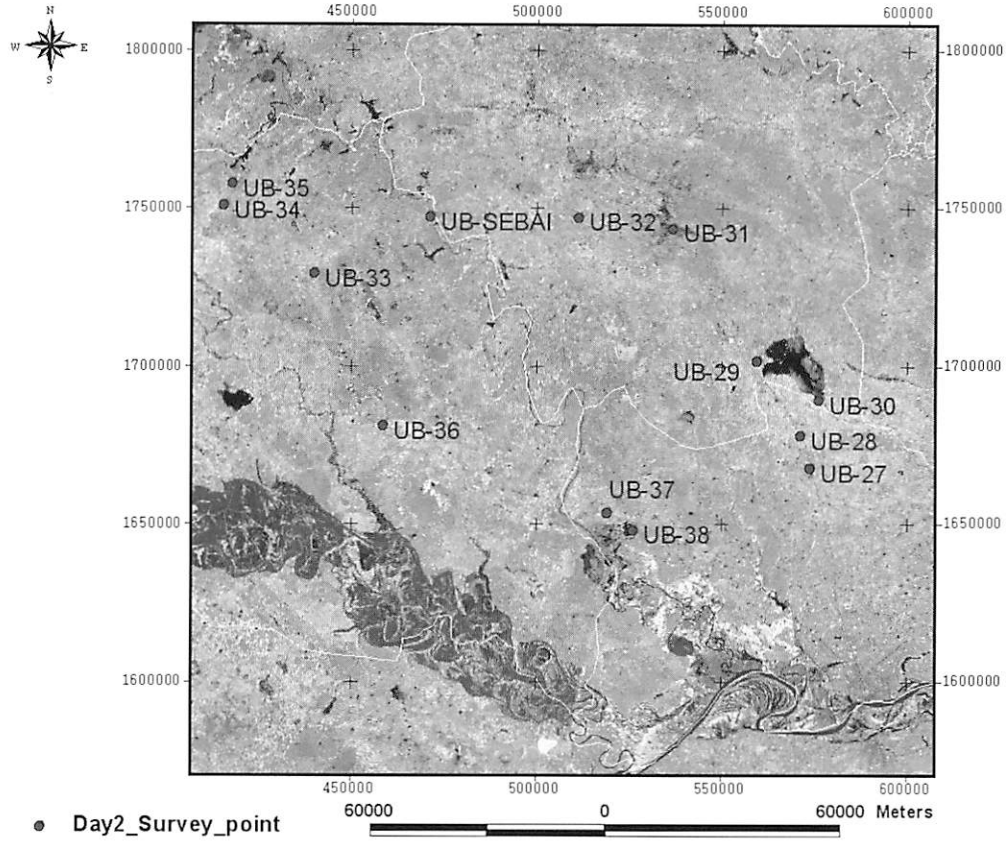
Site No.	UB-23	**Date** 30/10/2006	
Name	Amphoe: Kut Kao Pun		
Location	Lat: 15.640	Lon: 104.955	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	(Ripening)	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-24	**Date** 30/10/2006
Name	Amphoe: Trakan Phutphon	
Location	Lat: 15.566	Lon: 105.005
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-25	**Date** 30/10/2006
Name	Amphoe: Kingsawangweerawong	
Location	Lat: 15.511	Lon: 104.965
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	(Ripening)	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-26	**Date** 30/10/2006
Name	Amphoe: King Amphoe Don Mod Dang	
Location	Lat: 15.511	Lon: 104.965
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	(Major rice)	Minor rice
Drought		
Flood	Have in area near the road	
Notes		

3.2 Day 2: Site UB 27 to UB 38 (12 points)

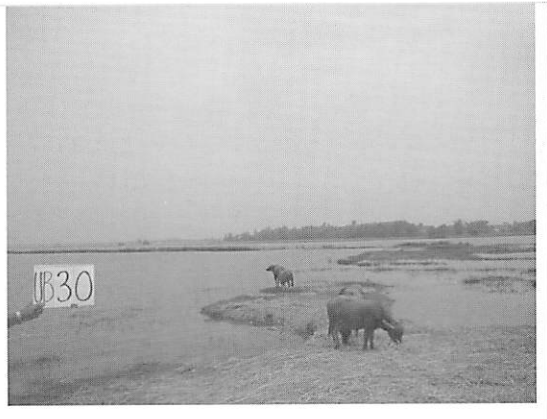


Site No.	UB-27	Date 31/10/2006
Name	Amphoe: Muang Ubonratchathani	
Location	Lat: 15.357	Lon: 104.823
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-28	**Date** 31/10/2006
Name	Amphoe: Muang Ubonratchathani	
Location	Lat: 15.376	Lon: 104.817
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	(Ripening)	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-29	**Date** 31/10/2006
Name		
Location	Lat: 15.420	Lon: 104.791
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	(Ripening)	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-30	**Date** 31/10/2006
Name	Amphoe: Muang Ubonratchathani	
Location	Lat: 15.397	Lon: 104.828
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Nong Chang Yai reservoir	



Site No.	UB-32	**Date** 31/10/2006
Name	Amphoe: Muang Samsip	
Location	Lat: 15.503	Lon: 104.684
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	2006 in June	
Flood	No flood	
Notes	In 2004 and 2005, it had normal rain. In 2006, rain came late Using underground water to plant chili Justmin rice	

Site No.	UB-Sebai	**Date** 31/10/2006
Name	Amphoe: Muang Samsip	
Location	Lat: 15.503	Lon: 104.595
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Lam Sebai	

Site No.	UB-33	**Date** 31/10/2006
Name	Amphoe: Khuang Nai	
Location	Lat: 15.470	Lon: 104.525
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-34 **Date** 31/10/2006	
Name	Amphoe: Khuang Nai	
Location	Lat: 15.509	Lon: 104.471
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

