EFFECT OF WATER PONDING PADDY FIELDS ON THE LOCAL THERMAL ENVIRONMENT

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SUMMARY:

The thermal environment around the area of water ponding paddy fields in the state of California are analyzed using Landsat TM image. After classifying landuse using data of five visible bands and one near infrared band, the averages of ground surface temperature for thirteen landuse categories are compared each other.

As a result, the ground surface temperature around water ponding paddy fields is as low as water surface of reservoirs. This fact means that an immense water surface appears in rice growing season; from May to September. The total acreage of water ponding paddy field in the studied Landsat image was about 175 thousand hectares, and this huge water ponding paddy fields must effect greatly on the local thermal environment. The most popular rice production area is near Sacramento city.

So, it is implied that water ponding paddy fields have effected on the local meteorology in Sacramento city, according with the development of paddy field. The meteorological data of this area since the early 20th century may have reflected the effects of paddy fields.

KEY WORDS: Thermal Environment Monitoring, Water-Ponding-Paddy Field, Landsat TM, Irrigation

1. INTRODUCTION

Rice Production in California began in 1912, and the total acreage of paddy field in California spreads recently more than two hundred thousand hectares.

Rice Production requires a great amount of fresh water for irrigation; more than 2100mm in average during growing period. So, the maximum amount of fresh water supplied to paddy field exceeds more than 5 billion ton a year.

Where do those irrigated water to paddy field go after harvest? A part of them are drained and go down the river to the ocean, but most of them must evaporate because of the strict limitation of drainage discharge and low permeability of soil in California.

Those great amount of ponding water need enormous latent heat to evaporate. So it must greatly effect on the local thermal environment. The air around water ponding paddy field must be cooled down,   then the atmosphere temperature by those paddy field area must drop.

Then,   following very interesting questions come up to us.

*How much do those water ponding paddy fields effect on the local thermal environment?
*Has the atmospheric temperature been changed by   enormous   latent   heat   with   the development of paddy field?

These questions are also very important to the studies of global climate change.   The large area of water ponding paddy fields play very important and positive roles to both global climate control and food supply in future.

2. OBJECT

The objectives of research to approach above questions is to estimate exactly the total heat balance around the study area by estimating exact total water balance. The important factors for both total water balance and total heat balance in rice producing area are the   total amount of supplied   water(irrigation water),   the   total amount of drainage discharge water, the total amount of subsurface drainage discharge,   and the total amount of precipitation. Also, the pattern of paddy field distribution is an important factor for throughout understandings of the heat balance in the area.

Some of the total amount of supplied water can be estimated from the data of the department of Water Resources. And the precipitation can be considered nearly   zero because rain is very   rare   in California during rice growing period. Then,   the pattern of paddy field distribution and other landuse,   or total acreage of paddy filed in the broad area can be fairly well obtained by the satellite remote sensing. Only the total amount of subsurface drainage discharge water can not be exactly estimated, but its value can be roughly calculated from the sample data in the field.

Then,   the following investigations have been done in the present study using the satellite remote sensing data.

(1) Analysis of the pattern of paddy field distribution by the satellite remote sensing and to measure the total acreage of paddy field in the area
(2) Measurement of the ground surface temperature using the thermal band of the satellite remote sensing data
(3) Assessment of the effect of paddy field on the local thermal environment considering both water balance and heat balance in this area

3.DATA ANALYSIS

3.1 Study Area and Image Data

The study area was selected in the northern part of Sacramento valley in California. This area is very famous for rice production, a lot of paddy field were developed in counties of Butte, Colusa, Glenn, Sutter, Tehema, Yolo, Yuba. The outline of this area is shown in figure 1.

The image data to analyze is a full scene of Landsat-5 TM data(WRS=44/33) acquired on August 23 in 1990. The type of geodetic processing is systematic. The type of resampling is cubic convolution. The type of projection is SOM. The pixel size is 28.5 m.

