SUSTAINABILITY OF A WARABANDHI SYSTEM: SRS and GIS Techniques to help Identify Issues

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Contents

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INTRODUCTION

Irrigated agriculture will play a major role in future food security of most Asian countries and also will be the major contributor to additional food production requirements for increasing world population (Svendsen and Rosegrant 1994). Therefore, it is important to increase agriculture performance of the low production systems, while sustaining the performance from the higher productive systems. This paper focuses on the sustainability issues of the Bhakra irrigation system in the state of Haryana in India. Agricultural performance of Bhakra is higher than the average national level (Statistical Abstract 1995). Currently, it contributes about 40 percent of the Haryana's wheat production and 6 percent of the national production. Bhakra, though ensures equity in canal supplies through Warabandhi system of rigid rotational water distribution, is a water short system. This leads to large scale groundwater withdrawal to obtain the present wheat area coverage and high production levels. Thus the long-term sustainability of high agricultural productivity with present water use pattern assumes crucial significance.

Effective evaluation of irrigation system performance and sustainability in many countries, and particularly in India, is hampered by lack of adequate irrigation statistics. Traditionally, emphasis on measuring the agricultural performance indicators such as yield, cropping intensity, irrigation intensity, is at aggregated level, often at state or national levels. Data at project level are rarely collected. If collected they are often unreliable or not easily accessible (Murray-Rust and Merrey 1994). It is in this context that IIMI, as part of its ongoing research program on the use of emerging technologies in irrigation management, applied remote sensing and Geographic Information System (GIS) techniques to study Bhakra irrigation project and to analyze sustainability issues. The programme involved both methodological developments and operational application to generate required agricultural performance data at a disaggregated level. This study executed by National Remote Sensing Agency in India in collaboration with IIMI complements an earlier study by IIMI on the Bhadra project, Karnataka a rice based irrigation system. Thus the two IIMI studies have demonstrated operational remote sensing and GIS applications for the two major irrigated food crops of India.

SRS applications typically involve analysis of multispectral data acquired by earth resources satellites such as Landsat and Indian Remote Sensing Satellite (IRS). They can be used to derive information on cropped area, cropping pattern and calendar, and crop productivity in irrigation systems (Bastianssen 1997). Waterlogged and salinity affected

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soils have been mapped. The benefits of SRS techniques are the spatial data generation and temporal monitoring capability through the season and years (Thiruvengadachari and Sakthivadivel 1997). Conventional surveys are often not adequate to provide disaggregated estimates of crop yield within a command area, and typically provide only overall estimate for the total command area.

The satellite derived data in raster format is also ideal for import into the GIS environment. The information can then be combined with other spatial data. While published literature exists on some specific applications, (Huston and Titus 1975; Draeger 1976; Pestemalci 1995; Azzali and Menenti 1989) the Bhakra system study is perhaps one of the first attempts to demonstrate a total package of applications to aid system performance evaluation. Another notable feature of this study is the extensive and synergetic use of other contemporary technologies such as Global Positioning System (GPS) and Geographic Information System (GIS). The relevance and promise that these technologies hold in hydrologic modeling, essential for effective water resources management , is highlighted in a recent review article (Tim 1996).

Earlier studies have demonstrated the usefulness of satellite remote sensing data in generating information on total irrigated area and area under different crop for the total project area (John et al 1978, Kolm 1984, Nageswara Rao et al 1990). Multispectral SPOT data and airborne data were analyzed for monitoring irrigated orchards and nine crops in South Australia (Williamson 1989). Several studies have demonstrated the utility of Normalized Difference Vegetation Index (NDVI) in monitoring crop phenology and condition. NOAA AVHRR derived NDVI was used to describe the phenology of Iberian vegetation (Daniel 1989), which indicated that irrigated crops can be characterized by the timing and magnitude of the maximum NDVI value. NDVI was again shown to be a sensitive indicator of variations in biomass which correlates with spatial and temporal changes in growing conditions (Kennedy 1989). Many studies have attempted crop yield estimates using satellite data (Pinter 1981, Quambay 1993), with Hatfield (1983) recommending the use of VI at heading stage of crop for estimating potential harvestable yield.

The main objective of the present study is to demonstrate the application of SRS and GIS techniques to evaluate the performance of a wheat based system and to demonstrate their utility and cost-effectiveness as a diagnostic tool for system improvement.

The specific objectives of this study are: (i) generation of disaggreated statistics on total irrigated area, area under major crops and wheat productivity, and (ii) integration of satellite derived statistics with other ground measured data to identify factors constraining agriculture performance and long term sustainability of the agricultural production system. One of the specific questions that this research addresses is whether present practices of water allocation and distribution of canal supplies can be maintained at current levels without detrimental impact on agricultural production and ground water regime or not.

SYSTEM DESCRIPTION : Warabandhi Principle and Rotational Water Distribution

Bhakra System

The Bhakra canal system in the state of Haryana in Northwestern India has a cultivable command area of 1.2 million ha (Figure 1). It provides 88 percent of the surface irrigation support in the State. With a semi-arid to arid climate, prolonged hot periods persist in the command between March to October with rainfall concentrated from July to September. The average minimum and maximum temperatures fluctuate around 5 C. Irrigation requirements vary from east to west with annual evapotranspiration varying over the command between 1250 mm in the northeastern part and 1650 mm in the southwestern part (Water Atlas 1997). The average annual rainfall in the north - eastern part of the command is 750 mm while in the south western part, it is less than 400 mm. Dry season (rabi) rainfall varies from 100 mm in the east to less than 50 mm across the command area in the west.

The Narwana - Sirsa system, Barwala - Sirsa system, and Bhakra Main Line (BML) system - the three operational systems of the Bhakra canal network - receive their water supplies from two sources. The Gobind Sagar Reservoir impounded by the Bhakra dam, from which Haryana draws its share of the flows of the rivers Ravi, Beas and Sutlej of the Indus river system; and the diversion barrage at Tajewala on the Yamuna river from which Haryana gets its share of the (uncontrolled) Yamuna flows from the Ganges river system. Waters from Bhakra storage are used to supplement the run-of-the river availability from the Yamuna through two links - the Narwana branch and the Bhakra Main Line (BML) - Barwala link. Of the three operational systems, the Narwana - Sirsa system and the BML - Barwala system are partly supplied from the Yamuna and partly from stored waters of the Indus rivers. The BML system is entirely supported from the storage waters of Bhakra dam. Among the three operational systems, BML system enjoys the most stable and predictable supplies.

In addition to canal water, groundwater plays a major role in the irrigated agriculture of Bhakra canal command. Area irrigated by groundwater through shallow and deep tube wells is equal to or greater than that irrigated by canal water. In Hisar, Sirsa and parts of Jind districts where groundwater development is low due to poor quality, water table rise during 1979-1994 was 5.5 m, 4.37 m and 1.8 m respectively. Sustained rise in ground water table in these areas is one of the major problems in the command. In Kaithal, Kurukshetra and Ambala districts the water table dropped during the same period by 2.02 m, 8.0 m and 4.67 m respectively due to extensive development of good quality groundwater.