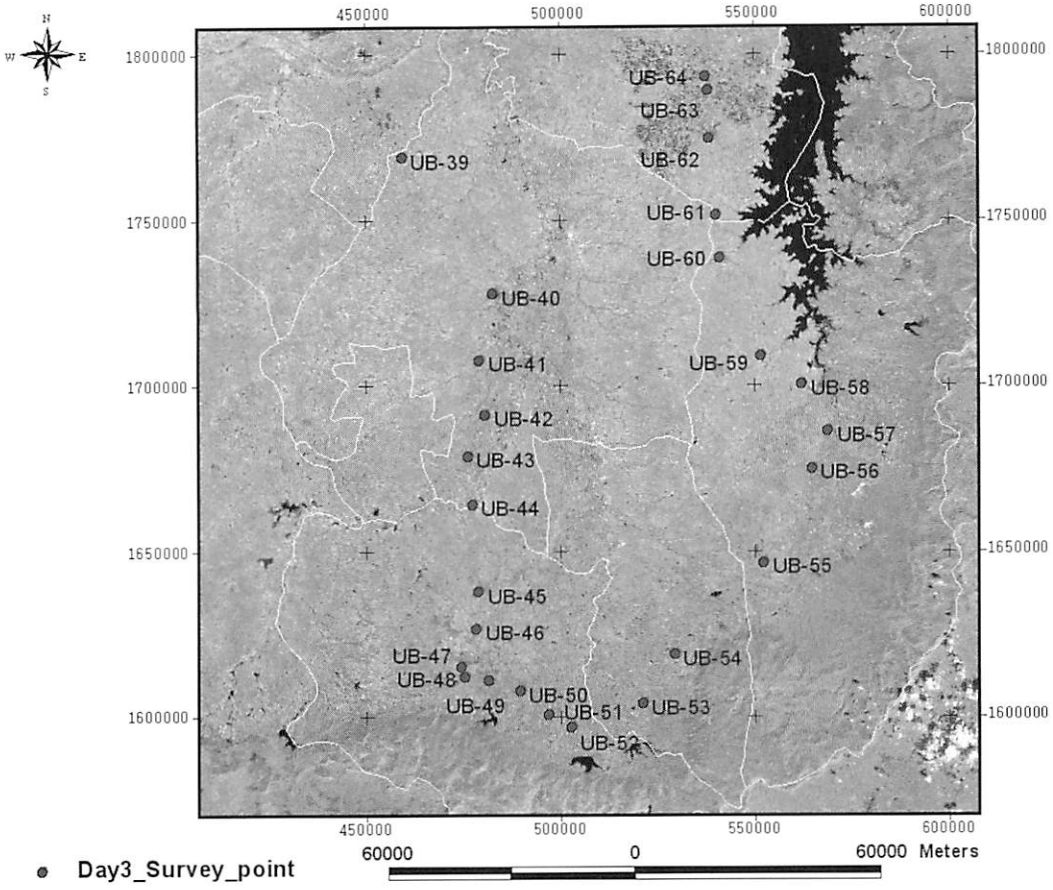
Site No.	UB-35 **Date** 31/10/2006	
Name	Amphoe: Khuang Nai	
Location	Lat: 15.521	Lon: 104.476
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	In 2006	
Flood	No flood	
Notes	Seeding in June	

Site No.	UB-36 **Date**31/10/2006	
Name	Amphoe: Khuang Nai	
Location	Lat: 15.382	Lon: 104.567
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-37	**Date** 31/10/2006
Name	Amphoe: Muang Ubonratchathani	
Location	Lat: 15.332	Lon: 104.702
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-38	**Date** 31/10/2006
Name	Amphoe: Muang Ubonratchathani	
Location	Lat: 15.322	Lon: 104.717
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Nong Khon (natural) pond	

3.3 Day 3: Site UB 39 to UB 64 (26 points)



Site No.	UB-39	**Date** 1/10/2006	
Name	Amphoe: Det Udom		
Location	Lat: 15.017	Lon: 104.955	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-40	**Date** 1/10/2006
Name	Amphoe: Det Udom	
Location	Lat: 14.880	Lon: 105.049
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-41	**Date** 1/10/2006
Name	Amphoe: Det Udom	
Location	Lat: 14.812	Lon: 105.035
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	In 2002	
Flood	Never	
Notes	In 2006, rain came late	

Site No.	UB-42	**Date** 1/10/2006
Name	Amphoe: Det Udom	
Location	Lat: 14.757	Lon: 105.041
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Para rubber plantation	

Site No.	UB-43 **Date** 1/10/2006	
Name	Amphoe: Det Udom	
Location	Lat: 14.715	Lon: 105.022
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Sugar cane crop field	

Site No.	UB-44 **Date** 1/10/2006	
Name	Amphoe: Det Udom	
Location	Lat: 14.667	Lon: 105.027
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-45 **Date** 1/10/2006	
Name	Amphoe: Nam Yun	
Location	Lat: 14.579	Lon: 105.034
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	In 2005	
Flood	Never flood	
Notes		

Site No.	UB-46	**Date** 1/10/2006	
Name	Amphoe: Nam Yun		
Location	Lat: 14.541	Lon: 105.031	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Dragon fruit		

Site No.	UB-47	**Date** 1/10/2006	
Name	Amphoe: Nam Yun		
Location	Lat: 14.503	Lon: 105.015	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-48	**Date** 1/10/2006	
Name	Amphoe: Nam Yun		
Location	Lat: 14.493	Lon: 105.019	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-49 **Date** 1/10/2006	
Name	Amphoe: Nam Yun	
Location	Lat: 14.489	Lon: 105.044
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-50 **Date** 1/10/2006	
Name	Amphoe: Nam Yun	
Location	Lat: 14.478	Lon: 105.077
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-51 **Date** 1/10/2006	
Name		
Location	Lat: 14.454	Lon: 105.107
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-52	**Date** 1/10/2006	
Name	Amphoe: Nam Yun		
Location	Lat: 14.442	Lon: 105.130	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-53	**Date** 1/10/2006	
Name	Amphoe: Nachaluai		
Location	Lat: 14.466	Lon: 105.204	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-54	**Date** 1/10/2006	
Name	Amphoe: Nachaluai		
Location	Lat: 14.515	Lon: 105.238	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Nachaluai weir		

Site No.	UB-55	**Date** 1/10/2006
Name	Amphoe: Nachaluai	
Location	Lat: 14.608	Lon: 105.331
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	Never	
Flood	Never	
Notes	Seedling in August	

