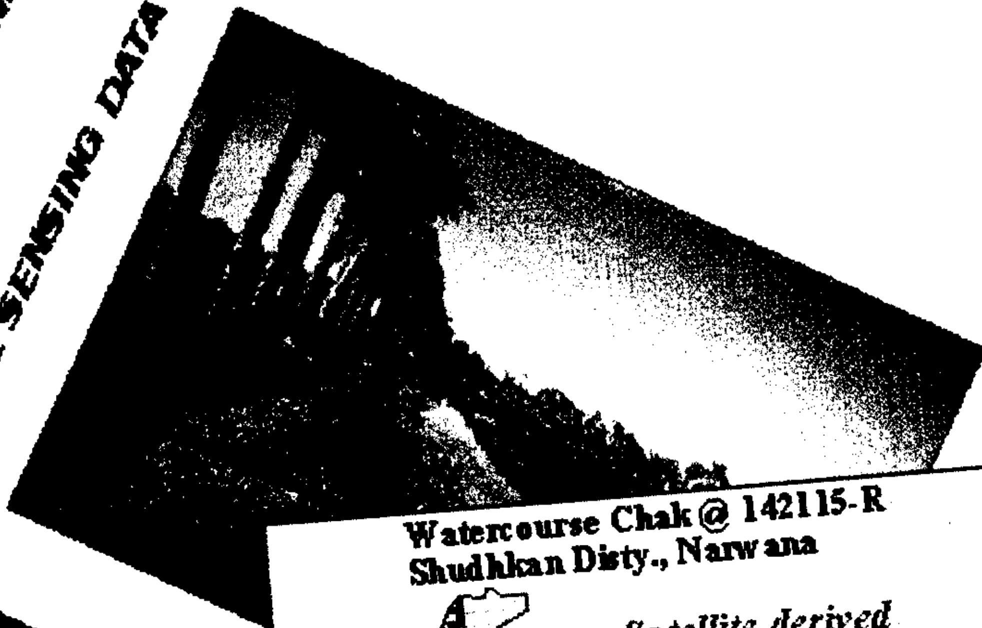
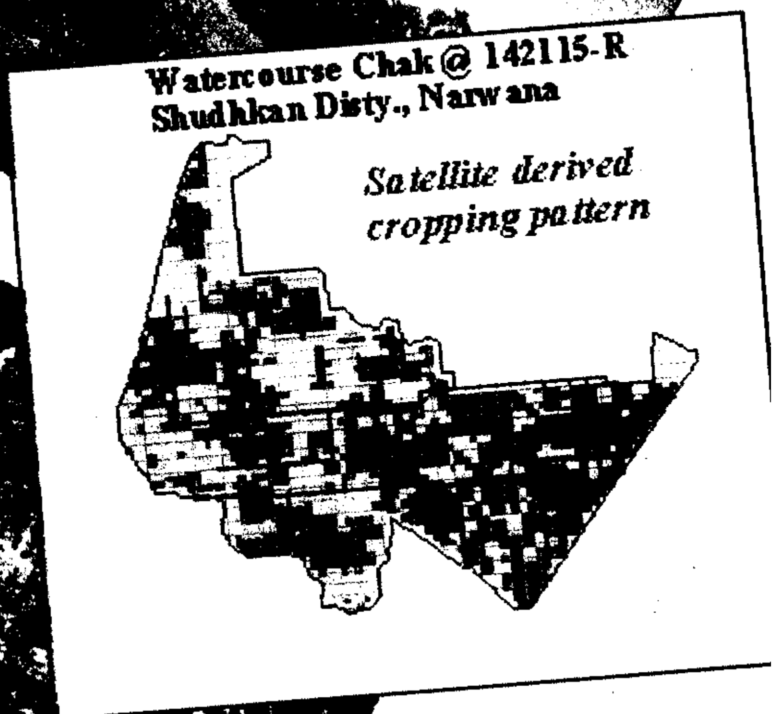
PERFORMANCE EVALUATION OF WATER COURSES

A STUDY IN BHAKRA CANAL COMMAND HARYANA STATE, INDIA USING SATELLITE REMOTE SENSING DATA





June 1998

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A STUDY IN BHAKRA CANAL COMMAND AREA HARYANA STATE, INDIA USING REMOTE SENSING DATA

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June1998

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EXECUTIVE SUMMARY

With the objective of using remote sensing data to study the impact of external interventions on irrigation system performance at micro level, International Irrigation Management Institute (IIMI), Colombo, Sri Lanaka, had requested Water Resources Group, NRSA, to conduct a study. The study was undertaken in Bhakra canal irrigation command area in Haryana State, India, during the rabi seasons of different years from 1986-87 to 1996-97, under the funding support of IIMI. Under this study, satellite data from various high resolution sensors, including IRS-1C PAN, was analysed to evaluate the performance of water courses and to study the impact of water course lining on the performance. Spatial and temporal information on the cropping pattern, crop intensity and crop condition derived from remote sensing data were analysed for evaluating the performance of water courses. The study was conducted in three blocks, namely, Hisar, Narwana and Sirsa and the selection of water courses was done through a stratified random sampling scheme.

The study has successfully demonstrated a methodology for more accurate registration of cadastral/chak maps of water courses (scale=1:6000) with data base of 30 metres pixel resolution (created with 1:50000 scale topographic maps), through complementary use of high resolution (5.8 metres) Panchromatic data from IRS-1C with the available multi-spectral data (23 metres - 36 metres pixel resolution). This in turn has enhanced the capabilities of remote sensing technology for micro level inventory in irrigation systems.

The satellite derived spatial and temporal information on cropping pattern and crop condition at water course level are the potential data sets for generating irrigation system performance indicators. In the absence of any institutional structure for collection and maintenance of such data in irrigated command areas, satellite remote sensing technology assumes greater importance.

The performance indicators evolved from remote sensing derived information on cropping pattern and crop condition could be used for evaluating the

irrigation system performance of grassroot level irrigation units such as water courses.

In Hisar block, the performance of water courses is strongly related to their location in tho respective parent distributary/minor. Water courses located in the head reach area have higher wheat intensity and total crop intensity. In the case of water courses, which were lined in 1992, there is a significant improvement in crop intensity in the post lining period. The disparities in crop condition between head and tail regions have not reduced significantly in the post lining period In this Llock, the quality of ground water is marginal and can be used to some extent for conjunctive use.

The performance of water courses in Narwana block, is in general stable over time. The location of water course, age and extent of lining do not show any relation with crop intensity. In general, in all the water courses, the crop condition is uniform in head and tail regions. However, in the water courses lined upto 1983, the disparities between head and tail are fluctuating from year to year. One of the important contributing factors for superior and stable performance of water courses in this block compared to the other two blocks is good quality ground water which is being extensively used as supplementary source of irrigation.

In Sirsa block, all the water courses selected for the study were lined before 1987. The performance of water courses in general is relatively unstable over time compared to the water courses in the other two blocks. The location of water courses in the parent distributary/minor, do not seem to have any relation to the performance of water courses. This block is characterized by poor ground water quality. As the supplies from canal water are not sufficient, farmers prefer low water consuming non-wheat crops. In some water courses, the disparities in crop condition between head and tail regions are high and fluctuating from year to year. The tail reaches are found to have highly unstable cropping intensity. The declining wheat crop intensity, fluctuating total crop intensity and differential wheat condition between head and tail, particularly in the water courses lined about 20 years back, signify the deteriorating condition of water courses.

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ACRONYMS

CCA - Culturable Command Area
GIS - Geographic Information System
ha - Heclare
IIMI - International Irrigation Management Institute
IRS - Indian Remote Sensing Satellite
IWRD - Irrigation and Water Resources Department
Km - Kilometre
LISS - Linear Imaging Self Scanning
m - Metre
m.ha -Million Hectare
ML - Maximum Likelihood (classification)
mm - Millimetre
NDC - NRSA Data Centre
NDVI - Normalised Difference Vegetation Index
NRSA - National Remote Sensing Agency
PC - Personal Computer
qtha - Quintal/hectare
RMS - Root Mean Square
TA - Training Area
WiFS -Wide Field Sensor
WRG -Water Resources Group

1 INTRODUCTION

National Remote Sensing Agency (NRSA), Department of Space, Government of India had successfully executed the project on the use of remote sensing technology for evaluating the performance of Bhakra irrigation system, Haryana, India. The project was executed for International Irrigation Management Institute, Sri Lanka, during rabi season (November-May) of 1995-96. The results of the project haw demonstrated the capabilities of remote sensing techniques to provide reliable disaggregated information on cropping pattern, cropping intensity, crop condition and crop yield. The analysis of such information helped to identify spatial variability with respect to agricultural performance. With the objective of using remote sensing data to study the impact of external interventions on irrigation system performance at micro level, IIMI has initiated another study during 1996 as part of its ongoing research program. The current report deals with this second study of IIMI which has again been executed by Water Resources Group (WRG), NRSA, India.

Under this study, multi-temporal remote sensing data has been analysed to evaluate the performance of water courses and to study the impact of water course lining on the performance. Spatial nnd temporal information on the cropping pattern, crop intensity and crop condition derived from remote sensing data has been analysed for evaluating the performance of water courses. The study was conducted in Bhakra command area in Haryana state, India, during the rabi seasons of different years.

The major objectives of this study were

1. To generate statistics on total irrigated area, nrea under wheat ond non wheat crops at water course level in different years

2. To generate wheat NDW data (spatial and temporal) in each water course

3. To evaluate the performance of water courses through performance indicators generated from remote sensing data

To study the impact of lining on the performance of water courses

5. To provide a report on satellite data used, methodology followed and analysis of results, to IIMI, Srilanka.

1.1 Bhakra canal command area

The total geographical area of Haryana State is d.4 million hectares (m ha) with 3.9 m ha. of amble land. The irrigated area in the State is 2.8 m ha which is 80 percent of 3.5 m ha. of cultivated area and is served equally by canal irrigation andground water. Two major canal systems namely (I) the Bhakra canal system which is fed from Indus basin and (2) the Western Yamuna Canal (WYC) system which receives supply from Yamuna ricer, with 12,100 km. long network, provide 88 percent of the surface irrigation support in the State. The Bhakra system has a Culturable Command Area (CCA) of 1.2 m ha. (Fig.1), with three operational systems namely Narwana-Sirsa system, the Barwala-Sirsa system nnd Bhakra Main Line (BML) system. Bhakra main line and Narwana branch are contour canals while others are ridge canals. Except Naggal lift scheme near Ambala, all other channels in the command area ore operated by gravity flow. The command area is divided into Ambala, Kaithal, Hisor-I, Hisar-2 and Sirsa water service circles which are in turn divided into 13 divisions and 41 sub-divisions .

Ground water table depth and quality are monitored by tltc ground ranter cell of Agriculture Department. Ground water levels arc observed in the months of June (before the commencement of the monsoon) nnd October (after the monsoon). In Hisar, Sirso and parts of Jind districts, where ground water development is low due to poor quality, water table has raisen over time. In Kiathal, Kurukhshetra ond Ambala districts, the water table hns gone down due to extensive development of good quality ground water. The area irrigated by the conjunctive use of canal and ground water within the canal command is not separately reported by the Revenue or Irrigation department. While the Agriculture department reports areas irrigated by canals andground water separately, only the former is reported by the Irrigation department.

The annual rainfall in the command varies from 750 mm in the north-eastern to less than 400mm in south-western parts. During rabi season, i.e. from November to March, rainfall varies from 100mm to less than 50mm. Kharif (June-October) and

Performance Evaluation of Water Courses
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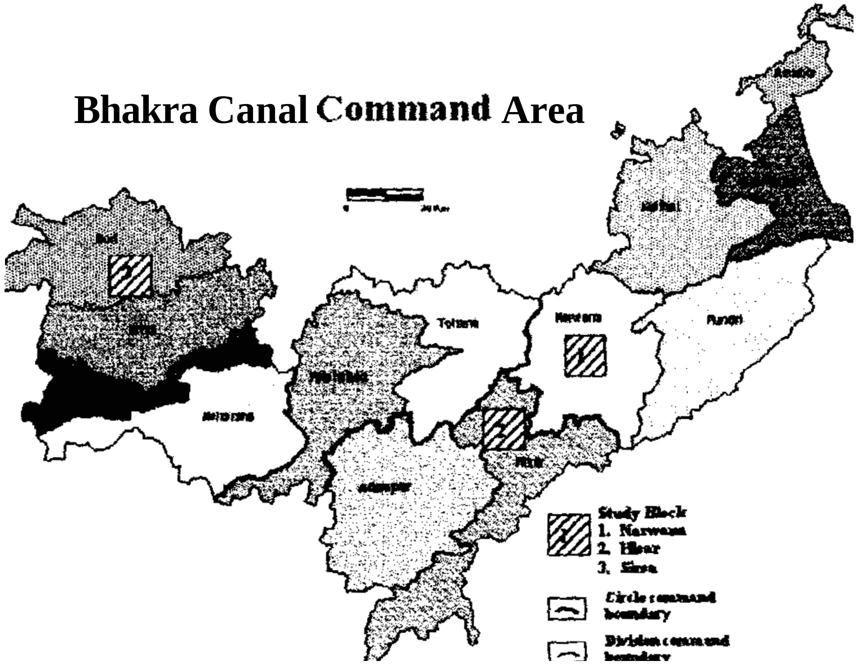

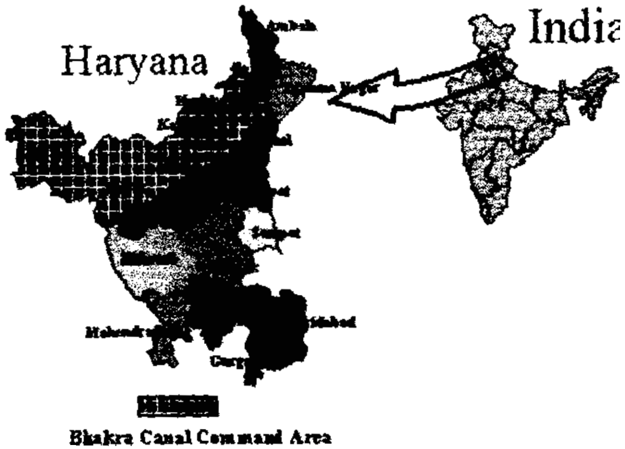

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rabi (November- May) are the two principal agricultural seasons. During rabi season, wheat is predominantly cultivated in all the irrigation circles. Toria is the principal oilseed crop in Ambala and Kaithal circles and Mustard in rest of the three circles. Bengal gram is cultivated mostly in Hisar-1 circle. Sowings commence during November and complete mostly within the month for oilseed crops and for wheat it extends up to December.

Irrigation renter is supplied following the 'warabandi system', which follows a rigid rotational cycle of fixed duration, frequency and priority level. Intensive irrigation and inadequate and inefficient on-farm water management hns resulted in waterlogging and soil salinity in Haryana State, though on a much reduced level in the Bhahra system. The problem of sodicity is mainly in Kurukshetra, Ambala and Jind districts while high salinity pockets ore noticed in Kurukshetra, Hisnr and Jind districts.

1.2 Lining of water courses and irrigation system performance

Lining of watercourses in Haryana state has been going on since 1973. By the middle of 1994, about one third of Haryana's 13,000 water courses had Len lined - some 20,000 km of lining. The impact of lining of watercourse is very specific in this systrm in the sense that there is not additional water delivery at the head of the watercourse, and the capacity of the watercourse remains unchanged after lining, the purpose of lining is simply to reduce seepage losses and hence to improve the equity of distribution of the water supply by increasing deliveries to tail-end users. The impact is easily measured because no allowances arc made for seepage, losses in the time fixed for water delivery to the formers of the watercourse. Hence, teith an unlined watercourse, losing perhaps 20-25% of the flow between the head and tail, there is significant inequity even though the duration of turns per unit of land may be constant. Once lining is introduced, inequity will be significantly reduced to the extent that seepage losses are avoided. Moreover, lining of watercourses increases the velocity of flow, reduces travel time, minimizes the instream storage of the watercourse, maintains the system integrity, incorporates improved, water-tight field outlets and reduces water logging and salinization.

The existing laws governing irrigation in northern India gives the responsibility to the farmers for operation and maintenance of watercourses. Traditionally, with earthen watercourses, farmers have undertaken this responsibility but the advent of lined water courses led to some former resistance to undertaking maintenance, because maintenance in lined watercourses is more complex. This, in turn, has led to the reported failure for the lining of watercourses and hence deterioration of their performance back to something closer to unlined watercourses. Variables which might be expected to contribute to the performance of watercourses in respect of improving the equity of water distribution include: their age, percent of lined length of water course; the water table conditions in tho area (because areas with high water table conditions result in unstable foundation conditions), the existence of groundwater development in the area, variations in the design of watercourse linking; and the extent to which maintenance or rehabilitation has becn carried out.

2 SELECTION OF WATERCOURSES FOR THE STUDY

Based on cost considerations, it was decided to select an area of 18km x 18km in each of the three divisions which will be covcrcd in 3 TM floppy diskette data products. The three areas (blocks) selected for the study are: Narwana block with fresh water quality, Hisar block with marginal water quality and Sirsa block with poor water quality. Narwana block has 82 water courscs while Hisar and Sirsa blocks contain 96 and 132 water courses respectively. It has been decided to take a sample of 10 lined water courses and I unlined water course from each block. The lining of water course commenced around the year, 1975, and is a continuing activity. Since one of the objectives of the study is to quantify the performance of water courses over time, the age of lining of a water course needs to be considered in the selection of watercourses.

As a first step, therefore, the lined water courscs were arranged in ascending order of the year of lining. Also, high resolution satellite remote sensing data are available from 1986 onwards and it was desired that toe should select 6 watercourses lined up to this year and 4 water courses lined later. To ensure that the selected water courses are well spread over different years, the lined rooter courses were grouped to form four cells (strata). Water courses lined up to 1985 were divided into two cells with approximately equal number of watercourses in each cell. From each of the first two cells, three water courses were randomly selected (with equal probability without replacement). Similarly, from each of the other two cells, two water courses were randomly selected. Thus, lined water courses representing different time periods of lining were selected. From the group of unlined watercourses, one water course was randomly selected. The details of selected water courses are shown in Tables 1-3 and Figs. 2-4.

Table 1 Water courses selected for the study

S.No	Source distributary (dy.) / minor (mr.)	Location of water course			Total length (ft)	Lined length (ft)	% lined	Year of lining
		Offtake point (RD)	% RD	Reach				
1	Badhawar dy.	45500-L	64.83	MRA	5424	3876	72	1/75
2	Pinghal mr.	11734-TR	100	TRA	8654	2972	34	2/75
3	Rana dy.	39500-R	26.40	HRA	4646	1675	36	3/75
4	Rajli mr.	16095-R	81.29	Tra	4836	3830	79	5/77
5	Kharkheri dy.	11500-R	29.90	HRA	4062	2134	53	5/76
6	Badhawar dy.	51600-L	73.52	TRA	4216	3486	83	9/76
7	Balak mr.	1000-L	1.01	HRA	11179	5910	53	11/92
8	Balak mr.	45872 R	46.16	MRA	10228	5639	55	12/92
9	Kharkhari dy.	2825-L	7.35	HRA	4782	3664	77	1/96
10	Kharkhari dy.	510-L	1.33	HRA	4479	3304	74	3/95
	Unlined watercourses							
11	Balak mr.	13.120-R	13.51	HRA				

Table . Water courses selected for the study in Narwana block

S.No	Source distributary (dy.) / minor (mr.)	Location of water course			Total length (ft)	Lined length (ft)	% lined	Year of lining
		Offtake point (RD)	% RD	Reach				
I	Barsola mr.	12000-R	14.55	HRA	9379	5570	59	
2	Chosala mr.	23275-L	90.56	TRA	7512	3998	80	8/83
3	Ghasso mr.	9475-L	27.90	MRA	11360	6201	55	
4'	Mohalgarh mr.	24980-R	44.61	MRA	7390	4093	54	1 1/92
5	Molgarh mr.	27910-R	49.84	MRA	7812	5816	74	7/82
6	Shudkan dy.	142115-	95.50	TRA	8600	4666	54	4/83
7	Sinsar mr.	8350-R	66.80	TRA	12324	4899	40	3/83
8	Sirsa Parallel	59878-L	89.80	TRA	9978	4403	44	8/95

Table 3 Water courses selected for the study in Sirsa block

S.No	Source distributary (dy.) / minor (mr.)	Location of water course			Total length (ft)	Lined length (ft)	% lined	Year of lining
		Offtake point (RD)	% RD	Reach				
1	Chormar mr.	32590-R	73.33	TRA	8493	6050	71	6/76
2	-do-	38000-R	8.50	TRA	23518	16750	71	8/76
3	Kaluana dy.	97745-R	53.12	MRA	25630	16127	63	4/77
4	Maujgarh dy.	17125-R	22.83	HRA	26680	21032	79	12/84
5	-do-	73815-L	98.42	TRA	32191	21929	68	7/85
6	-do-	75100-R	100	TRA	41090	27590	67	2/78
7	Mithri dy.	20960-L	26.17	TRA	28179	22682	80	6/82
8	-do-	80100-L	100	TRA	40039	27478	69	1/87
9	Panna dy.	14500-L	91.01	TRA	14857	10197	68	7/81
10	-do-	12625-L	25.82	HRA	14718	11236	76	2/81
	Unlined water courses							
11	Kaluana dy.	121765-L	66.18	TRA				

