GIS Studies at JIRCAS in Collaboration with Foreign Institutes

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Abstract

Remote Sensing and Geographic Information Systems (GIS) are suitable techniques for environmental monitoring and data processing. Particularly in the countries and regions where nation or region-wide basic information infrastructure consisting of spatial data, statistical materials and distribution systems has not been developed sufficiently, the expectation of GIS utilization is increasing gradually. At the Japan International Research Center for Agricultural Sciences (JIRCAS), many collaborative studies focused on GIS technology have been carried out with some national or international organizations in Syria, India, Pakistan, Thailand, China, Indonesia, etc. Various research topics were selected, such as land use changes, land degradation, desertification, soil salinity, etc. These issues concerning agro-environmental analysis are reflecting the particular problems which must be overcome for the promotion of sustainable agriculture in each region. The studies have been carried out based on long-term and short-term assignments of visiting researchers and through counterpart invitation programs under the specific schemes. In this paper, the GIS-related collaborative research conducted by JIRCAS, and a case study about salinity-affected areas in Northeast Thailand are introduced as an example of current GIS-related research activities at JIRCAS.

International collaborative research at JIRCAS

As shown in Table 1, JIRCAS has implemented several collaborative projects focusing on the use of GIS and Remote Sensing with foreign institutes. Most of the research sites are located in developing countries. In such regions, practical use of Remote Sensing and GIS is very important, because basic information is often inadequate and there is a need for monitoring various land degradation phenomena (Uchida, 1998).

JIRCAS has conducted collaborative studies to address problems relating to land resources and the agro-environment to secure sustainable agricultural production in each area, on a long-term or short-term basis in addition to counterpart invitation programs. There are many common aspects in the objectives and methods. Some studies have been conducted by data sharing and feedback of results from other studies, and some by applying similar methods and objectives. However, some of the studies aim at the analysis of environmental characteristics such as physical factor analysis and categorization, while others deal with dynamic aspects such as chronological land use changes.

Most of the current GIS-related studies at JIRCAS recently have been carried out within the framework of comprehensive research projects such as in China, "Development of Sustainable Production and Utilization of Major Food Resources in China". In Indonesia, the studies elucidated the factors controlling agro-environmental resources under the scheme of "Evaluation of On-Going Farming Systems and Identification of Problems Hampering their Development", within the project on "Evaluation and Improvement of Regional Farming Systems in Indonesia." Such comprehensive projects are implemented to deal with general objectives through the linkage of various analytical, technical and socio-economic aspects. In the following chapter, the study conducted in Northeast Thailand will be introduced as an example of GIS-related subject within the comprehensive project implemented by JIRCAS.

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Table 1 Collaborative projects executed by JIRCAS with foreign institutes

Research Title	Nation and Test site	Period	Objectives
Estimation and conservation of regional edible feed resources in dry marginal lands	Syria Abdel Aziz Range	1992-1995	Collection of fundamental information, data base construction and land evaluation for feed resources management
Analysis of soil erosion in rainfed agricultural land	Pakistan Pothwar Plateau	1993-1997	Spatial analysis of soil-eroded area using satellite data
Environmental changes associated with land use conversion in the semi-arid tropics	India Deccan Plateau	1993-1998	Analysis of spectral reflectance of typical soils in the smi-arid tropics and agricultural land use changes
Development of methods for land degradation assessment in areas undergoing desertification and data base transformation	Australia Northern Territory	1994-1997	Construction of land assessment model for soil stability based on vegetation index variance
Study on the characteristics of water resources in high-altitude and high-latitude areas	Mongolia	1994-2000	Development of monitoring method for water resources and evapotranspiration
Development of methods for GIS construction and agricultural land use evaluation in Northeast Thailand	Thailand Northeast Thailand	1995-2001	Database construction for agro-environmental conditions relating to water balance of crops
Analysis of physical factors for sustainable agriculture and land use	Thailand Northeast Thailand	1998-2001	Analysis of the physical conditions and land evaluation for sustainable agriculture
Physical factor analysis for regional farming systems	Indonesia West Jawa	1998-2000	Analysis of farming systems by physical factors and characterization of agro-environment in the region
Analysis of factors and mechanisms of land use changes in agricultural areas	Indonesia West Jawa	1998-2000	Investigation of mechanisms of land use changes and relation to natural and socio-economic factors
Monitoring of agro-environmental conditions for food production and distribution	China Huang-Huai-Hai Plain	1998-2002	Characterization of typical crop cultivation systems associated with soil properties

Case study : Analysis of salinity-affected areas in Northeast Thailand

The Northeast Thailand region has vast land resources covering approximately 170,000 km^2 area. It accounts for 33 % of the whole land area in Thailand. In spite of the remarkable economic growth associated with rapid industrialization in Thailand, agriculture remains the major production activity in the region. However, agricultural productivity in this region is very low because of unstable rainfall, poor soil environment, insufficient irrigation systems, etc.