The reason why this scene was adopted is that it has very little cloud and it was acquired in the ripening period of rice in California.
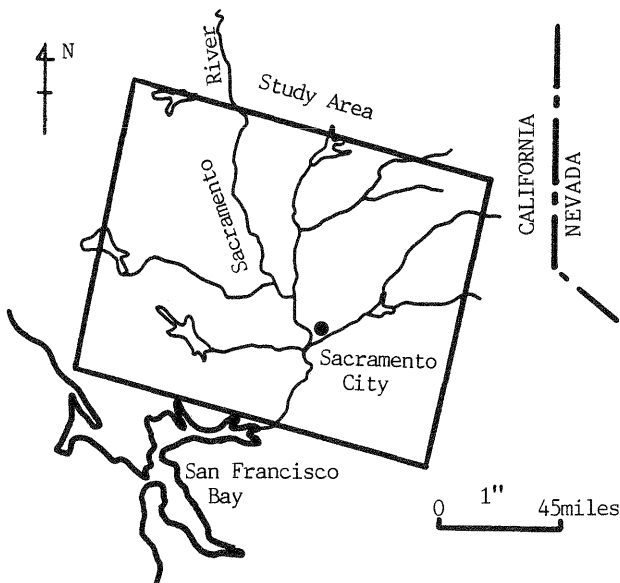

Figure 1. Outline of Study Area

3.2 Landuse Analysis

A. Landuse Classification Method   The landuse of this area was obtained by the ordinal supervised classification of the maximum likelihood method. In this whole study area, thirteen landuse categories were selected and those training areas were defined using aerophotographics and a road map.

Those categories are as follows.
1.paddy field
2.upland field; some vegetation on the field
3.wet soil field; irrigated and dark field
4.dry soil field; bright fields
5.sandy area;outside of field and very bright area
6.hazard ; complicated area like swamp or hazard
7.town; residential area
8.water body ; lakes, reservoirs and rivers
9.orchard
a.forest
b.rocky area
c.cloud shadow
d.cloud

B. Training data statistics The statistics of six bands of thirteen training data were shown in Table 1. Six bands are band 1 to band 5 and band 7. For each category, the upper values are averages, and the lower values are standard deviations. These training areas for training data were carefully selected by checking Euclidean distance each other.

TABLE 1.   TRAINING DATA STATISTICS

CATEGORY NAME	BND1	BND2	BND3	BND4	BND5	BND7
1 PADDY	63.5	31.8	30.0	102.7	52.8	18.7
FIELD	1.9	1.6	3.2	12.2	4.6	2.7
2 UPLAND	66.0	31.4	34.5	87.8	63.4	30.4
FIELD	5.7	3.4	10.6	26.2	14.7	16.4
3 WET SOIL	80.0	35.7	51.9	59.9	128.9	65.9
FILED	2.3	1.6	3.4	3.8	7.4	4.7
4 DRY SOIL	92.2	52.4	89.4	80.8	143.1	81.1
FIELD	2.7	2.5	5.1	4.3	5.9	5.1
5 SANDY	85.7	41.9	62.2	56.2	135.4	81.3
AREA	4.1	2.9	5.1	4.9	13.4	8.5
6 HAZARD	74.7	35.3	49.0	64.7	94.5	47.1
	10.5	8.4	17.5	17.3	36.0	21.8
7 TOWN	83.0	38.0	48.1	52.8	67.6	40.9
	19.0	11.4	17.9	16.3	22.7	16.6
8 WATER	60.9	22.5	16.0	5.4	2.8	1.2
BODY	2.9	2.2	2.5	0.9	1.2	1.0
9 ORCHARD	64.2	27.1	30.3	60.3	64.7	32.7
	3.8	2.7	5.5	4.7	8.9	8.4
a FOREST	52.1	19.9	18.9	59.3	40.5	14.5
	3.0	2.2	3.2	11.7	12.1	5.4
b ROCKY	90.8	45.8	67.1	57.6	115.5	66.3
AREA	12.2	7.4	9.0	7.4	23.1	9.4
c CLOUD	43.5	13.2	10.1	5.3	2.3	1.1
SHADOW	1.0	0.7	0.7	1.1	0.9	0.9
d CLOUD	233.8	116.0	157.2	126.6	189.9	123.7
	28.2	19.6	26.9	17.9	23.1	17.9

C. Classification Reliability   Table 2. shows the classification error matrix table of reference data of 228 pixels which are located around the centers of training areas.

The number of correctly classified pixels are 196, so overall classification accuracy is 86%. Most of the categories, except HAZARD, ORCHARD, are expected to be exactly classified.

D. Classification   The result of classification of thirteen categories by the maximum likelihood method is shown in the photo 1. The photo 1. shows the result of landuse classification of thirteen categories in the whole image; paddy field, forest, town and other landuse categories.