HRA Head Reach Area, MRA Middle Reach Area and TRA Tail Reach Area

RD - Reduced distance from offtake point of parent distribuary/minor

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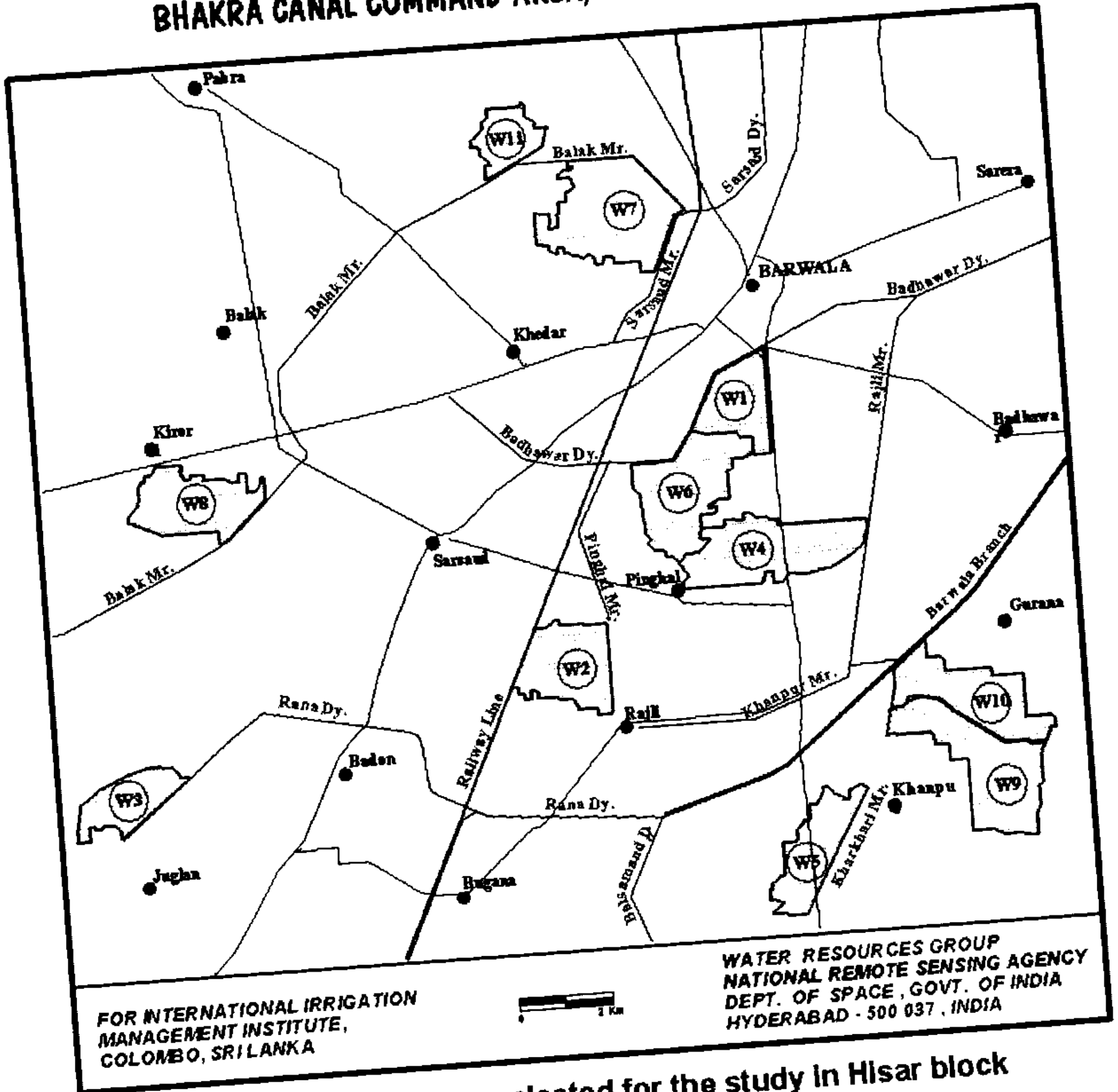

Fig.2 Water courses selected for the study in Hisar block

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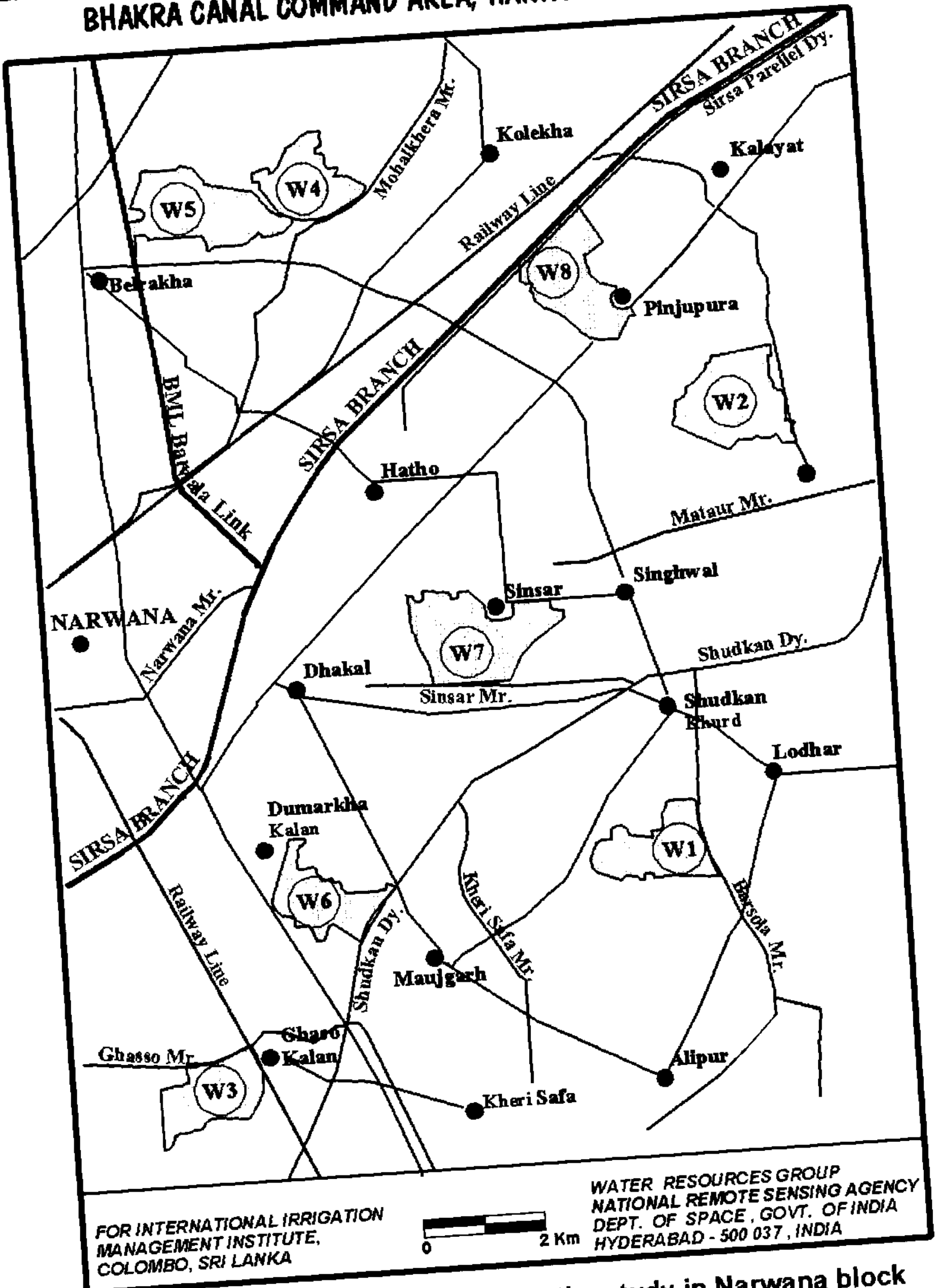

Fig.3 Water courses selected for the study in Narwana block

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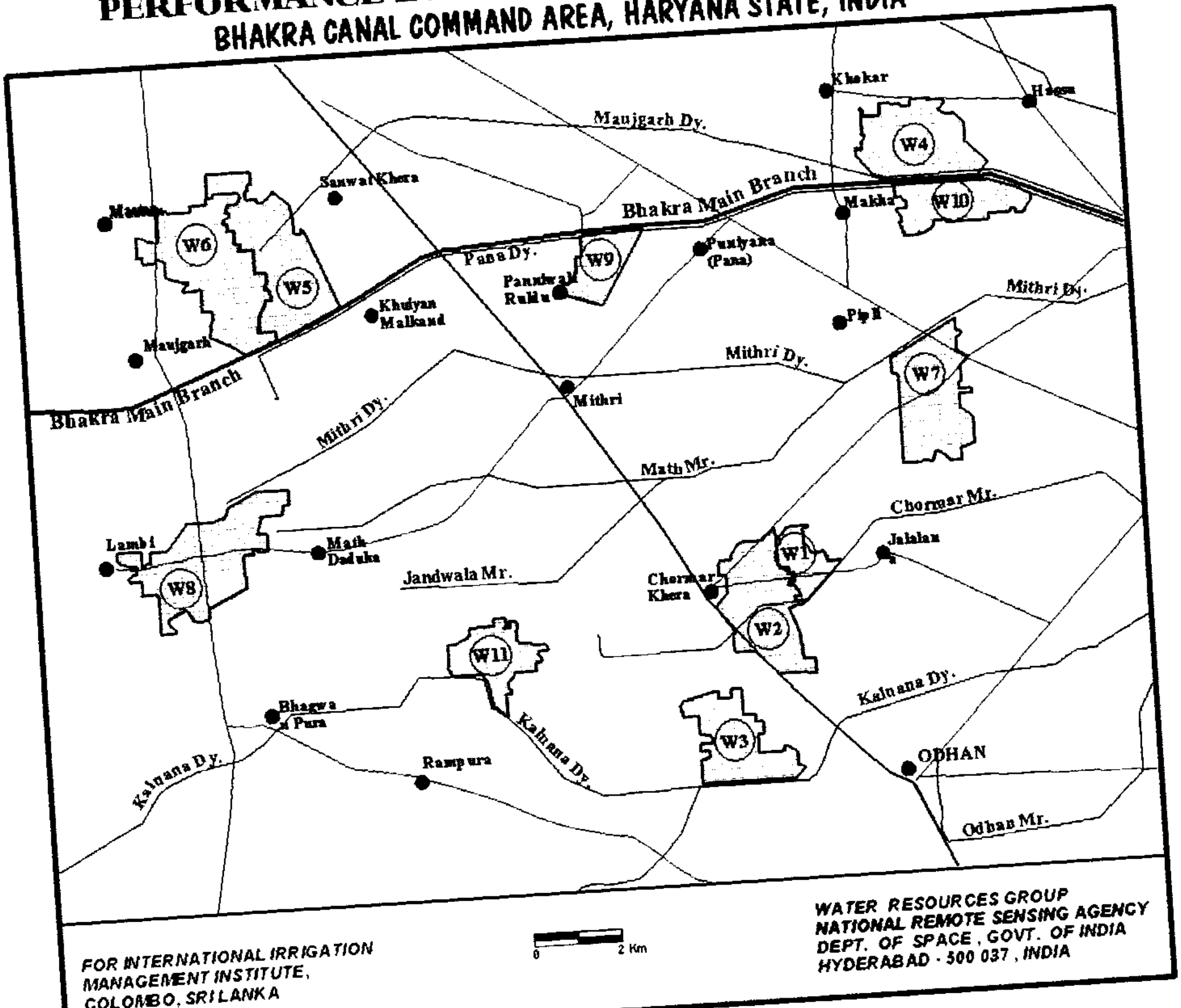


Fig.4 Water courses selected for the study in Sirsa block

3 ANALYSIS OF SATELLITE DAT

3.1 Overview of Analysis Methodolog

The overview of analysis methodology is given in Fig.5. The digital imnge processing and analysis was carried out on IBM Workstation RISC 6000 with EASI/PACE image analysis software. The analysis results were output in the form of classification maps (cropping pattern), filmed on Colorfire film recorder and processed at NRSA Photoprocessing Laboratory while statistics were imported into Pentium PCS ond compiled by Quatropro/Presentations software in Windows 95 environment.

3.1.1 Satellite data selection and acquisition

As the study involves the analysis of multi-year information during the last one decade, the data from various satellites were synergistically used thruogh judicial combination of different overpass dotes in o season. Keeping in view the cropping pattern and crop calendar, cloud free satellite data coverage was obtained (Table 4).

The sensor characteristics of LANDSAT, IRS-1A, 1B and 1C satellites are shown in Table 5. The satellite data was acquired at the satellite data reception station at Hyderabad and distributed by NRSA Data Centre (NDC). The satellite data was obtained in the form of floppies.

3.1.2 Field visits and ground truth collection

Ground truth collection was organised in three phases. In the first phase (February 1997), the whole study area was visited and representative sample sites Training areas) for various theme classes of wheat, non wheat crops nnd fallow areas were identified. Ancillary information on crop calendar, crop condition, ground water quality/utilization was also obtained from office records and through informal interviews with farmers. The ground truth collected during this phase was essential for classification of satellite data into crop types and groups. During second phase (July 1997), the accuracy of crop classification was evaluated. However, a quick and short field oisit was also undertaken during November 1997 to reconfirm the occrrrncg in some of the critical areas located in some water courses.

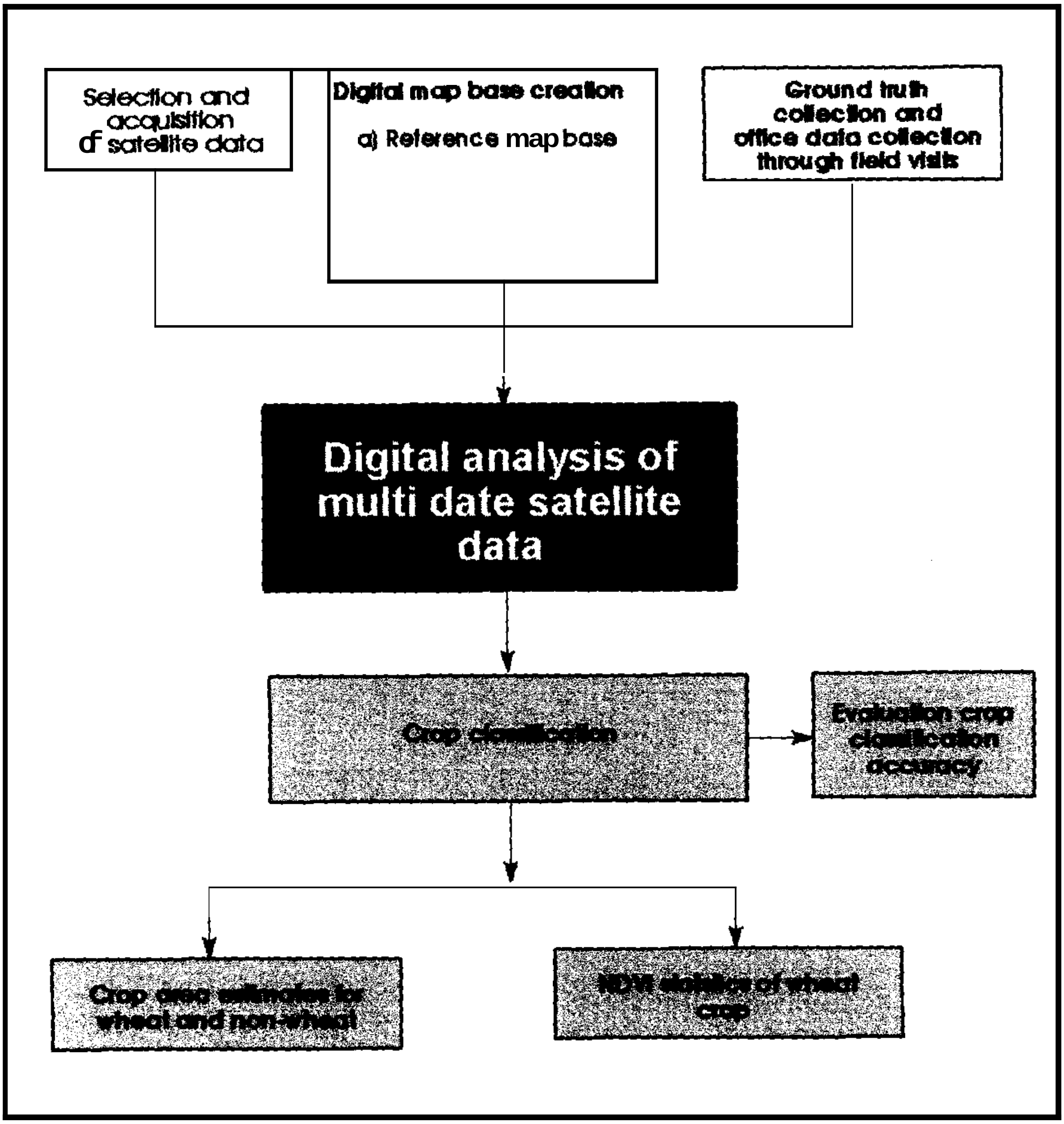


Fig.5 Flowchart of analysis methodology

Table 4 Satellite data analyzed in the study

Year	Overpass date/ Satellite *		
	Hisar block	Narwana block	Sirsa block
1996-97	15 Dec 96 IRS-1C 12 Jan 97 IRS-1B 17 Feb 97 WNDSAT	15 Dec 96 IRS-1C 12 Jan 97 IRS-1B 17 Feb 97 LANDSAT 02 Nov 96 IRS-1C **	22 Dec 96 IRS-1B 13 Jan 97 IRS-1B 26 Feb 97 IRS-1B 21 Mar 97 IRS-1C **
1995-96	21 Nov 95 IRS 1B 4 Jan 96 IRS 1B 26 Jan 96 IRS 1B 17 Feb 96 IRS1B 10 Mar 96 IRS 1B 01 Ayr 96 IRS 1B	21 Nou 95 IRS 1B 4 Jan 96 IRS 1B 26 Jan 96 IRS 1B 17 Feb 96 IRS1B 10 Mar 96 IRS 1B 01 Apr 96 IRS 1B	22 Nov 95 IRS 1B 27 Jan 96 IRS 1B 18 Feb 96 IRS 1B 11 Mar 96 IRS 1B 02 Apr 96 IRS 1B
1992-93	22 Feb 03 LANDSAT 10 Mar 03 LANDSAT 26 Mar 93 LANDSAT	22 Feb 93 LANDSAT 10 Mar 93 WNDSAT 26 Mar 03 WNDSAT	27 Dec 92 LANDSAT 01 Mar 93 WNDSAT 02 Apr 93 LANDSAT
1989-90	12 Dec 89 LANDSAT 02 Mar 90 LANDSAT 04 Apr 90 WNDSAT	12 Dec 89 LANDSAT 02 Mar 90 LANDSAT 04 Apr 90 IRS 1A	03 Dec 89 LANDSAT 20 Feb 90 LANDSAT 10 Apr 90 LANDSAT
1986-87	20 Dec 86 LANDSAT 10 Mar 87 LANDSAT 26 Mar 87 LANDSAT	20 Dec 86 LANDSAT 10 Mar 87 LANDSAT 26 Mar 87 WNDSAT	27 Dec 86 LANDSAT 01 Mar 87 LANDSAT 17 Mar 87 LANDSAT

* Sensors are TM in Landsat, LISS II in . S-1A &1B, LISS III and PAN in IRS-1C.
** PAN data only

Table 5 Satellite sensor characteristics

Satellite	Sensors	Spectral resolution (Microns)	Spatial resolution (m)/ swath (km)	Revisit period
Landsat 5	MSS	0.5-0.6 0.6-0.7 0.7-0.8 0.8-1.1	80/185	16
	TM	0.45-0.52 0.52-0.60 0.63-0.69 0.76-0.90 1.55-1.75 2.08-2.35 10.4-12.5	30/185 120/85	16
IRS-1A/1B	LISS-I	0.45-0.52 0.52-0.59 0.62-0.69 0.77-0.86	72.5/148	22
IRS-1A/1B	LISS II	0.45-0.52 0.52-0.59 0.62-0.69 0.77-0.86 0.5-0.73	36.25/74	22
IRS 1C	PAN	0.5-0.73	5.8/70	24
	LISS-III	0.52-0.59 0.62-0.69 0.77-0.86 1.55-1.75	23.5/141 70.5/148	24 24
	WiFS	0.62-0.69 0.77-0.86	188/810	24* (5**)

* Steerable Camera, Offnadir coverage

** revisit at equator

3.1.3 Digital map base creation

The pixel resolution of database was kept at 30 metres since the data from LANDSAT - TM and IRS - LISS II was mostly used in the study. All the toposheets of tbe study area in I: 50,000 scale were collected and scanned at 30 metre pixel resolution. First, the georeferenced data base was created in polyconic projection for each of the study area blocks, namely, Hisar, Narwana and Sirsa by identifying tho geographic coordinates (Latitude and Longitude) of four corners. Grid lines representing an interval of 15' by 15' were created on the georeferenced data base. Then all the concerned toposheets were mosaiced one by one using the coordinates of four corners of each toposheet as control points. Thematic features such as major roads, railway lines, canal network and rivers were then digitised.