In order to reduce seepage and to improve the conveyance efficiency of canal networks as well as to control the groundwater rise, lining of canals and watercourses commenced about 18 years ago and is still continuing. Out of 17,500 km length of watercourses in the command, about 12,300 km length (70%) have been lined. However, the water saved due to lining has not been quantified and accounted for in water allocation and distribution.

Kharif (June - October) and Rabi (November - April) are the two principal agricultural seasons. At the time of planning the Bhakra canal command, the following cropping pattern was assumed: in Kharif, fodder, cotton, gram, barley, orchards and vegetables; and in rabi, wheat, fodder, gram, barley and vegetables. Presently, the cropping pattern and the cropping intensity has changed with most of the irrigated area occupied by high yielding varieties of rice, wheat and cotton. The irrigated area has also increased over the years. The total irrigated wheat area during rabi 1992-93 and 1993-94 were respectively 68.6 and 71.4 percent of the total irrigated rabi area in the respective years. This is about double the percentage of planned wheat area in the project cropping pattern.

The Warabandhi Principle of Irrigation

The surface irrigation schemes in Haryana including Bhakra project are designed and operated according to the Warabandhi principle which follows a rigid rotational cycle of fixed duration, frequency and priority level. The Warabandhi system of water distribution has the advantages of simplicity in planning and operation. The principle of distributing the water proportional to the area is a feature which makes it attractive. Since the Warabandhi principle of water distribution has a bearing in the sustainability issues of the system to be discussed later, a brief outline of the design principles followed under the Warabandhi system is presented:

- individual farms are aggregated into hydrological units (chaks) of 100-400 ha (50-200 farms).

- each chak is served by a watercourse whose capacity is proportional to the size of the chak. Design duty at the chak level in the study area is 0.17 l/s/ha[3]; so that water courses range in capacity from 17 to 70 l/s.

- each farm holding in the chak is entitled to take the full supply in the watercourse during a specified period proportional to its size, during the week. This proportionality of entitlement period to holding size and watercourse flow to size of chak ensures uniform volumetric allocation per hectare per week for all farmers in the command under distributaries that receive supply in that week.

- water courses are ungated and are served by parent channels (minors) with a capacity exactly equal to the sum of the capacity of off-taking minors and direct outlets to watercourses (again allowing for losses).

[3] 0.17 l/s/ha is equal to 1.5mm/day, while peak ET in the irrigation season is 3 to 5 times this amount.

- minors in turn are usually gated and are served by a distirbutary whose capacity is exactly equal to the combined capacity of off-taking minors and direct outlets to water courses (again allowing for losses).

Since the water allowance/ha is very low, water scarcity is an inbuilt feature of the system. Originally the operating principle was conceived with a view to equitably distributing run-of-river flows. Since the pattern of availability of water was unknown, a further procedure was required to deal with uncertainty. This procedure known as `rostering', consists of assigning the distributaries into groups and defining rotating `performance orders' (priority orders) for the groups. Typically, there are three groups (say A,B,and C) in a large command. In the first week, group A has first priority, B the second and C the last priority. In the second week, group C moves to first priority, B to third and A to the second. In the third week, the priority order changes again, and in the fourth week the cycle begins all over. Fluctuations in flow during a week are absorbed in the lower priority groups. For further details with regard to Warabandhi principle of water distribution reference is made to the publication by Mahhotra ( ).

With the creation of reservoirs across the major rivers, a substantial degree of control was added to the system and it became possible to schedule deliveries more actively to coincide with critical periods in the agricultural year. Despite these improvements to the infrastructure, the system of allocating water has remained essentially unchanged in respect of the turn system at the chak level and canal rostering.

Rotational Programme of Bhakra Canals for Rabi 1995-96

During Rabi 1995-96 the Bhakra system was operated from 3 October 1995 to 14 April 1996 following the set pattern of rotations among different systems as described below. The Narwana - Sirsa system is divided into three groups of channels and each group is operated with 8 day turns. In the BML - Barwala link, channels are divided into two groups, each group getting its water in 16 day turns. In the tail BML, the distributaries are divided into 3 groups and the priorities are rotated after every 8 days turn. Usually, the BML brings enough water to run two groups at their authorized capacity.

The above allocation schedule with constant water allowance per unit area allows the command area serviced by tail BML channels to have the best availability of supply in terms of quantity of water per unit command area among the three systems, followed by the Barwala - Sirsa system getting only 80 percent of the BML supply per unit area. The Narwana - Sirsa system has the least availability, with the distributaries receiving only 50 percent of the BML's supply per unit area. It must also be noted that fresh groundwater zones (Narwana - Sirsa System) got the least surface water supply while the saline and marginal groundwater zones (Bhakra Main Line system) got the maximum surface water supply per unit command area.

METHODOLOGY : Use of SRS and GIS Techniques

Satellite Inventory of Bhakra Canal Command Area

The overview of satellite image analysis is shown in Figure 2. The innovations in analysis methodology include development of an iterative supervised - unsupervised classification approach and wheat yield modeling.

The command area is covered by nine IRS - IB satellite LISS II scenes of 74 km x 74 km sizes. Cloud cover free satellite coverage representing seasonal agricultural progress were obtained on five overpass dates during the rabi season of 1995-96 agriculture year (Table 1).

The satellite scenes, in which digital counts were first transformed into radiance values, were geometrically corrected with reference to accurate topographic maps in 1: 50,000 scale and mosaiced to provide complete coverage of command area. The corrected data set had location accuracy within 15 meters, pixel size of 30m x 30m, north-south oriented and in polyconic projection.

The canal network, major road/rail road, rivers and settlements as well as boundary of 364 distributaries/minors were digitized, geometrically corrected and co registered with the satellite data set, for overlaying on hard copies or for generating statistics for specified area units such as distributary command area. The base map showing the area commanded by distributaries/minors had to be specially prepared in consultation with field officers, as this was not readily available.

The analysis was supported and results are validated by ground truth campaigns during 10 January to 5 February and 14 to 28 June 1996. The field visits helped in the identification of sample sites representing target crops to be classified as well as crop cutting plots where wheat was harvested and yields estimated. The location of sample sites and crop cutting plots was obtained within 100 m accuracy through a hand held GPS receiver. Ancillary information on rainfall, canal discharge, groundwater levels and quality, and cropping pattern and crop calendar was also collected during field visits. The satellite related analysis was completed in eight months time at a unit cost of about US 3 cents per ha. This covers the cost of purchasing satellite data from the Indian Remote Sensing Data Centre and includes processing cost.