For the development of sustainable agriculture in Northeast Thailand under the unfavorable agro-environmental conditions mentioned above, JIRCAS is conducting a comprehensive research project entitled; "Comprehensive Studies on Sustainable Agricultural Systems in Northeast Thailand" (JIRCAS, 1996 ; Suzuki and Ando, 1999). The project consists of the following five components:

1) Evaluation and effective utilization of environmental and biological resources in the region
2) Development of sustainable crop production systems
3) Improvement of livestock feeding management with locally available feed resources
4) Development of postharvest technologies for local agricultural products
5) Economic evaluation of multiple cropping systems and livestock farming

GIS-related study is under scheme 1) and it is expected to contribute to the analysis and evaluation of the physical agro-environment to achieve sustainability.

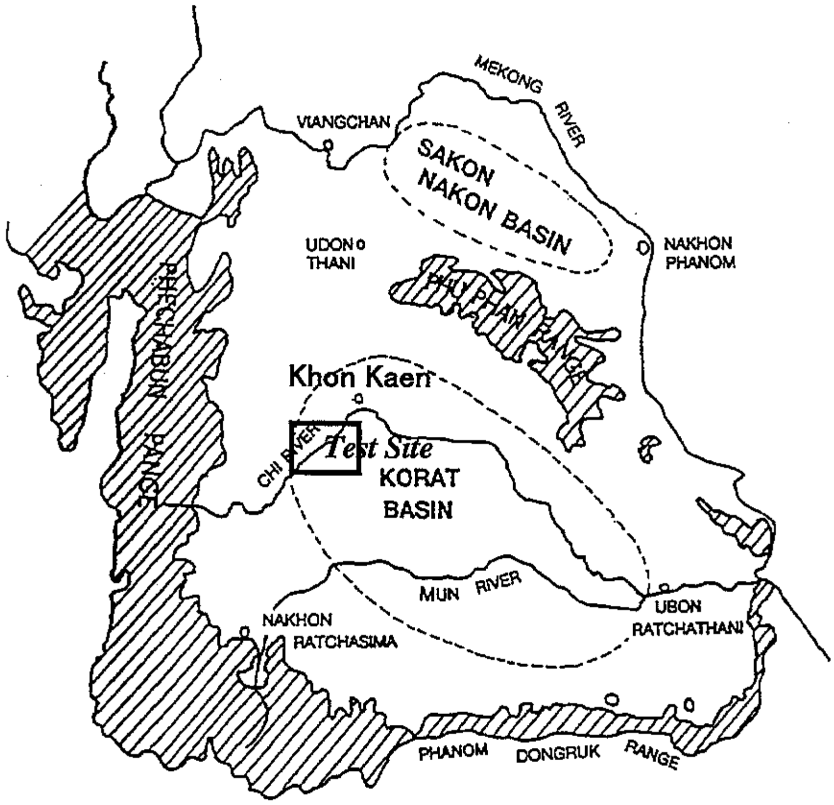
1 Objective and study site

To develop sustainable agriculture, a suitable land use system adapted to the land characteristics is essential to maintain a balance between agricultural productivity and environmental conservation. To achieve this objective, the GIS-related study aims at the analysis and evaluation of the agro-environment in Northeast Thailand regionally and quantitatively using information over a wide area. As the first step of this approach, emphasis was placed on areas affected with salinity which is one of the most typical and serious land degradation problems in Northeast Thailand. In this paper, the results of analysis of salinity-affected areas and degradation estimated by satellite data sets are introduced.

The mechanism of salinization in Northeast Thailand has been reviewed and attributed to physical and artificial causes. Basically, salinization in this region originates from rock salt widely underlain and saline groundwater (Imaizumi, 1997; Imaizumi *et al.*, 1999). Deforestation which altered the balance between rainfall and evapotranspiration promoted salinity due to the increase of percolation and seepage water with salts (Miura and Subhasaram, 1991). Salinity-affected land is estimated at approximately 17% in this region. The salinity-affected areas are distributed on hilly and low flat areas including many paddy fields. Salinization of fields leads to a decline in productivity, fallow and eventually abandonment of fields. Therefore, monitoring of areas affected with salinity to determine its appearance and severity is an important technology for agricultural land management.