3.1.4 Geometric rectification of satellite data

Satellite data ore distorted by the curvature of the earth and its rotation, and the platform and sensor aspects. Hence there is a need to geometrically correct the image so that it can be represented on a planar surface and conforms to other images and has the integrity of a mop. Rectification is performed by transforming the raster data from one grid system to the other using first or higher order polynomial. Since the pixels of the new grid may not align with the pixels of the original grid, the pixels must be resampled. Resampling is the process of extrapolating data values for the pixels on the new grid from the values of the source pixels. The digital data of each satellite overpass was first converted into radiance from digital numbers using sensor calibration coefficients. Then each scene data was registered into reference map Lase using Ground Control Points (GCPs). GCPs are specified pixels in an image far which output coordinntes or reference coordinates are known. Accurate and well distributed GCPs arc essential for accurate rectification. Polynomial equations are used to convert source file (slave image or image under rectification) coordinates in to reference coordinates. A transformation matrix is computed from the GCPs. The matrix consists of coefficients which are used in polynomial equations to convert the coordinates. The transformation matris is useful to derive the polynomial equation for which there is the Last possible error when used for transformating. RMS (Root Mean Square) error is the distance between the input (source) location of a GCP and the retransformed location far the same GCP. In the current study, a 2nd order transformation function was used in all rectifications. After selecting GCPs, a transformotion matrix was calculated alongwith RMS error for which GCPs with high RMS error, were removed and the transformation matrix was again computed. Finally, it was ensured that RMS error either individual GCP wise or overall, do not exceed 0.5 pixel i.e., 15 metres. Once the transformation was over, resampling was performed to assign grey levels to the new data file. While various techniques are available in resampling to suit different situations, in the present case, nearest neighbour method was employed since it has the advantage that original data values are transferred without averaging and therefore extremes and subtlities are not lost. This is an important consideration when discriminating between crop types.

3.1.5 Registration of water course maps to database

Accurate registration of water course maps to satellite database is crucial for generating reliable statistics pertaining to water courses. The water course maps provided by the authorities of Irrigation department were in the scale of 1:6000 while the topomaps of 1:50,000 scale were used to create working database. The field maps of water course were first scanned at a resolution of 1016 microns resulting in the scanned image of 6 metres pixel resolution. Then a vector image was created from each water course map image, showing the details of outer boundary, and some features like village roads, water course offtake point, distributary etc. Then the vectors were registered to main data base (pixel resolution = 30 mtrs) through ground control points. The average RMS pixel line error was about 2.5 pixels. The post registration gross area under each water course was calculated and compared with pre registration gross area. It was found that there is significant mismatch between the two areas (Table 6). This is due to significant differences between the scales of two source maps, the water course map 1:6000 scale and the other toposheet 1:50,000 scale which limits the availability of sufficient number of ground control points. To overcome this limitation, on alternate methodology was adopted (Fig. 6). IRS-1C PAN sensor data which has got a spatial resolution of 6 metres was used for intermediate registration between water course maps and main database. First, the water course vectors were registered with PAN data. The number of GCPs were significantly improved compared to previous registration, due to finer resolution of PAN data. The average pisel-line RMS error iuas about 1 ½ pixels. After registration, all water course vectors were encoded into a channel. Then

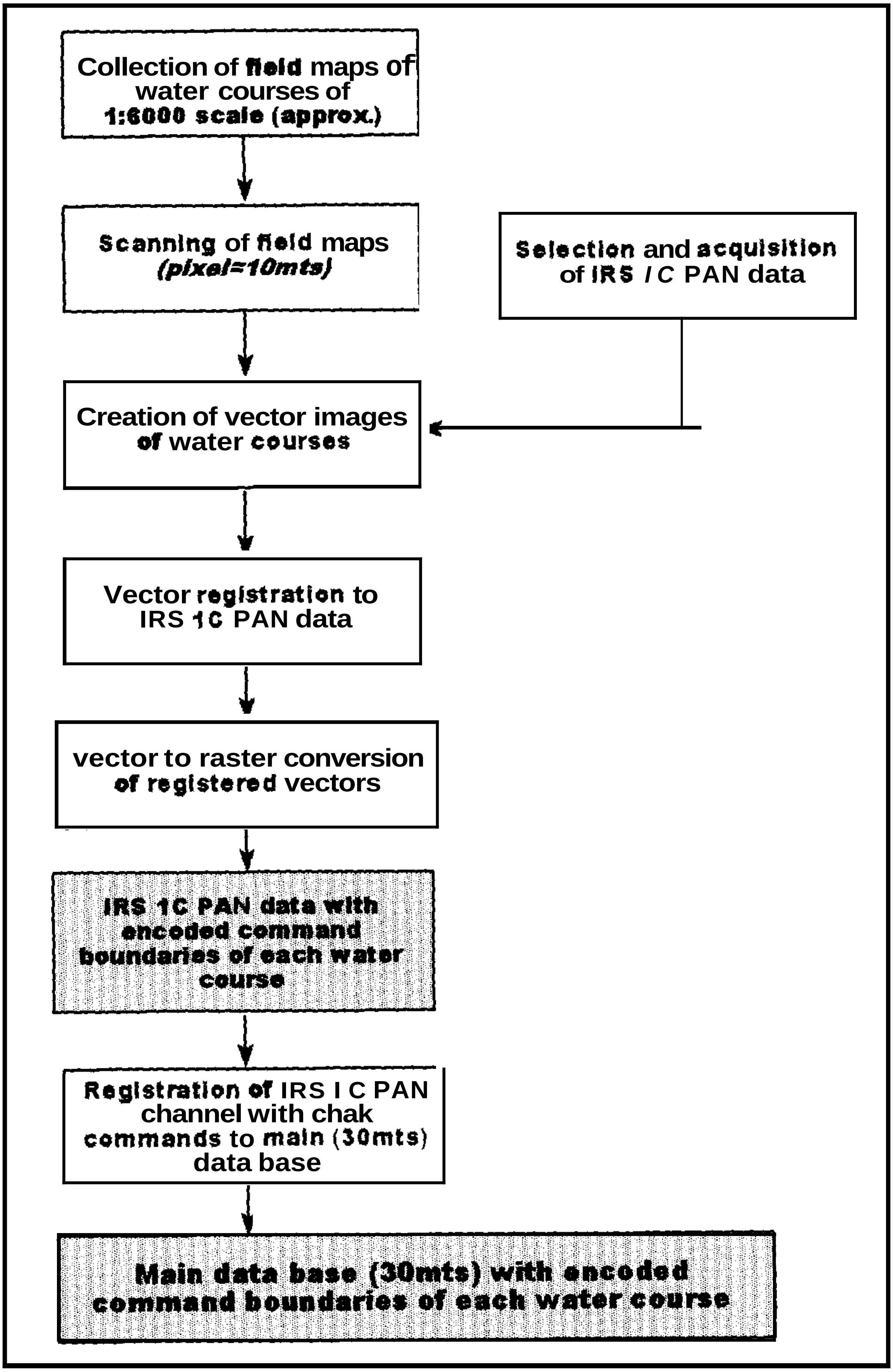


Fig.6 Registration of water course chak map with satellite data base

GCPs were selected using PAN image as slave and rectified satellite data (TM/LISS-II) of main database as master. Using these GCPs, the encoded channel water course vectors in PAN database was registered to main database. The average pixel-line RMS error in this case was about 2.5 - 3 pixels. The gross area under each water course in main database was calculated and compared with actual gross area and found that there was no significant difference. Thus, the use of IRS-1C PAN data has tremendously improved the accuracy of registration and facilitated the more accurate registration of field mays to the satellite data base of high resolution multispectral images such as from LANDSAT and IRS. This in turn improves the capabilities of remote sensing technology for micro level inventories.

Table 6 Pre registration and post registration gross areas of water courses in Narwana block

W. No	Pre registration Gross area (ha)	Gross area (ha)		
		Direct registration to main database	Registration to PAN data	Registration to main database through PAN data
01	216	257	214	231
02	294	337	292	315
03	226	280	226	244
05	212	232	197	211
06	332	342	310	332
08	214	504	226	224
09	368	420	388	370
10	293	340	296	302

3.1.6 Crop classification

The classification of satellite remote sensing images is an information extraction process that involves pattern recognition of spectral properties of various surface features and categorising the similar features. Spectral recognition of a target surface feature can be enhanced by adding spatial and temporal dimensions to the spectral pattern. Traditionally, classification strategies have been grouped into two broad categories, namely, supervised and un-supervised according to the procedure employed to obtain the training statistics. In case of supervised classifcation, the analyst specifies the areas of known cover type in the image as training areas, which statistically characterize the informational categories of interest. The supervised technique is subjective in that the analyst tries to classify thematic categories which are often composed of several spectral classes (Jensen, 1986; Chevico and Congalton 1988). "he un-supervised approach attempts to identify spectrally homogeneous groups within the image and these groups haw to be labeled from user point of view.

The goal of classification in the current study was to delineate wheat and non-wheat crops. The ground truth data on crop calendar showed that the satellite data of December and February/March were most crucial for classification. The non-wheat crops mostly mustard and toria were sown early in the season (October-November) while wheat sowings were staggered over a period of two months during November-December. Hence, during December, the non-wheat crops were in good vegetative phase and wheat was in growing stage (thinly vegetated). During February/March wheat crop was in peak greenness stage while non-wheat crops in senescence phara. Therefore, multidate data of December and February/March were used to achieve complete classifcation of crops. However in Narwana and Hisar blocks during 192-93 rabi season, the data of February/March alone was used due to non-availability of data in December. The training areas were identified for wheat, non-wheat and fallows. Spectral signatures were generated for each class and spectral separability index was calculated using Bhattacharga Distance measure (Jensen 1986).

A hybrid classification strategy was adopted by combining supervised (Maximum Likelihood) and un-supervised (iso-clustering) techniques to achieve complete and accurate classification. First, Maximum Likelihood(ML) classification runs performed over multidate data. This had resulted in acceptable classification but only over 60-70 percent of image. This is essentially due to multi dimensional nature of data set providing pure spectral signatures of classes, with areas even slightly different in signature being left unclassified. Visual evaluation of unclassified portion of image indicated the presence of crop signatures. Hence the unclassified portion of the image was subjected to isoclustering to result in 50 spectrally homogenous clusters. The signature of each cluster was compared with reference signatures and the clusters with similar signatures were used to define new Training Areas (TAs) of respective theme class. Thus TAs for wheat and other classes were increased wherever possible and the revised TAs were isoclustered to yield reasonably large number of clusters. The TAs of each class were increased, purified and sub-grouped into homogenous groups through isoclustering technique. This was then followed by ML classification as in the first step. This process was repeated till the image classification was complete.

3.1.7 Classification accuracy

Satellite remote sensing technology has introduced a new dimension to generating information on earth resources and in the last few years, this technology has been increasingly recognised for evolving objective, standardised and possibly cheaper and faster methodology for earth resources inventory. Thematic accuracy, is om of the vital yardsticks to judge the quality and thereby the value of remote sensing derived maps. Thematic accuracy often termed as classification accuracy in remote sensing reflects the degree of correspondence between the classified label and true class label. The need for assessing the accuracy of maps derived from remote sensing is receiving more interest every year. Several studies have been conducted during the last two decades on thematic map accuracy evaluation. The statistical basis of map or classification accuracy estimation and the importance of considering both the probabilities of incorrectly rejecting an acceptable map (producer's risk) and of accepting an inaccurate map (consumer's risk) were discuss by Story (1976) and Arnoff (1982). The most common way to represent the accuracy of a classification is in the form of an error matrix/confusion matrix (Card 1982, Mead and Meyer 1977, Hoffer 1975). An error matrix is a square array of numbers set out in rows and columns which express the number of pixels assigned as a particular land cover type relative to the actual kind cover type as verified in the field. The columns usually represent the reference data and rows indicate the classified-data. Consumer and producer risks, overall map accuracy, individual class contingency table, evaluation matrix or mis-classification matrix (Story and Goyal 1980, Aronoff 1984) accuracy are summerised through a reporting format on map accuracy (Arnoff 1982). Discrete multivariate statistics techniques have been developed for map accuracy evaluation by Congalton and Meed 1983 and Congalton et al 1983. Since its introduction to the remote sensing community by Congalton et al 1983, several studies haw reported the usefulness of Kappa coefficient of agreement as a measure of classification accuracy (Rosenfield and Fitzpatric-Lins 1986, Congalton and Howarth 1990, Fitzgerald and Lees 1991). In the present study, Kappa coefficient was calculated for overall classes as well as for wheat and non-wheat classes. The evaluation was done at tioo levels, one at total scene level and the other at water course level. Total scene level analysis was performed for each of the three blocks. Due to time and logistic constraints it was not possible to carry out evaluation in each water course. Hence, two water courses in Hisar block, three water courses in Narwana block and three water courses in Sirsa block were randomly selected. The fundamentalassumption in any map accuracy evaluation procedure is that the error matrix is indicative or representative of total map area under consideration. It is practically not possible to check each and every parcel or field in the remotely sensed maps. Hence, some sampling strategy has to be adopted. Here, in the present study, simple random sampling technique was adopted in each thematic unit. In the evaluation at total scene level, at least 20 points for wheat and 10 points for non-wheat were selected at random At touter course level at least 15-20 points for wheat and about 10 points for non-wheat were randomly selected. The field verification of selected points was carried out through field visits in case of total scene accuracy evaluation. The field verification in case of evaluation at water course level is mostly aided by real-time crop map prepared by field staff and partly by field visits.

The Kappa coefficient of accuracy is calculated for overall accuracy as well as for individual classes. The accuracies at total scene level and at water course level are presented in Table 7.

4. RESULTS AND DISCUSSION

The remote sensing derived information on area under wheat and non-wheat crop, the condition of wheat crop as expressed by NDVI at water course level has been analyzed to evaluate the performance of water courses. The False Colour Composite (FCC) and the derived information on cropping pattern at water course level are presented in Figs. 7-12

Table 7 Classification accuracy

	Kappa coefficient of accuracy		
	Overall	Wheat	Non-wheat
Total scene level			
Hisar block	0.92	0.92	0.92
Narwana block	0.91	0.92	0.90
Sirsa block	0.93	0.95	0.90
Water course level			
Hisar block			
W4	0.90	0.90	0.90
W5	0.92	0.94	0.89
Narwana block			
W1	0.89	0.94	0.82
W6	0.93	0.88	0.95
W8	0.89	0.94	0.80
Sirsa block			
W3	0.96	0.94	1.00
W5	0.93	0.94	0.93
W8	0.94	0.95	0.92

