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# Irrigated Area Mapping Using Multi-Temporal IRS WiFS Data

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**ABSTRACT:** Irrigated agriculture in many areas of the world is currently being practiced from multiple water sources such as precipitation, canal, wetlands, ground aquifer, etc. This study highlights the use of high temporal remote sensing data (IRS-1D Wide Field Sensor (WiFS), 188-m resolution) to map landuse/cover along with irrigated classes (canal water, groundwater or wetland irrigated crop) of the rice cropping systems in the 6 Main Canal (6MC) command of Damodar Irrigation Project West Bengal, India for summer season of the year 2000. A multi-date (10 dates 2 bands) image stack was prepared. Using this image stack an unsupervised classification (Fuzzy k-means) backed by Space-Time Spiral Curve (ST-SCs) technique, canal release and wetlands information was used to prepare irrigated classes (canal, groundwater or wetlands) map for summer 2000. ST-SCs have been used to analyze temporal WiFS data to continuously monitor class dynamics over time and space and to determine class separability (different types of irrigated-classes) at various time periods within the season. Results showed that the areas under agriculture, non-agriculture and water were 81%, 18.5% and 0.5%, respectively. While, groundwater, canal water and wetland irrigated rice were 67.6%, 25.6% and 6.8%, respectively out of the agriculture area. Accuracies for the different irrigated classes varied from 85% to 95%. A productivity index (LAI/water-requirement) was also developed and weighed against the observed yield data. Results showed a close agreement between the observed yield and productivity index.

**Keywords:** WiFS, Reflectance, Spiral Curves, Conjunctive Water Use, LAI, Irrigation Mapping.

## INTRODUCTION

Improving the water use efficiency in irrigated agriculture is now the thrust area of research. Rice systems have special significance in this aspect as a major source of increase in rice yield in the past was due to public and private sector investment on irrigation, flood control and drainage that has converted rainfed into irrigated ecosystems. Theoretically, the potential for further increase in rice yield through this source is still large, as only 55% of Asian rice land is irrigated. However, water is becoming a scarce resource. Also, environmental concerns regarding adverse effects of irrigation and flood control projects on water logging, salinity, and the quality of groundwater have been growing. Hence, conjunctive use of water from different sources i.e. precipitation, canal water, groundwater, surface water etc., is gaining attention (IRRI, 1978; Wolf and Rice, 1980). Accurate information of irrigation source as well as changes in their aerial extent over time in relation to the crops grown is the essential input required to model the water use efficiency and long-term sustainability. The spatial database is an added advantage as it provides location specific information that is essential to evaluate and improve the water delivery system at local to regional scale. In this context, satellite Remote Sensing (RS) and Geographic Information System (GIS) have special significance. The potential of RS and GIS for command area studies has been demonstrated by many research works (Bastiaanssen *et al.*, 1999, Ray *et al.*, 2004). However, work related to irrigation source and productivity analysis in rice agriculture is scares. Temporal information is the most important requirement for such study, as single or selected RS images can hardly capture the complex and dynamic irrigated agricultural systems practiced (Thenkabail *et al.*, 2007a,

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Biggs *et al*., 2006, Foody, 2002; Huete *et al*., 2002; DeFries and Los, 1999). Thekabail, *et al*. (2005) used near continuous time series remote sensing MODIS data along with innovative methods and techniques like space-time spiral curves to map the irrigated areas in pat of the Indo-Gangetic region. Thenkabail *et al*., 2006 prepared an Irrigated Area Map of the World (1999) derived from Remote Sensing. However, not much work has been reported to address the irrigated source and their productivity efficiency in typical rice growing systems. This study highlights the methodology using temporal RS data and ancillary data in GIS to analyze the conjunctive water use pattern and its productivity in a typical rice agriculture area in West Bengal, India.

## STUDY AREA

Damodar Valley Corporation (DVC) irrigation project is one of the largest multipurpose projects in the States of Jharkhand and West Bengal, India, spread over 0.36 Mha area. The present study has been done for the command of 6 Main Canal (6MC), that lies between the latitudes 23° 16′ and 23° 32′ N and longitudes 87° 56′ and 88° 16′ E. It is a gravity irrigation system with 12 distributaries and two water channels off taking from the main canal. Total length of the main canal was 37.4 km, while command area was about 54800 ha. The designed discharge at 6MC head regulator was 28 $m^3$/s. The average annual rainfall in the command is about 1400 mm, which is spread over 75 rainy days from June to September months. Rice is the main crop grown twice in a year. The main crop is the wet season rice coinciding with monsoon (July to October). The second rice crop is dry season rice (locally called Boro) grown during January–May. We address in this study the dry season cropping system.