Crop Classification :

The details of classifying satellite data into specified crop classes are shown in Figure 3. A review of spectral signatures of wheat, oil seeds and other crops indicated a wide range and possible confusion between classes. Application of traditional supervised classification of wheat by Pestemalci et al. (1995) resulted in an accuracy of only 85 percent. Further non-availability of full cloud free coverage in March 1996, critical for use in simple or sequential maximum likelihood classifiers, necessitated new approaches. Consequently, an innovative classification methodology of iterative supervised and unsupervised classification approach (Figure 3) was developed to analyze satellite data acquired in the month of November, January and February. These three periods were optimally selected based on analysis of spectral signatures in all 5 dates and after evaluating separability index through Bhattacharya distance measure (Jensen 1986).

Only the green, red and near-infrared spectral band data of three selected dates were combined in a 9 dimensional data set and analyzed . An earlier study has also shown that in the maximum likelihood classifier the classification accuracy and computational speed decreases as the number of spectral channels increase(Lee and Richards 1985). The supervised classification was applied first, leaving 53% of the image pixels unlabelled, as the result of 9 dimensional data set providing pure spectral signatures of crop categories, with even marginal deviations resulting in non-classification. The unclassified portion of the images was then subjected to unsupervised classification that yielded 50 homogeneous spectral clusters. The signature of each cluster was compared with reference signatures to create additional training sets. The earlier and additional training sets were combined and spectrally clustered to provide revised training sets , which were used for further supervised classification. This approach of random selection of pixels in training sets has been shown in a contemporary study to increase classification accuracy in simulated satellite images of high spatial auto correlation(Dobbertin and Biging 1996) This process was repeated until all pixels were classified as wheat, oilseed or others. Once the classification was completed the results were confirmed by reference to 01/02 April data, because on this date most of the crops were in senescence phase.

The crop classification was validated against both sample areas identified during the first field visit but not used in classification and randomly selected area during the second field visit. An overall kappa accuracy of 95 percent was obtained (Congalton 1991). Satellite inventory provided data on the total irrigated area in the command, while the Irrigation Department reports only areas irrigated by canal supplies.

Wheat yield estimation

Agricultural productivity is the ultimate yardstick for assessing not only farm income but also water distribution and use efficiency. Conventionally crop cutting experiments (CCE) are conducted for the principal crops involving harvesting the crop at selected plots and obtaining average yield from the sampled scheme. Many studies while investigating the relationship between satellite data and crop yield have attempted to relate the end-of-season crop yield to satellite derived Normalized Difference Vegetation Index (NDVI) at heading stage, since the crop condition at this stage is a major determinant of crop yield. Pestemalci et al (1995) used similar single date regression model for a limited number of wheat parcels in Turkey to obtain a correlation coefficient of 0.84.

In the Bhakra study ground harvested wheat yield in 270 plots were obtained from Agriculture Department of Government of Haryana. The latitude and longitude of CCE plots were measured through hand held GPS receiver. Each CCE plot is represented by a window of 5 x 5 pixels (150m x 150 m) to account for the residual location inaccuracy in GPS readings. The NDVI of 17/18 February 1996, representing maximum value corresponding to heading phase of wheat was used as independent variable in the regression. CCE plots where farm size is less than 0.4 ha and where within- window NDVI variability is high were excluded as not representative. The outliers in the scatter plot of yield versus NDVI were also removed from further analysis. The wheat yield model based on the remaining 151 plots is computed as yield (t/ha)= -3.75+0.043 NDVI with coefficient of determination of 0.85 and standard error of estimate of 0.217 t/ha and with no identifiable bias (Figure 4). NDVI which is a fraction was converted to integer by scaling over a dynamic range of 0 to 255. The regression coefficient is significant at 1% significance level.

Using the linear regression model, the yield was estimated for every wheat pixel. These estimates can be aggregated over any desired aerial unit such as distributary/minor command, canal sub-division, division and water service circle.

Integration of Geographic Information System

To enable more comprehensive spatial analysis and to integrate more ground data which are in different scales and information levels, all relevant data have been organized in geographic information system (GIS) environment using IDRISI software. Table 2 characterizes the spatial and non-spatial data in regard to source data type, resolution and scale used in GIS analysis. Information integration and analysis was attempted through union and intersection techniques (Figure 5).

The GIS applications covered two main aspects:

1. Characterization of command area with regard to agricultural productivity, canal supply and groundwater regime and their interrelationships in order to help clarify policy issues on long term sustainability.

2. Answer specific queries on location specific corrective management, such as areas with potential waterlogging problem, areas for reclamation and soil limitations to wheat productivity etc.,

RESULTS OF ANALYSIS

Agricultural Characterization of Bhakra Command Area

The spatial variability of irrigation intensity (irrigated cropped area to cultivable command area), and wheat, oil seeds and other crop areas as percent of total cropped areas has been determined and mapped. An overview of irrigated statistics across the command area is presented in Table 3. The overall irrigation intensity of the command for the rabi 1995-96 is 83 percent both by surface and groundwater against a designed surface water irrigation intensity of 32 percent. The contribution of groundwater to irrigated agriculture in this command is significant and surpasses in irrigating more area than that by surface water supplies (Agricultural Statistics 1995). Among the rabi crops, wheat is predominant , occupying more than 70% of cropped area. These figures compare favourably with the figures quoted in irrigation and agricultural statistics of the government of Haryana (1995).

The wheat yield and production for different water service circles for rabi 1995-96 is shown in Table 3. The maximum wheat yield is in Kaithal circle which is mostly having fresh groundwater while the minimum wheat yield occurs in Hisar-1 and Sirsa circles underlain by marginal and saline groundwater's.

The average wheat yield over the whole command area is estimated to be 4.09 t/ha. Also, distributary/minor wise wheat yield was computed and compared with divisional mean wheat yield. Distributaries/minors having less than 90 percent of divisional mean wheat yield are considered to be poorly performing distributaries/minors. Based on this criterion, Table 4 provides the list of distributaries/minors of poor wheat productivity. The list provides an initial screening of poorly performing distributaries for which causes can be identified to diagnose constraints to productivity.

Spatial variation of wheat area and wheat yield

In order to study the spatial variation of wheat irrigated area and wheat-yield as function of distance from the supply channels, two typical water circles - Kaithal and Sirsa - having different groundwater quality were selected. Using the GIS, the nearest distance from the supply channel network[4] to each pixel was calculated and the average wheat yield and wheat irrigated area were computed at an incremental length of 500m. In Sirsa circle with poor ground water quality about 45% of wheat irrigated area was concentrated within a distance of 500 m from the canal network, while only 28% of wheat area is concentrated within a distance of 500 m in Kaithal circle with good ground water quality. However, in both circles as one moved away from the canal network, the percent wheat area decreased. The above results indicate that most irrigated wheat area in a water circle is concentrated in and around canal networks due to seepage water availability and nearness to the water source. Farmers appear to capture seepage water from canals through wells to increase their wheat irrigated area.

[4] Supply channel network considered are main channel, branch canal and distributary/minor.