Site No.	UB-56	**Date** 1/10/2006
Name	Amphoe: Buntharik	
Location	Lat: 14.703	Lon: 105.381
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Canal	

Site No.	UB-57	**Date** 1/10/2006
Name	Amphoe: Buntharik	
Location	Lat: 14.740	Lon: 105.399
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-58 **Date** 1/10/2006	
Name	Amphoe: Buntharik	
Location	Lat: 14.787	Lon: 105.399
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-59 **Date** 1/10/2006	
Name	Amphoe: Buntharik	
Location	Lat: 14.817	Lon: 105.328
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Many trees inside paddy fields	

Site No.	UB-60 **Date** 1/10/2006	
Name	Amphoe: Buntharik	
Location	Lat: 14.915	Lon: 105.286
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UB-61	**Date** 1/10/2006
Name	Amphoe: Phibunmangsahan	
Location	Lat: 14.9591	Lon: 105.282
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	In 2003, 2004	
Flood	Never	
Notes	Seeding in Aug.	

Site No.	UB-62	**Date** 1/10/2006
Name	Amphoe: Phibunmangsahan	
Location	Lat: 15.036	Lon: 105.275
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Irrigation canal	

Site No.	UB-63	**Date** 1/10/2006
Name	Amphoe: Phibunmangsahan	
Location	Lat: 15.084	Lon: 105.275
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought	Some periods	
Flood	Never	
Notes	In Aug. 2006, it rained Irrigation system is not good then, they can not get enough water to grow minor rice	

Site No.	UB-64 **Date** 1/10/2006		
Name	Amphoe: Phibunmangsahan		
Location	Lat: 15.097	Lon: 105.27255	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought	Never		
Flood	Never		
Notes	Have good irrigation system from Sirindhorn Dam Seeding in July and January Harvest in November and April		

B.4 REMARKS

After surveyed paddy fields in Ubon Ratchathani province, we found that

- Low rice production has three major factors as follows
  - Rainfall
  - Irrigation system and farmer's land management
  - Paddy fields topography such as mountainous area, highland, flat plain and soil type in each paddy field (small scale units)
- Paddy fields in Trakan Phutphon and Khemrat are under better management system than other areas.
- In Amphoe Nam Yun, southern part of province, paddy field are mixed with crop and agriculture areas such as cassava, dragon fruit, sugar cane, longan and para rubber because of undulated area.
- Different parts of province have different periods of cropping.
- Even though it has two big dams in eastern part, irrigation system has not been properly developed for all farmers in irrigated areas.

APPENDIX C: FIELD SURVEY TO PADDY FIELDS IN UDON THANI PROVINCE

C.1 INTRODUCTION

The province is most famous for the archeological site Ban Chiang with its remains of the Bronze age. Udon is one of the more bustling markets for agricultural goods in the relatively dry northeast of Thailand, and received its biggest economic boost in the 1960s when the US built the Udon Royal Thai Air Force Base as a joint-force military base during the Vietnam War. Udonthani has been selected to be the center of trades and services connecting with Indochinese countries according to the National Economic and Social Development Plan. Because of it have the third biggest economic system and the biggest products of sugar cane and live-stock in this region. There are sugar refinery, cassava factories and rice mills.

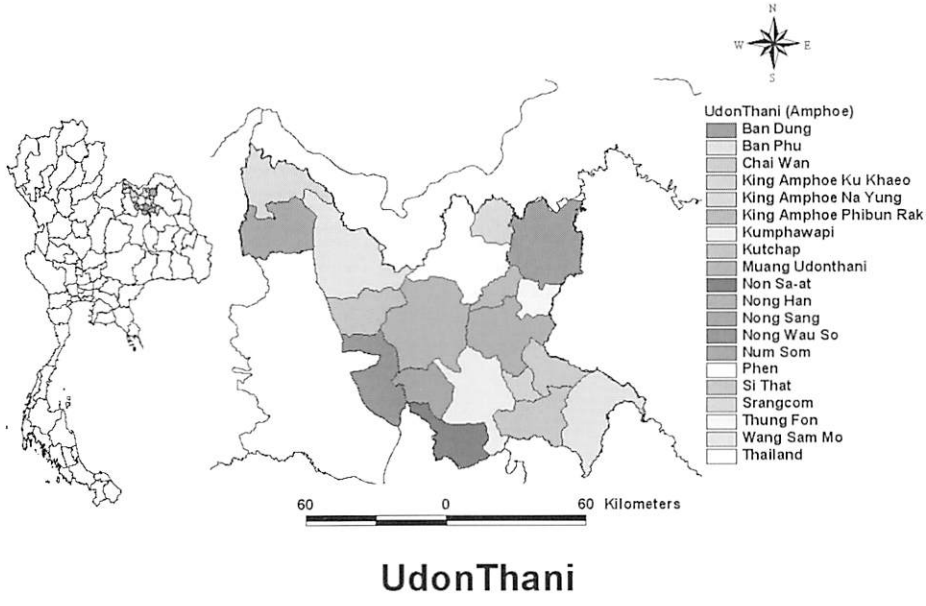


Figure C.1: Map of Udon Thani province, Thailand, with districts (Amphoe) boundary

Table C.1: Major Rice and Second Rice: Area, production and yield by province, Year 1992/93 -2005

	Planted area (rais)		Harvested area (rais)		Production (tons)		Yield per rai (kgs.)	
	Major Rice	Second Rice	Major Rice	Second Rice	Major Rice	Second Rice	Major Rice	Second Rice
1992/93	2739939	11,476	2,568,201	10,443	693,205	3,971	270	380
1993/94	2,682,600	20,904	2,249,092	18,568	552,616	6,747	246	363
1994/95	2,003,540	4,748	1,906,585	3,974	482,921	1,263	253	318
1995/96	2,064,828	5,377	1,858,345	5,229	476,975	2,081	257	398
1996/97	2,039,943	13,634	1,685,415	13,634	517,878	5,273	307	387
1997/98	1,925,070	7,298	1,879,355	7,281	486,228	2,030	259	279
1998/99	1,856,633	13,100	1,721,118	12,409	503,406	5,441	292	438
1999/00	2,051,918	17,608	1,939,376	15,060	575,324	7,976	297	530
2000/01	2,066,085	13926	1,763,084	13718	573,228	5361	325	391
2001	2,024,807	19493	1,824,139	19448	516,605	9265	283	476
2002	1,901,768	23,310	1,551,505	22,278	489,891	9,486	316	426
2003	1,882,750	23,257	1,860,586	22,179	584,286	9,666	314	436
2004	1,944,030	23,620	1,762,263	23,620	408,246	10,173	232	431
2005	1,892,840	22,439	1,840,330	18,896	579,091	8,751	-	-