The study was performed in cooperation with the Soil Survey and Classification Division, Department of Land Development (LDD), Ministry of Agriculture and Cooperatives of Thailand in Khon Kaen. LDD has conducted many kinds of field surveys and interpreted remotely sensed data for mapping (JICA, 1986). Salt-affected soil maps in each prefecture on a scale of 1:250,000 and 1:100,000 have been produced (Imaizumi *et al.*, 1999). However, to detect salinity at the field level more precisely, high-resolution and time sequential analysis is necessary.

For the study, the Ban Phai district (E102°30' - 102°45', N16°00' - 16°15') located in the Korat Basin was selected as the test site (Fig.1). It is located at 40km south of Khon Kaen City, covering an area of 676 km^2. In the Chi river basin and peripheral lakes and marshes, lowland agriculture predominates while upland agriculture predominates in the hilly area of the northwestern and southwestern parts. Although the site is characterized by typical agricultural land use in Northeast Thailand, including crop fields, eucalyptus plantations, rainfed paddy fields, etc., large-scale salinity can be observed.



Northeast Thailand

(Mitsuchi et al., 1986)

Fig. 1 Location of test site

Table 2 Geographic characteristics of Ban Phai district [km^2 ; ( ):%]

Elevation	Area	Slope (°)	Area
<160	201.8 (29.7)	< 3	658.9 (97.1)
<170	193.8 (28.5)	< 6	17.0 (2.5)
<180	132.4 (19.5)	< 9	2.3 (0.3)
<190	51.2 (7.5)	<12	0.4 (0.1)
<200	38.0 (5.6)	<15	0.2 (0.0)
>=200	61.7 (9.1)	>=15	0.0 (0.0)
Total	678.9 (100.0)		678.9 (100.0)

	EROSION				
SALINITY	Very slight	Slight	Moderate	Others	Total
Salinity-affected	133.8 (19.7)	39.1 (5.8)	5.1 (0.8)	0.4 (0.1)	178.4 (26.3)
Potentially affected	111.0 (16.4)	31.2 (4.6)	13.9 (2.0)	0.4 (0.1)	156.5 (23.1)
High land salt-source	70.2 (10.3)	53.4 (7.9)	123.7 (18.2)	4.3 (0.6)	251.6 (37.1)
Non-affected	8.8 (1.3)	0.0 (0.0)	28.5 (4.2)	6.4 (0.9)	43.7 (6.4)
Others (WB, ot)	0.4 (0.1)	0.0 (0.0)	0.4 (0.1)	47.9 (7.1)	48.7 (7.2)
Total	457.9 (67.4)	162.8 (24.0)	176.8 (26.0)	59.7 (8.8)	678.9 (100.0)

Table 2 shows the geographic characteristics of the Ban Phai district determined by the map data sets produced by LDD. 78% of the sites are located in areas below an elevation of 180m, and 97% consists of a flat area with a slope less than 3° in inclination. In approximately 25% of the site, though the occurrence of moderate soil erosion and salinity is assumed, the area affected by erosion and salinity at once is not very large. However, it has a high potential of undergoing salinity and of becoming a salt-source area. Therefore, careful land use and development of a sound land management system to prevent salinization are important for the future.

2 Analysis

1) Data and methods

LDD has produced various thematic maps, such as soil series, land use, available groundwater level, etc. In our analysis, these map data and satellite data were utilized. The flow of analysis is shown in Fig.2. In this analysis, four sets of satellite data observed during the dry season, LANDSAT/TM on 1990.2.9 and 1997.12.29 and MOS-1/MESSR on 1989.3.27 and 1992.3.11, were used. All the data were geometrically corrected into the same coordinate system, and the resolution was set at 30m per pixel. To make the land cover / land use maps, supervised classification was performed. Due to the difference in the observation dates, classification was performed with sub-classes for each data set. Then, the sub-classes were integrated into the common categories shown in Table 3.