On the other hand, spatial wheat yield variation is not very perceptible although the mean wheat yield in the two circles differed by 0.6t/ha. In fact, the wheat yield in Kaithal water circle where fresh ground water is available is higher in the tail-reach compared to the head reach of that circle.

Canal Water Supply

The spatial variability in canal supplies (Figure 6) indicates that low canal supply areas are mostly in fresh groundwater zones while high canal supply areas are in saline or marginal groundwater zone. As per Warabandhi principle, one would expect to receive more or less equal supply of water per unit command area. However, the canal supply vary from less than 150 mm in 35 percent of the command area to more than 300 mm in about 41 percent of the command area. The remaining 24 percent command area receives between 150 mm and 300 mm.

IDRISI GIS helped in defining the regional agriculture, ground water and canal supply setting of the command area for analyzing their inter-relationship. Table 5 presents the relationship among groundwater quality, percentage of rabi irrigated area, percentage wheat area with yield less than 4t/ha, percentage of command area with low canal water supply/unit command area, percentage of area with falling groundwater trend and percentage area with groundwater depth greater than 10m. This table brings out some interesting results: in marginal/saline groundwater zone, the percent of rabi irrigated area is low and the percent of wheat area is also low. On the otherhand, only 9 percent of command area in marginal/saline groundwater zones gets low surface water supply compared to 70 percent command area in the fresh water zone. This unequal aerial distribution of water seems to have been consciously implemented by the agency under the assumption that those who have fresh groundwater can pump groundwater and supplement their canal water supplies while those in saline groundwater area need more canal supplies to make their crop mature. However, this assumption has implications for sustainability of the system which will be discussed in a subsequent section.

Also the variation of wheat yield, wheat irrigation intensity, cropping intensity, surface water supply per unit irrigated area, groundwater depth, groundwater quality and groundwater level fluctuations from 1979 - 1994 as a function of distance along five major canals were studied and the results are summarized in Table 6. Two main observations can be made from this table:

1. In canals having fresh groundwater, mean wheat yield is high; percent wheat area is also high; surface water supply per unit area is low; wheat yield, percent wheat - area and canal supply remain constant along the channel length. Groundwater is about 10 m depth and is moderately falling over the years.

2. In canals having marginal and saline water, mean wheat yield and percent wheat irrigated area are low; surface water supply is high. Wheat yield and percent

wheat area decreases along the canal length while surface water supply remain constant or increases. Groundwater level is fast raising and in many places the groundwater depth is less than 3 meters.

A multiple regression of wheat yield as dependent variable against canal distance expressed as cumulative percent of cultivable command area (CCA), surface water supply per unit irrigated area, percent CCA with groundwater depth less than 3m, percent CCA with marginal and saline water quality and percent CCA with water table changes greater than 10m from 1979-1994 was carried out and the results are presented in Table 7.

The results indicate that wheat yield decreases significantly (99% probability level): with increase in distance along the canal length; with increase in the percent CCA with groundwater depth less than 3m; and with increase in the percent CCA with groundwater level increase greater than 10m. Variations of groundwater quality and water supply are not significantly related with wheat yield.

The above observations and results have certain bearings for the present canal operation practices and raises the following questions:

i. Why the canal supply in some of the canals increases along its length?

ii. What is the impact of this additional water to downstream reaches on wheat area and wheat yield of the canals?

When we discussed the aspect of increasing discharge along the canal length with canal operating managers, one of the probable reasons for this increase suggested by them is that after lining of many of these canals, water supply allowance originally stipulated (when the canals were unlined) were not changed over a period of time. As a result, water saved due to seepage reduction by lining is the additional water that reached downstream. This has not been redistributed among the distributaries/minors. Secondly, these are the areas which were supplied with more canal supplies per unit command.

One would expect that this additional water to the tail reach area would increase the wheat yield and wheat irrigated area; on the other hand, the multiple regression analysis and the results presented in Table 6 indicate that wheat yield in the tail reach area is low and the area irrigated with wheat is also low.. The water supply is based on Warabandhi principle which follows a rigid rotational cycle of fixed duration, frequency and priority level. When water is supplied at fairly long intervals (once in 15 days), our hypothesis is that most of the water supplied in a turn, in this area of highly permeable sandy loam, instead of meeting the crop water requirement percolates and reaches the underlying saline groundwater, rather than being retained and available in the root zone for crop growth. The inadequate rootzone soil moisture is likely to be a major factor for decrease in the wheat yield. The NDVI profile of low yield distributaries indicates consistently lower-than-normal values through the season suggesting` inadequate irrigation support. When the yield goes down, farmers are reluctant to raise a wheat crop; instead they go for oilseed crops which are less water consuming; this switching over to less water consuming crops allows more water to reach the saline groundwater and to build the groundwater table at a fast rate. While the irrigation agency provides more canal water to areas having saline groundwater in order to meet the crop water requirement, the supply of more water has not had the desired impact on wheat yield and wheat irrigated area, but has aggravated the water table build-up and potential waterlogging and soil salinization. When this aspect was discussed with the officials of Water Resources Department of the government of Haryana in a workshop, they did not come up with any other alternative reasons for the observed results; they have agreed to monitor these aspects more carefully in the coming seasons to confirm our hypothesis and to arrive at possible remedial measures.

Longterm Sustainability of Bhakra Irrigation System

From agricultural production point of view especially with respect to wheat productivity, the Bhakra system in Haryana is performing well compared to many other wheat growing systems in India. The performance parameters (Molden et al. 1997) for Rabi 1995-96 worked out based on wheat as the sole crop in the command area indicates that the gross value of output per unit irrigation supply works out to 20 US cents/m^3 which is three times the Mahi-kadana system's performance which is one of the best performing system in India[5], (Sakthivadivel 1996). One of the important questions raised in this connection is how sustainable in the long run is this high agricultural production system, given that in 49 percent of the freshwater area water table is falling steadily while it is rising in 68 percent of poor ground water area (Table 5). In nearly half the fresh groundwater area water table depth is already greater than 10 meters and is falling which will cause additional pumping costs impacting on farm income. The high irrigation and wheat intensity and low canal supplies and consequent ground water extraction in this area thus have longterm sustainability implications. In marginal and submarginal groundwater zone, the water table is rising in 68 % of area leading to potential water logging and secondary salinization. The critical areas of sub-marginal, marginal and saline groundwater within 3 meters of surface and generally rising in recent years are shown in Figure 7. The criticality is demonstrated by water table rising within 3 meters depth over about 100,000ha in the command area (most of Hissar I circle and parts of Sirsa and Hisar II circles) due to the heavy rainfall in the latter part of 1995 southwest monsoon.