(Source: http://www.oae.go.th)

Table C.2: Number of water resources by type of water resources and district in 2005

District/Minor district	Total	Reservoirs			Concrete wire	Dam	Pond	Canal, ditch	Artesian well	Hollow well
		Big	Med	Small						
	1508	**1**	**17**	**138**	**105**	**0**	**487**	**734**	**0**	**0**
Mueang Udon Thani	125	1	9	14	5	-	50	41	-	-
Kut Chap	52	-	2	5	3	-	12	32	-	-
Kumpawapi	109	-	-	4	10	-	55	38	-	-
Chai Wan	54	-	-	9	5	-	11	29	-	-
Thung Fon	39	-	-	6	-	-	10	23	-	-
Na Yung	44	-	1	4	10	-	10	16	-	-
Nam Som	57	-	1	4	10	-	19	18	-	-
Non Sa-at	68	-	1	7	1	-	33	26	-	-
Ban Dung	139	-	-	13	5	-	37	81	-	-
Ban Phae	141	-	-	9	18	-	48	64	-	-
Phen	133	-	1	12	7	-	28	80	-	-
Phibun Rak	40	-	-	2	2	-	10	25	-	-
Wang Sam Mo	87	-	-	16	7	-	12	51	-	-
Si That	74	-	-	7	5	-	31	30	-	-
Sang Khom	45	-	-	6	1	-	13	25	-	-
Nong Wua So	65	-	-	9	5	-	17	34	-	-
Nong Saeng	54	-	1	4	1	-	22	26	-	-
Nong Han	140	-	1	5	6	-	52	76	-	-
King Amphoe Ku Kaeo	20	-	-	1	2	-	5	12	-	-
King Amphoe Prachaksinlapakhom	22	-	-	1	2	-	12	7	-	-

(Source: Regional Irrigation Office Udonthani Provincial)

Table C.3: Monthly rainfall in 2004-2005

	2004				2005			
	Rainfall (mm.)	No. of rainy day	Daily maximum (mm.)	Date of daily highest	Rainfall (mm.)	No. of rainy day	Daily maximum (mm.)	Date of daily highest
Annual	**1,512.1**	**126**	**75.8**	**22**	**1,423.1**	**122**	**79.2**	**14**
January	1.7	2	1.4	18	0.6	1	0.6	13
February	64.9	6	41.4	7	15.7	1	15.7	2
March	38.2	3	15.2	30	5.3	2	5.1	29
April	98.7	12	34.2	2	30.6	7	16.9	27
May	250.4	19	59.2	31	102.3	16	20.4	7
June	229.7	17	56.9	14	293.5	24	79.2	23
July	524.8	26	75.8	22	246.9	17	62.3	13
August	133.8	22	32.5	19	268.6	26	66.0	30
September	166.9	15	57.0	20	429.5	20	60.1	6
October	2.0	1	2.0	2	18.2	5	8.1	2
November	1.0	3	0.4	26,27	11.9	3	8.4	7
December	0.0	0	0.0	-	0.0	0	0.0	-

(Source: Udonthani Meteorological Station)

Table C.4: Monthly Humid in 2004

Relative humidity					
	Mean	Mean maximum	Mean minimum	Minimum	Date minimum
Annual	**69.25**	**86.17**	**49.25**	**13**	**18**
January	62.00	83	36.00	24	25
February	59.00	82	34.00	13	18
March	55.00	76	34.00	22	12
April	59.00	80	39.00	20	7,8
May	70.00	87	50.00	25	6
June	79.00	91	61.00	46	5
July	79.00	91	63.00	47	17
August	81.00	92	66.00	55	21
September	83.00	94	66.00	56	17
October	71.00	88	51.00	43	22
November	71.00	89	49.00	34	22
December	62.00	81	42.00	25	22

(Source: Udonthani Meteorological Station)

Table C.5: Monthly Temperature in 2005

	Mean	Max	Date Max	Min	Date Min	Mean atmospheric pressure (HPA)
Annual	**27.68**	**33.09**	**22.29**	**42.5**	**31**	**9.8**
January	23.63	31.01	16.24	36.9	30	9.8
February	27.92	35.36	20.47	38.5	18,27	16.3
March	27.80	34.54	21.06	41.6	31	11.4
April	30.80	37.3	24.40	42.5	11	20.1
May	30.78	35.99	25.56	40.2	5	23.3
June	29.24	33.39	25.09	37.1	4	23.0
July	28.81	32.88	24.74	36.6	17,18	22.8
August	27.97	31.67	24.27	34.8	28	22.0
September	28.20	32.19	24.21	35.0	24	22.7
October	27.77	32.46	23.30	34.0	3	20.8
November	26.32	31.63	21.01	34.9	6	14.6
December	22.92	28.68	17.16	32.5	3,4	10.7

(Source: Udonthani Meteorological Station)