Table 3 Categories and sub-classes for land cover/land use classification

Category	Sub-class		
Waterbody	River	Pond	Swamp
Urban area			
Bare land	Dry soil	Wet soil	
Forest	Natural forest	Eucalyptus plantation	
Upland fields	Planted field	Non-planted field	
Paddy fields			
Wetland			
Salinity-affected area (slightly)			
Salinity-affected area (moderately)			
Salinity-affected area (severely)			

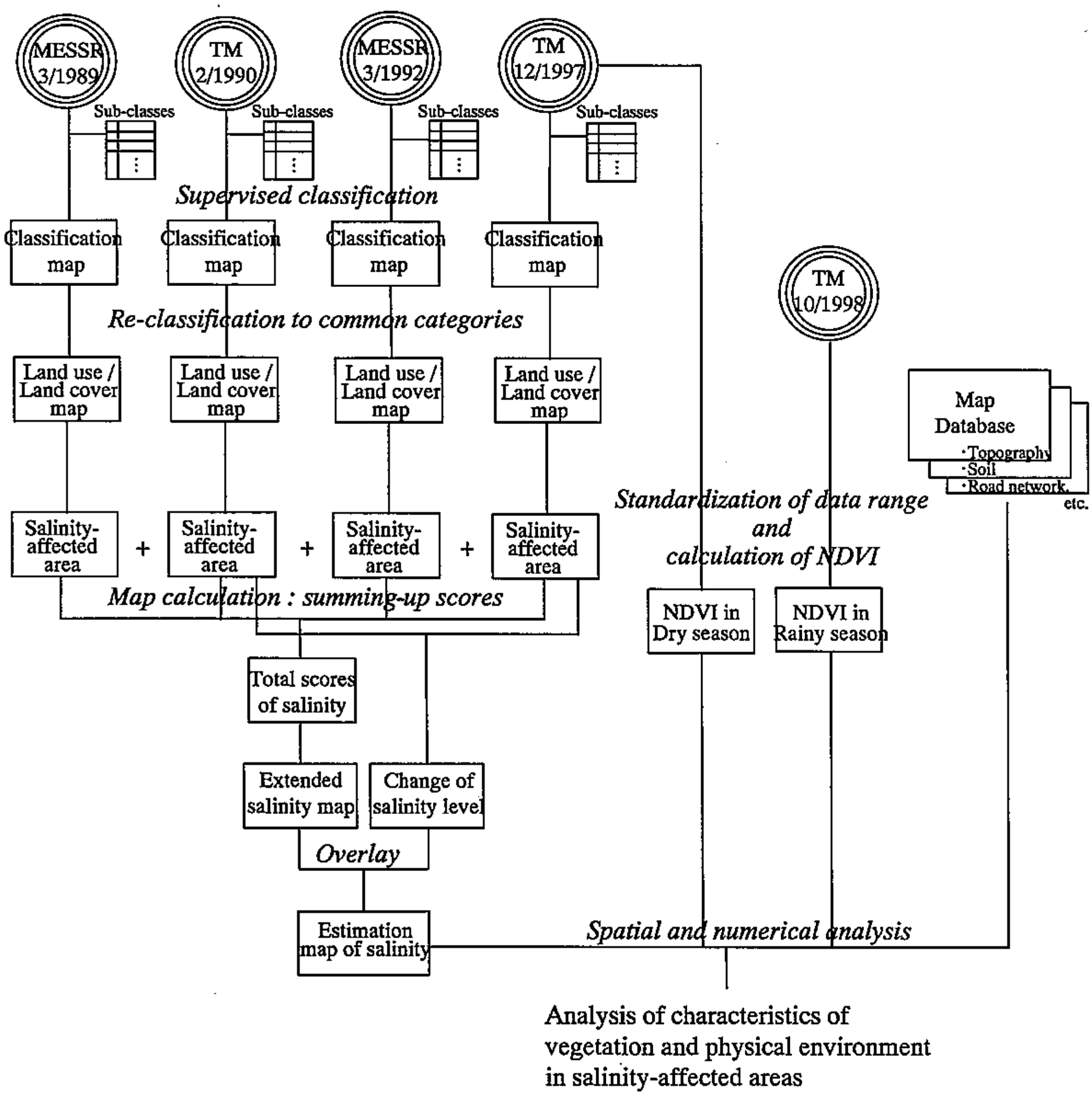


Fig. 2 Flowchart of analysis of salinity-affected areas

The salinity-affected areas were extracted from each classification map, and given scores 1, 2 and 3 for "Slightly affected", "Moderately affected" and "Severely affected", respectively. Then, the total of scores on the same point were calculated, and reclassified into three categories. Level 1 corresponded to less than 4 for the total score, indicating that the area was slightly affected throughout the period of satellite observation. Level 2 corresponded to less than 8 and Level 3 to less than 12, indicating that the areas were moderately and severely affected, respectively. On the other hand, to determine whether salinity had progressed, the area where the score on the data of 1997.12.29 became higher than in 1990.2.9 was extracted. By producing a cross-image combining these 2 kinds of estimation results, an integrated assessment map showing the level and progression of salinity was produced.

