USE OF SATELLITE IMAGERY FOR LAND USE MAPPING AND CROP IDENTIFICATION IN IRRIGATION SYSTEMS IN PAKISTAN

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Abstract

The size of the irrigation system in Pakistan makes monitoring a difficult process by traditional methods, like the extensive surveys usually conducted in the past. In this context, satellite remote sensing may be an effective way to obtain information on a wide area basis for monitoring and evaluation purposes. The present paper focuses on the use of satellite imagery for land use mapping and crop identification in large irrigation systems in Pakistan. Based on land use mapping and crop identification experiences developed in other countries, a metliodology is developed and applied in one irrigation system located in South-Punjab. The results of this application are presented and discussed in this paper to identify existing limitations in the methodology. Based on the lessons from this first application, a follow-up activity is proposed to be undertaken in the command area of the Fordwah/Eastern Sadiqia (South) Irrigation and Drainage project.

Introduction

With more than 16 million hectares of irrigated land, the Indus Basin Irrigation System represents the largest contiguous irrigation system in the world. The system includes **3** major reservoirs, **43** main canals, 12 **link** canals (bringing water from the Western to the Eastern part of the country), and a large number of secondary canals, or ***distributaries,*** that distribute surface water to more than 89,000 tertiary canals, or ***watercourses.*** Although the size of the system is in itself an authentic achievement of British and Pakistani engineers, it may be one of the reasons that explains the difficulties in tackling current problems encountered in the Indus Basin irrigation system, such as poor canal water system performance, waterlogging and salinity (World Bank, **1994).**

The size of the Indus Basin irrigation system also makes it difficult to assess the magnitude of these problems. In the past, large surveys have been undertaken to collect information on physical and economic variables for planning and monitoring purposes[1]. However, these surveys (and the information they produce) are difficult to manage in a given period of time, and cannot be repeated at regular time intervals. **Also,** sample sizes are often too small to estimate these

1 See, for example, the large surveys undertaken by the Master Planning & Review Division **of** the Water & Power Development Authority in 1976-77 to prepare the Revised Action Program **for** Irrigated Agriculture.

variables with good accuracy. In this context, satellite imagery may be an effective way to obtain information for large areas of the irrigation system, whether for planning purposes, appraisal, monitoring, and evaluation of irrigation and drainage projects. However, so far, in Pakistan, little has been done to assess the potential for satellite imagery in irrigation management.

Objectives of the Paper

The present paper focuses on the use of satellite imagery for land use mapping and crop identification in large irrigation systems. The main objectives of the paper are:

- To describe the methodology developed and applied to use satellite imagery for land use mapping and crop identification;
- To present the results of this application in one irrigation system and for one season;
- To identify the limitations of the methodology applied so far; and
- To propose improvements for follow-up activities to be undertaken in another irrigation system.

The research is undertaken in the Chishtian Sub-division of the Fordwah Branch irrigation system, South-Punjab, Pakistan, and is part of the collaboration between the International Irrigation Management Institute (IIMI), Watercourse Monitoring and Evaluation Directorate **of** WAPDA, and the French research institute, Cemagref. This irrigation system of around 70,000 hectares of Cultivable Command Area (CCA) lies on the left bank of the Sutlej River, and is boarded by the Cholistan Desert to the South, and by the Indian Border to the East. The climate is semi-arid, with a large deficit between the annual rainfall of 260 mm, and the annual evaporation of 2,400 mm.

The main source of irrigation water is surface water distributed to farmers through a network of **14** distributaries and 510 watercourses. Groundwater resources pumped by more than 4,500 tubewells complement canal water. These tubewells have been installed by farmers to compensate for canal water supply inadequacy and unreliability, The main crops cultivated in the area are cotton, rice, sugarcane and fodder during the ***Kharif*** (or summer) season; and, wheat, sugarcane (annual) and fodder during the *Rahi* (or winter) season[2].

Methodology for Land Use Mapping and Crop Classification

The different steps of the methodology used for land use mapping and crop classification are summarized in Figure 1. Supervised classification techniques are used for this classification, using maximum likelihood decision rules. The methodology is applied for the ***Kharif*** 1994 season and the *Rahi* 1994-95 season, using **SPOT XS** images acquired in October 1994 and March 1995 with a 20x20m spatial resolution'. These images are geo-referenced and projected

2 For more information on the Chishtian Sub-division, see Kuper and Strosser (1992).

3 Financial constraints **have** limited the number of satellite images available for the study to one image **per** season.

with the Lambert Conformal Conic projection system. Ground truth is based on land use data at the field, or *Killa,* level[4]. Two crop surveys were undertaken in September and October 1994 (*Kharif* season) and in February 1995 (*Rabi* season), for all the fields of **31** well-scattered sample watercourse command areas (approximately 6 percent of the total command area of the Chishtian Sub-division).