133

Paddy field seems to be pretty correctly classified, and the distribution of paddy field and total acreage of it are thought to be reliable.

Table 2.   Classification Error Matrix

CD\RD	1	2	3	4	5	6	7	8	9	a	b	c	d	total
1	30	3	0	0	0	0	0	0	0	0	0	0	0	33
2	0	27	0	1	0	0	0	0	0	0	0	0	0	28
3	0	0	18	0	0	0	0	0	0	1	2	3	0	24
4	0	0	1	17	0	0	0	0	0	0	0	0	0	18
5	0	0	0	0	9	0	0	0	0	0	0	1	0	10
6	1	1	0	0	0	7	0	0	0	1	2	0	0	12
7	0	1	0	0	0	0	16	0	0	1	0	0	0	18
8	0	0	0	0	0	0	0	20	0	0	0	0	0	20
9	0	2	0	0	0	0	0	0	4	0	0	0	0	6
a	0	0	0	0	0	0	0	0	0	13	0	0	0	13
b	0	1	0	6	2	1	0	0	0	0	29	0	0	39
c	0	0	0	0	0	0	0	0	0	0	1	5	0	6
d	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total	31	35	19	24	11	8	16	20	5	17	36	5	1	228

CD: Classified Data   RD: Reference Data

3.3   Land Surface Temperature

The CCT data of band 6 was transformed to the temperature before farther analysis. The transforming equations shown in the equation (1) to (3) were used to transform CCT counts of band 6 to the ground surface temperature(degree centigrade).

Figure 2. shows the calibration curve for data transformation. Using this calibration curve, all the data of band 6 were transformed to ground surface temperature(degree centigrade).

$$R = V(Rb - Ra)/255 + Ra \qquad \text{----- Equation (1)}$$

$$R/L = (5.1292 \times T2 - 1.7651 \times T \times 1000 + 1.6023)/100000 \qquad \text{----- Equation (2)}$$

$$t = T - 273 \qquad \text{----- Equation (3)}$$

where,
- V : CCT count of Band 6
- R : Radiation brightness in CCT count (V)
- Ra: Minimum radiation brightness in CCT count(V=0)
- Rb: Maximum radiation brightness in CCT count(V=255)
- L : Wave length range of band6(1.239x10-6m)
- T : Temperature in Kelvin
- t : Temperature in degree centigrade

The histograms of ground surface temperature for each training area of thirteen categories were obtained. And also, the histogram of ground surface for the pixels classified to each categories. Their averages and standard deviations are shown in figure 3. In thirteen landuse , water body, forest, paddy field, cloud shadow area, and cloud have low surface temperature. What interesting things are paddy field and forest have as low temperature as water body; about 21 degrees centigrade. But, in other landuse categories of upland field; dry soil field, wet soil field, sandy area, orchard, hazard, town, rocky area have high surface temperature, over 24 degrees centigrade.

This means that the moisture evaporates highly from the surface of water body, paddy field and forest, comparing other landuse categories like dry soil field or sandy area. So, ground surfaces of water body, paddy field, forest are cooled down as the latent heat is taken away from those surfaces.
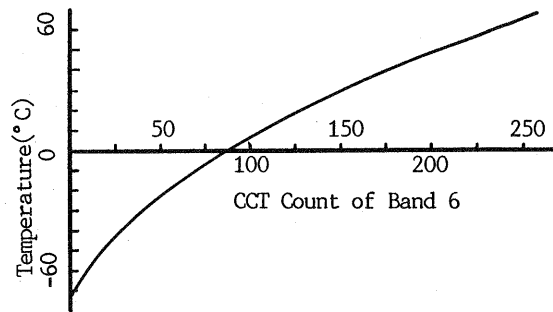