The analysis of canal water supplies in Bhakra command revealed that agricultural performance was quite good for the rabi 1995-96 resulting in high productivity of wheat crop per unit of water consumed. However, in the sub-marginal and marginal saline groundwater areas, the combined effect of water distribution practices, canal seepage, water holding capacity of soils and irrigation methods used by farmers resulted in considerable percolation losses to the aquifer. The percolation losses together with canal

[5] This system was awarded to Government of India, Ministry of Water Resources price for the best performing system in 1993-94.

seepage and conveyance losses caused in major parts of Bhakra command a groundwater table rise more than 10m over a period of 15 years in the saline and marginal groundwater zones. The effective porosity in the aquifer system of the areas varies from 0.08 to 0.16 m^3m^{-3} (Bastiannssen et al 1996). So a change of 1m in water table depth is caused by a recharge of 80 to 160 mm. This means that on an average, about 60 to 100 mm of water is being added every year to the saline groundwater zones having porous soils. The impact of recharge by fresh canal water on the salt balance of the deep aquifer which is generally saline also needs to be studied. A recent study has shown that because of high ET in arid areas salt concentration in recharge water increases and adds to salt balance in already saline ground water which could have serious consequences in the context of rising water table (Sulaimi et al 1996).

Future water management strategies for Bhakra command should address the problem of rising water-table in the saline groundwater zones of the command and the problem of declining water table in the fresh ground water zones of the command. Although a lasting solution cannot be achieved without a drainage outlet to remove the salts imported with irrigation water (because of the closed nature of the saucer type basin), the question remains whether an improved water management strategy could delay the rise or fall of water-table in the endangered zones.

Therefore, alternate strategies should focus on reducing aquifer recharge and increasing groundwater use in the rising water-table areas , and increased recharge or restricted groundwater use in the areas of falling water table .

Increased groundwater use in areas with rising water-tables and poor groundwater quality is an issue which should be solved at the level of on-farm water management. Among the various components that contribute to aquifer recharge, reduction of canal seepage losses is one option to reduce the recharge to aquifer. The canal seepage losses were estimated to be 10% of the canal water-supply (Bastiannssen et al 1996). Further reduction of those losses of this heavily lined system will be very difficult to achieve. On the other hand, reduced irrigation application per unit area can be attempted through change of frequency of water application. Weekly rotation is adopted now among distributaries/minors under Warabandhi principle. The rotational period can be reduced to say 3.5 days and more number of turns can be introduced, with smaller depth of water application for each turn.

The rising water-table in more than 68 percent of the Bhakra command underlain by poor quality ground water forms a direct threat to the future of irrigated agriculture. Unless timely preventive and curative measures are taken, the good productive land of the command will be endangered by the present water distribution practices. The future of intensive agriculture and soil productivity will depend on selection and implementation of appropriate on-farm and irrigation system level management in the irrigated areas. Therefore, there is an urgent need to look at the issues raised in this report more carefully through detailed investigation by combining SRS and GIS techniques with hydrologic modeling, supported by selective and intensive data collection campaigns. Hydrologic modeling is an important tool to understand the transfer process of salt and water from surface to groundwater and the process of groundwater build-up. This has not been attempted in this investigation.

Conclusions

1. The present investigation has demonstrated the utility of SRS and GIS techniques to diagnose the problems associated with current and long-term sustainable irrigation performance of a wheat based irrigation system. The satellite inventory completed at a unit cost of about US 3 cents per ha. indicates the cost - effectiveness of this methodlogy to get data at disaggregated levels.

2. The present practice of allocating and distributing the surface water supplies under Warabandhi principle leads to current level of high productivity of water but the longterm sustainability seems to be under threat.

3. There is an urgent need by the irrigation agency to look at water management problems at farm, regional and system wide level in greater depth by combining SRS and GIS techniques with hydrologic modeling to suitably modify the present water allocation and distribution practices to sustain the system productivity and to maintain the system health.

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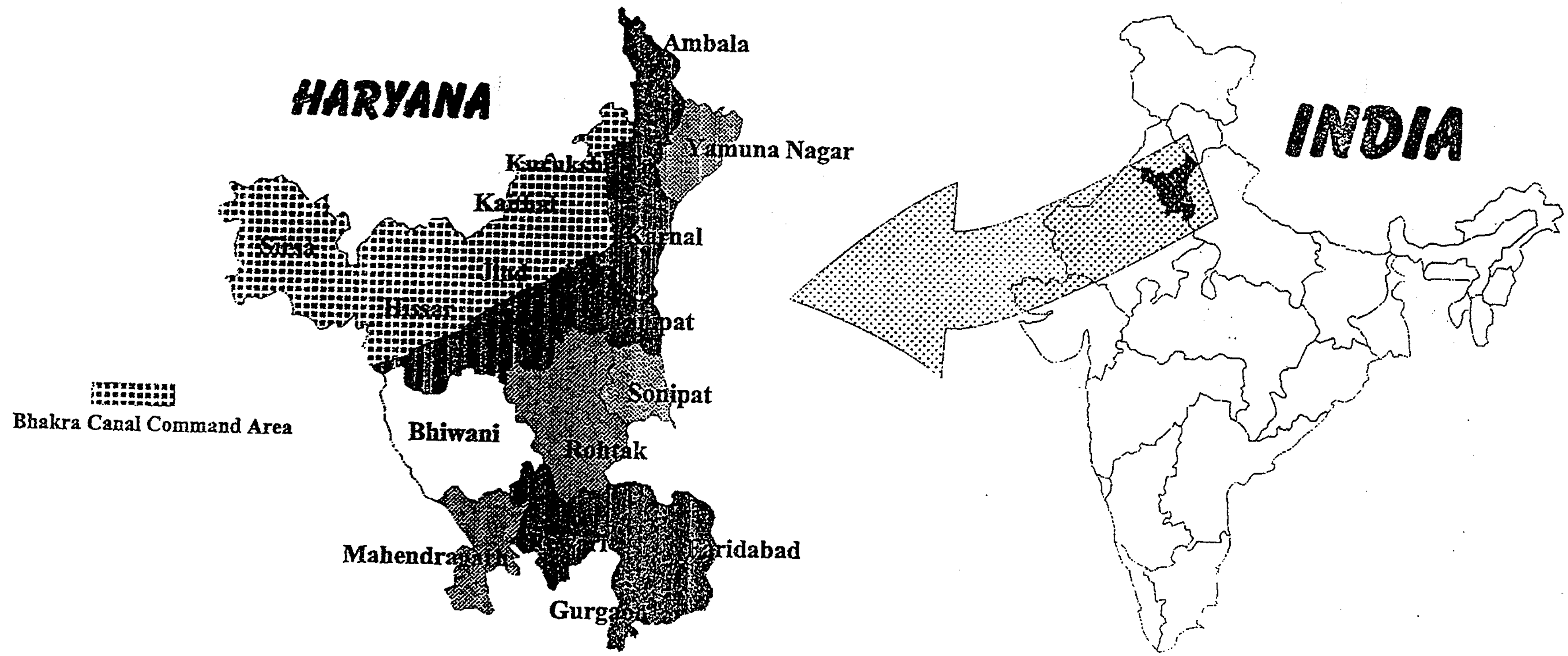