Table C.6: Udonthani province: rice area and production in 2004

Amphoe	No.of villeges	Major irce				Minor rice	
		No.of rice family	Rice area (rai)	Product per rice (x 15 kg.)		No.of villeges	Rice area (rai)
				Non-Glutinous Rice	Glutinous Rice		
Mueang Udon Thani	183	21,282	288,532	35	41	210	747
Kut Chap	67	6,194	87,344	36	37	296	2,164
Nong Wua So	56	5,326	54,253	40	39	0	0
Kumpawapi	128	13,709	173,654	34	33	127	2,270
Non Sa-at	58	6,748	52,857	34	39	0	0
Nong Han	129	15,104	217,584	29	32	12	967
Thung Fon	31	4,289	63,995	36	61	9	0
Chai Wan	33	3,977	45,917	39	38	249	2,000
Si That	74	6,787	109,881	42	45	1	4
Wang Sam Mo	62	5,960	73,401	23	33	161	5,000
Ban Dung	127	17,001	280,890	30	30	595	6,296
Ban Phae	134	16,325	206,947	57	44	34	195
Nam Som	65	5,654	66,062	58	48	0	1,411
Phen	141	17,733	335,469	32	31	619	9,620
Sang Khom	50	4,994	99,709	32	29	885	10,262
Nong Saeng	31	2,225	25,427	44	37	29	197
Na Yung	40	2,842	26,303	43	38	3	15
Phibun Rak	36	4,445	84,399	28	28	90	1,466
King Amphoe Ku Kaeo	36	3,816	44,473	43	38	43	100
King Amphoe Prachaksinlapakhom	40	4,026	58,189	33	35	63	963
Total	1,521	168,437	2,395,286	35	36	3,426	43,677

(Source: Thailand Agricultural Statistics, crop year 2004; Ministry of Agriculture and Cooperatives)

C.2 STUDY AREA

C.2-1 Geography Location

Udon Thani Province is selected as study area. Geographical Located in 17°25 N and longitude 102°45E. Udon Thani is a northeastern province covering as area of 15,589 square kilometers. The provincial capital is 562 kilometers northeast of Bangkok. Udon Thani is probably best known for its archaeological wonders. Udon Thani is administratively divided into 18 districts and 2 sub-districts: Muang Udon Thani, Kumpawapi, Kud Chab, Nam Som, Noen Sa-ad, Tung Fon, Ban Phue, Prachak, Pen, Ban Dung, Nong Wua So, Wang Sam Moh, Nong Saeng, Chai Wan, Na Yung, Sang Com, Si Tat, Pibun Rak sub-district and Ku Kaew sub-district.and near by

North : Nong Khai
East : Sakon Nakhon, Kalasin
South : Khon Kaen
West : Nong Bua Lamphu and Loei
Average height above mean sea level is 177 meters. (FigureC-2)

Source: http://en.wikipedia.org/wiki/Udon_Thani_Province

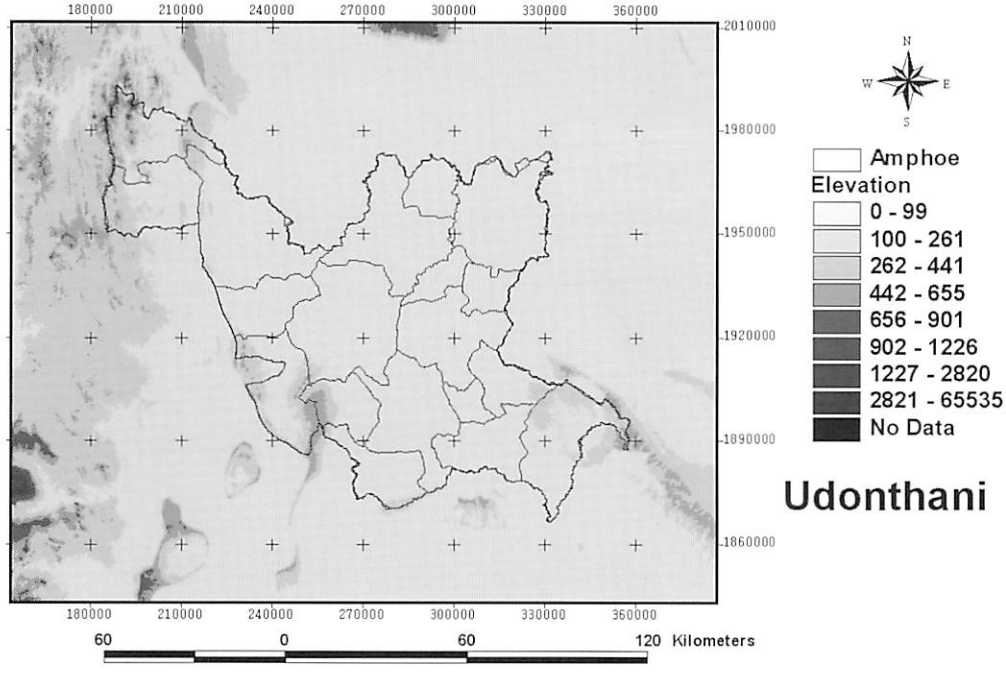


Figure C.2: Map of Elevation of Udon Thani province.

C.2-2 Climates and temperature

The temperature over a period of 30 years, highest temperature was 43.9 Celsius. Coldest temperature was 2.5 Celsius. The Amount of Rainfall, date with the highest amount of rainfall, 274.5 millimeters, was July 1, 2000. The month with the highest amount of rainfall, 656.1 millimeters, was

June 1970. The year with the highest amount of rainfall, 2418.7 millimeters, was 1970.

C.2-3 Land Use and Land Cover

Agriculture is major landuse such as paddy field and field crop (In-season rice, Tapioca, Corn and Sugar cane). Udon Thani have 21 reserve forests cover an area of 3,120,260 rai, and the remaining intact forest covers an area of 1,154,075 rai or about 15.74% of the provincial land. (Figure C.3)