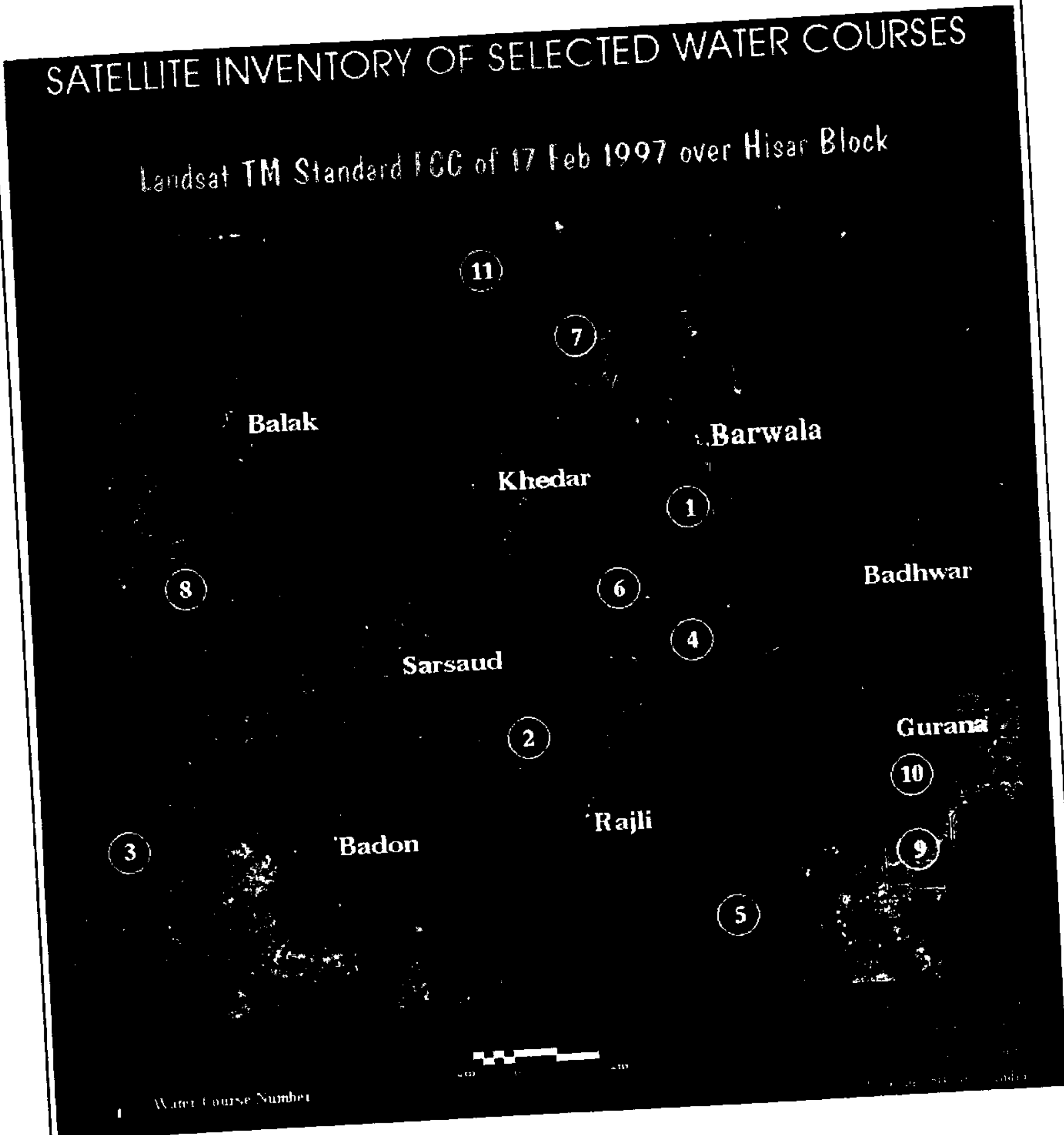


Fig. 7 False colour composite image of Hisar block during rabi 1996-97

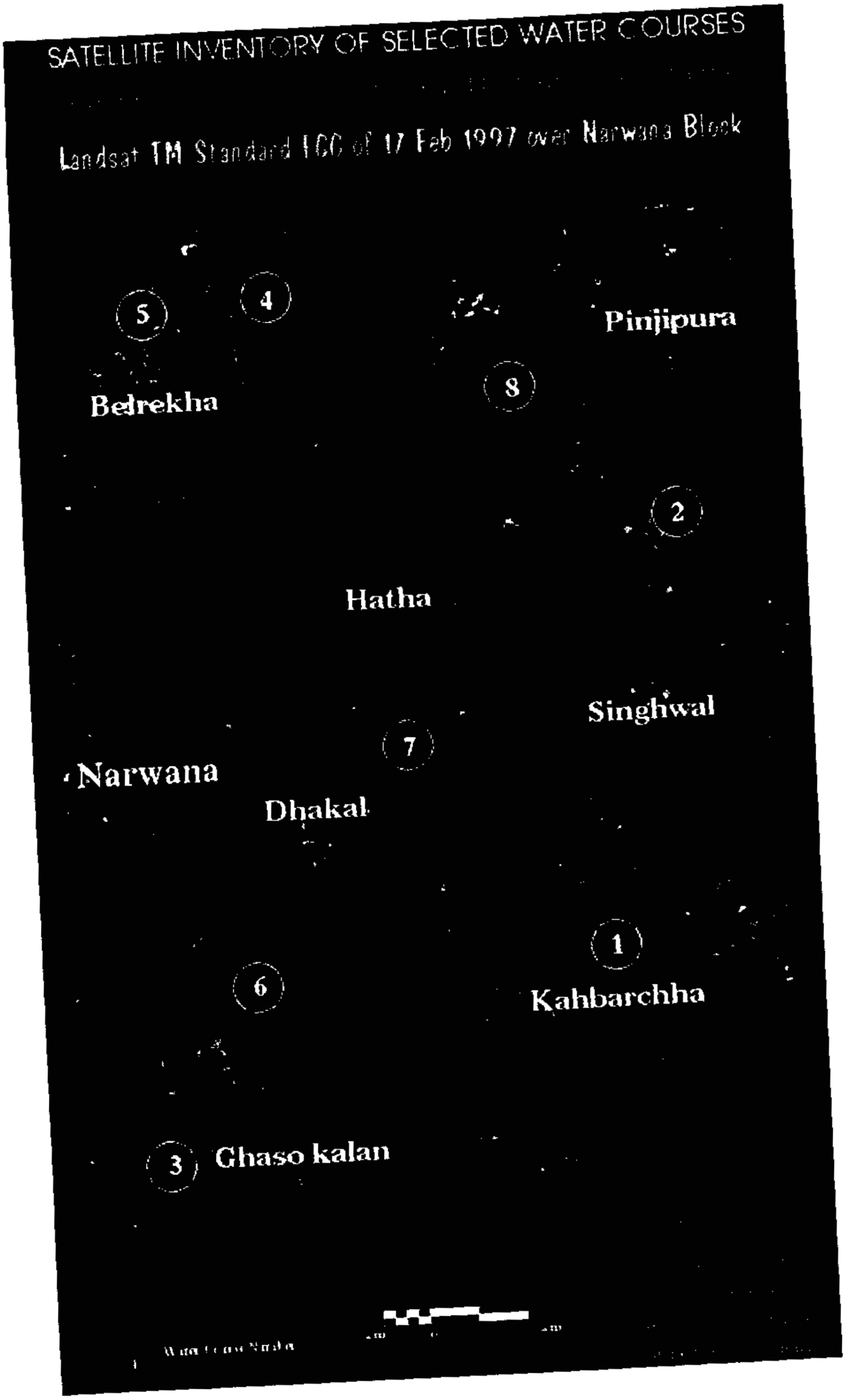


Fig. 8 False colour composite image of Narwana block during rabi 1996-97

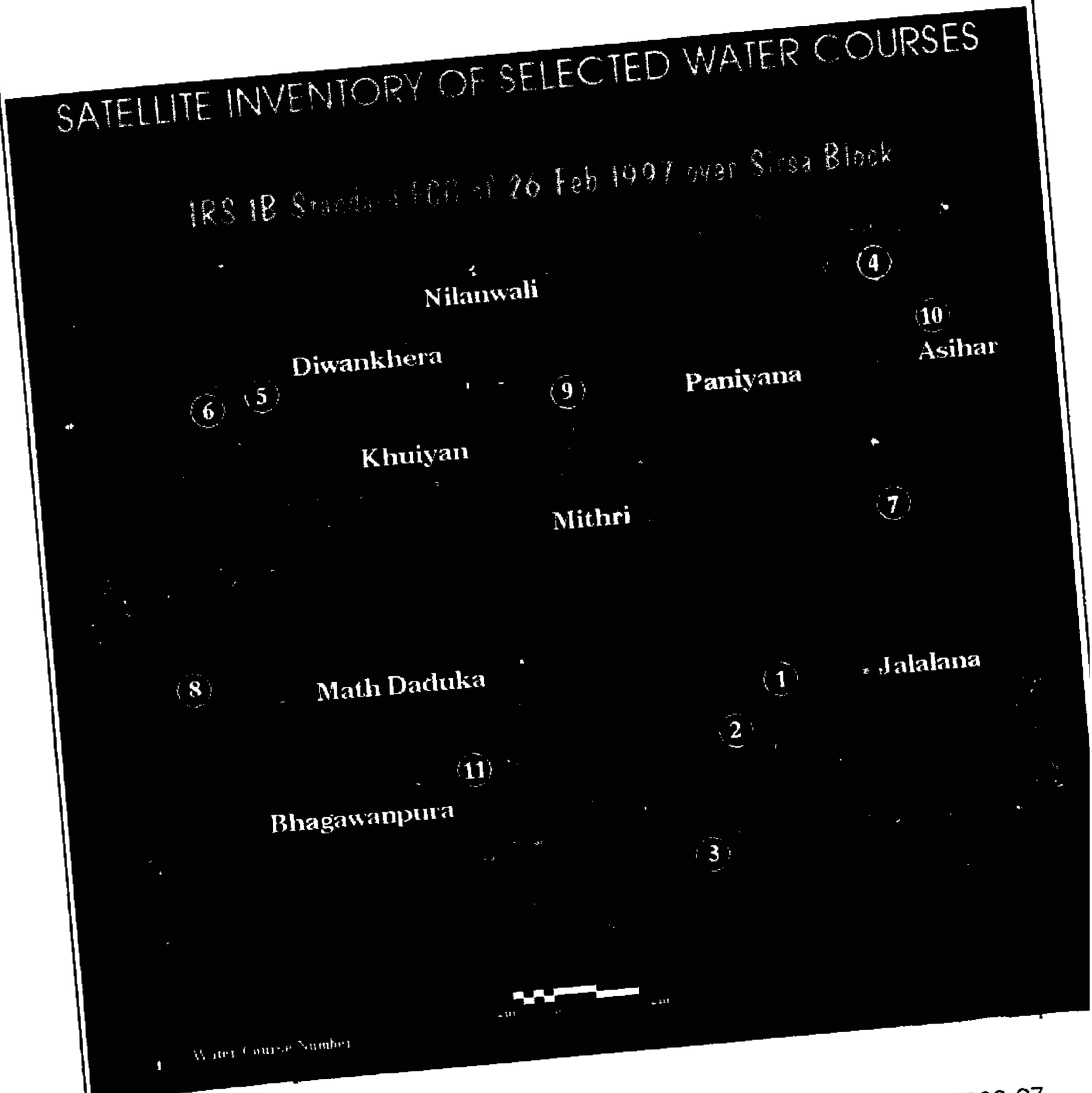


Fig. 9 False colour composite image of Sirsa block during rabi 1996-97

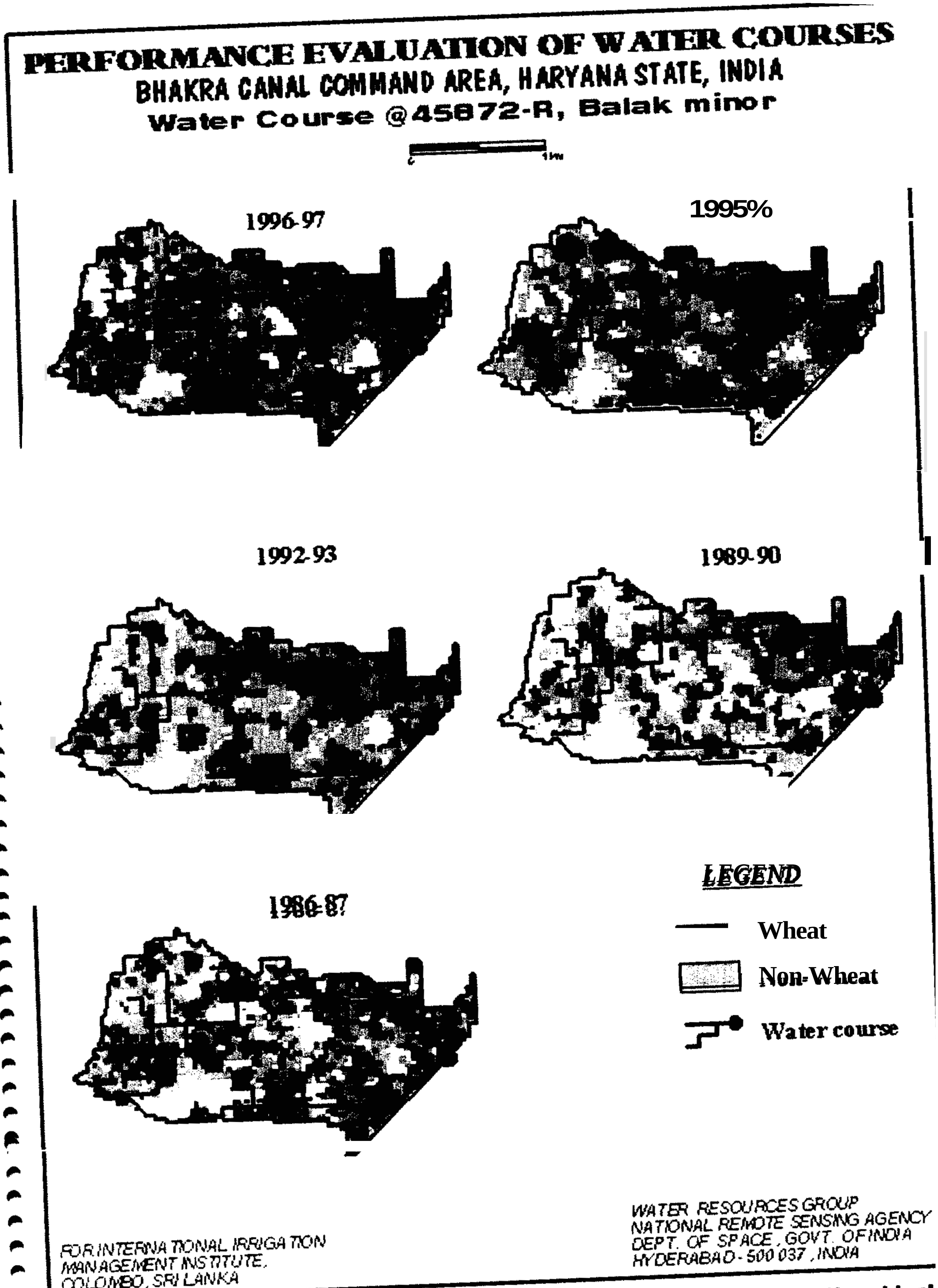


Fig.10 Temporal changes in rabi cropping pattern in a water course of Hisar bloc

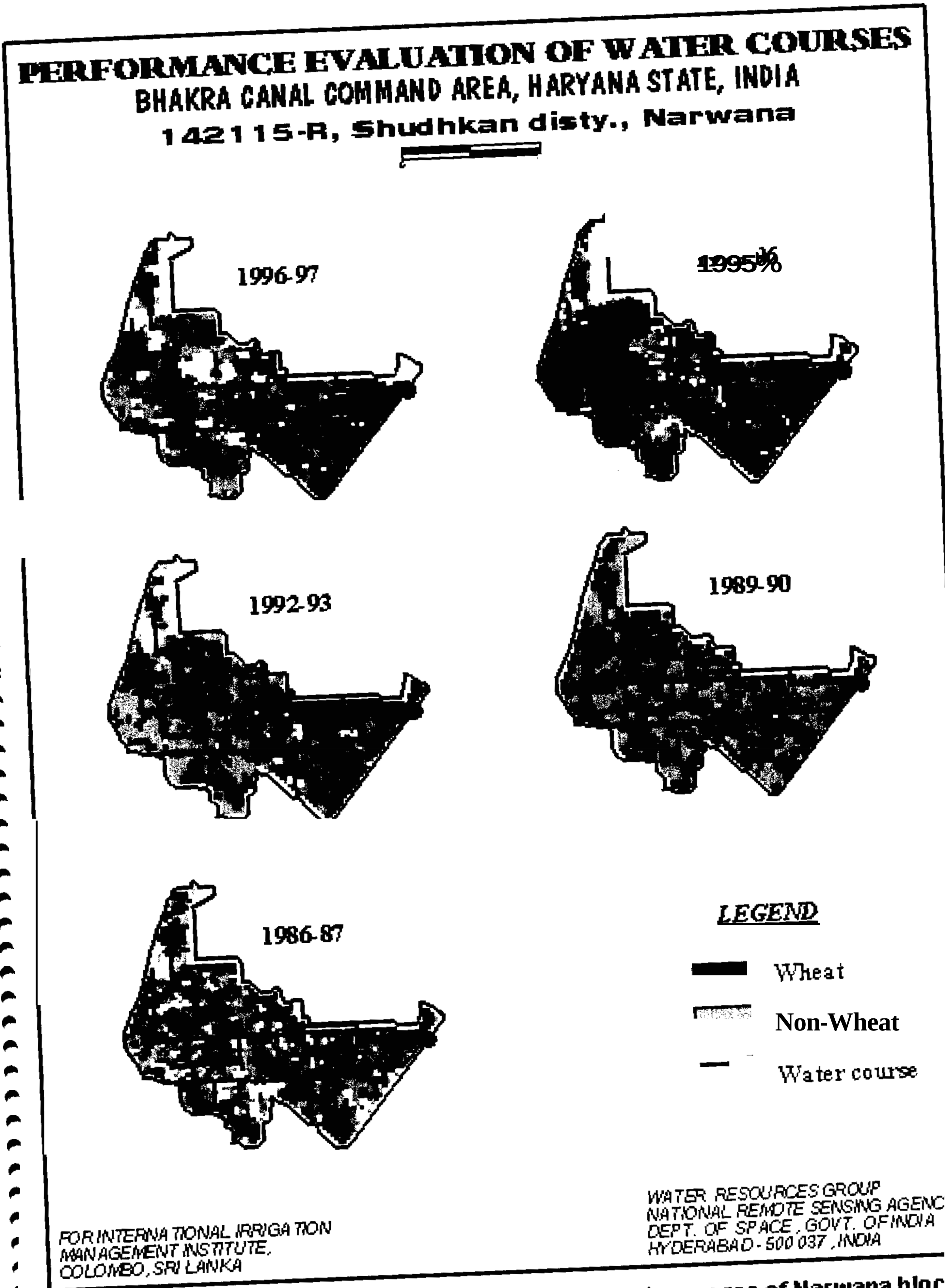


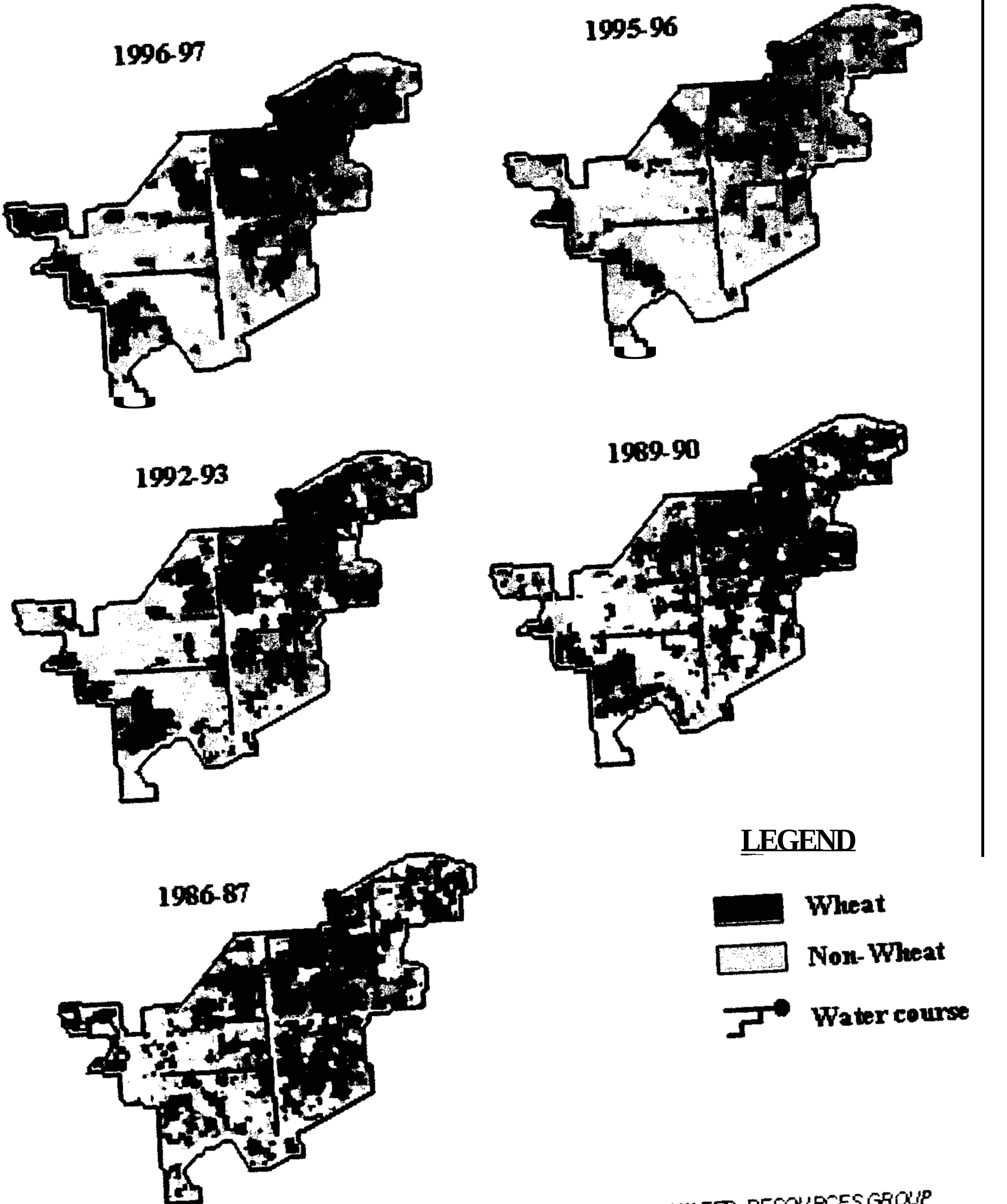
Fig.11 Temporal changes in cropping pattem in a water course of Narwana bloc

ERFORMANCE EVALUATION OF WATER COURSES

HARYANA STATE, INDIA

BHAKRA CANAL COMMAND AREA, HARYANA STATE, INDIA

BO 100-L, Mithri dirty., Sirsa



FOR INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE, COLOMBO, SRI LANKA

WATER RESOURCES GROUP
NATIONAL REMOTE SENSING AGENCY
DEPT. OF SPACE, GOVT. OF INDIA
HYDERABAD - 500 037, INDIA

...ping pattern in a water course of Sirsa block

4.1 Indicators of water course performance

In the current study, five indicators of performance were identified for analysis. These indicators are essentially derived for remote sensing data. They are:

1. Wheat crop intensity (WI)
2. Equivalent Wheat crop Area Intensity (EWAI)
3. Proportionate Crop Intensity (PCI)
4. Tail - Head Ratio of NDVI (THR_{NDVI})
5. Coefficient of variation of NDVI (CV_{NDVI})

4.1.1 Wheat crop Intensity (WI)

Wheat is the most preferred crop in the study area. Subject to the availability of sufficient irrigation water, farmers generally prefer wheat crop to non-wheat crop. Hence the extent of wheat crop is directly related to the degree of availability of irrigation water either from canals or from borewells. In the regions such as Sirsa block, where the ground water quality is not suitable for irrigating crops, the WI parameter reflects the dependance on the canal water supplies.

4.1.2 Equivalent Wheat crop Area Intensity (EWAI)

Among the non wheat crop found in the study area, oilseed crops like mustard ond pulses like gram are mostly cultivated. Non-wheat crop arc cultivated in the areas where conol water availability is limited and ground water is not suitable for irrigation. EWAI is the index which expresses the total crop area in terms of wheat to facilitate easy and straight forward comparison of cropping intensity and irrigation water consumption. The non-wheat crops acreage is converted into wheat. The factor applied in such conversion is 1 acre of non wheat crop area = 0.6 acre of wheat crop area. This factor is approximately proportional to the ratio of average irrigation water requirements of wheat and non-wheat crops. Through this conversion, this index enables easy comparison of total cropped area and iriigation water usage. The EWAI is directly proportional to irrigation water usage.

4.1.3 Proportionate Crop Intensity (PCI)

PCI is the ratio between crop area of a water course and the total crop area of all water courses of a given block. It essentially indicates the contribution of a water course in the total crop area of a group. Any changes in PCI over time indicates the relative performance of a water course in terms of crop area contribution to the group. The cmp area of a given water course is given by soil type, canal water availability, ground water quality fot conjunctive use, etc,. All these factors except canal water availability can be assumed to be uniform over small geographical areas such ns block in the current study. The canal water supplies also uniform i.e, the quantity of water released nt different off take points is proportional to the CCA under canal in Warabandi system. However such uniformity may not be retained at field level because it is affected by farmers' adherence to the regulations of cropping pattern, water usage etc. As a result, imbalances/disparities in water availability occurs at field level affecting the cropping pattern. Hence, the index PCI overtime signifies the consistency in crop intensity of a water course relative to the neighboring water courses.

4.1.4 Tail-Head Ratio of NDVI (THR_{NDVI})

Normalized Difference Vegetation Index (NDVI) which is a mathematical combination of the reflectance values of near infrared and red bands of electromagnetic spectrum is found to be a potential indicator of density and health of vegetation. The NDVI of n crop typically follows a bell shaped trajectory through its growth cycle. Deviations from the typical (normal) NDVI is indicative of stresses due to moisture or nutrient deficiency or pest/ disease incidence. THR_{NDVI} of a water course is derived from

$$THR_{NDVI} = \frac{\text{Tail Reach Area NDVI}}{\text{Head Reach Area NDVI}}$$

Head Reach Area (HRA) is defined as the nrea falling in the first 1/3rd length of a water course from the point of its offtake and Tail Reach Area (TRA) is the area falling in the last 1/3rd length of water course. High NDVI reflects better crop condition and low NDVI reflects poor crop condition. The observed deviations of NDVI from HRA to TRA can be attributed to disparities in water distribution since the other factors contributing to crop condition such as soil characteristics, plant varieties, agronomic practices, meteorological parameters could be assumed to be uniform at micro level i.e., at water course level. Thus $TIIR_{NDVI}$ can be a potential tool to evaluate the quality of irrigation service.

4.1.5 NDVI variability in Tail and Head Regions (CV_{NDVI})

NDVI variability expressed as coefficient of variation reflects the variability in crop condition in a given area. High variability indicates the differences in the resources available to crop such as soil, meteorological factors, agronomic practices, water etc. Again, the resources other than iuater may be assumed to be uniform over small areas and hence NDVI variability can be attributed to some extent to the degree of water availability. It is a common phenomenon happening in Indian irrigation systems that the tail reach farmers suffer from insufficient canal water supplies. Under this pretext, NDVI variability could be ti potential indicator of reliability of irrigation service in Head and Tail regions.