## OBJECTIVES AND RATIONAL

The dry season rice crop is grown under fully irrigated condition. The aim of the study is to identify three sources of irrigation followed in the area viz. canal, ground water and surface water. The canal system provides on an average, three irrigations. A variable discharge, duration and frequency delivery scheduling is practiced in the command. Since, the water available in the diversion system is not enough to irrigate the full area, farmers use groundwater to cover more area under the crop. Tube wells irrigation has increased over the years as the area has shallow groundwater table. Like any other typical high rainfall rice systems, the area has many lowlands that remain water logged during monsoon. These areas are taken up for rice cultivation as the submerged water recedes. Rice grown in such areas are very productive.

The rational of the methodology is based on the fact that the rice planting from these three sources varies significantly. Secondly, variation in management practices that result variation in plant vigor/biophysical parameters (mainly leaf area index and biomass). Thus high temporal resolution data have the potential to differentiate these classes due to spectral variation in red and Near Infrared (NIR) bands.

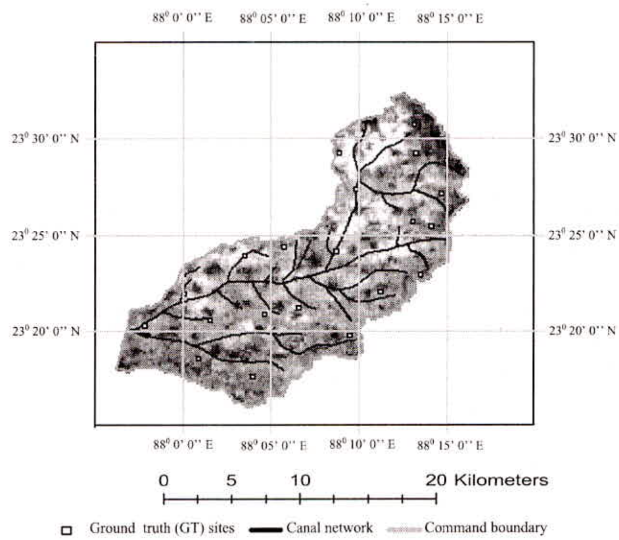


**Fig. 1:** Study area (FCC for 30th November 2000) overlaid with command boundary, canal network and GT sites

## DATA USED

Indian Remote Sensing satellite (IRS-1D) Wide Field Sensor (WiFS) data has been used due to its high temporal resolution (5 days). The sensor provides data in 188-m spatial resolution in two spectral bands RED (0.62 to 0.68 μm), and (NIR) (0.77 to 0.86 μm). Multi-dates (10 dates) data spread over from November 1999 to April 2000 have been used (Table 1).

The ancillary data used were the command boundary, canal network information, canal water release and potential evapotranspiration. Ground-truth data was collected by field visits for different growth stages. Total 21 locations/sites have been used that were spread over the area (Figure 1). The precise locations of the samples were recorded using the GPS in the latitude/longitude coordinate system. Field information included source of irrigation (canal water or groundwater or surface), planting periods, LAI measurements (synchronized satellite pass dates; 16th Feb. and 15th March) and grain yield.

**Table 1:** Remote Sensing Data Used in the Study

| Sl. No. | Date | Purpose | Sensor |
|---|---|---|---|
| 1. | $11^{th}$ November, 1999 | Wetland areas identification | (IRS-1D) WiFS |
| 2. | $30^{th}$ November, 1999 | | |
| 3. | 25th December, 1999 | | |
| 4. | $16^{th}$ January, 2000 | Pre-canal release Groundwater irrigated area and also planting period | |
| 5. | $25^{th}$ January, 2000 | | |
| 6. | 16th February, 2000 | Planting periods, irrigated class identification and maximum LAI computation | |
| 7. | 24th February, 2000 | | |
| 8. | 15th March, 2000 | | |
| 9. | 31st March, 2000 | | |
| 10. | 9th April, 2000 | | |

## ANALYSIS APPROACH AND METHODOLOGY

### Preprocessing of the Data Sets

The November image has been used as the master image and geo-referenced using the command area map as the base map through standard methods of map-image registration. The other temporal data were geo-referenced with this master image to obtain a stack of co-registered data set. The command area boundary, canal and road network and the GT locations were overlaid on the image as vectors using the standard methods of GIS.