Specific manipulations are undertaken on the ground truth data prinr the classification procedure. *Killa* layout grids are created for each sample watercourse and geo-referenced, using a Geographic Information System (GIS). Then, crop information **is** attached to this coverage.
Fields/*killas* further sub-divided into sub-units with different crops (totally 40 percent of the total number of fields surveyed) are eliminated at this stage, as it is not possible to spatially reference these sub-units, nor **to** use them in the following steps of the analysis.

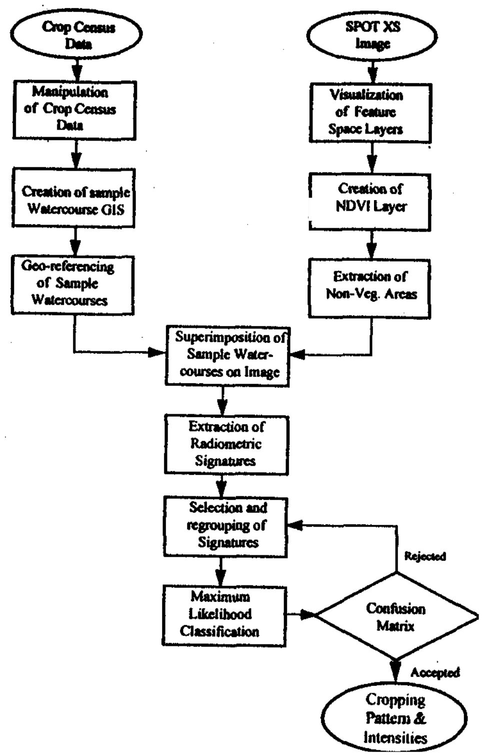


Figure 1. Different Steps of the Methodology for Land use Mapping and Crop Identification.

The next step includes the calculation of the Normalized Differential Vegetation Index (NDVI)[5] for each pixel of the image. The classification will be carried out with the original bands XS1 and **XS3** of SPOT, along with the computed NDVI[6].

The superimposition of the *Killa* layout grid developed for the sample watercourses and the satellite image allows the extraction of the radiometric signature for the sample fields. This

4 Most **of** the command area **of** the Indus Basin irrigation system in Pakistan **is** sub-divided into a regular grid of fields, or ***killas*** (basic unit of 60 m x 67 m), squares (25 ***killas***) and blocks (16 squares).

5 NDVI is obtained from the signature of the bands XS2 and XS3, as expressed by the following formula: NDVI = (XS3-XS2)/(XS3+XS2)

6 The hand XS2 is **not** used in the classification procedure, as it is strongly correlated to the band XS1.

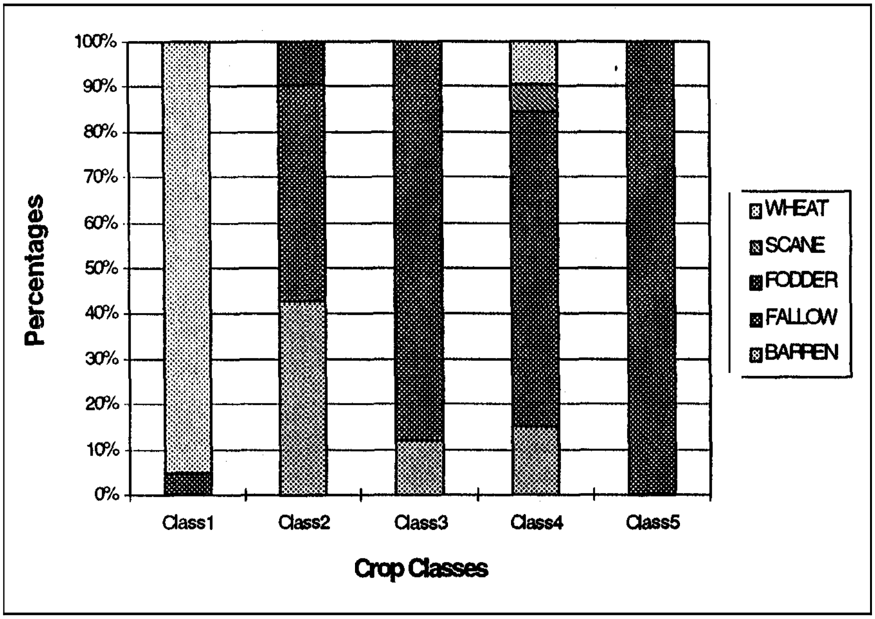
signature contains statistical information for each polygon (field or group of fields with the same crop) such as the number of pixel, the average values and standard deviations of the radiometric response for XS1, XS3 and NDVI.