4.2 Factors affecting the performance of water courses

The differential performance of water courses in a given block can be attributed to various factors which are grouped in to tico categories namely, (1) irrigation related and (2) others. The irrigation related factors include tlie location of water course in the respective source/parent distributary or minor, lining factors such as age of lining and extent of lining. The other factors affecting the performance are soil type, ground water quality, agronomic practices, crop varieties etc., can be assumed to be more or less homogeneous over smaller areas such us at block level in the current study. Therefore, only the irrigation related parameters are considered for analysis in this study. Three irrigation related factors are identified for further analysis;

(I) Location of water courses in the parent or source distributary/minor
(2) Age of lining of iuater course
(3) Extent of fining i.e., per cent of lined area of water course

The following hypothesis have been kept in mind tv guide the analysis;

- The water courses located in the Head Reach Area (HRA) of parent distributary perform better than that located in the Tail Reach Area (TRA) of parent distributury due to better touter availability.
- As the age of lining increases, the performance gets deteriorated.
- The water courses which were lined to a greater extent perform better than those lined to a lesser extent i.e., the per cent of lining and performance tire directly related
- The performance of water courses in the post-lining period is significantly better than that in the pre-lining period

4.3 Analysis of results over Hisar block

4.3.1 Wheat crop Intensity (WI)

The intensity of wheat crop in different water courses is shown in Fig. 13. In the iuater courses (nos. 3,5,7,9,10 and 11) located in the HRA of respective source distributaries / minors (Table I) there is an increase in the intensity of wheat crop from 1986 to 1997. The wheat intensity is low and fluctuating from year to year in the water courses (no. 2, 4 and 6) which are located in the tail end of respective source distributaries / minors (Table 1). As preference for wheat crop is associated with water availability, the higher WI values in head reach area water courses may be due to better water supplies over time. The source of irrigation water in this block is canals andground ioater. The ground water quality is marginal and can be used as supplementary source for irrigation. It may also be observed from Fig. 13 that in general there is a sudden increase in wheat intensity during 1996. This is due to heavy rainfall and flooding during September-October 1995 which resulted in the availability of sufficient soil moisture during the subsequent rabi season. Several new borewells were commissioned during this season to avail the supplies from increased ground water source. Consequently, farmers responded to use the available soil moisture and preferred wheat crop. Among the water courses (nos. 1-6) which were

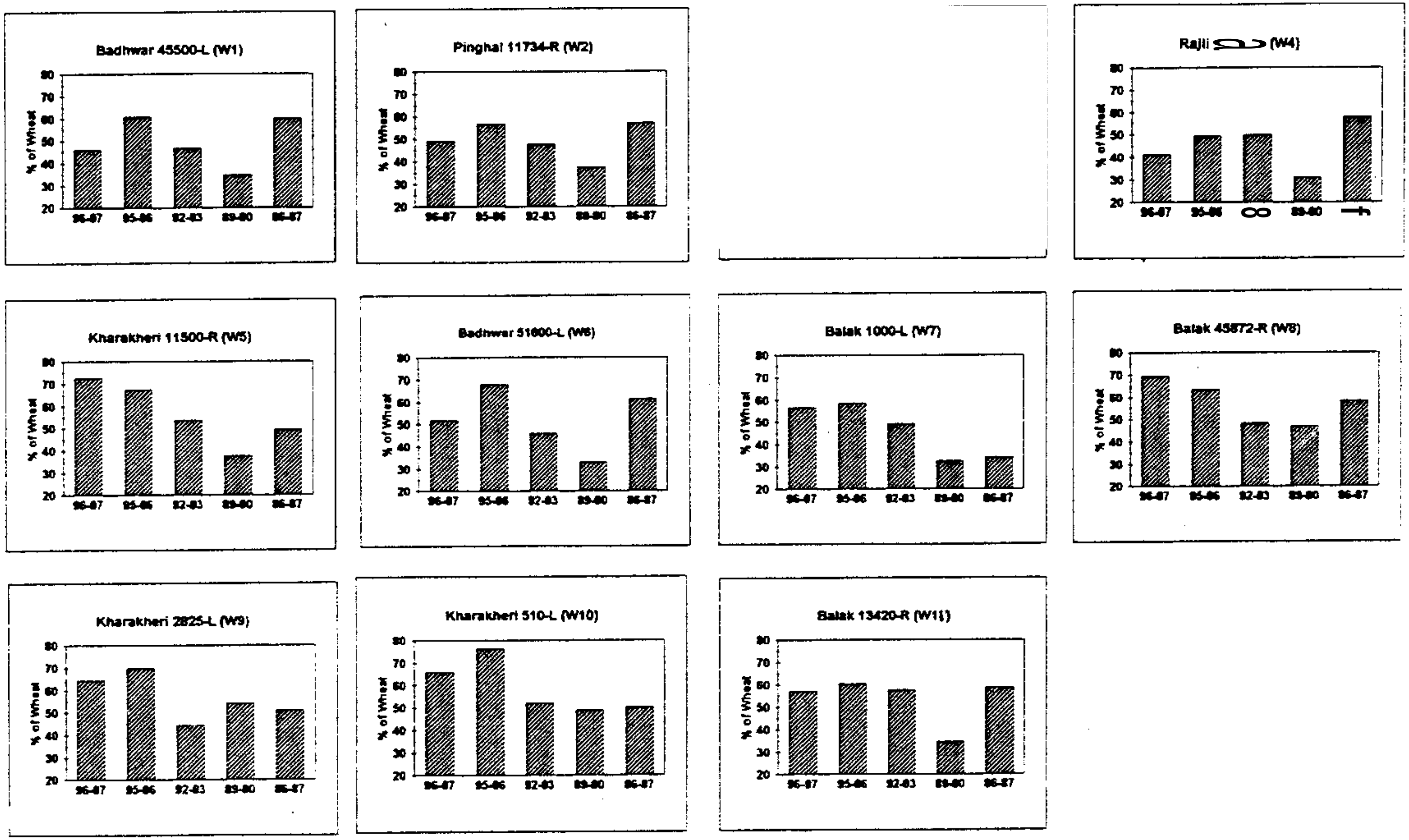


Fig. 13 Wheat Intensity in water courses of Hisar Block

lined during 1975-76 i.e., age of lining is 21 years approximately, wheat intensity is fluctuating significantly between years as well as between tuater courses (Fig. 13). Of these, two water courses (nos.3 and 5) remain unique iuith consistently increasing WI over time. In others trend is consistent with low WI having high variability. In this group of iuater courses, the length oflining varies from 34 per cent to 83 per cent. Again the water course 3 and 5 with high WI have only 36 per cent and 53 per cent oflining i.e., though the kngth oflining is less, the wheat intensity is high. Thus length of iuater course lining does not seem to be affecting WI in this group. In the iuater courses at no.7 and 8 which were lined in 1992 and more or less to tlie same extent the wheat intensity is steadily increasing in the post-lining period i.e., 1993 onwards. However, the WI is higher in water course 8. In other group of water courses at no.9 and 10 which were lined during 1995 and 1996 and almost to the same extent, the WI has increased compared to pre lining seasons. In the unlined water course (no.11), the wheat intensity is less compared to recently lined water courses and did not show much variation over time.

From the foregoing discussion the following observations may be obtained.

1.The intensity of wheat crop is influenced by the location of water courses in the respective source distributaries / minors. Water courses offtaking from the head reach areas have increasing wheat intensity over time while water courses in tail reach area have declining wheat intensity.

2. Water courses which were lined recently i.e., after 1992 have shown significant improvement in wheat intensity in the post-lining periods.

3. In the iuater courses which were lined in 1975-76, there is no clear relation between iuheat intensity and age/extent of lining. However, in this group, locution of water courses seems to be an important factor i.e., water courses located in the head reach area of respective distributary / minor have higher wheat intensity.

4.3.2 Equivalent Wheat crop Area Intensity (EWAI)

EWAI which reflects the intensity of total irrigated crop area (converted to equivalent wheat crop area) increased in 1996 in most of the water courses (Fig.14). This is

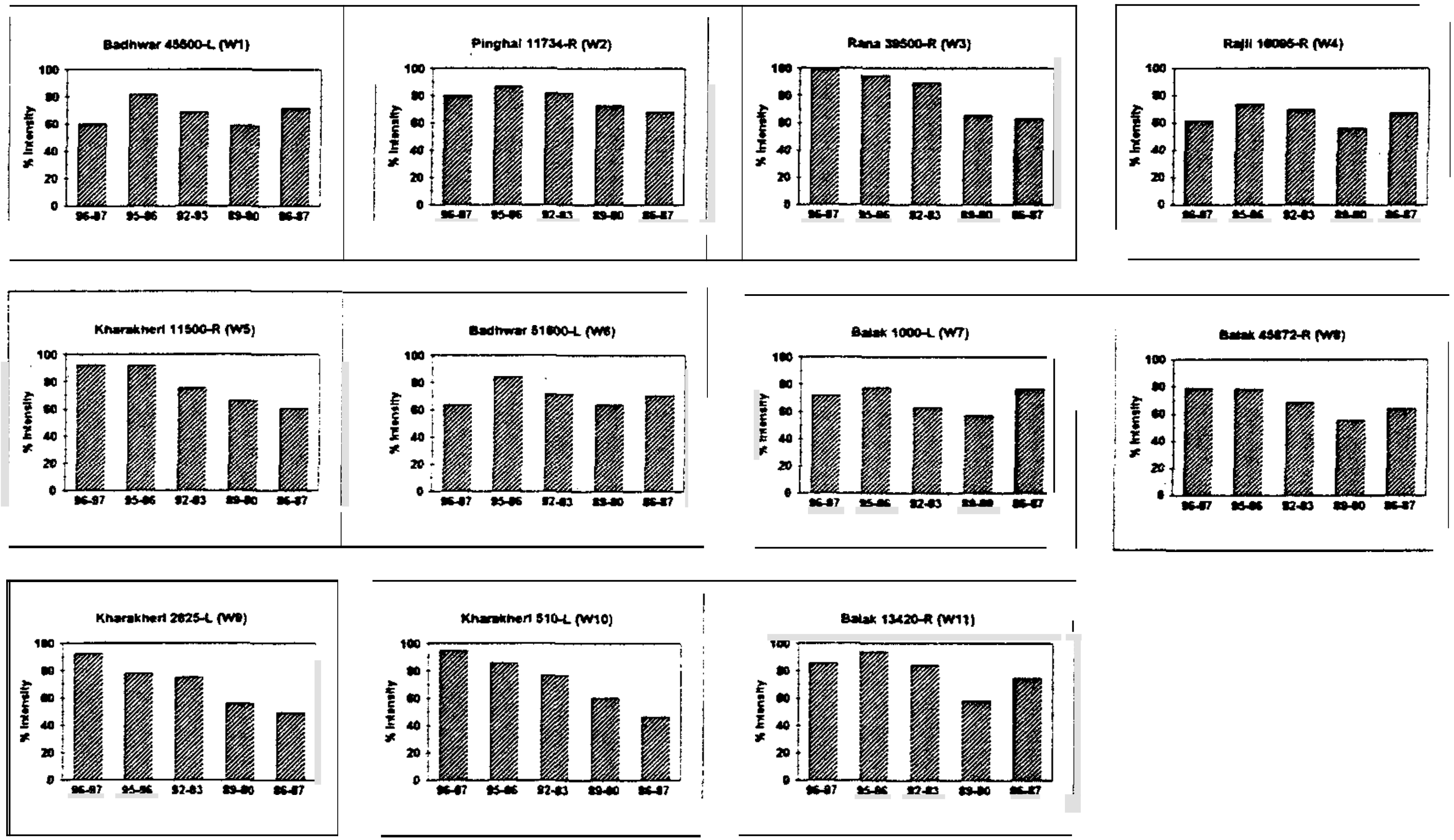


Fig. 14 Equivalent Wheat Area Intensity in water courses of Hisar Block

due to increased soil moisture availability caused by floods occurred in October, 1995. The EWAI has decreased to the level of 1993 in majority water courses during 1997. In the water courses (nos.3,5,7,9,10 and 11) located in tlie HRA of respective distributaries (Table I) the EWAI is on increasing trend ouer time. The water courses of tail region (nos.4 and 6) do not show this trend. With an exception of water course (no.2), in these water courses (no.4 and 6) the EWAI is declining i.e., total irrigated crop area is declining. In case of water course (no.2), it is more or less stable ouer time. Thus it is evident that total irrigated crop area in a water course is influenced by its location in the source distributaries or minors.

For water course (nos.1 to 6) the age of lining is same and tlie extent of lining is different. In this group, the EWAI does not show any significant relation with extent of lining. Here water course 1,4 and 6 have more lined length (72% - 83%) but the crop area is less, i.e., around 60 per cent. Whereas in water courses (nos.2,3 and 5), even though the extent of lining is less, the irrigation intensity is high. Incidentally water courses (nos. 3 and 5) are in HRA and in the earlier group of 1,4 and 6, water courses (nos, 4 and 6) are in TRA and 1 in middle reach. Thus it is euident in this group of iuater courses location of water course has more influence on total irrigated crop area rather than age and extent of lining. Water courses (no.7 and 8), which were lined in 1992, to the same extent showed increased EWAI in the post lining period. However, the EWAI is around 70-80 per cent only which is not significantly more than that of water course lined 20 years back. In case of water courses (nos.9 and 10), the EWAI is high and is consistently increasing ouer time. These were lined recently to the extent of 75 per cent and added to that, these were located in the HRA.

The unlined water course (no.11) located in the HRA has higher irrigated crop area compared to lined water courses.

From the foregoing discussion, the following observations may be derived.

1. EWAI which indicates the total irrigated crop in a watercourse is influenced by the location of water courses with head reach area water courses having more crop area and tail reach area water courses having less area.

2. In the water courses having same age of lining but different length of lining, the EWAI is more in water courses though the length of lining is less because of its location in HRA. Thus the factor of location of router course looks to be having more influence than extent of lining.

3. The EWAI is more in an unlined water course located in head region than lined water courses.

4.3.3 Proportionate Crop Intensity (PCI)

The water courses of Hisar block offtake from two branch canals. Water courses (nos.8 and 11) offtake from Sirsa branch canal and tlie rest offtake from Barwala branch. PCI is calculated for these two groups separately to offset the differences in water allocation rates of two branch canals. PCI for the water courses (nos.7,8 and 11) is obtained by summation of cropped areas of these three water courses only. The analysis is presented for two branch canals separately.

4.3.3.1 Barwala branch canal

Out of eight water courses, the PCI is increasing in four water courses (nos.3,5,9 and 10) and it is decreasing in the rest (Fig.15). Increased PCI implies improved performance in terms of crop area. All the four water courses with increasing PCI are located in HRA. Among these, water courses nos. 9 and 10 were recently lined. and the extent of fining is about 75 per cent. Water courses nos. 3 and 5 which were lined in 1975-76 are located in head region. Rest of the water courses (no.1,2,4 and 6) which are in TRA were lined in tlie year 1975. Thus it is evident that the performance of water course in terms of PCI is more in the water courses lined after 1995-96 and that which are located in HRA. Age of lining and length of lining does not seem to have any influence on PCI.

4.3.3.2 Sirsa branch canal

Water courses (nos.7 and 8) were lined in 1992 and to the same extent but PCI is slightly different (Fig.15). The performance of unlined water course (no.11) is also stable and its PCI is comparable to that of lined water course (no.7). That means,

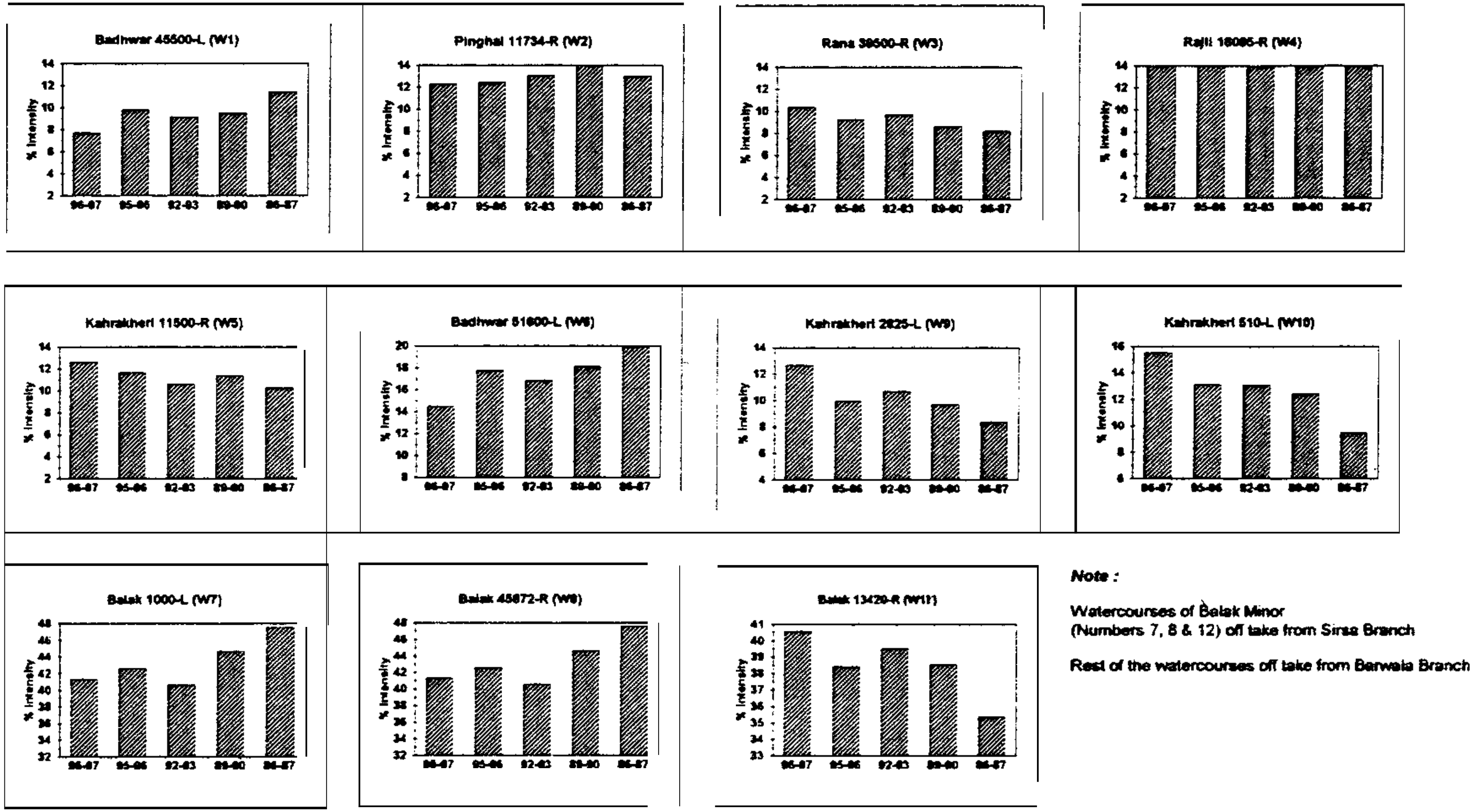


Fig. 15 Proportionate Crop Intensity in water courses of Hisar Block

though it is unlined, because of its location in HRA, its PCI is stable indicating stable performance in recent years.

From the foregoing discussion, the following inference may be drawn.

1) PCI which reflects the relative performance of water courses in terms of crop area is increasing over time in recently lined water courses (lined in 1995-96).

2) In the water courses which were lined in 1975-76, PCI is influenced Ly location of water course

3) Even the unlined water course located in Head Reach Area of parent distributary, the PCI is better and comparable to that of lined water courses.

4) Extent of lining does not seem to have any relation with PCI..

4.3.4 $TIIR_{NDVI}$

THR_{NDVI} values, close to one, indicate better performance of water courses with less disparities in crop condition between Tail and Head regions. The temporal variation in THR_{NDVI} is shown in Fig.16. It is evident from the Figure that THR_{NDVI} is more or less stable and its value is around 0.95. It has no conspicuous relation with location of water course. Both HRA water courses and TRA water courses have same values. That means in terms of crop condition there are no disparities between Tail and Head regions and are uniform among the water courses. But there is a unique trend in water course No.4. Here THR_{NDVI} is less and is stable from 1987 to 1993 and increased suddenly in 1996 and 1997. That is, the disparities in crop condition have reduced in these two seasons.