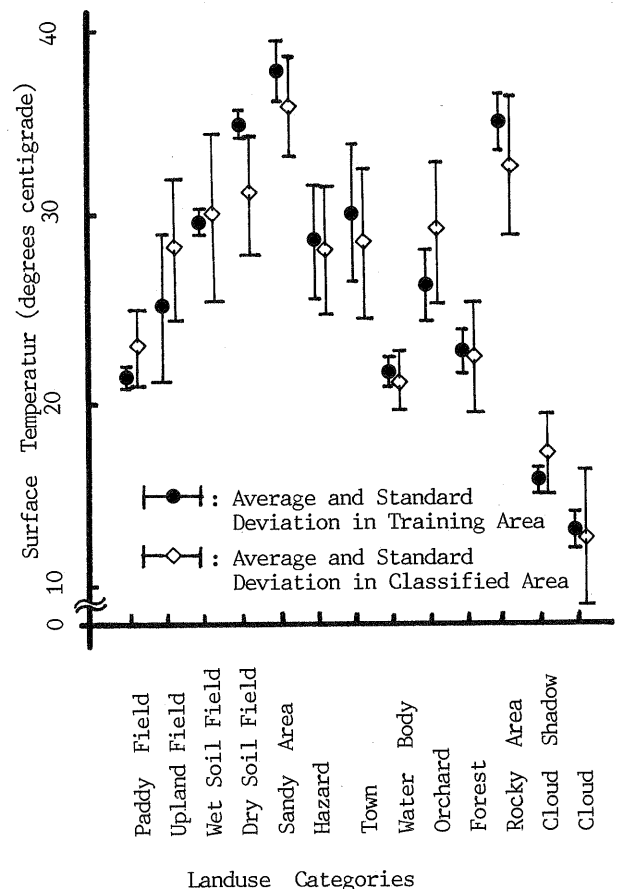Figure 2.   Calibration Curve of CCT Count of Band 6 to Temperature

Figure 3.   The Statistics of The Surface Temperature in Training Areas and Classified Areas

134

The photo 2. shows the distribution of ground surface temperature in the whole image. In the level of 22 to 24 degrees centigrade, a lot of paddy field are expanding.

4. DISCUSSION

4.1 Effects of Paddy Field on local thermal Environment

A. Total Acreage of paddy fields in the scene
The total number of pixels that is classified to paddy field is 2,174,892. As a pixel size equals to 28.5m. So, the total acreage of paddy field by satellite remote sensing data was estimated as 176,656 ha in the scene; in Sacramento valley.

According to the statistics, the total acreage of paddy field in 1988 was 170 thousand ha in California, and 170 thousand ha in 1991. Considering that ninety percent of paddy field is in Sacramento valley, and that California has suffered from drought for six years, the calculated total acreage by satellite remote sensing data; 176 thousand ha in 1990, can be thought relatively accurate.

B. Total Water Balance   Water balance in paddy field is described as the equation (4).

$$Ir + Pr = Dr + ET + Per \quad ----- \text{Equation (4)}$$

where,
 Ir : Irrigation
 Pr : Precipitation
 Dr : Drainage discharge
 ET : Evapotranspiration
 Per: Percolation
Then,   the evapotranspiration is expressed as

$$ET = Ir + Pr - Dr - Per \quad ----- \text{equation (5)}$$

In California, the amount of irrigation water for paddy field for rice production is estimated seven acre-feet in average. And the precipitation during rice growing period is almost zero because there is seldom rain in summer.

The ratio of drainage discharge water to total water use can be thought very low because of reasons as follows.

(1) Severe limitation of drainage discharge after spreading pesticide by the government
(2) Farmers pay for water cost, then they carefully use water. They do not like to drain water to outside of paddy field

The amount of percolation water can not be exactly estimated. But, it is said that the percolation rate is about -5 or -6 powers of 10 mm/sec in Sacramento valley, because the soil around alluvial plane near the Sacramento river is categorized to heavy clay. So, the total amount of percolation is guessed less than 900 mm(three acre-feet) per year.

The average of pan evapotranspiration in this area are 6 to 8.5 inches per month, between May to August. So, the total amount of pan Evapotranspiration is 30 inches; less than 3 feet

in rice growing period.

In this paper, the total Evapotranspiration from paddy field is thought as the equation (5). It is estimated between 4 acre-feet to 7 acre-feet. The figure 4. shows the water balance in paddy field.
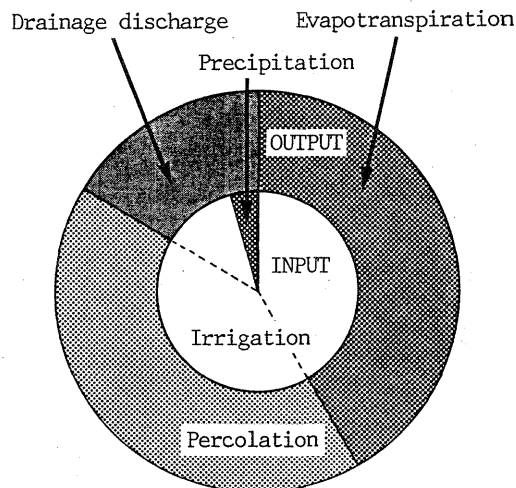

Figure 4.   Water Balance in Paddy Field

C. Total Latent Heat in four months   Using the total acreage of paddy field and the range of evapotranspiration , the total latent heat in this area is calculated 5.2 followed by eighteen zeros J to 9.2 followed by eighteen zeros J.   This latent heat is very immense.