2) Results and discussion

The classification results of the four satellite data sets are shown in Fig.3 and Table 4. The classification accuracy indicating the ratio of the pixels classified correctly to the whole pixels of the supervised data set, was in the range of 84 - 94% suggesting that the categories for classification and the results were appropriate. Comparison of the four classification results revealed that some categories, except for forest and urban areas, showed considerable changes in the areas covered in the respective data. Even waterbodies, which do not

Table 4 Classification of land cover area using four satellite data sets (km^2)

	27/03/89 (ME)	09/02/90 (TM)	11/03/92(ME)	29/12/97 (TM)
Waterbody	44.7	89.8	84.8	43.8
Wetland	50.5	13.6	15.7	36.9
(sub-total)	95.2	103.3	100.4	80.6
Forest	57.4	60.9	64.7	59.8
Paddy fields	65.1	163.0	77.8	175.5
Upland fields	250.1	153.4	324.9	98.4
Bare soil	147.7	24.3	45.2	109.5
(sub-total)	462.9	340.7	447.9	383.3
Salinity-affected area s1:slightly	13.5	71.3	21.0	79.7
s2:moderately	14.7	62.1	4.7	30.0
s3:severely	4.6	2.0	6.2	4.8
(sub-total)	32.8	135.3	31.8	114.5
Urban area	–	7.3	3.5	10.1
Unclassified	0.0	0.8	0.0	0.0
Total	648.4	648.4	648.4	648.4

Table 5 Distribution of estimated salinity-affected areas depending on elevation classes [km^2 ; ( ):%]

	Slightly affected area			
Elevation	Degraded	Ameliorated	No change	Total
<160	11.6	32.7	11.4	55.7 (8.2)
<170	28.7	29.5	14.8	73.1 (10.8)
<180	22.2	14.4	9.0	45.7 (6.7)
>=180	12.8	11.8	3.3	27.9 (4.1)
Total	75.4 (11.1)	88.5 (13.0)	38.5 (5.7)	202.4 (29.8) (29.8)

	Moderately affected area			
Elevation	Degraded	Ameliorated	No change	Total
<160	2.1	3.1	2.9	8.1 (1.2)
<170	1.2	1.3	1.2	3.7 (0.5)
<180	2.3	0.9	1.5	4.7 (0.7)
>=180	0.4	0.2	0.3	0.9 (0.1)
Total	6.0 (0.9)	5.5 (0.8)	5.8 (0.9)	17.3 (2.6) (2.6)

	Severely affected area				Non-affected area
Elevation	Degraded	Ameliorated	No change	Total	
<160	0.2	0.2	0.6	0.9 (0.1)	137.0 (20.2)
<170	0.0	0.0	0.0	0.0 (0.0)	116.9 (17.2)
<180	0.1	0.0	0.1	0.2 (0.0)	81.9 (12.1)
>=180	0.0	0.0	0.0	0.0 (0.0)	122.1 (18.0)
Total	0.3 (0.0)	0.2 (0.0)	0.7 (0.1)	1.2 (0.2) (0.2)	457.9 (67.4)

conspicuously change in classifications in Japan, varied in the range of 45 - 90km². In Northeast Thailand, since rainfall is erratic, the volume of water kept in ponds varies with the year and the shape of the waterbodies changes. The area with waterbodies and wetlands surrounding ponds and river covered almost 100km² in all the data, suggesting that the lowland area is alternatively occupied by waterbodies or wetlands depending on the year. The changes of areas in the categories of paddy fields, upland fields and bare soil were also remarkable. Since during the dry season, rainfed paddy fields are not cultivated and sugarcane in upland fields has been harvested, land surface conditions are identical with bare soil. Therefore, these three categories were assimilated to the cultivated area and they covered 340 - 460 km^2, corresponding to an area of 50 - 70% in the test site. Furthermore, some paddy fields were classified into salinity-affected areas because salinity is observed in rainfed paddy fields. However, the detection of salinity-affected areas depended on the sensor. Compared with MESSR, TM data could detect small patches affected by salinity, presumably due to the difference in the discernment performance associated with the resolution of the sensors.