Since, the approach was to use the temporal spectral information; zenith angle and dark object based correction have been carried out to normalize the data set. Zenith angle can be computed using the Julian day calendar and geographical position of the site as follows,

$$A = A\text{Cos}(\text{Sin}(L)\text{Sin}(D) + \text{Cos}(L)\,\text{Cos}(D)\text{Cos}(0.261(10.3 - t_0))) \quad \dots (1)$$

Where, $A$ = zenith angle; $L$ = latitude (radians); $D$ = solar declination angle; $t_0$ = local standard time, which depend on the longitude and equation of time (calculated using the day angle and Julian days).

NIR and RED bands radiances were corrected for dark objects using the equation 2 and 3 as follows,

$$SR = (L_{\max} - L_{\min})(R_m - R_{water})/256 \quad \dots (2)$$

Where, $SR$ = spectral radiances; $L_{max} - L_{min}$ = 15.99 and 15.24 for RED and NIR band, respectively; $R_m$ = mean reflectance; $R_{water}$ = water reflectance

Actual reflectance after correcting for zenith angle and dark objects was calculated using the following equation,

$$AR = \pi(SR)/(E_0 Cos(A))100 \quad \dots (3)$$

Where, $E_0$ = solar exoatmospheric solar irradiance (159.83 and 111.27 for RED and NIR band, respectively) (Mehul, *et al.*, 2002).

### Classification

Unsupervised fuzzy logic K- means classification of all the data (20 bands of 10 dates) have been carried out. The fuzzy K-means classify image data into different fuzzy regions (clusters) (Bezdeck, 1973). In this study 7 classes and 16 iterations were used. A new cluster is added at each iteration as long as maximum cluster is not exceeded. The result of the clustering is a theme map directed to a specified database image channel. A theme map encodes each cluster with a unique gray level.

The classes were then first assigned to crop, non-crop (mainly built-up, settlement/homesteads, sand) and water bodies categories. Further, grouping of the crop classes was carried to label it to source of irrigation using the GT data, ancillary data and image inspection. For example, to confirm the rice class assigned to surface irrigation early, November month images (for 11 and 30 November) were used where the same class signature was that of water/water logged.

Further verification of the classes was confirmed using the space-time spiral curves technique to represent and track near continuous changes in a class behavior over time and space. A methodology of the image processing and interpretation in this study is provided in Figure 2.

### Productivity Analysis

Productivity index has been used to analyze the comparative productivity of rice crop belonging to different planting periods and irrigation sources and was compared with the observed yield data. Index was computed as,

$$\text{Productivity Index} = \frac{LAI_{\max}}{ET_{crop}}$$

$$ET_{crop} = ET_0 \times K_c$$

Where, $LAI_{max}$ = maximum LAI; $ET_{crop}$ = crop water requirement; $ET_0$ = potential evapotranspiration (PET) and $K_c$ = crop coefficient

LAI was derived using an inversion technique. First, a regression relationship between measured LAI and reflectance ratio (atmospheric corrected NIR/RED) has been established. Field measurement of LAI at 12