4.2 Transition of Total Acreage of Paddy Field in California

According to the statistics published by University of California, the total acreage of rice field in California in 1975 was 217 thousand ha. In 1981,1988,1991, the total acreage of paddy field in California were respectively 240 thousand ha, 170 thousand ha, 170 thousand ha. Recently, the total acreage of paddy field is limited by the department of Water Resources and USDA because of heavy drought in these five years and set aside.

5. CONCLUSION

5.1 Water Ponding Paddy Field and Local Thermal Environment

The thermal environment around the area of water ponding paddy fields in the state of California are analyzed using Landsat TM image. The ground surface temperature around water ponding paddy fields is as low as water surface of reservoirs.

This fact means that an immense water surface appears in rice growing season; from May to September. The total acreage of water ponding paddy fields in the studied Landsat image is about 175 thousand hectares, and this huge water ponding paddy fields effects greatly on the local thermal environment. The most popular rice production area is near Sacramento city.

It is implied that water ponding paddy fields have effected on the local meteorology in the state of California, according with the development of

paddy fields in this state. The meteorological data of this area since the early 20th century may have reflected the effects of paddy fields.

5.2 Future Problems

As a result of this analysis, Some important problems are remaining unsolved. For example, the ground surface temperature of wet soil field, that of dry soil field and that of upland are different. So, the study to estimate the water content in the ground surface soil is very important. Future studies should be focused on the estimation of the water content in the soil.
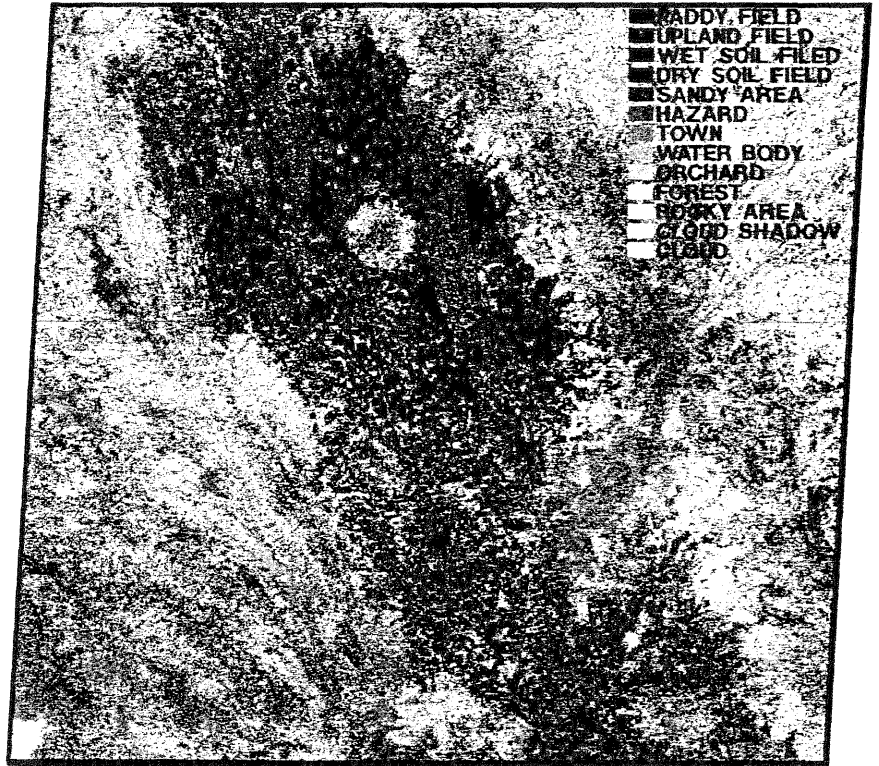
Photo 1. Landuse Classification

Photo 2. The Distribution of Ground Surface Temperature

136