There seems to be no significant impact of either age of lining or length of lining on THR_{NDVI}. For the water courses lined in 1975-76 (nos.1-6), there is no relation between length of lining and THR_{NDVI} values. All the water courses in this group haw more or less same THR_{NDVI} values irrespective of length of lining. There is one exception in this group i.e., water course no.4 which has slightly higher values indicating better crop condition. In the second group (nos.7 and 8), which were lined

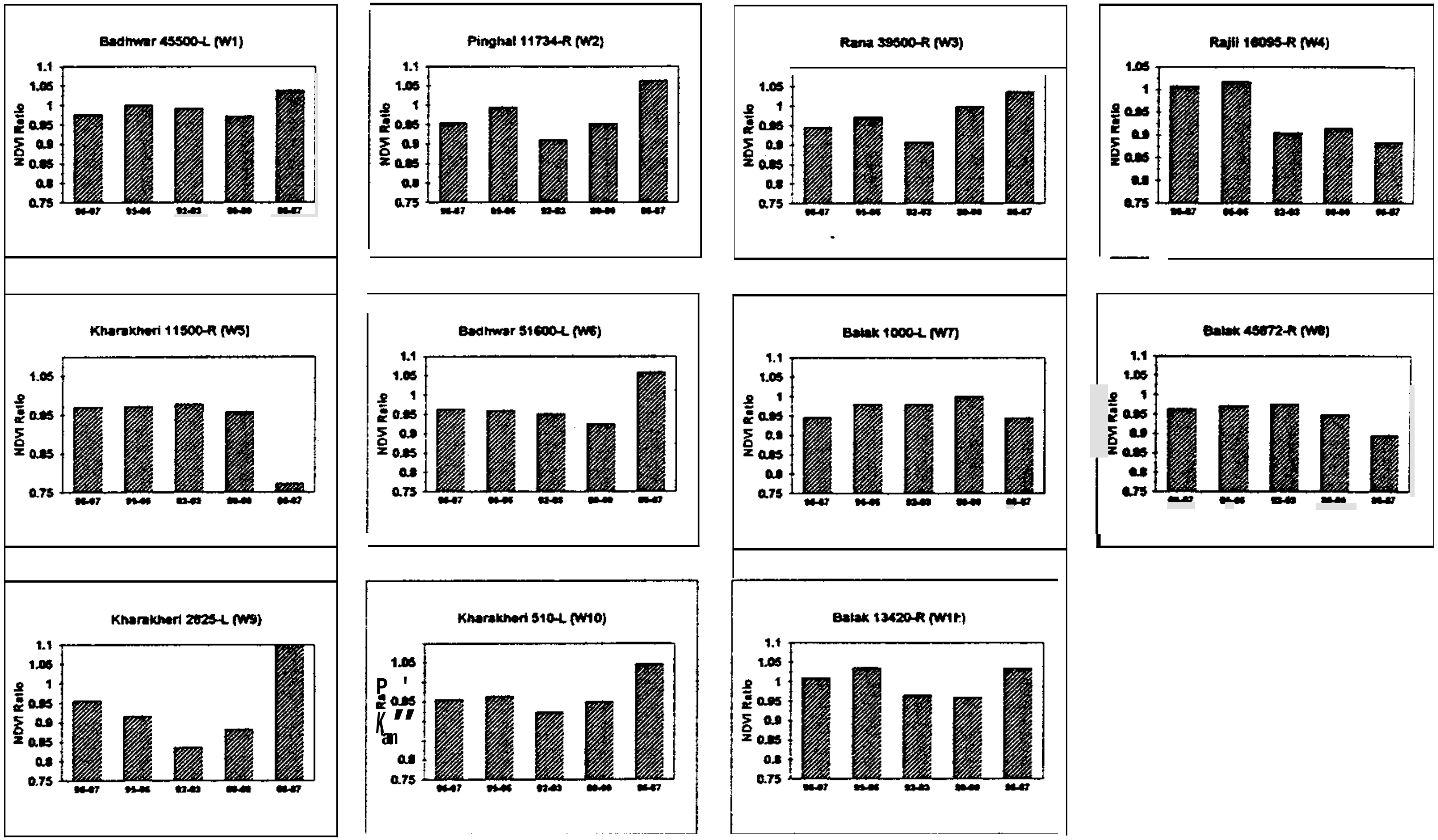


Fig. 16 THR ndvi in water courses of Hisar Block

in 1992-93 and almost to the same extent, there is no change in THR_{NDVI} values in the post lining period. That means, in the post lining period the disparities in crop condition between Head and Tail region are not reduced significantly. In the third group of water courses (no.9, 10) which were lined recently (1995-96) and almost to the same extent, there is significant reduction in the Tail-Head disparities in the water course (no.9), with increased THR_{NDVI} in the post lining period. Even in the unlined water course (no.11) the THR_{NDVI} values are stable over time and comparable to that of lined water courses.

From the foregoing discussion, the following inference may be drawn.

1. The disparities between Tail and Head regions of water courses are in general not significant as indicated by the THR_{NDVI} values closer to 1.

2. Location of water course in the source distributary / minor does not have any impact on crop condition disparities in Tail and Head regions.

3. Age of lining and extent of lining do not have any influence on the crop condition disparities between head and tail regions.

4.3.5 NDVI variation in Head and Tail regions (CV_{NDVI})

The coefficient of variation in Head and Tail regions of each water course was presented in Fig.17. Two aspects are evident from the Figure.

1. The CV_{NDVI} is more or less same in both head and tail regions.

2. The CV_{NDVI} has decreased significantly over time from 1987.

3. The CV_{NDVI} values are mostly around 0.1 i.e., 10 per cent in all the water courses.

4. These observations are valid irrespective of the location, age of lining and extent of lining of water courses.

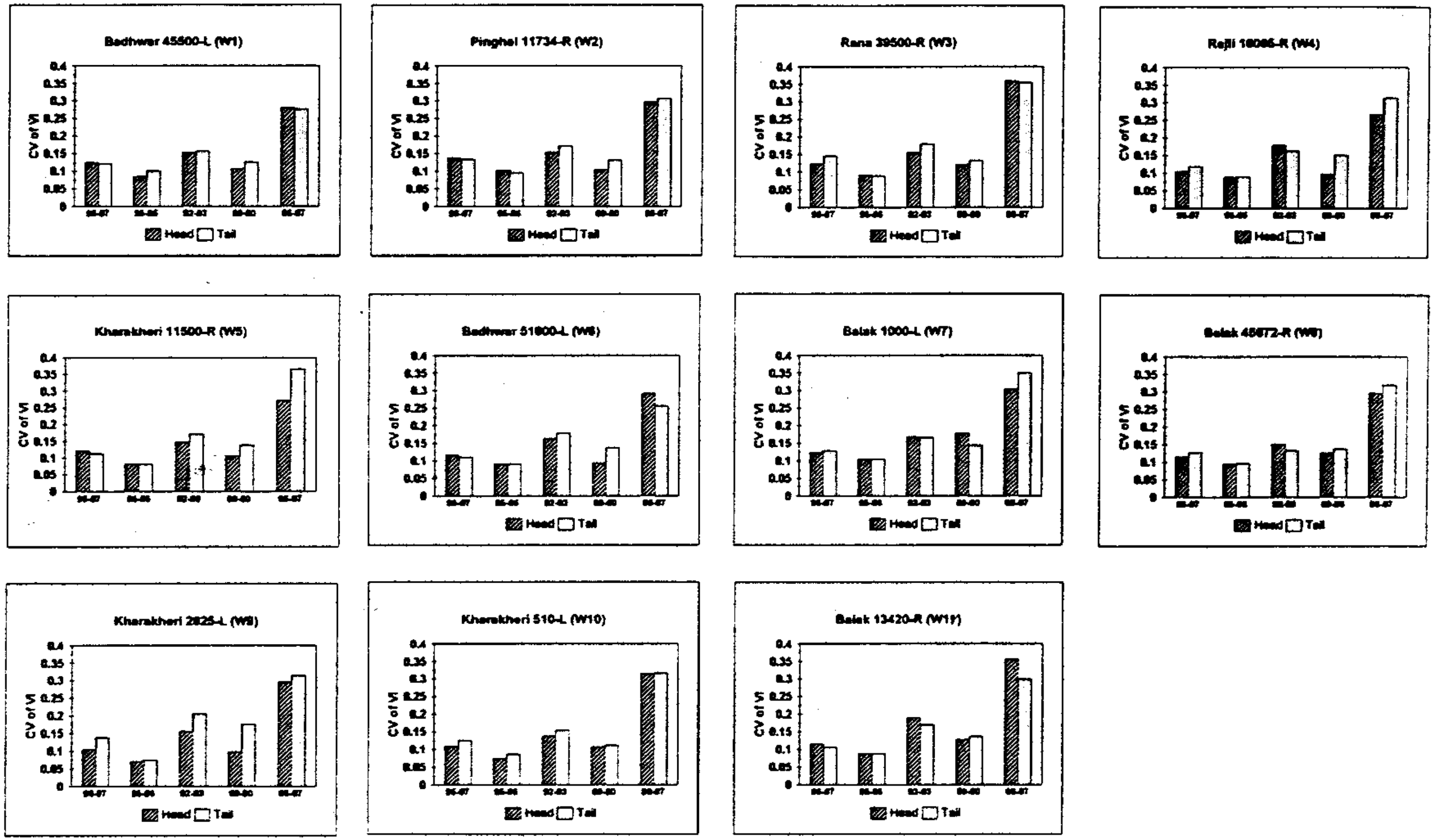


Fig. 17 Coeff. of Variation in Head and Tail NDVI in water courses of Hisar Block

4.4 Analysis of results over Narwana block

4.4.1 Wheat Intensity (WI)

The WI over time for different water courses is presented in Fig.18. It may be observed that in general wheat intensity has remained stable over time with only 10-15 per cent variation. There is slight increase in WI in 1996 and slight decrease in 1997. The reasons for increased wheat intensity in 1996 i.e., due to flood in the preceding season as it was discussed in Hisar block analysis, is valid here too. There is no clear-cut relationship between wheat intensity and location of water course because WI is more or less same in HRA water course (no.1) and TRA water courses (nos.2,6,7 and 8) of Table 2.

Similarly, there is no significant difference in wheat intensity between the water courses which were lined in 1980s (nos. 1,2,3,5,6 and 7) and that which were lined recently i.e., 1992 and 1995 (nos.4 and 8). Also, in the water courses lined during 1992 (no.4) and 1995 (no.8), there is no significant difference in WI in the post lining and pre lining period. In all the water courses which were lined up to 1983 (no.1,2,3,5,6,7) the water courses (no. 2 and 5) with 70-80 per cent of lining and that (1,3,6 and 7) with 40-60 per cent of lining have more or less same WI values. Thus, the extent of lining also does not seem to have any relation with wheat intensity.

The following inference may be drawn from the above discussion;

1. Wheat intensity is more or less stable over time with slight increase in 1996.

2. Wheat intensity does not have any clear cut relation with location of water courses, age of lining and per cent of lining.

4.4.2 Equivalent Wheat Area Intensity (EWAI)

EWAI which indicates the intensity of total crop area is more or less stable over time (Fig.19) in all the water courses except in water course (no.1). Hence, the influence of location of water course, age of lining and extent of lining is insignificant. Even

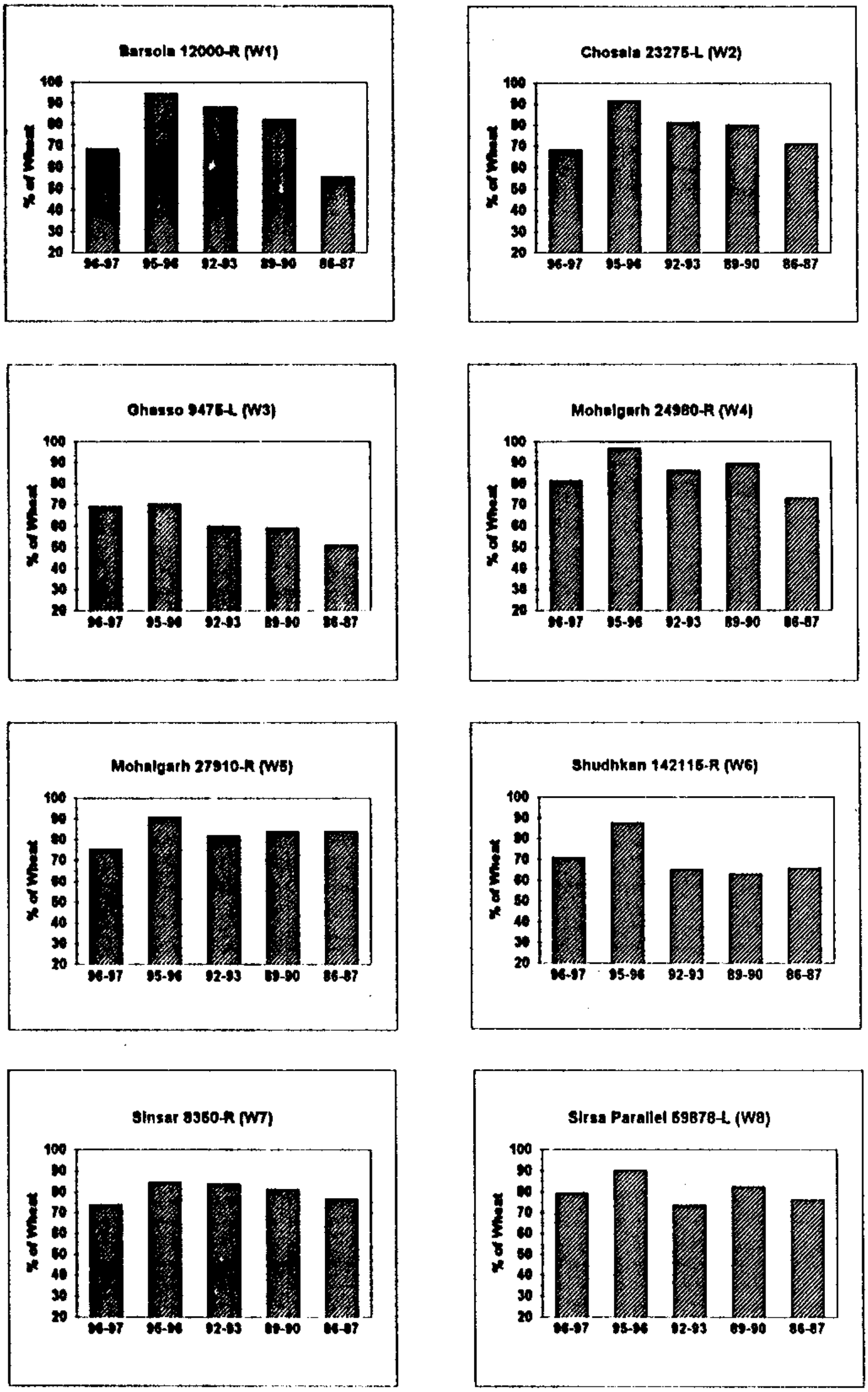


Fig. 18 Wheat Intensity in water courses of Narwana Block

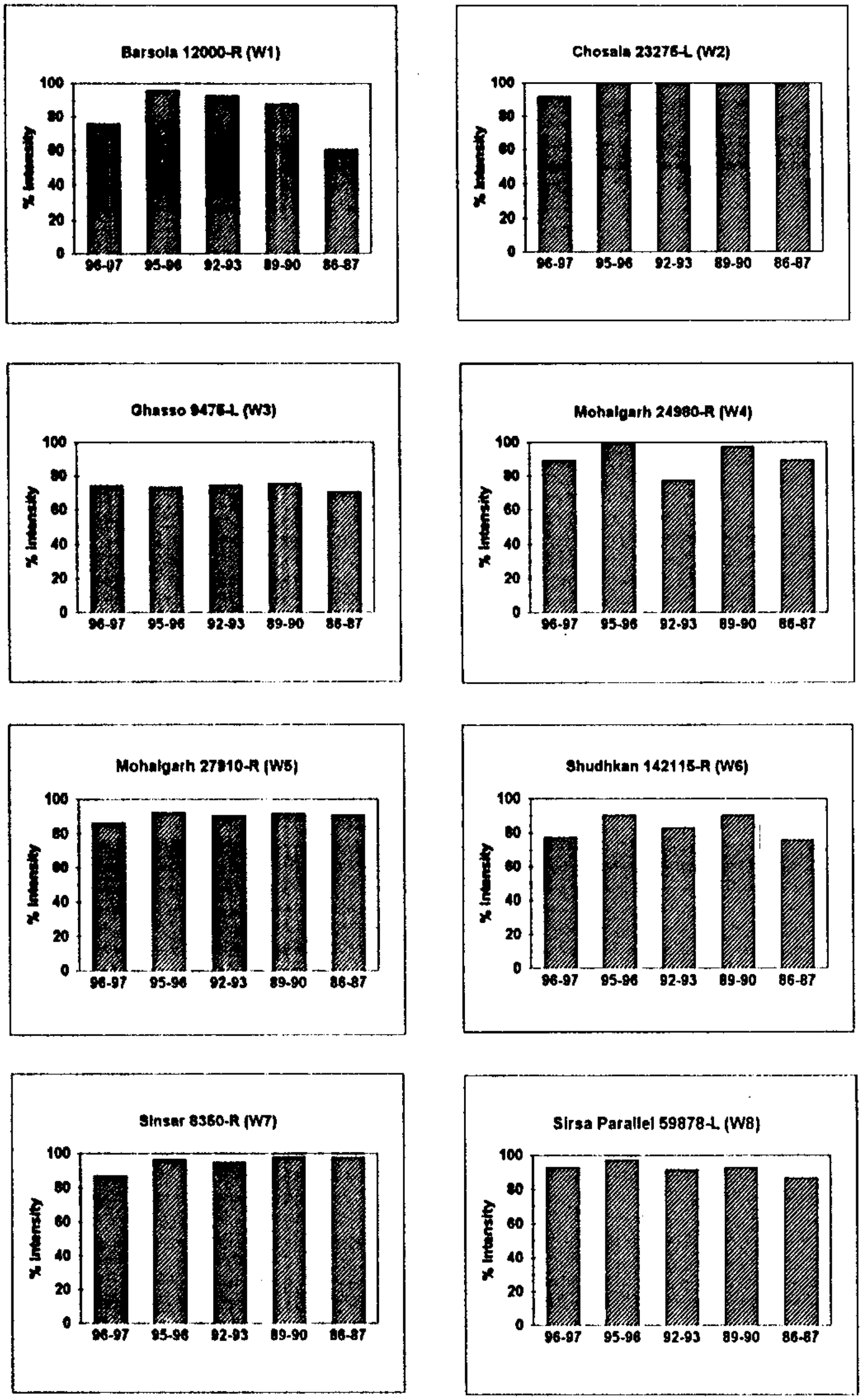


Fig. 19 Equivalent Wheat Area Intensity in water courses of Narwana Block

within water courses (no.4,5 and 8) there is no significant difference in EWAI in the pre and post lining periods. In water course (no.1) which was lined in 1981 and the extent of lining was 59 per cent, the EWAI has increased from 1987 to 1996 and then declined in 1997. Thus it has got unique performance with reference to EWAI compared to the rest of water courses.

4.4.3 Proportionate Crop Intensity (PCI)

Over time the PCI values are stable in most of the water courses indicating that the relative performance of water courses over time does not vary significantly irrespective of the location of water course, length of lining and age of lining (Fig.20). The post-lining and pre-lining contribution to total crop area in case of water courses (no.4,5 and 8) does not show any significant difference, as PCI values are same. That means, lining of water course does not have any influence on crop area. However in water courses (1 and 2), the decrease in PCI during 1997, reflects reduced performance, reasons for which have to be investigated.

4.4.4 THR_{NDVI}

THR_{NDVI} values are more or less closer to 1 (0.95) and remained stable over time in majority of water courses (Fig.21). That means, the crop condition in head and tail reaches is more or less stable with less disparities over time. The performance of crop is more or less same between head and tail reaches. The location of water courses in the respective source distributaries / minors does not have any bearing on tail-head crop condition. In water courses located in TRA (no.6) and mid reach (3,4) , the tail area performance is almost equal to that of head or even exceeded head region in some years whereas in water course no.1 located in HRA, the THR_{NDVI} is 0.95 only. There is no improvement in THR_{NDVI} in the post lining period (water courses no.4,5 and 8). However, in water courses (no.2,6) the inter-annual variability in THR_{NDVI} reflects the fluctuating performance of crop. These water courses were lined in 1983 and hence the age of lining could be a contributing factor.