Fig.4 shows the overlaid image with the results of re-classification by the total score and degraded areas. Table 5 shows a cross-tabulation with the elevation. About 30% of the areas of the test site were affected by salinity, while many parts were slightly affected. The area with the same score in 1990 and 1997 covered 45 km^2. The degraded areas and ameliorated areas were estimated at 82 km^2 and 94 km^2. The ameliorated areas were distributed at an elevation below 160m in the periphery of a waterbody. The degraded areas were located in the northwestern and the southeastern parts of the test site.

Fig.5 shows the relation between salinity and the Normalized Difference Vegetation Index(NDVI) calculated by TM data observed in the dry season (December, 1997) and rainy season (October, 1998). Compared to the non-affected areas, the average value of NDVI in the affected areas was low and the distribution range (average $\pm$ 1sigma) was wide. Furthermore, the average of NDVI was low in the area where salinity was more severe in both seasons. In the data of the rainy season, when the growth of plants becomes more active than in the dry season, the salinity-affected areas also showed an increase of NDVI.

At this site, since a large area of land with salinity is used as rainfed paddy fields, rice cultivation is practiced in the rainy season. The increase of NDVI in the rainy season is due to such agricultural land use, mainly. However, the fact that the increase was negligible in the area most affected by salinity implies that the productivity is likely to decline due to degradation associated with salinity.

Vegetation in the salinity-affected areas is not abundant generally, and not uniform due to the formation of salt crusts and salt patches, as well as growth disturbance by salt, etc. The results showing that NDVI in the salinity-affected areas has a low average with a wide range of values, and the difference in seasonal increase depending on the level of salinity, support such an assumption. The results suggest that the relation between

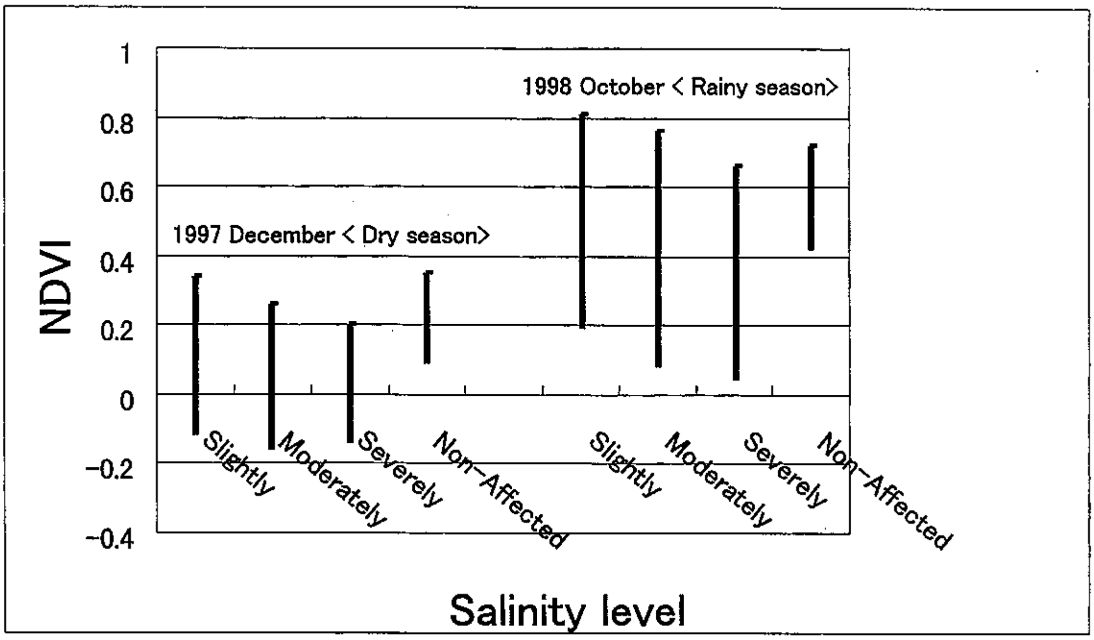


Fig. 5 NDVI range in relation to salinity levels in two seasons

salinity and vegetation production can be determined.

To prevent the expansion of salinity, it is important to develop a technology to monitor the actual conditions of salt accumulation and growth disturbance of plants. The results of this study may contribute to the improvement of monitoring methods for land management and conservation.