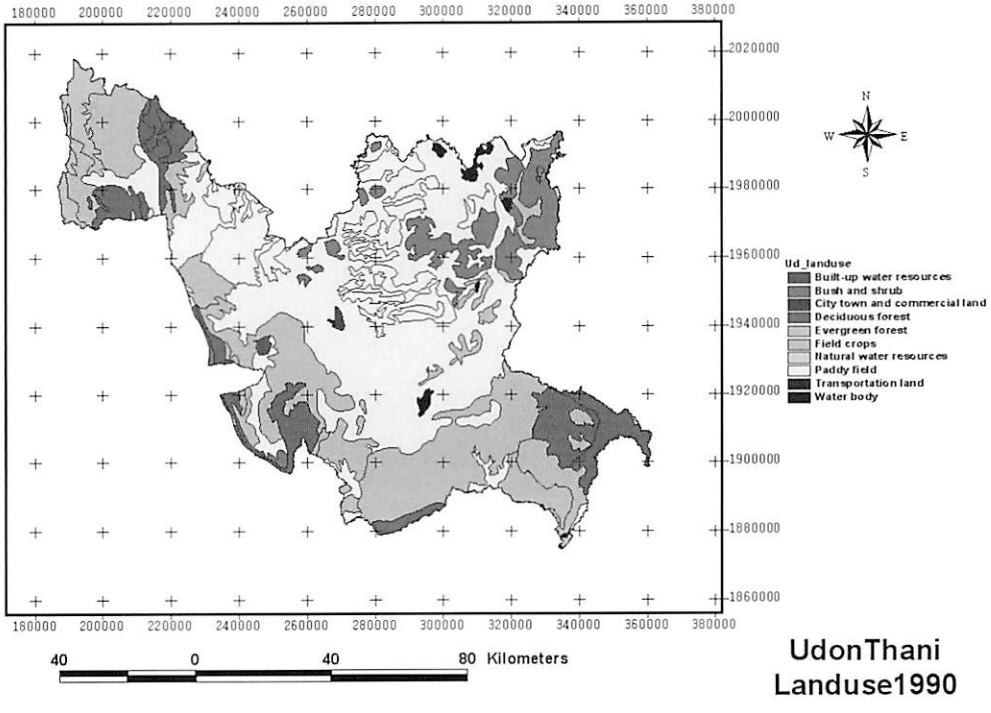


Figure C.3: Landuse map in Udon Thani province

C.2-4 Hydrology

The province has 9 wetland areas of 11,249 square kilometres, with 90,235.34 million cubic metres. There is one large irrigation project based around Huay Luang Reservoir which provides 118,326,000 cubic metres of water to 92,558 rai of irrigated land. There are 14 medium-sized irrigation projects and 217 small irrigation projects. (Figure C-4)

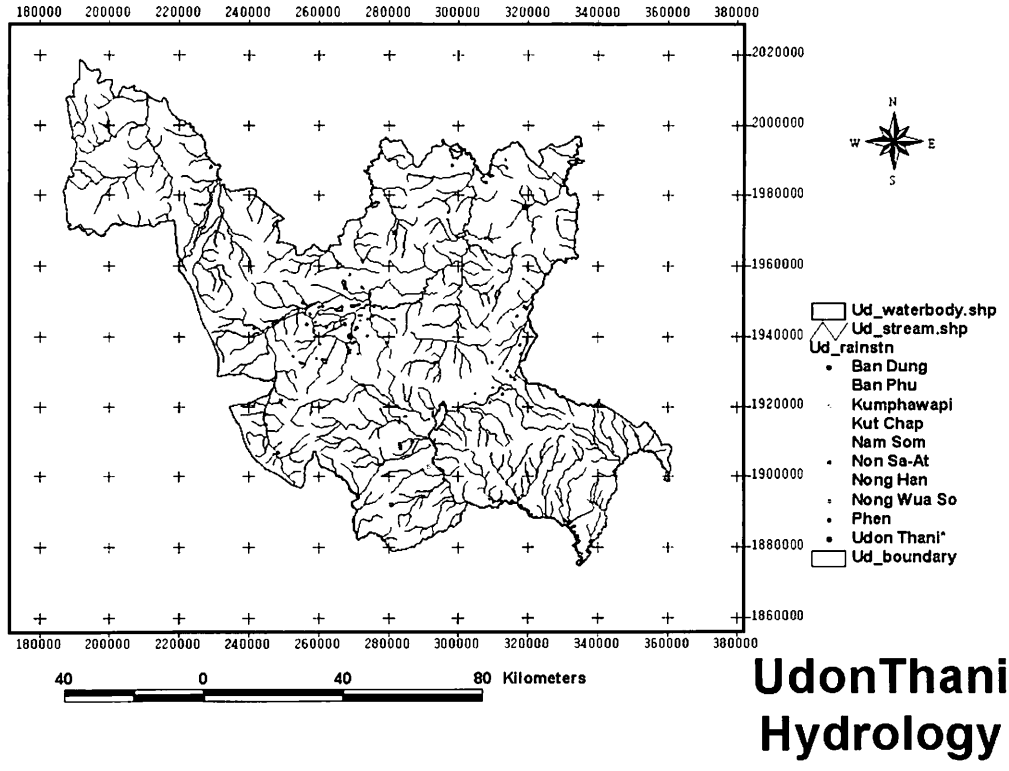


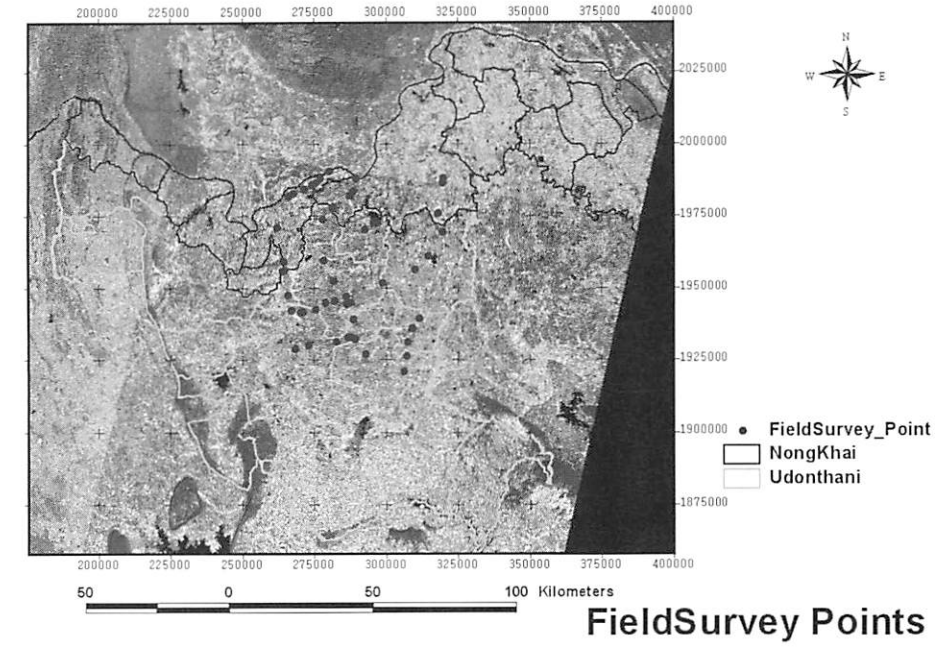
Figure C-4. Streams and Meteorological stations in Udon Thani province

C.2-5 Soil

In recent years the province has received international attention due to the discovery of a large potash deposit in the area and some anticipate that the region will become a major exporter of the mineral. Many villagers who live directly above the proposed mine site have expressed concern that the company and its Environmental Impact Assessment(EIA) have not adequately addressed concerns of salinization of groundwater and soil or land subsidence. Most of the land is sandy and stony. And in some areas the soil is salty. The soil in Ban Duang, Nong Han and Kumpawapi is unfertiled sandy soil with Ba, K and gold.