The most homogeneous polygons (i.e. with standard deviations lower than a specific level) are then selected for the classification itself, and are grouped according to the crop type. The use of scatter plots to visualize the signature of different crops already highlights the large degree of confusion existing between crops. For the final classification, the Maximum Likelihood decision rule is used, and classes with mixed crops are obtained. In order to estimate the accuracy of the classification developed (i.e. how well the classification predicts the type of crop grown in *killas* that have **not** been used for the establishment of the classification), a confusion matrix is developed using all the information that has not been used for the classification itself (around ***60*** percent **of** the information available for the 31 sample watercourses).

The results obtained for the *Rabi* 1994-95 season are presented in the following section.

Results and Discussion

Five different classes have been identified as the result of the classification for the *Rahi* 1994-95 season. The percentage of each crop in these classes is presented in Figure 2, showing that only Class I and Class **3** are pure crop classes representing wheat and fallow/barren. The remaining confusion between barren and fodder **in** class **2** may be explained by fodder areas that have been harvested in the middle of the season. The confusion between the area under sugarcane and fallow **or** barren (expressed by the mixed Class **4,** and also by the low level of User Accuracy for sugarcane in the confusion matrix of Table **1)** is related to the fact that sugarcane is planted in February/March, and looks like fallow in March when the satellite image has been taken.



'igure 2. Composition of Final Land Use Classes Obtained; Supervised Classification of Satellite Imagery.

Table 1. A Confusion Matrix to Assess the Accuracy of the Supervised Classification

Land Use Type	Class 1	Class 2	Class 3	Class 4	Class 5	Total	User's Accuracy
Barren	20108	46103	21526	224620	286793	599151	49%
Fallow	91691	286337	115455	888409	641662	2023555	81%
Fodder	316236	69962	411	65570	9484	461663	84%
Sugarcane	29985	73651	3181	126516	51120	284452	44%
Wheat	4573158	541723	5265	398861	57769	5576776	89%
Total	5031178	1017775	145839	1703976	1046828	8945597	-
Producer's Accuracy	97%	11%	94%	89%	61%	-	82%

No specific reason could be found for the fact that 50 percent of the pixels classified under Class 2 are wheat pixels. The poor status of the wheat crop, and salinity patches in wheat fields that are frequently seen in the Chishtian Sub-division, could be one explanation.

Further analysis of the classes and confusion matrix shows that there is a good accuracy in separating crop and non-cropped area. Although barren land has a very low User Accuracy in the confusion matrix, it is mainly confused with fallow land, a result that is not very surprising. Using the results presented in the confusion matrix, the joint User Accuracy for fallow and barren land is estimated at around 95 percent. In summary, the classification is rather accurate to estimate cropping intensity of irrigated areas, but still remains problematic to estimate the area under different crops.

Using the watercourse coverage of the GIS developed for the Chishtian Sub-division, the results of the classification are used to estimate distributary and watercourse level cropping intensities[7] for the *Rabi* 1994-95 season. The watercourse level information obtained for the Sub-division is presented in Figure 3.[8].

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7 The cropping intensities computed are obtained by dividing cropped area over the total Gross Command Area (GCA) of each watercourse. Thus, the values computed are expected to differ from cropping intensities obtained by dividing the total cropped area by the Cultivable Command Area (CCA).

8 In this paper, no attempt is made to explain this spatial distribution of cropping intensities along the distributary. Analysis is currently undertaken to investigate the relationship between canal water supplies, soil types, salinity, etc. and seasonal and yearly cropping intensities.