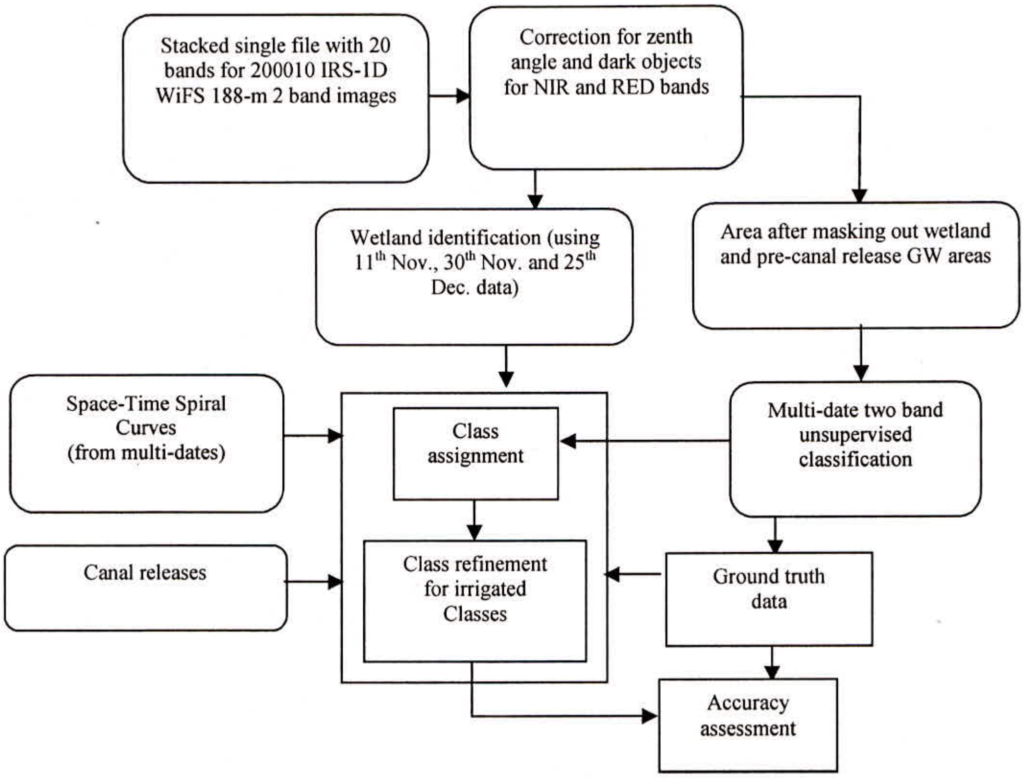


**Fig. 2:** Methods and techniques for irrigated class mapping

different locations was done during early and peak stages (synchronized with the satellite pass dates; 16th February and 15th March 2000). The model thus developed was used to generate temporal LAI maps of rice crop. Maximum LAI map has been generated from this time series data using a logical algorithm.

Crop water requirement was computed using daily PET data (considering crop growth period associated to different transplanting dates) and crop coefficients. The value of crop coefficient varies with the development stages of the crop. Crop coefficient for three stages like initial stage, vegetative stage and maturity stage were 1.1, 1.2 and 0.98, respectively. The maximum LAI and crop water have been used to develop the productivity index.

Normalized Difference Vegetation Index (NDVI) has been used to segregate the rice area based on planting period (early, normal, late and very late). A threshold value has been used to identify the crop emergence using a logical sequential program. For example, crops identified using the first two dates gets masked out, when the next two dates are used in sequence. The planting periods obtained by model were further verified using GT locations and accordingly the threshold value was fine tuned to obtain best possible results. Ultimately, the crops were assigned to four planting periods. This information has been used to build the crop growth stage and period of each pixel.

## RESULTS AND DISCUSSION

### Land Use/cover and Irrigation Source-wise Rice Area Mapping

Unsupervised fuzzy k-means classifier resulted unambiguous classes. After several iterations 7 classes were obtained. With GT information, these classes were assigned to 5 classes as built-up, water and rice (3 sub-classes) (Figure 3). The spectral separability of these classes was confirmed using the ST-SC technique (section 6.1.1). Rice was the single dominant class and occupied 81 percent of geographical area. The built-up areas and water bodies occupied 18.5% and 0.5% of the total area, respectively. The three rice sub-classes viz. canal irrigated, groundwater irrigated, wetland based occupied 25.6%, 67.6% and 6.8% of rice area (Figure 3).

Spatial locations of groundwater-irrigated areas were observed at the tail end of the distributaries in which design discharge is less. Similarly, rice areas of waterlogged area/wetlands also were observed in the extreme tail end of the Command. Field verification showed that these areas get flooded in general during the monsoon due to water release (for flood management) from upstream. Rice crop is planted early in these areas (by late January).