C.3 FIELD SURVEY

Trip to Udon Thani (include Nong Khai) start from 27 Nov -28 Nov 2006. Within 2 days, we surveys 52 points in various type of land use mainly in paddy field (Figure C.5).



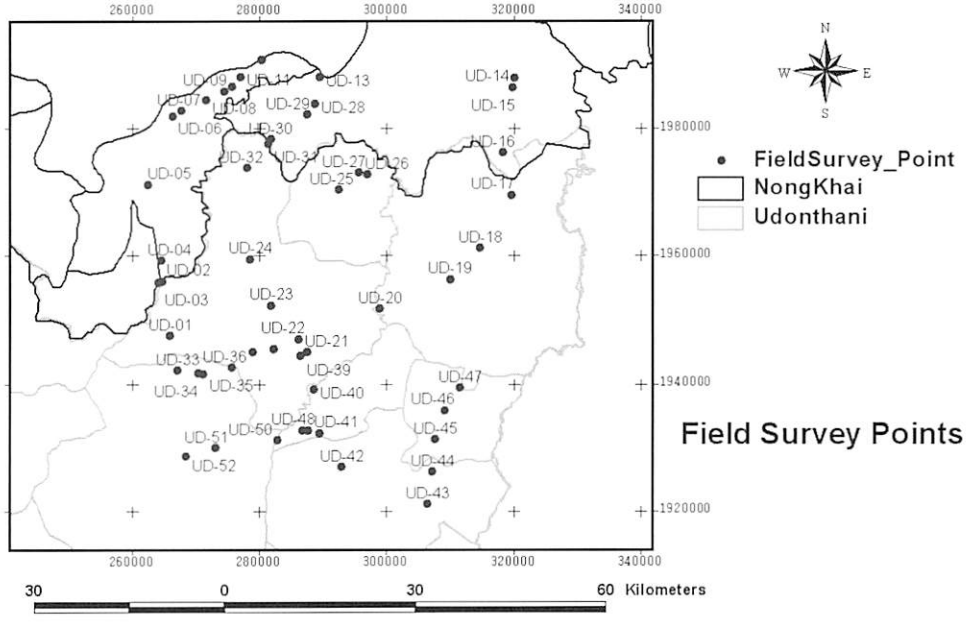


Figure C.5: Survey points in Udon Thani province (LANDSAT ETM$^+$: Path 129 row 47,48,49 of 2 Nov 2000, Path 128 row 47,48,49 of 27 Dec 1999)

Site No.	UB-01	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.601	Lon: 102.794	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UB-02	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.677	Lon: 102.781	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Canal		

Site No.	UB-03	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.676	Lon: 102.776	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvested)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-04	**Date** 27/11/2006	
Name	Amphoe: Muang Nongkhai		
Location	Lat: 17.706	Lon: 102.780	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-05	**Date** 27/11/2006	
Name	Amphoe: Muang Nongkhai		
Location	Lat: 17.814	Lon: 102.758	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Bare land		

Site No.	UD-06	**Date** 27/11/2006	
Name	Amphoe: Muang Nongkhai		
Location	Lat: 17.911	Lon: 102.794	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Built-up area		

Site No.	UD-07	Date 27/11/2006
Name	Amphoe: Muang Nongkhai	
Location	Lat: 17.919	Lon: 102.807
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-08	Date 27/11/2006
Name	Amphoe: Muang Nongkhai	
Location	Lat: 17.935	Lon: 102.844
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-09	Date 27/11/2006
Name	Amphoe: Muang Nongkhai	
Location	Lat: 17.948	Lon: 102.871
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-10	**Date** 27/11/2006	
Name	Amphoe: Muang Nongkhai		
Location	Lat: 17.955	Lon: 102.881	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-11	**Date** 27/11/2006	
Name	Amphoe: Muang Nongkhai		
Location	Lat: 17.96	Lon: 102.895	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Irrigation canal		

Site No.	UD-12	**Date** 27/11/2006	
Name	Amphoe: Muang Nongkhai		
Location	Lat: 17.992	Lon: 102.925	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought	2006 river level decrease rapidly		
Flood	No flood		
Notes	Mekong River, Glutinous rice		

Site No.	UD-13	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.969	Lon: 103.012	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Glutinous rice		

Site No.	UD-14	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.971	Lon: 103.301	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-15	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.958	Lon: 103.298	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Not paddy field		

Site No.	UD-16	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.864	Lon: 103.285	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Many big trees in paddy filed		

Site No.	UD-17	**Date** 27/11/2006	
Name	Amphoe: Ban Dung		
Location	Lat: 17.804	Lon: 103.299	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-18	**Date** 27/11/2006	
Name	Amphoe: Ban Dung		
Location	Lat: 17.728	Lon: 103.252	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Sodium Chloride (salt) that are extracted from salty soil. Such soil is found in the northeast of Thailand where there are underground salt deposits		

Site No.	UD-19	Date 27/11/2006
Name	Amphoe: Ban Dung	
Location	Lat: 17.684	Lon: 103.208
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Tree and crops	