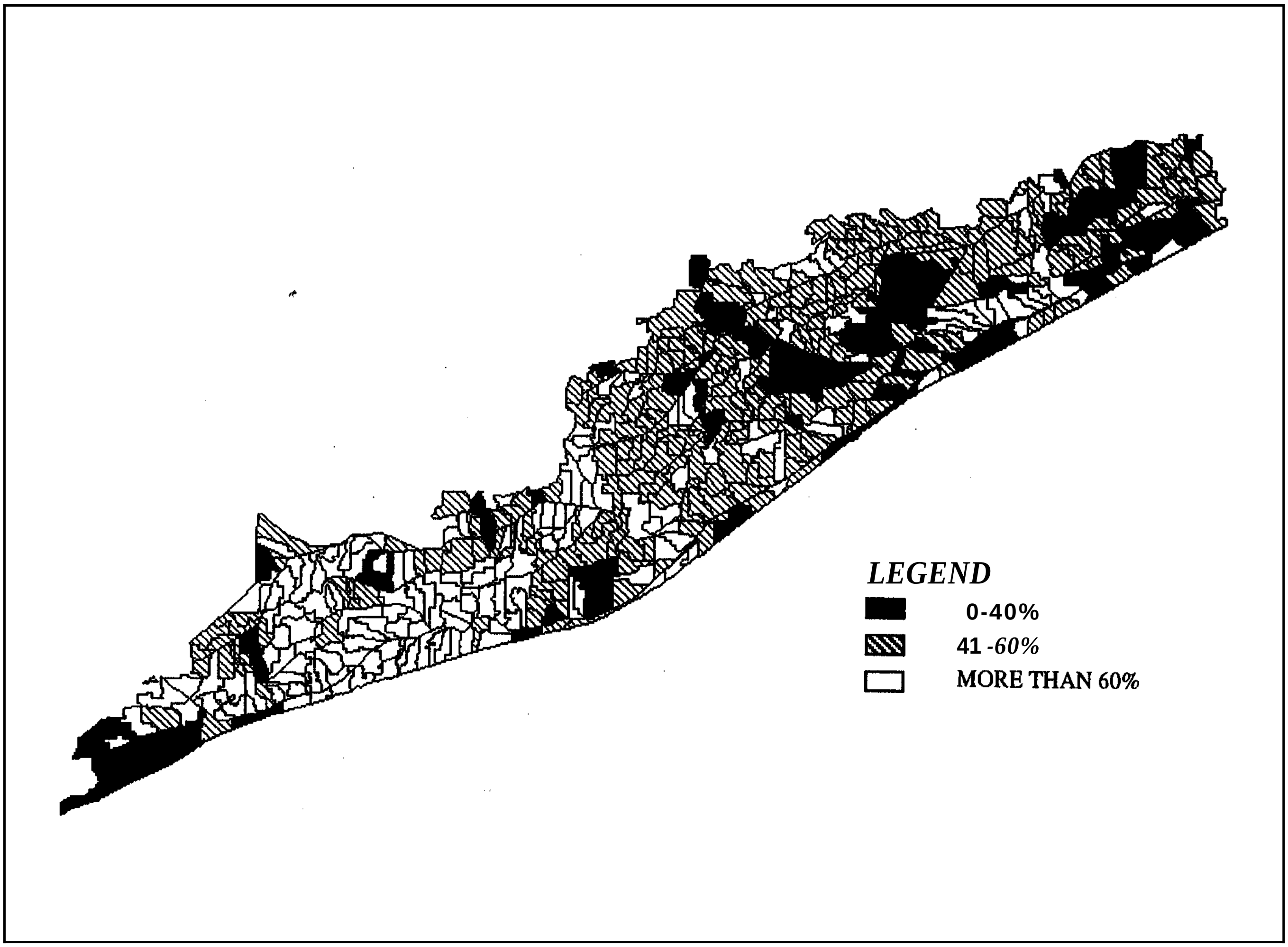

Figure 3. Seasonal Watercourse Level Cropping Intensities for the Chishtian Sub-division (Rabi 1994-95).

Lessons Learned

The present study is a first step towards the development of methodologies for land use mapping and crop identification. The results presented for the Chishtian Sub-division and for the ***Rahi*** 1994-95 season highlights that the distinction between cropped and non-cropped area is possible with a good level of accuracy. However, difficulties remain with the identification of different crops. Similar results have also been obtained for the *Kharif* 1994 season (Jamieson, 1995).

The evaluation of the initial effort highlights the need to have a larger number of images, instead of only one per season, as acquired during the initial exercise. Also, the sampling frame developed using the watercourse as the basic sampling unit may not be appropriate from a statistical point of view. And, the information collected during the crop survey (i.e type of crop occupying each field of the sample watercourses) has not been sufficient to explain the heterogeneity in signals obtained for given crops.