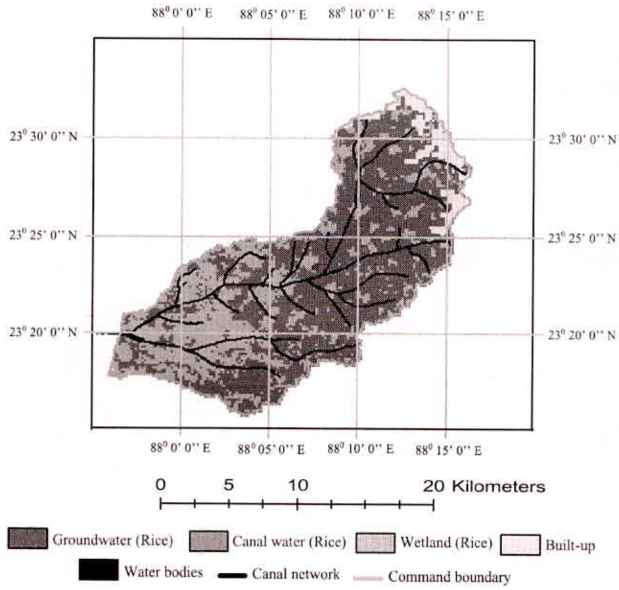


**Fig. 3:** Irrigation sources along with major land cover classes and canal network in the study area

## Space-time Spiral Curves

The space-time spiral curves technique (Thenkabail, 2005) was used to represent and track near continuous changes in a class behavior. ST-SCs capture the magnitude of change over time and space. The dynamics of four broad classes are shown in a 2-D feature space (Figure 4). These Land Use Land Cover (LULC) classes showed a distinct territory and mostly move around within it over a near continuous time interval. The classes shown rarely overlap one another, providing an excellent opportunity to separate classes on most dates. In Figure 4 broad LULC classes follow "brightness territory" (sand), "greenness territory" (irrigated class) and "wetness territory" (water).

SC-STs depict when two classes have similar spectra and when they are most separable. The irrigated area classes significantly overlap one another on most dates (Figure 5) since these classes are spectrally close to one another. All irrigated classes have a distinct planting period, onset-peak-senescence cycle and the biomass magnitude. However, there are one or more dates when a given class is separable spectrally from other classes. For example, on day 55 all classes have a unique place in the 2D feature space as shown in ST-SCs (Figure 5) and, similarly, on day 47 and 74.

The accuracy was further verified with the help of 12 ground truth data points used as blind sites. Overall accuracy of broad LULC (3 categories) was 95 per cent. The accuracy of the sub-classes of rice obtained was 85%, 88% and 95% for canal, groundwater and wetland irrigation respectively. The results confirm that high temporal data provides a substantial within-class variance (Friedl *et al.*, 2000; McIver and Friedl, 2002) that is essential to study dynamics of agricultural systems.

## Crop Calendar and Canal Release

It was observed that temporal NDVI picks up planting periods very well and have shown a good agreement with the observed data. Four planting periods were established and named for early; 16$^{th}$ to 26 January, normal; 27$^{th}$ January to 15$^{th}$ February, late; 16$^{th}$–23$^{rd}$ February and very late; 24$^{th}$ February to 2$^{nd}$ March.

Canal water discharge data showed release of water from January 27$^{th}$ till 23$^{rd}$ of April 2000 (Figure 6). It can be inferred from the data that, the canal-irrigated rice has been planted during February. Thus, rice crop planted before January 30$^{th}$ can safely be assigned to ground water source (excluding the surface water rice). Also, observed that there is a variable discharge and duration delivery scheduling is practiced in the command.