4.4.5 NDVI variation in Head and Tail regions (CV_{NDVI})

There is no significant difference in CV_{NDVI} of head and tail reaches of water courses

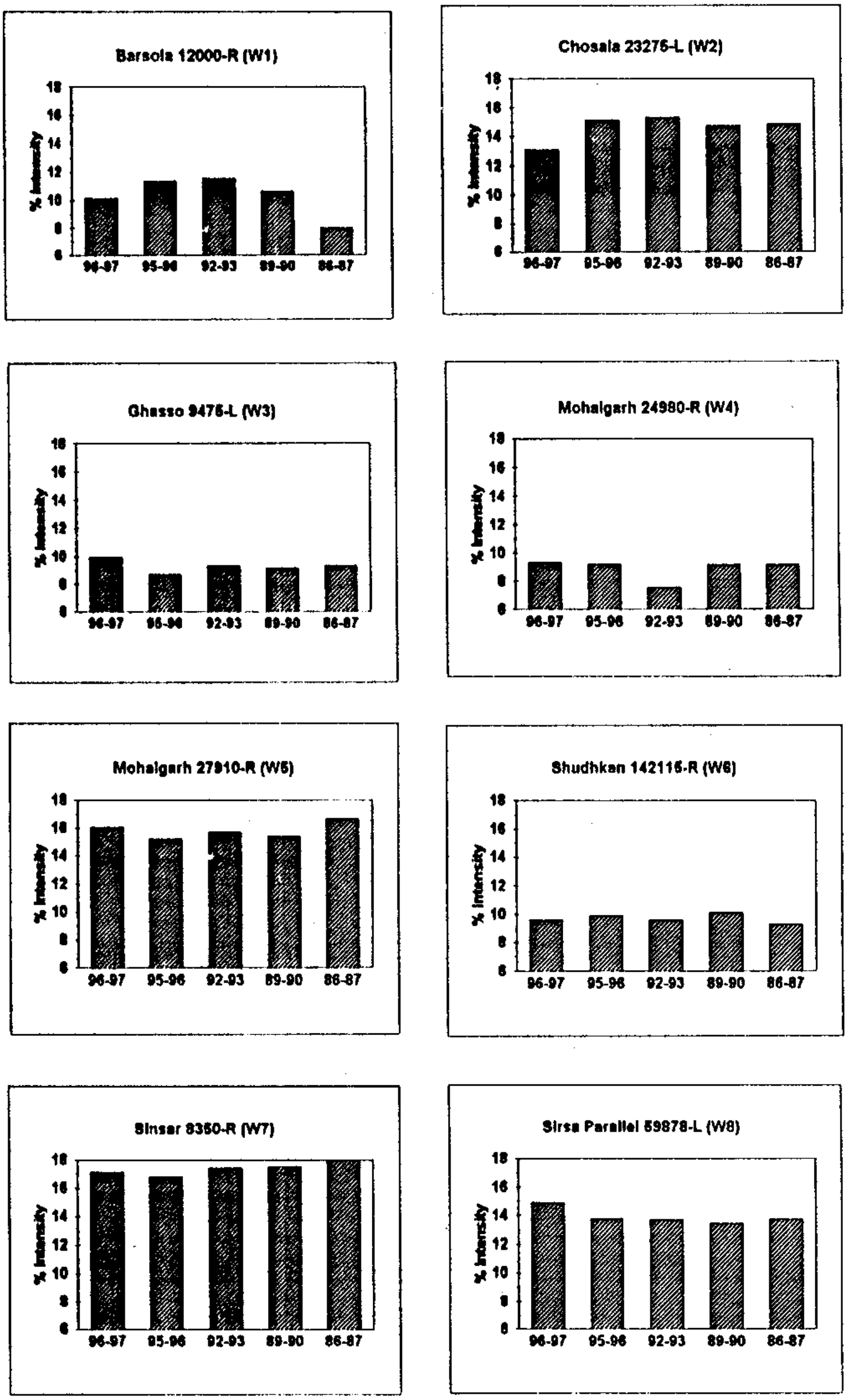


Fig. 20 Proportionate Crop Intensity in Narwana Block

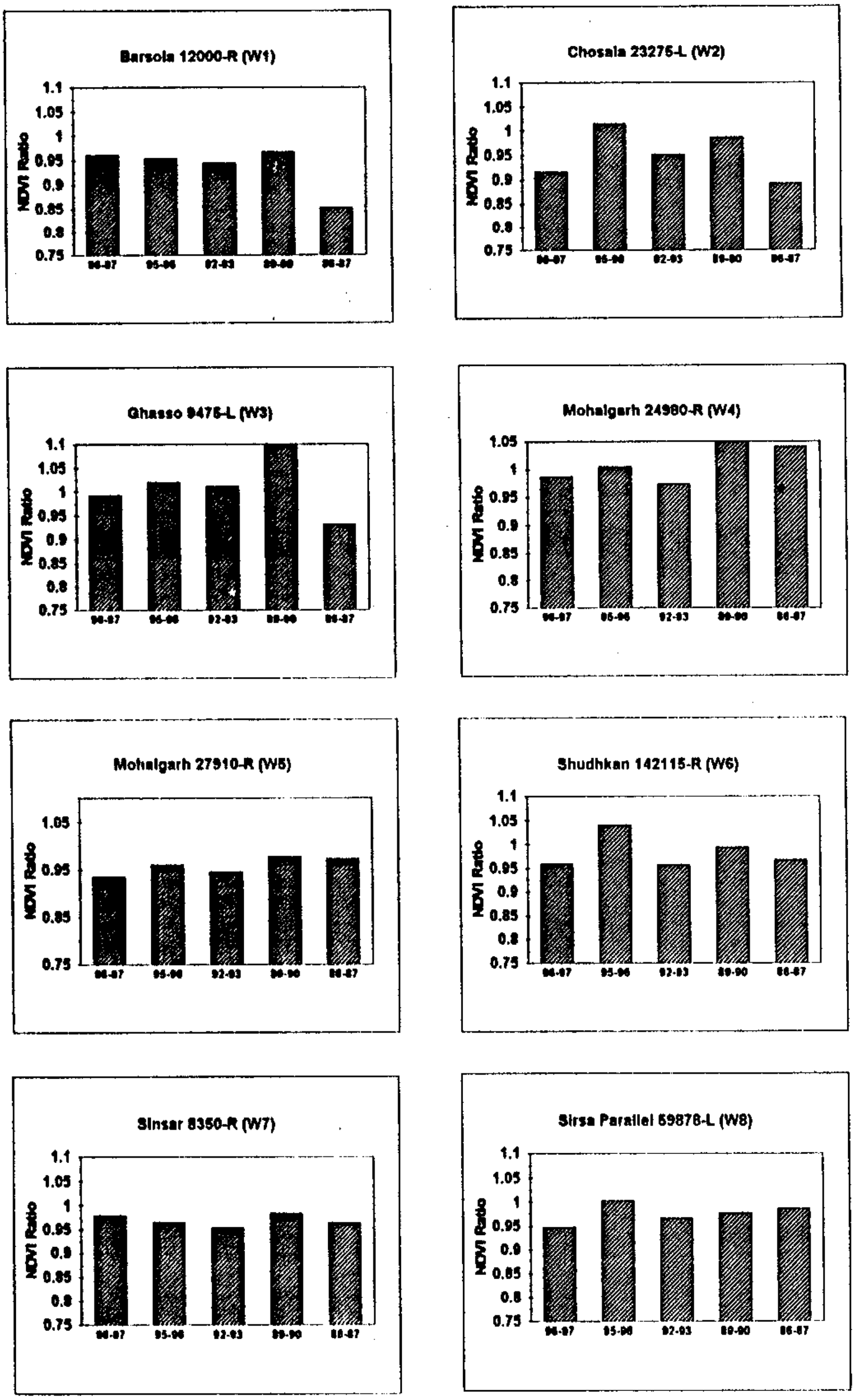


Fig. 21 THR ndvi in water courses of Narwana Block

over time and across space (Fig.22). Therefore, the condition of wheat crop did not vary between head and tail reaches in different water courses. It is not being influenced by the location of water course. However, with respect to age of lining and extent of lining certain associations are visible in Fig.22. In the water courses which were lined in 1992, the CV_{NDVI} has reduced in the post lining period in both head and tail regions (no.4) and CV_{NDVI} had increased wherein water course no.6, the tail performance has deteriorated in 1997 which increased CV_{NDVI}

From the foregoing discussion, the following inference may be drawn;

1. The performance of water courses over time is more or less stable

2. The location of water courses in the respective source distributaries / minors does not have any influence on the performance of water courses.

3. Age of lining and extent of lining of water course does not influence the absolute crop area either wheat or wheat equivalent total crop area, or its relative contribution to total crop area of all the water courses over time. That means, the age of lining and extent of lining did not change either cropping pattern or cropping intensity.

4. The condition of wheat crop in tail and head regions of water courses is uniform in general, without being influenced by location of water course, age of lining and extent of lining. However, there is an indication that in the water course lined up to 1983, the tail vs. head disparity in crop condition is fluctuating from year to year.

4.5 Analysis of results over Sirsa block

The set of 11 water courses selected in Sirsa block are located in Rori division of Sirsa WS Circle and their source distributaries are fed by Bhakra main branch canal. The marginal to saline quality of ground water forces the farmers to rely mostly on canal water supplies. However in head reaches of main canals shallow tubewells are dug to tap the canal seepages. It was also noticed during the field visits that saline groundwater is being marginalised by mixing with canal water to overcome the shortages in canal water supply through conjunctive use. As all the selected 11 watercourses, were lined during/before 1987, the satellite data analysis

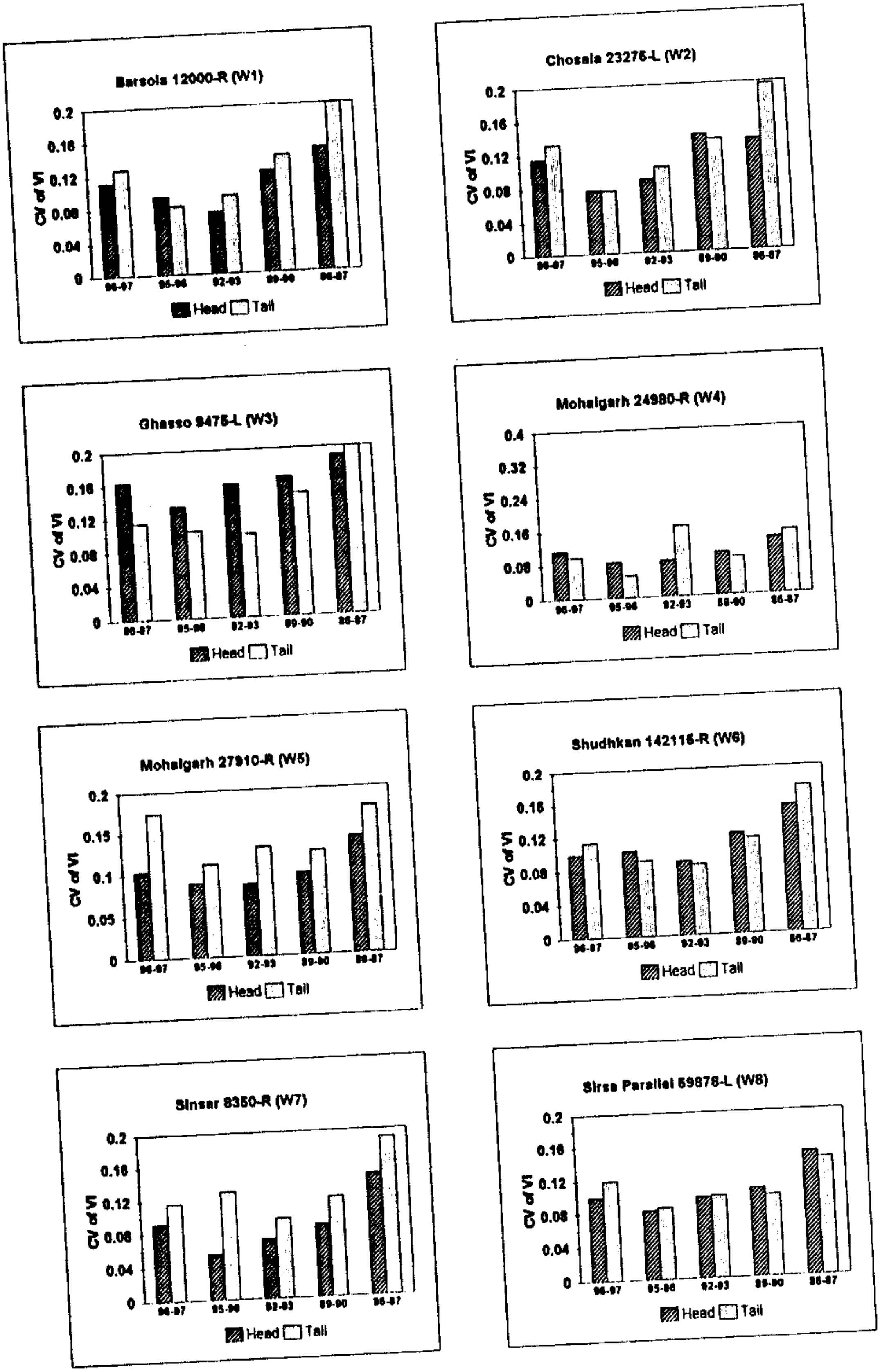


Fig. 22 Coeff. of Variation in Head and Tail NDVI in water courses of Narwana Bloc

represents the post lining period. Interestingly, all the watercourses under study in this block are having more or less same percentage of lining ranging from 63 to 80 per cent and also all of them were lined before 1987. On the basis of age of lining, these water courses may be categorised into three groups namely;

Group I (water course nos. 5,8)	Watercourses lined during 1987 or just 2 years before 1987
Group II (water course nos. 4,7,9,10)	Watercourses lined 5 to 6 years before 1987
Group III (water course nos. 1,2,3,6)	Watercourses lined 10 to 11 years before 1987

4.5.1 Wheat Intensity (WI)

All the three groups show a steady decline in wheat intensity from 1987 to 1997 (Fig.23). The trend is same in all the water courses irrespective of location and age of lining and extent of lining,. This signifies the general preference of farmers to non wheat crops. The non wheat crops are mostly mustard and gram. The duration of mustard is same as that of wheat while that of gram is slightly more than that of wheat. However, the irrigation water requirement of non wheat crops is significantly less than that of wheat; may be about 60 per cent of that of wheat. The economic benefits from mustard and gram are not higher than that of wheat as indicated by farmers' interviews during field visits. Therefore, the farmers' preference to non wheat crop could be attributed to irrigation water availability. The shortage of canal water coupled with poor ground water quality might have resulted the replacement of wheat by non wheat.

Further the differences in wheat intensity among the water courses does not seem to be influenced by location, age and extent of lining. Even the TRA water courses (nos.1,9,8) have about 60-70 per cent of wheat intensity on par with HRA water course (no.10). Similarly, different ages of lining do not reflect the differences in wheat intensity. However, the unlined water course has got much less wheat intensity compared to the rest, particularly in 1995-96.

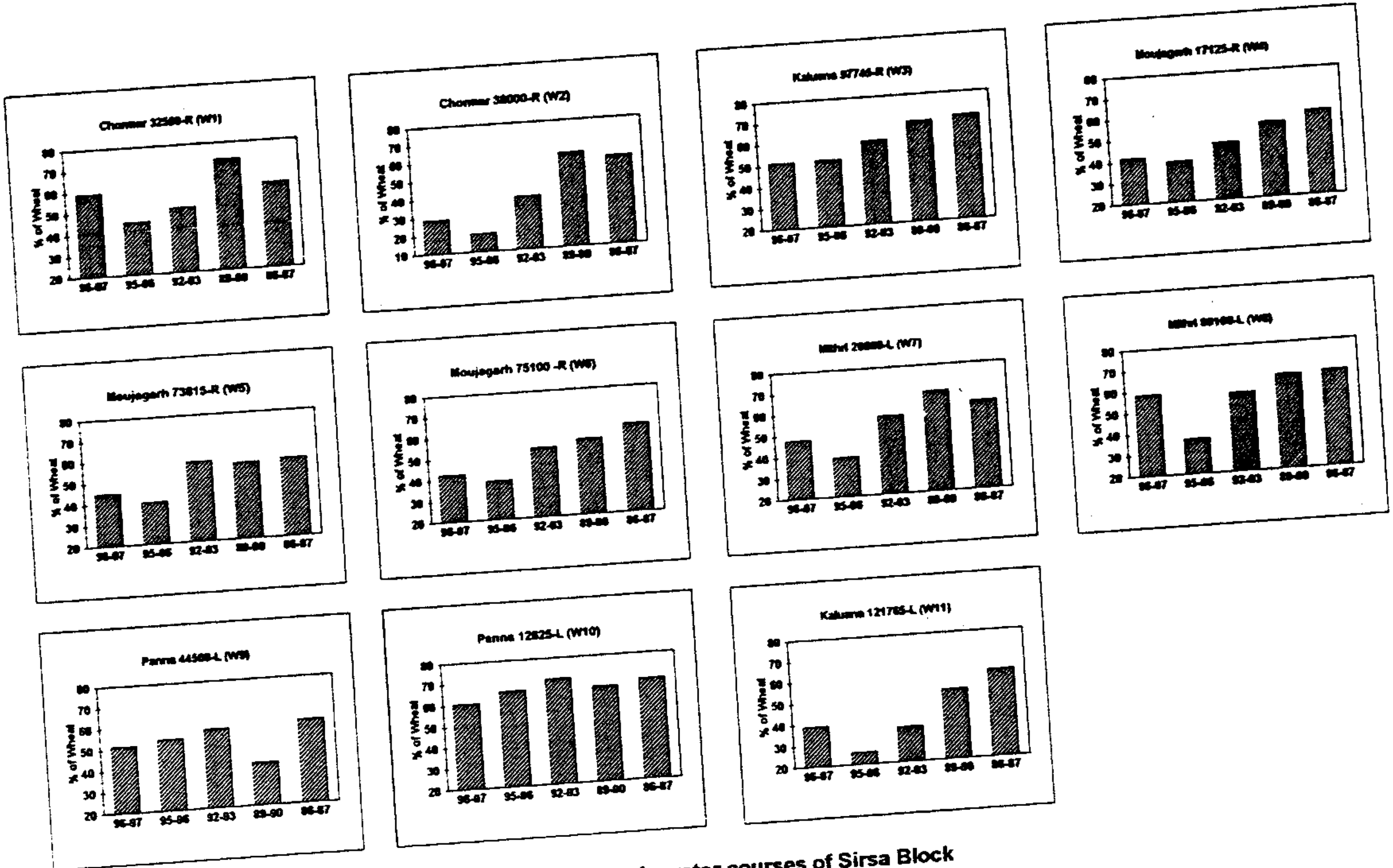


Fig. 23 Wheat Intensity in water courses of Sirsa Block

The following inference may be drawn from the above discussion;

1. The intensity of wheat crop among the water courses does not show any significant relation with location and age of lining. However in the unlined water course, the wheat intensity is much less.

2. All the water courses show a general decline in the wheat intensity.

4.5.2 Equivalent Wheat Area Intensity (EWAI)

Overtime the EWAI has remained same more or less in all water courses (Fig.24). That means, the intensity of total crop area remained consistent. It is evident from previous section (4.5.1) that wheat intensity shows a declining trend in all the water courses. That means, whatever reduction in wheat area is compensated by non wheat crops, so that total crop area is stable. The EWAI is not significantly different even in unlined water course (no.11) compared to lined water courses (nos.4,6,8). Similarly, though the water course (no.4) is located in HRA, its EWAI is much less compared to that located in TRA and MRA. In case of water courses (nos.1 & 9), despite their location in TRA, the EWAI is onpar with that located in HRA (no.10) and more than that located in MRA (no.3). Similarly the age of lining seems to be not influencing EWAI.

Thus it may be inferred from the foregoing discussion, that the crop intensity as represented by EWAI is stable over time and it is not influenced by location and age of lining.

4.5.3 Proportionate Crop Intensity (PCI)

The PCI values are consistent over time in most of the water courses indicating that the relative crop area contribution of each to the group remained stable over years (Fig.25). That means, the performance of water courses in terms of crop intensity is more or less uniform. However, in some water courses (nos. 1 & 2), the inter annual fluctuations of PCI, reflect the unstable performance compared to the rest of the water courses in the group. These two water courses are located in the tail regions and were lined in 1976.