This initial effort has led to the development of a research work plan for the period **1997-98,** which is focused on the development of methodologies for the assessment of irrigation system performance using satellite imagery. This work, presented below, will be undertaken jointly by WMED, IIMI and Cemagref.

Towards an Appropriated Methodology to Use Satellite Imagery for Land Use Mapping and Crop Identification

In consideration of the cost involved, there is a need to provide satellite imagery to potential users with the required information and expertise, that will allow them to better identify methodologies to be implemented that fulfill their requirement in terms of information and accuracy. This will enhance the allocation of financial resources, particularly scarce for monitoring and evaluation of irrigation system performance in developing countries, like Pakistan.

Objectives of the Planned Study

To tackle methodological issues related to the use of satellite imagery for assessing irrigation system performance, a specific research activity is proposed for the *Kharif* 97 season. The overall objective of this activity is:

> **The identification of appropriate methodologies to use satellite imagery for assessing irrigation system performance.**

By appropriate methodology, we mean the right combination of satellite images with specific spatial and spectral resolutions, time of satellite image acquisition, and ground truth survey, to obtain performance indicators at a specific scale of the irrigation system (*killa*, watercourse, distributary, project area) with **a** given accuracy.

At present, as a result of discussion between the collaborators involved in the study and the needs of WMED, only two performance indicators have been selected; cropping pattern and cropping intensity. The study will provide results in two steps. First, the research will establish whether it is possible to identify crops (and at which scale) with the use of satellite imagery. Second, the research will provide information that will allow users to select the appropriate methodology in terms of satellite images and ground truth information ,that is adapted to the required accuracy level.

Selection of Study Site

The site selected for the study is the command area of the Hakra **3-R** Distributary, off-taking from the Hakra Branch canal. The Cultivable Command Area of this distributary is equal to **28,468** ha, partly irrigated through **3** minors; 1R Qazi Wala Minor, 1-L Jourkhan Wala Minor and **2L** Fazal Minor. This distributary has been selected because **WMED** already monitors **5** watercourses in the command area as part of monitoring activities undertaken in the context of the Fordwah/Eastern Sadiqia (South) Irrigation and Drainage project.

Planned Methodology and Activities

The methodology is based on a systematic assessment of the various technical options that have an impact on the accuracy of the results obtained through classification. The various options (range of options) to be tested include:

- Number of satellite images: from 1 image for the season to 4-5 images per season;
- Date of image: comparing results obtained with images taken at different months (or combination of images taken at different months);
- Resolution and number of bands available on different satellites: comparison between information obtained from the satellites IRS, SPOT and Landsat for a given date;
- Number of crop surveys undertaken in the field: from 1 field visit to **3** field visits;
- Information collected through crop survey: from simple information such as the crop name for each field, to information related to agricultural and irrigation practices, and parameters influencing crop growth (salinity, soil type, etc.); and
- Sampling frame: statistically drawn sample of square (10 ha) segments versus a sample of 5 watercourses; different sampling ratio from **2%** to **8%** of the total CCA.

Initially, each satellite image will be processed separately. Then, computer-intensive manipulation will take place to combine the information obtained from different images, classify pixels, and develop confusion matrix to assess the accuracy of the classification developed. The end result will be a three-dimensional matrix that specify for different combinations of images and ground truth data collection the accuracy obtained for cropping pattern and cropping intensity indicators.

Conclusion

Follow-up research activities are undertaken jointly by staff from **WMED** of WAPDA, IIMI and Cemagref, in the context of the Fordwah/Eastern Sadiqia (South) Irrigation and Drainage Project. **A** whole set **of** variables factors will be analyzed, an attempt to sketch methodologies that can be optimum for one given objective, i.e., area under a crop type with a given accuracy level. The evaluation **of** the methodologies developed for the **3-R** Distributary will be further undertaken at the level of the Fordwah/Eastern Sadiqia Irrigation and Drainage project area, providing a first operational assessment of these methodologies. Although the initial efforts concentrate on two indicators only, namely, cropping intensity and cropping pattern, it is clear that similar efforts would be of interest for other performance indicators, such as crop yields, evapo-transpiration, water stress, etc.. Such indicators may also be investigated in the future **as** a result of collaborative efforts with IIMI-HQ researchers.

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