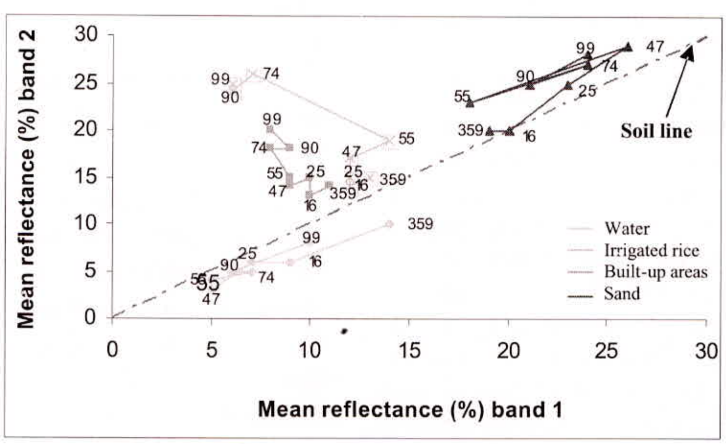


**Fig. 4:** Space-time spiral curves (ST-SCs) for spectrally distinct LULC classes

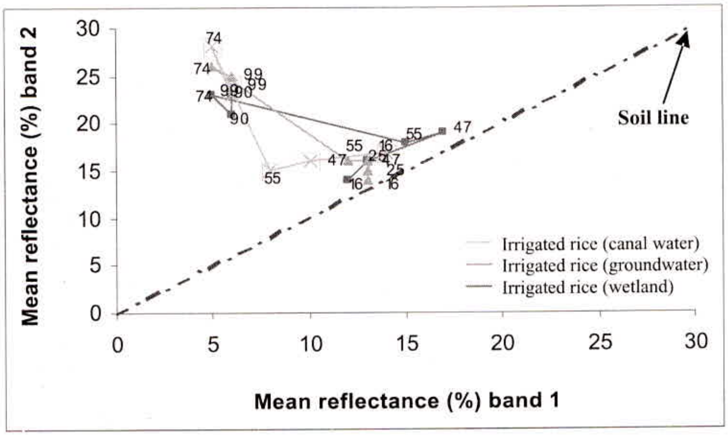


**Fig. 5:** Space-time spiral curves (ST-SCs) for spectrally close irrigated classes

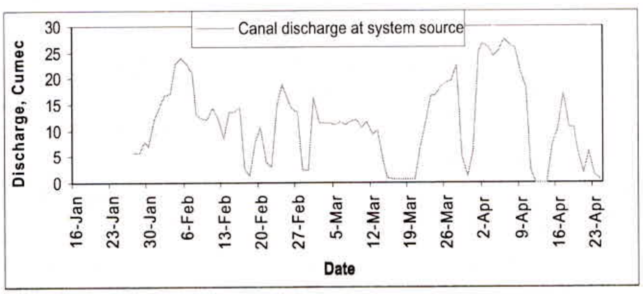


**Fig. 6:** Canal discharge at the system source of 6MC

## Productivity Index

Regression analysis carried out between reflectance ratio (NIR/RED) values and measured LAI (Chen *et al.*, 2002), which has resulted a statistically significant linear regression model, with correlation coefficient (r) of 0.89. The regression included low (1–2) to high (3–4) LAI values taken at different growth stages.

This model was used to generate LAI maps of rice pixels in different dates. The temporal LAI was then used to compute maximum LAI for each pixel. Error analysis was also conducted and found to be within the permissible limits (0.11). Overall mean value of maximum LAI were 2.7, 3.04 and 3.14 for rice crop irrigated by canal water, groundwater and wetlands, respectively.

There was more than one-month difference in the early and very late rice crop. This difference in transplanting periods has resulted difference in the crop water requirements and also in the productivity of rice (planting period-wise). Therefore, maximum LAI alone was found not suitable to compare with yield data. Hence, a crop water model was used (section 4.3) to compute planting period-wise crop water requirements. A scatter plot between productivity index and observed yield was also plotted (Figure 7). It can be depicted that observed yield follow the productivity index satisfactorily i.e., as the yield increases productivity index also increases. Irrigation productive (water use efficiency) in the form of ratio of LAI to water-requirement was high for wetland (0.55) and groundwater (0.48) irrigated rice as compared to canal-irrigated rice (0.36). This irrigation source-wise difference in the productivity was due to variation in the crop water demands, ignorance of critical growth stages (vegetative stage) in the canal scheduling and non-availability of sufficient canal water.

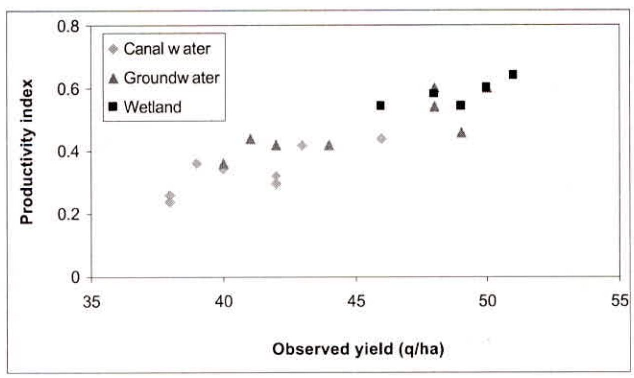


**Fig. 7:** Relationship between observed yield and the water use efficiency in terms of LAI

## CONCLUSIONS

This study highlights the utility of temporal data of RED and NIR bands of IRS-1D WiFS data to map rice areas grown under different irrigation sources (canal water, ground water and wetlands). An unsupervised fuzzy logic *K* means classification of temporal data set was found to result more than 90 per cent classification accuracy of broad land cover classes and separate the sub-classes of rice with reasonably good accuracy. The concept of space-time spiral curves, which tracks subtle and not-so-subtle changes of spectral reflectivity of different classes in the 2-dimentional feature space over time, has been found very useful in validating the separability of the classes. The ST-SCs demarcate the precise regions in which a particular class roams over time, and identify the date/s on which a class is best separable from other classes. For example, it showed that early November data (end of wet cropping season) is crucial for identifying the wetland based rice, while March data was essential to differentiate the canal and ground water rice.

A LAI model developed using ratio reflectance (NIR/RED) and measured LAI has been used to generate maximum LAI. However, further improvement of this model can be carried out incorporating water background correction using SWIR as proposed by many authors (Shibayama *et al.*, 1989; Xiao, *et al.*, 2002; Qi *et al.*, 2000).

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