The role of GIS studies at JIRCAS

Agriculture is a production activity based on land resources and climatic conditions in a region. The major role of agricultural studies is to identify methods of optimal and efficient utilization of regional resources. Especially in the developing regions, agriculture chiefly depends on natural factors. To develop more efficient and stable agricultural activities, therefore, it is essential to adopt farming systems suited to the regional characteristics.

For a comprehensive project which aims at the improvement of agricultural productivity in a specific area, various studies have been conducted to identify the restrictions of the agro-environment and to overcome them. To analyze the characteristics of the target site spatially, GIS is a powerful and effective tool, because information on the natural and socio-economic environment can be integrated into a map database, and various methods for spatial analysis are available. For comprehensive projects involving a large number of studies and researchers, the results of analysis over a wide area based on various kinds of information will contribute to a common understanding about the test site. Furthermore, since the potential of regional and environmental resources is spatially and quantitatively represented, it becomes possible to identify the site where developed technologies could be applied. This may contribute to the introduction and extension of new technologies. The utilization of GIS at JIRCAS is expanding through analysis over a wide area and the acquisition of fundamental regional information.

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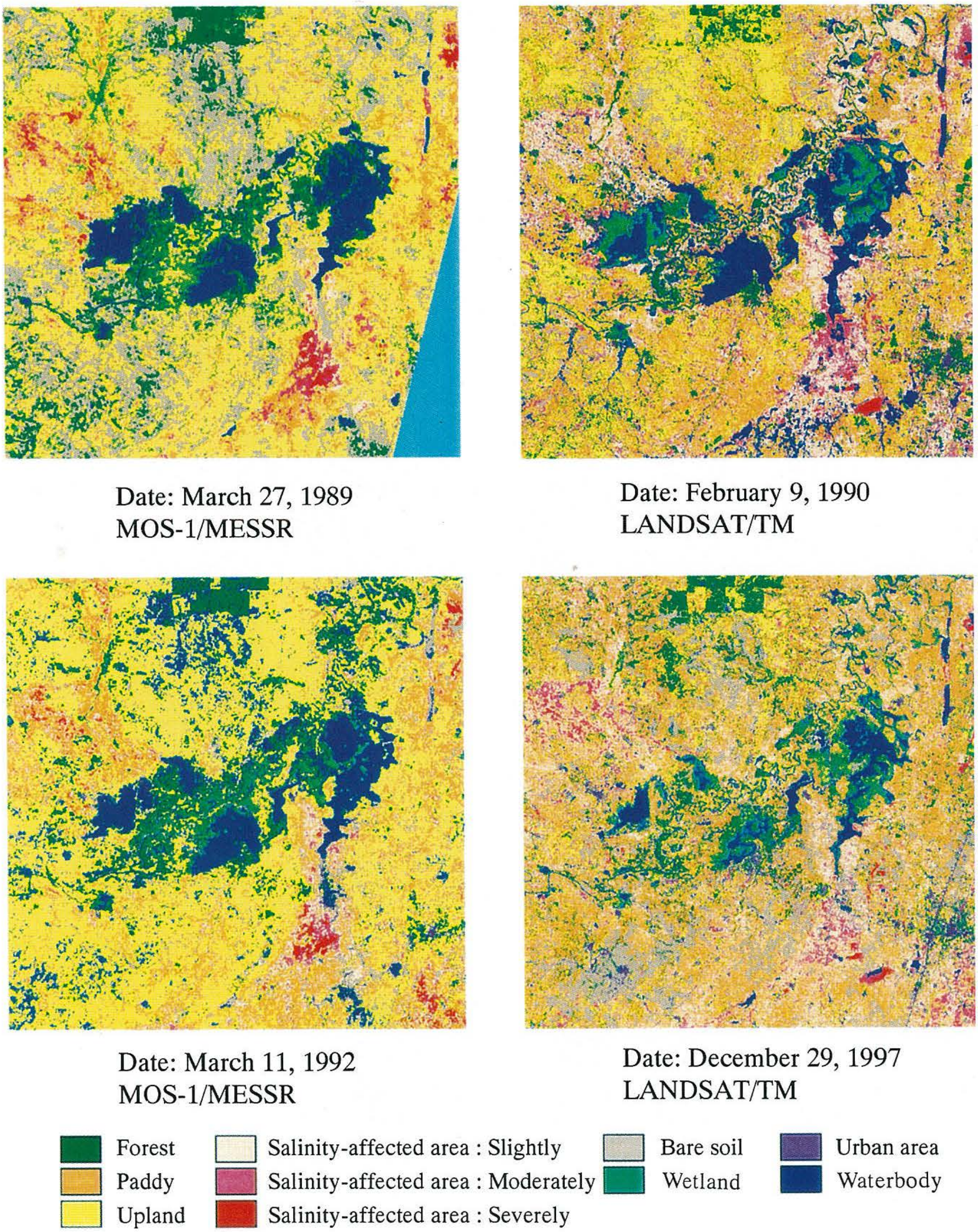