Site No.	UD-20	Date 27/11/2006
Name	Amphoe: Ban Dung	
Location	Lat: 17.642	Lon: 103.105
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-21	Date 27/11/2006
Name	Amphoe: Phen	
Location	Lat: 17.580	Lon: 102.998
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-22	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.598	Lon: 102.985	
Irrigation	(Irrigated)	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvesting)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-23	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.645	Lon: 102.944	
Irrigation	(Irrigated)	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvesting)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-24	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.710	Lon: 102.911	
Irrigation	Irrigated	(Rain-fed)	
Growth stage	Vegetative	Reproductive	
	Ripening	(Harvesting)	
Rice type	(Major rice)	Minor rice	
Drought			
Flood			
Notes	Natural pond		

Site No.	UD-25	Date 27/11/2006
Name	Amphoe: Srangcom	
Location	Lat: 17.810	Lon: 103.043
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Bush shrub and big trees	

Site No.	UD-26	Date 27/11/2006
Name	Amphoe: Srangcom	
Location	Lat: 17.831	Lon: 103.085
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-27	Date 27/11/2006
Name	Amphoe: Srangcom	
Location	Lat: 17.834	Lon: 103.072
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood	Every year	
Notes	Soil preparation for second rice Use water; from reservoir opposite side of road	

Site No.	UD-28	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.931	Lon: 103.005	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-29	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.916	Lon: 102.994	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-30	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.880	Lon: 102.940	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes	Bush shrub		

Site No.	UD-31	**Date** 27/11/2006	
Name	Amphoe: Phon Phisai		
Location	Lat: 17.874	Lon: 102.937	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-32	**Date** 27/11/2006	
Name	Amphoe: Phen		
Location	Lat: 17.839	Lon: 102.906	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvested	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-33	**Date** 27/11/2006	
Name	Amphoe: Muang Udonthani		
Location	Lat: 17.552	Lon: 102.806	
Irrigation	Irrigated	Rain-fed	
Growth stage	Vegetative	Reproductive	
	Ripening	Harvesting	
Rice type	Major rice	Minor rice	
Drought			
Flood			
Notes			

Site No.	UD-34	Date 28/11/2006
Name	Amphoe: Muang Udonthani	
Location	Lat: 17.548	Lon: 102.837
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Bare land	

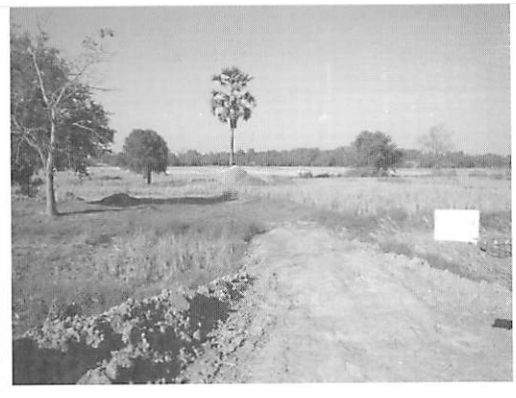
Site No.	UD-35	Date 28/11/2006
Name	Amphoe: Muang Udonthani	
Location	Lat: 17.547	Lon: 102.844
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-36	Date 28/11/2006
Name	Amphoe: Muang Udonthani	
Location	Lat: 17.556	Lon: 102.886
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-37	Date 28/11/2006
Name	Amphoe: Phen	
Location	Lat: 17.579	Lon: 102.917
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-38	Date 28/11/2006
Name	Amphoe: Phen	
Location	Lat: 17.584	Lon: 102.948
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-39	Date 28/11/2006
Name	Amphoe: Phen	
Location	Lat: 17.575	Lon: 102.988
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		



Site No.	UD-40	Date 28/11/2006
Name	Amphoe: King Amphoe Phibun Rak	
Location	Lat: 17.527	Lon: 103.008
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-41	Date 28/11/2006
Name	Amphoe: King Amphoe Phibun Rak	
Location	Lat: 17.465	Lon: 103.017
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-42	Date 28/11/2006
Name	Amphoe: Nong Han	
Location	Lat: 17.417	Lon: 103.050
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-43	Date 28/11/2006
Name	Amphoe: Nong Han	
Location	Lat: 17.366	Lon: 103.178
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvesting)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-44	Date 28/11/2006
Name	Amphoe: Nong Han	
Location	Lat: 17.412	Lon: 103.185
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Some field crops	

Site No.	UD-45	Date 28/11/2006
Name	Amphoe: Thung Fon	
Location	Lat: 17.458	Lon: 103.188
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	(Harvested)
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-46	Date 28/11/2006
Name	Amphoe: Thung Fon	
Location	Lat: 17.500	Lon: 103.203
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Bare land	

Site No.	UD-47	Date 28/11/2006
Name	Amphoe: Thung Fon	
Location	Lat: 17.531	Lon: 103.225
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-49	Date 28/11/2006
Name	Amphoe: King Amphoe Phibun Rak	
Location	Lat: 17.469	Lon: 103.001
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-50	Date 28/11/2006
Name	Amphoe: King Amphoe Phibun Rak	
Location	Lat: 17.454	Lon: 102.955
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Paddy field near bush and shrub	

Site No.	UD-51	Date 28/11/2006
Name	Amphoe: Muang Udonthani	
Location	Lat: 17.443	Lon: 102.863
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvested
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes		

Site No.	UD-52	Date 28/11/2006
Name	Amphoe: Muang Udonthani	
Location	Lat: 17.430	Lon: 102.821
Irrigation	Irrigated	Rain-fed
Growth stage	Vegetative	Reproductive
	Ripening	Harvesting
Rice type	Major rice	Minor rice
Drought		
Flood		
Notes	Multi-purpose reservoir	

C.4 Remarks

After surveyed paddy fields in Udon thani province, we found that

- Western part of province is high land and has forest areas. Northeastern part has many paddy fields and eastern part has a mixture of land uses such as paddy field, filed crop, bush and shrub.
- Almost all paddy fields in Udon thani are rain fed paddy fields.

INTERNATIONAL CENTER FOR URBAN SAFETY ENGINEERING
Institute of Industrial Science, The Universiy of Tokyo
4-6-1 Komaba, Meguro-ku,
Tokyo 153-8505, Japan
http://icus.iis.u-tokyo.ac.jp
E-mail: icus@iis.u-tokyo.ac.jp

Tel: (+81-3)5452-6472
Fax: (+81-3)5452-6476