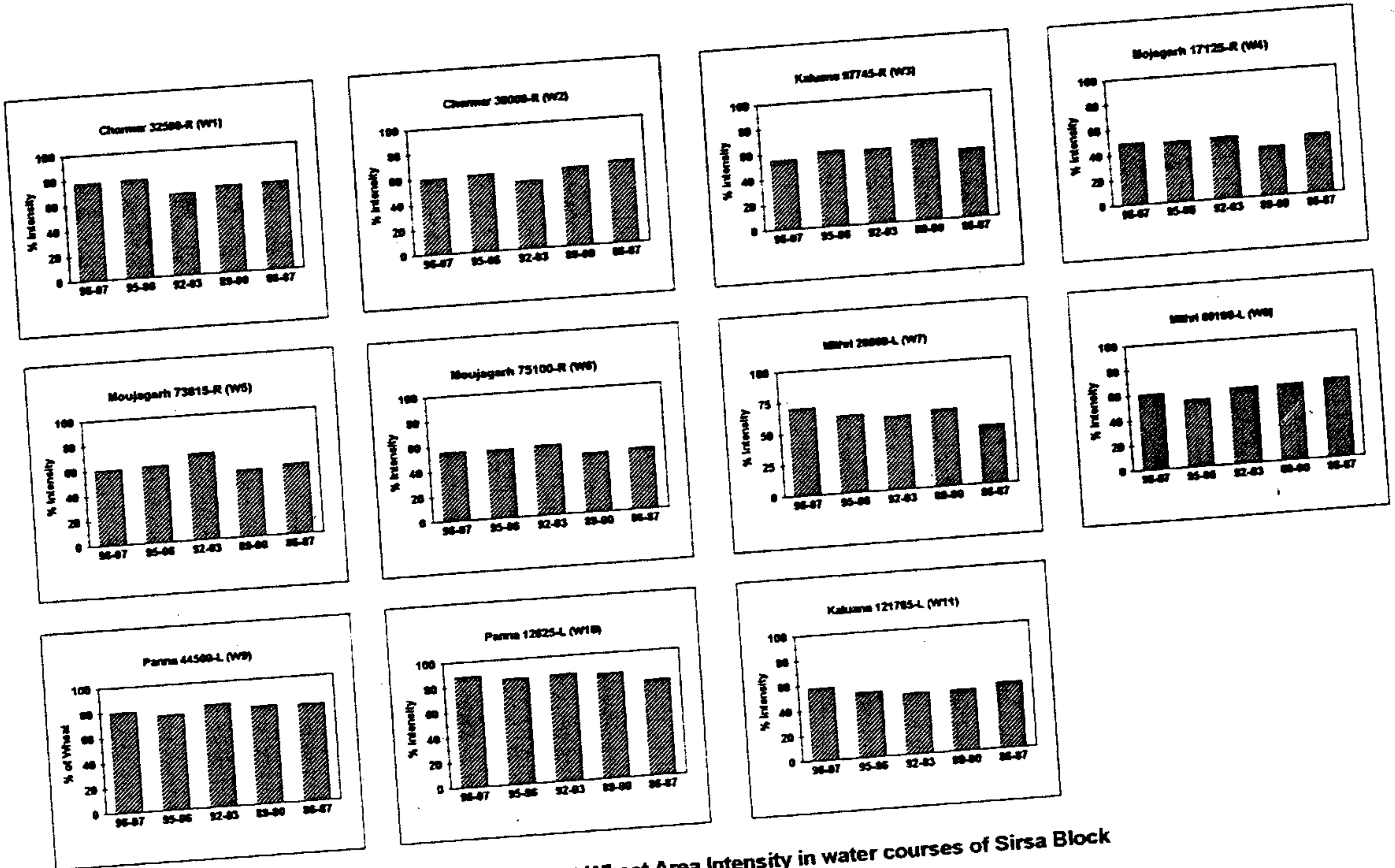


Fig. 24 Equivalent Wheat Area Intensity in water courses of Sirsa Block

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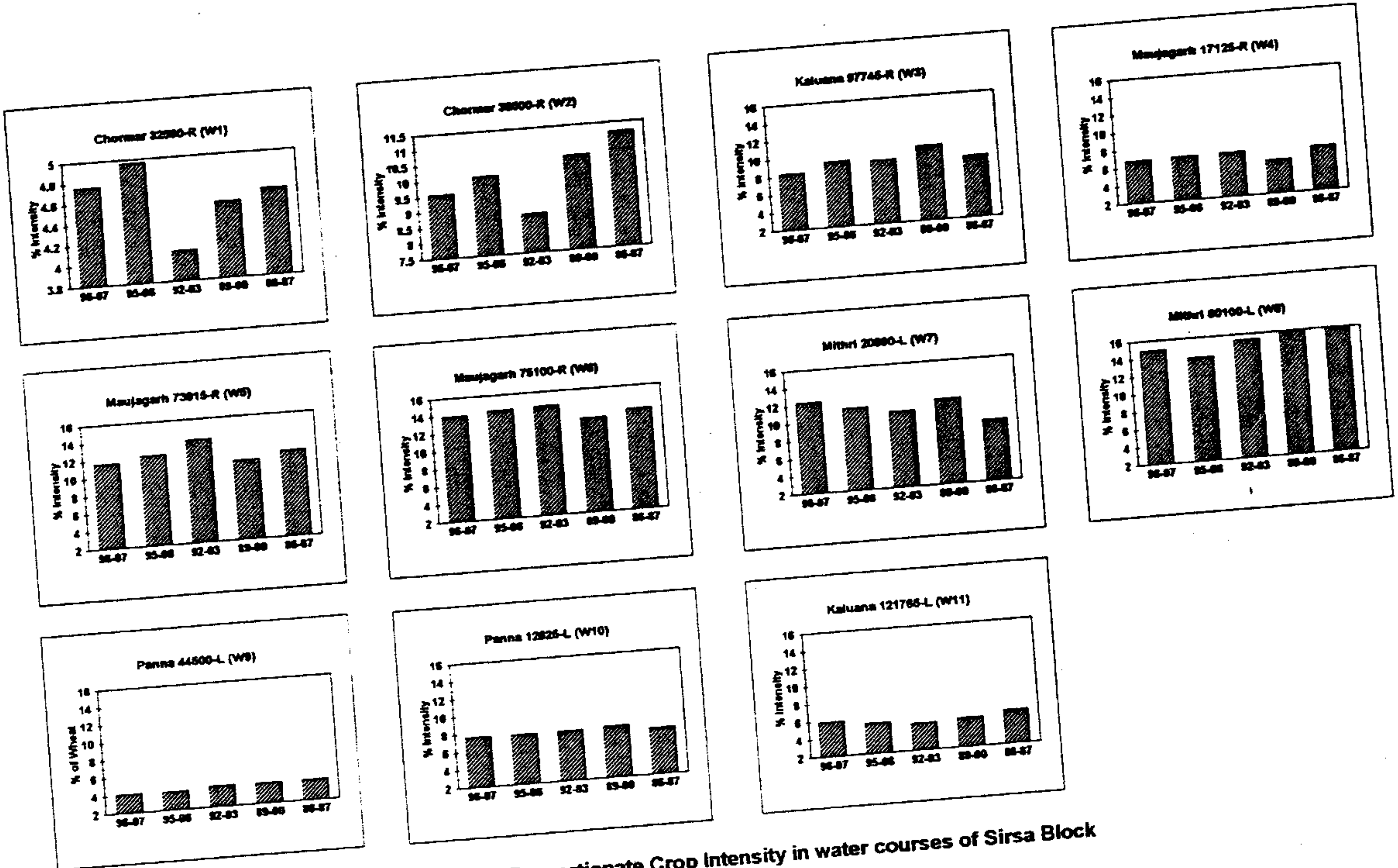

Fig. 25 Proportionate Crop Intensity in water courses of Sirsa Block

4.5.4 THR $_{NDVI}$

in Group I water courses (Fig.26). THR $_{NDVI}$ remained consistent over time is closer to 1 indicating lesser disparities in crop Further, the value of THR $_{NDVI}$ condition between head and tail regions. It is interesting to note that in the water course (no.5), the tail crop is better than that of head. In Group II water courses, the disparities are less and uniform over time in water courses (no.7 and 10), while the situation is entirely different in water courses (no.4 and 9) where the disparities are high and fluctuating over time. Again in Group III water courses also, one can find mixed trend with some water courses having less disparities (nos. 1 and 6) and others with high disparities (no.2 and 3). The unlined water course is performing better with no disparities within. The location of water course does not have any influence on crop condition as seen from water course (no.4) which is located in HRA but high and inconsistent disparities and water course no.1 located in TRA with low and consistent disparities. Similarly, age of lining also do not have any influence on crop condition in head and tail regions.

From the above discussion, it may be inferred that;

1. In majority of water courses, crop condition in head and tail regions is uniform and consistent over time.

2. The head and tail differences in wheat condition are not related to location and age of lining.

4.5.5 NDVI variation in Head and Tail regions (CV $_{NDVI}$)

In group I & II, the CV of wheat NDVI shows a declining trend in both head and tail reaches, indicating that more uniform crop conditions are prevailing in both head and tail reaches (Fig.27). However in Group III, the head reach CV shows a steady decline indicating more uniform crop condition over the time, the tail reach CV remained higher and consistent over the time. This indicates that in this set of water courses, which were lined about 10 years before 1987, tail reach wheat crop performance is variable and nonuniform.

The CV of wheat NDVI in both head and tail regions have been decreasing over time

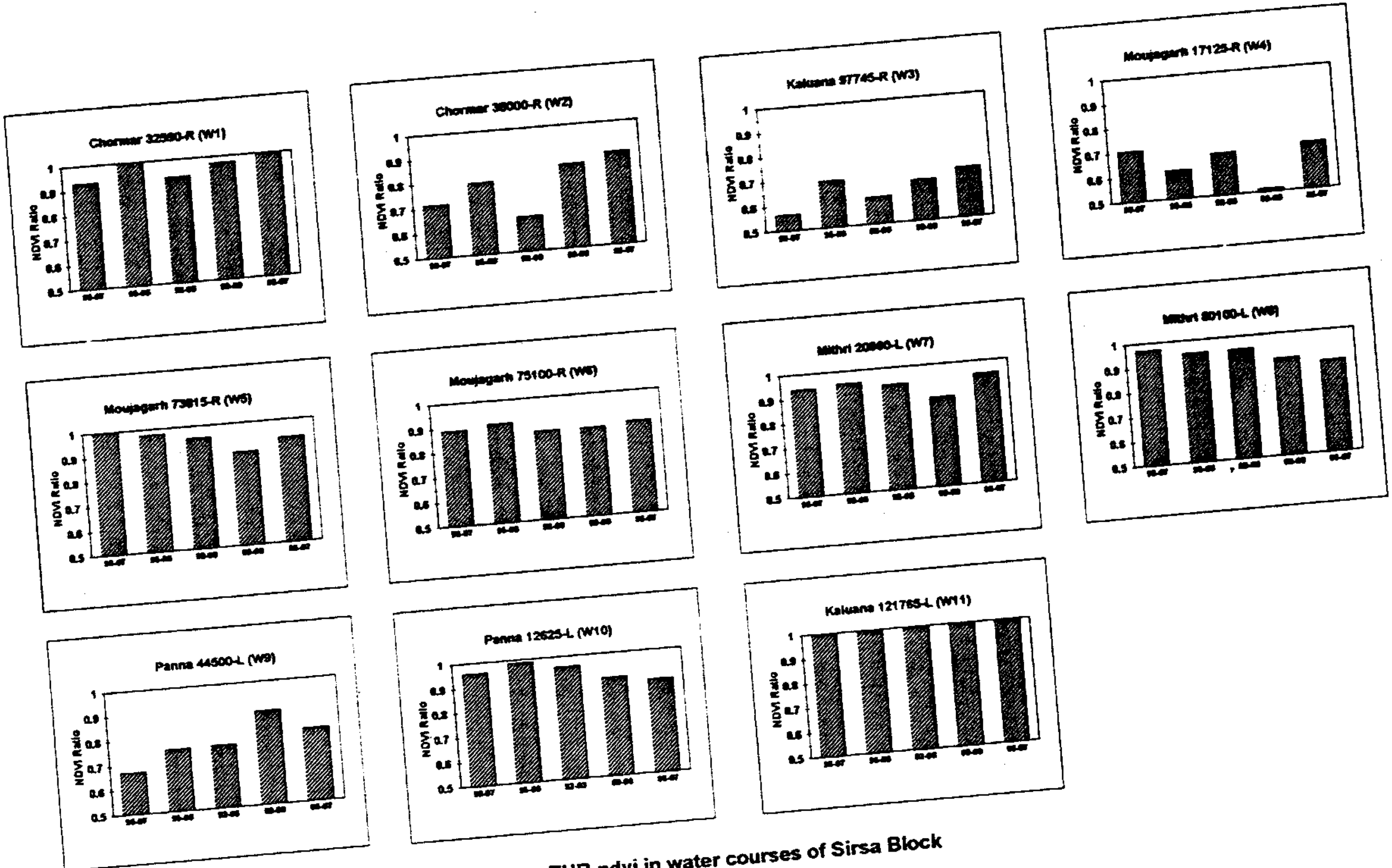

Fig. 26 THR ndvi in water courses of Sirsa Block

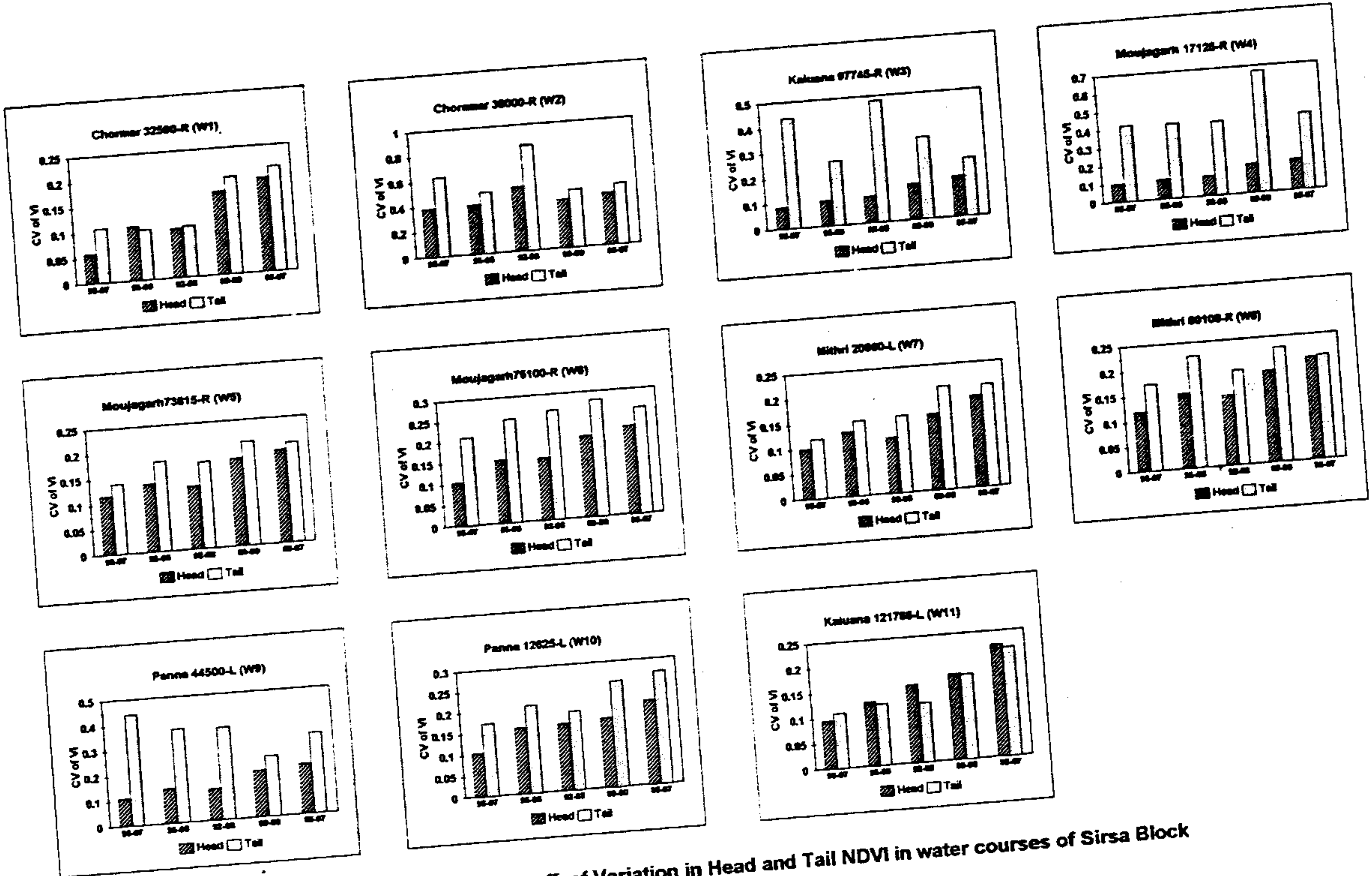

Fig. 27 Coeff. of Variation in Head and Tail NDVI in water courses of Sirsa Block

generally in all the water courses reflecting uniform crop condition within head and tail regions. But the disparities in CV of NDVI are significant and consistent over time in water courses (nos. 2,3,4,6 and 9). In these water courses the tail regions have higher NDVI variability compared to head regions, signifying the differences in wheat productivity. These water course have different ages of lining and located in different regions of respective parent distributaries. It is interesting to note that the unlined water course is more uniform in terms of head and tail NDVI variability.

It may be inferred from the foregoing discussion that;

1. The variability in wheat crop condition is reducing over time in both head and tail regions of water courses.

2. The tail reach areas have higher variability in wheat condition than head reach areas

3. The head and tail differences in NDVI variability are not related to location and age of lining

4.7 Sustainability in crop intensity

The coefficient of variation(CV) in crop intensity as represented by EWAI during 1986-87 to 1996-97 reflects the performance of water courses. Temporal changes in crop intensity can be attributed to changes in water availability. High values of CV signify inconsistent/deteriprating performance. The values of CV in EWAI at water course level as well as at head and tail reaches within water courses for the water courses which were lined before 1986 are presented in Table 8. The CV values up to 10 percent may be considered insignificant.

It is evident from Table 8 that in general in most of the water courses of three blocks the CV values are less than 10 percent. That means, at water course level the crop intensity is sustainable over time. However, in water courses (nos. 1,3 and 5 in Hisar block, no.1 in Narwana block and no. 7 in Sirsa block) the CV is greater than 10 percent. The situation within the water courses i.e., in head and tail reaches indicates a completely different picture. The CV values are significantly high in most of the water courses of Sirsa and Hisar blocks. The crop intensity in tail reaches shows very high variations in Sirsa block. This is due to the fact that in this block the source of water is mostly canals as ground water quality is poor and since the canal water are limited, the disparities between head and tail reaches have aggravated over time. In this block water course nos. 2,3,4 and 9 have very high CV values. In Hisar block, CV values in tail reaches are relatively less compared to that of Sirsa block. In this block, water course nos. 3,5 and 6 show greater variations in crop intensity in tail reaches. In this block, the ground water quality is marginal and hence its usage is more than that of Sirsa block. In Narwana block, the CV values are significantly less,indicating stable crop intensity within water courses. This is due to good quality ground water for conjunctive use.

Table 8 Coefficient of Variation (CV) in crop intensity

	Water course no.	Total water course	Head Reach	Tail Reach
Hisar block	1	12	15	15
	2	9	10	13
	3	18	17	10
	4	10	10	16
	5	17	12	27
	6	10	9	18
Narwana block	1	16	13	26
	2	9	9	12
	3	2	3	8
	6	2	2	7
	8	7	6	14
	9	4	5	11
Sirsa block	1	7	10	17
	2	6	7	23
	3	6	7	20
	4	8	6	37
	5	9	8	17
	6	7	9	10
	7	13	20	15

5. SUMMARY AND CONCLUSIONS

Multidate high resolution satellite data has been analyzed during the rabi seasons of five different years and information on cropping pattern and crop condition has been generated for every pixel of 0.09 ha size.

The study has successfully demonstrated that the synergistic use of high resolution (5.8 metres) Panchromatic data with multi spectral data (23 mts - 36 mts pixel resolution) could enhance the capabilities of remote sensing technology for disaggregated inventory of irrigation systems.

The use of IRS-1C PAN data of 5.8 metres spatial resolution has resulted in increased accuracy in the registration of high scale (1:6000) cadastral maps of water courses to the most commonly used topographic maps of 1:50,000 scale.

The satellite derived spatial and temporal information on cropping pattern and crop condition at water course level are the potential data sets for generating irrigation performance indicators. In the absence of any institutional structure for collection and maintenance of such data in irrigated command areas, satellite remote sensing technology assumes greater importance.

The performance indicators evolved from remote sensing derived information on cropping pattern and crop condition have been used for evaluating the irrigation system performance of gross root level irrigation units such as water courses.

In Hisar block, the ground water quality is marginal and is suitable for conjunctive use to some extent. In this block, the performance of water corses is strongly related to the location in the respective distributary/minor. Water course located in the head reach area have higher wheat intensity and total crop intensity. In the case of water courses which were lined in 1992, there is a significant improvement in crop intensity in the post lining period. Even the unlined water course located in the head region has higher crop intensity. However, the condition of wheat crop is not being influenced by location, age and extent of lining. The disparities in crop condition between head and tail regions have not reduced significantly in the post lining period.

In Narwana block, the ground water quality is good and is being extensively used as supplementary source. The performance of water courses is in general stable over time. The location of water course, age and extent of lining does not show any relation with crop intensity. In general, in all the water courses the crop condition is uniform in head and tail regions. However, in the water courses lined upto 1983, the disparities between head and tail are fluctuating from year to year.

In Sirsa block, all the water courses selected for the study have been lined before 1987. The location of water courses in the parent distributary/minor, age of lining and extent of lining do not seem to have related to the performance of water courses. The wheat intensity in general is decreasing over time and non wheat crops are increasing. Going by the general preference of farmers to wheat crop, the replacement of wheat by non wheat over time can be attributed to decreasing irrigation water availability. This block is characterized by poor ground water quality. As the supplies from canal water are not sufficient, farmers prefer low water consuming non wheat crops. The intensity of total crop area is more or less stable over time indicating that the reduction in wheat area is compensated by increased non wheat area. In majority of water courses, the condition of wheat crop in head and tail regions is uniform and consistent over time. In some water courses, the disparities in crop condition between head and tail regions are high and fluctuating from year to year. The NDVI variability within head and tail regions is decreasing over time, however tail regions have significantly greater variations.

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GLOSSARY OF TECHNICAL AND INDIAN TERMS

Branch canal is the primary artery of canal water delivery system of offtakes from reservoir.

Command Area represents the area irrigated or capable of being irrigated either by gravitational flow or by lift irrigation or by any other method and includes every such area by law inforce in the State; also referred as ayacut.

Critical Period is the period during crop growth when moisture stress will have a lasting effect on crop growth and yields.

Crop calendar is the chronological sequence of occurrence of various physiological stages in crop growth cycle.

Cropping Pattern is determined according to relative acreage of various crops in the command.

Culturable Command Area is the portion of the Gross Culturable Area which is cultivable.

Distributary is the secondary artery of the canal water delivery system. It takes off from the main canal.

Gross Command Area is the total area which can be irrigated in a project command. It includes the area covered by roads, culverts, settlements, unculturable area etc.

Growing Period for a given crop, is the period between planting or sowing and harvest; also referred as base period; days.

Intensity of Irrigation is the ratio of the actual area irrigated In a season to the total culturable command area; expressed as %.

Kharif is an important agricultural season and commences during June-July after the onset of south-west monsoon and ends during October-November.

Main Canal is the principal artery of the distribution system.

Minor is the tertiary artery of the canal water delivery system. It takes off from the distributary and can be a ridge canal irrigating on both sides.

Moisture Stress is a deficit state of water availability experienced by the crop wherein the rate of water loss from the crop exceeds the rate of water absorption by the crop, resulting in below normal crop growth and crop yields

Monitoring is the process of collecting information about the actual execution of planned tasks and factors which might affect their execution; analysing these in relation to the plan and exercising control so that the deviations from the plan are minimal.

Outlet is a control structure to regulate releases in the water courses and field channels.

Quintals is the Indian weight measure eqivalent to 100 kilo grams

Rabi is the second important agricultural season and commences during October-November and ends during March-April.

Vegetation Index is derived from the reflectance of vegetation in near infra red and Red bands and indicates the density and health of vegetation at the time of observation.

Water Course is a channel built, generally at government expense, to convey water from an outlet to a hundred acre block or as may be prescribed.