Fig. 3 Land cover/land use classification

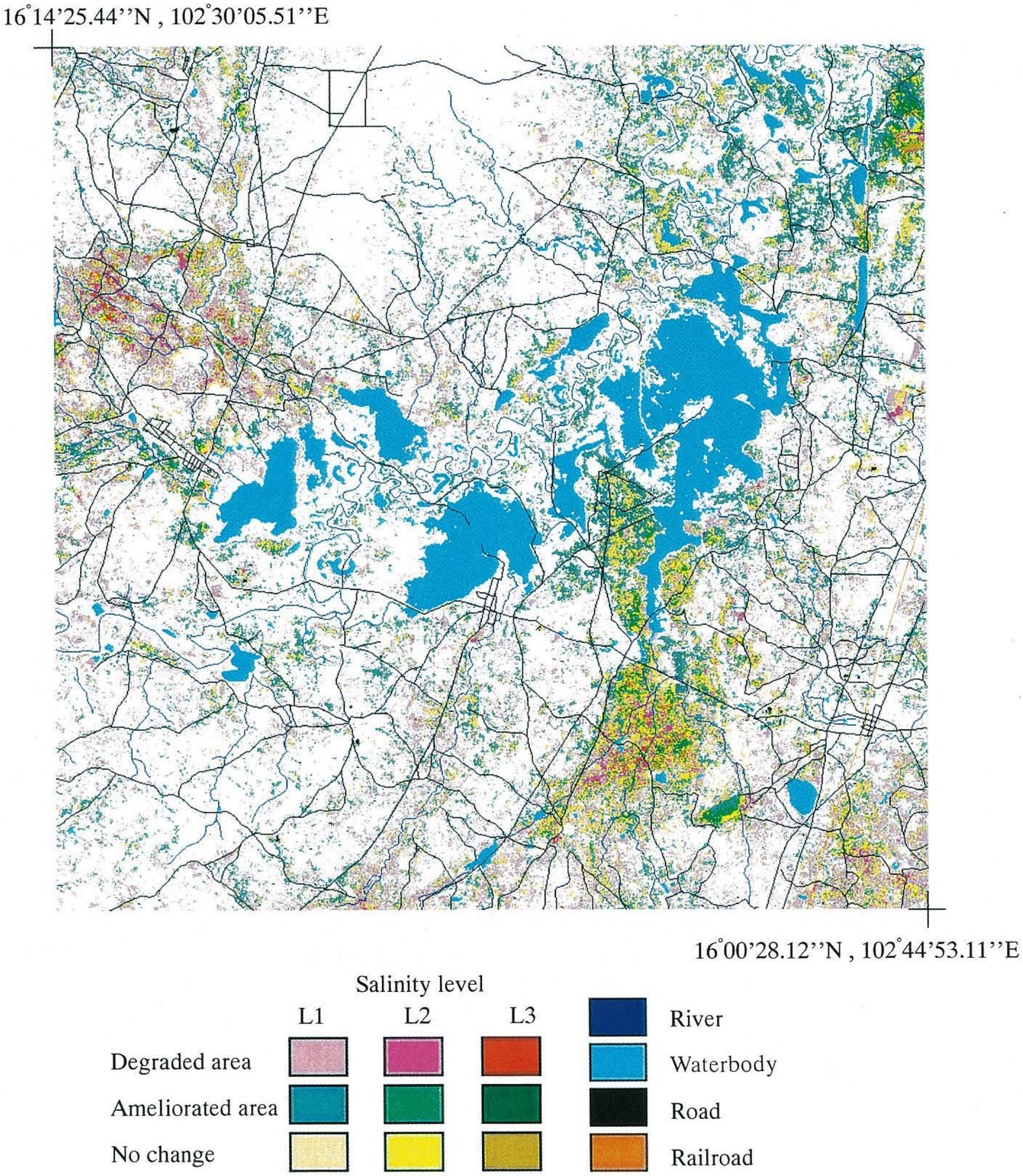

Fig. 4 Estimation of salinity-affected areas