Figure 1 : Index Map

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MANAGEMENT INSTITUTE,
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Figure 2 : Flow Chart of Analysis Methodology

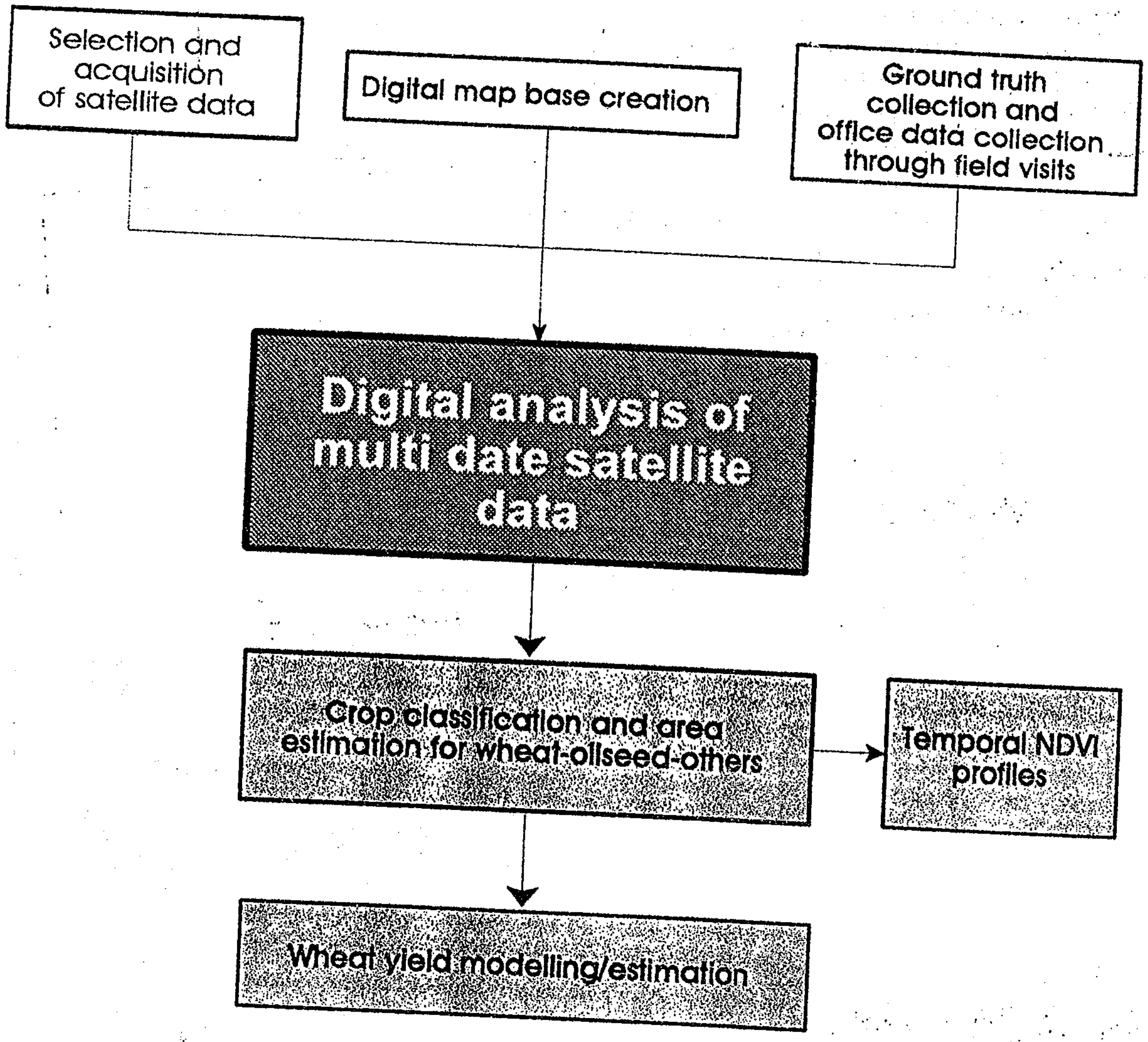
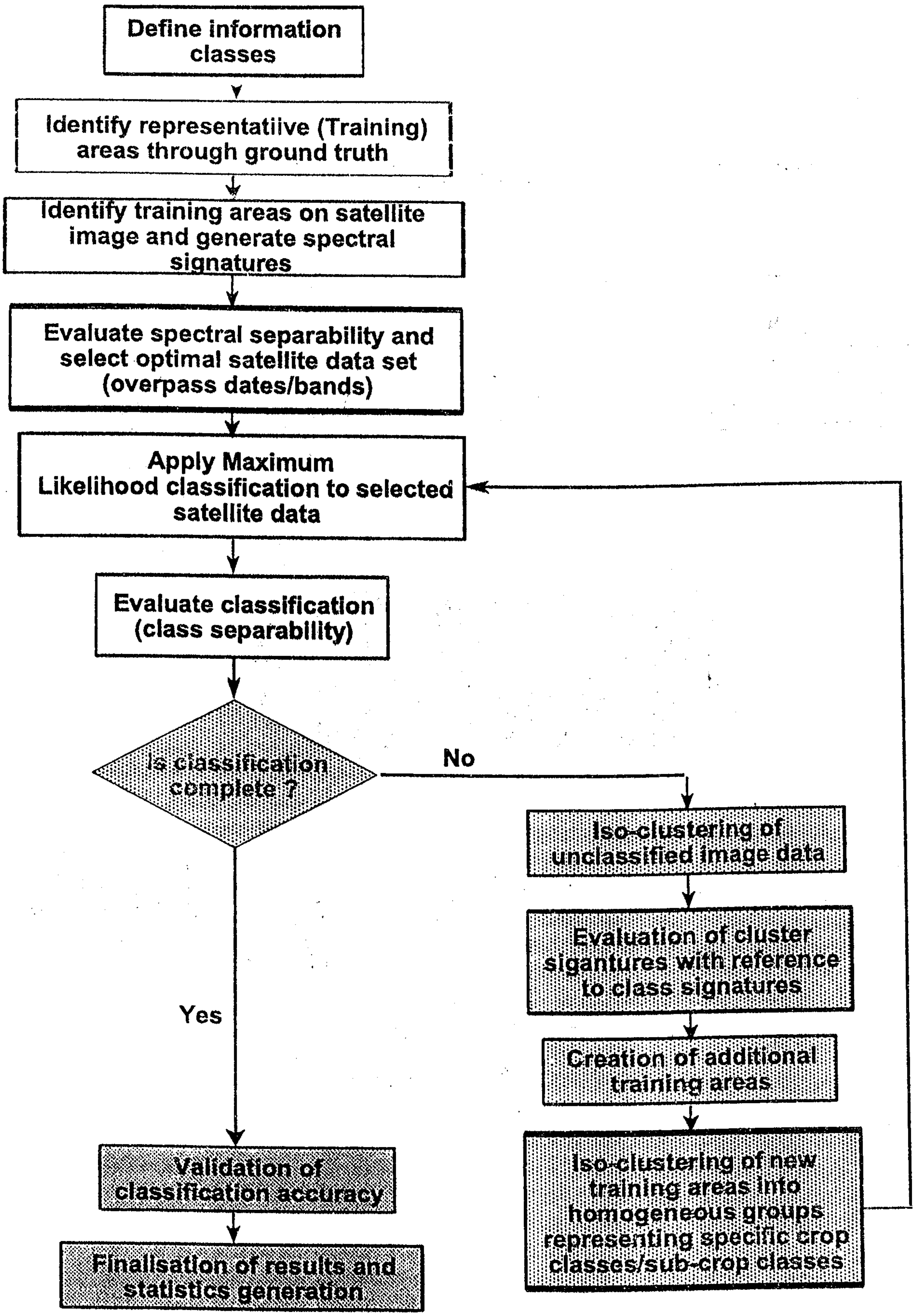


Figure 3 : Flow Chart of Classification Methodology



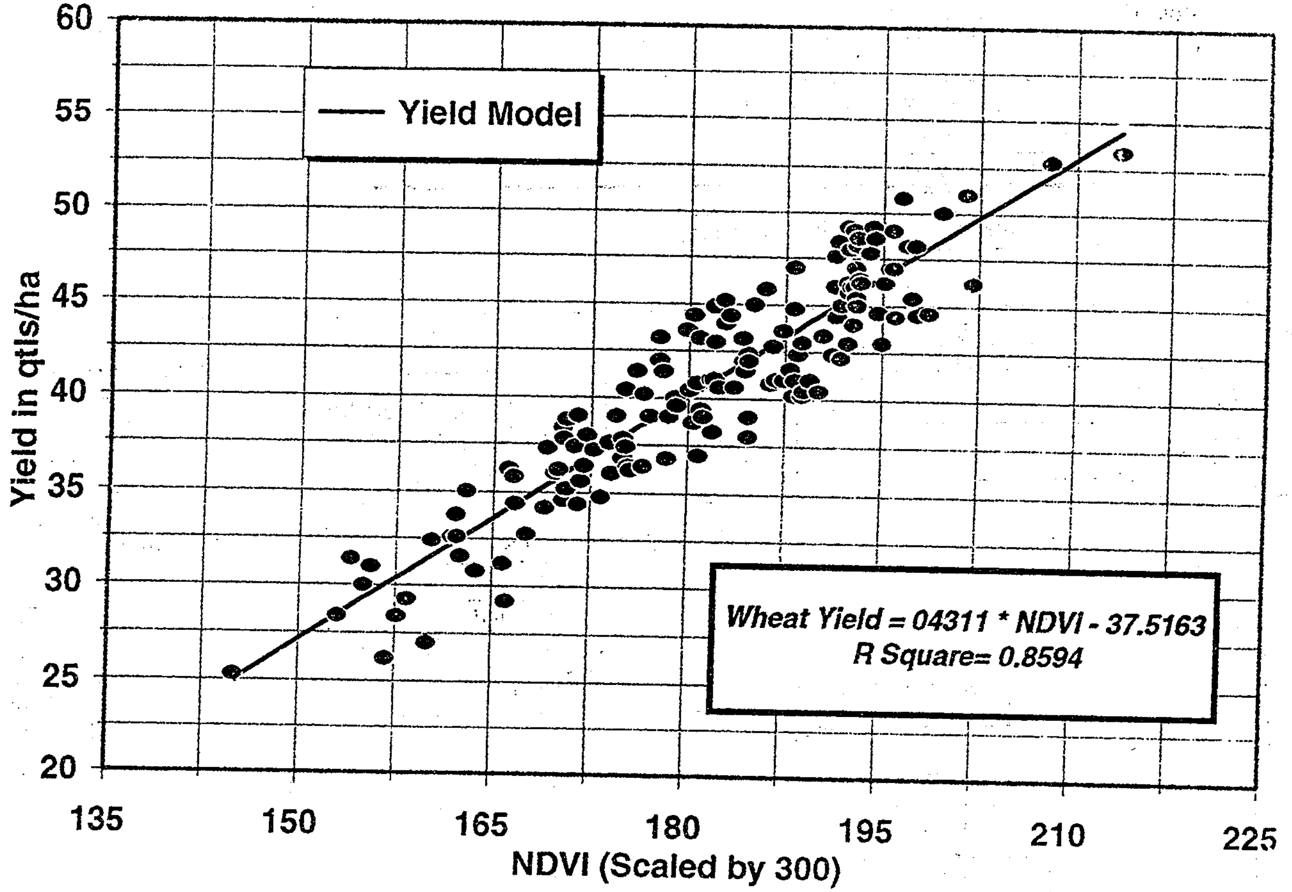
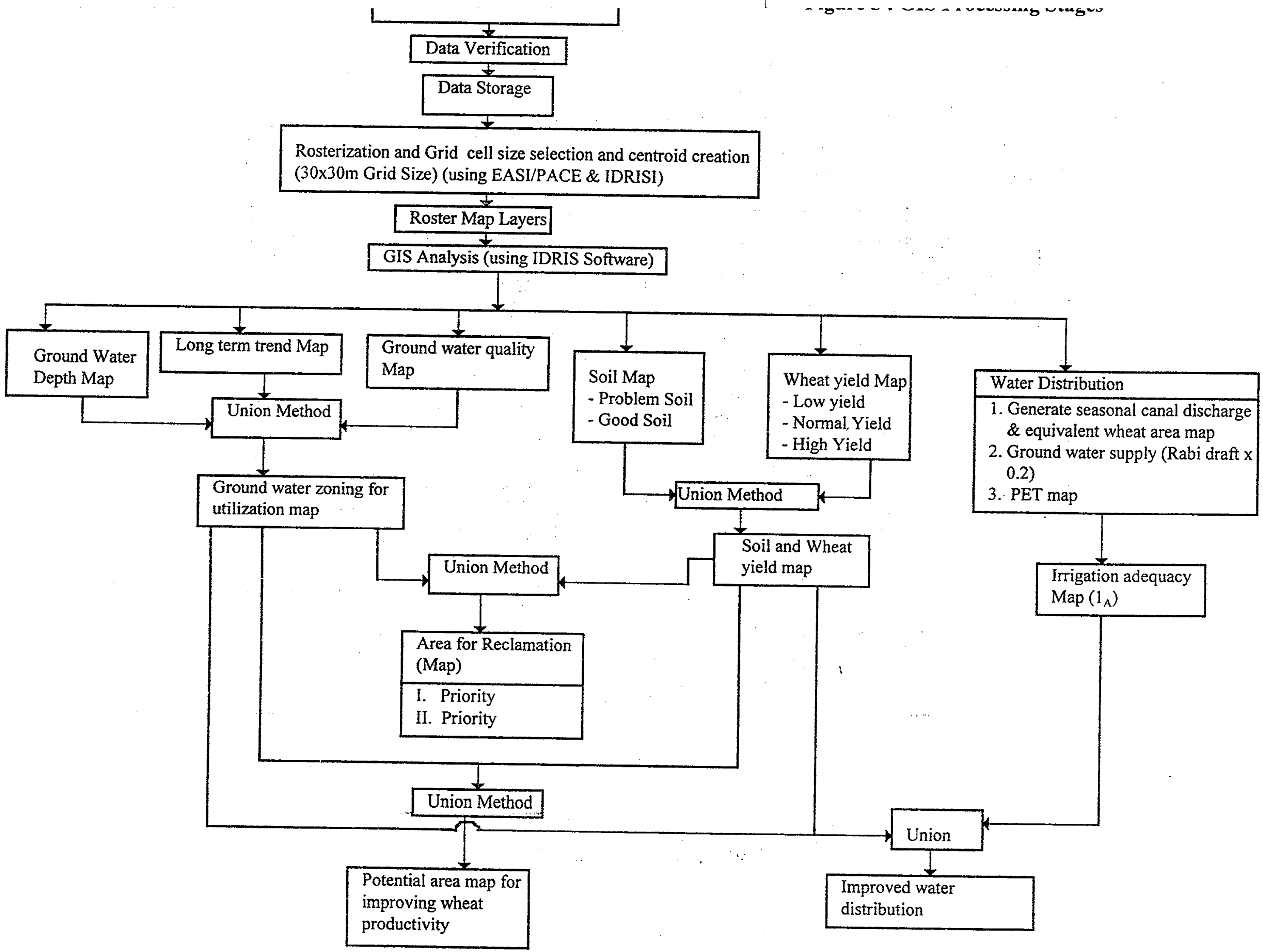
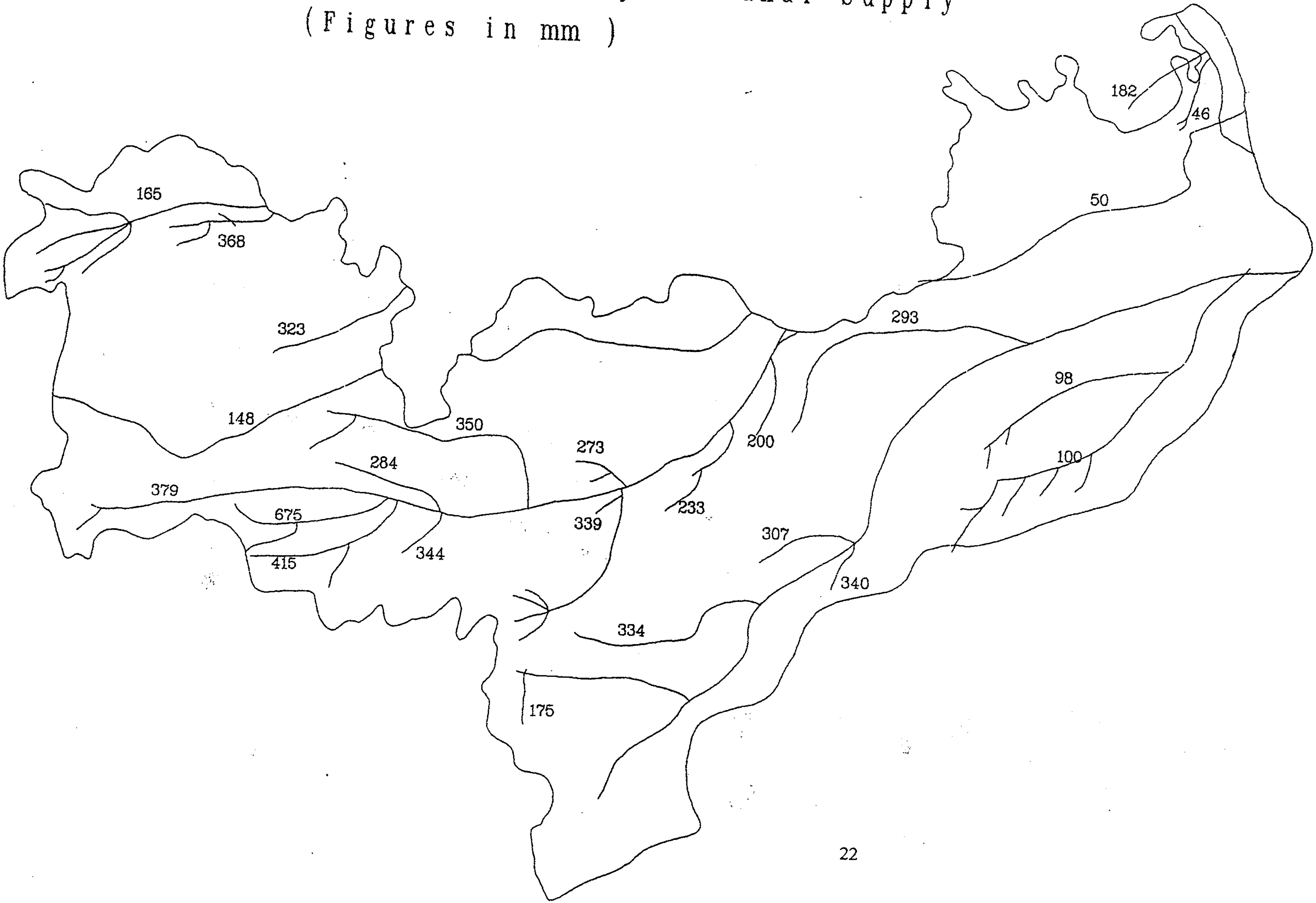


Figure 4 : NDVI - Wheat Yield Relationship



Data Verification
Data Storage
Rosterization and Grid cell size selection and centroid creation (30x30m Grid Size) (using EASI/PACE & IDRISI)
Roster Map Layers
GIS Analysis (using IDRIS Software)
Ground Water Depth Map
Long term trend Map
Ground water quality Map
Soil Map
- Problem Soil
- Good Soil
Wheat yield Map
- Low yield
- Normal Yield
- High Yield
Water Distribution
1. Generate seasonal canal discharge & equivalent wheat area map
2. Ground water supply (Rabi draft x 0.2)
3. PET map
Union Method
Ground water zoning for utilization map
Union Method
Soil and Wheat yield map
Irrigation adequacy Map (1_A)
Union Method
Area for Reclamation (Map)
I. Priority
II. Priority
Union Method
Union
Potential area map for improving wheat productivity
Improved water distribution

Figure 6: Spatial Variability of Canal Supply
(Figures in mm)



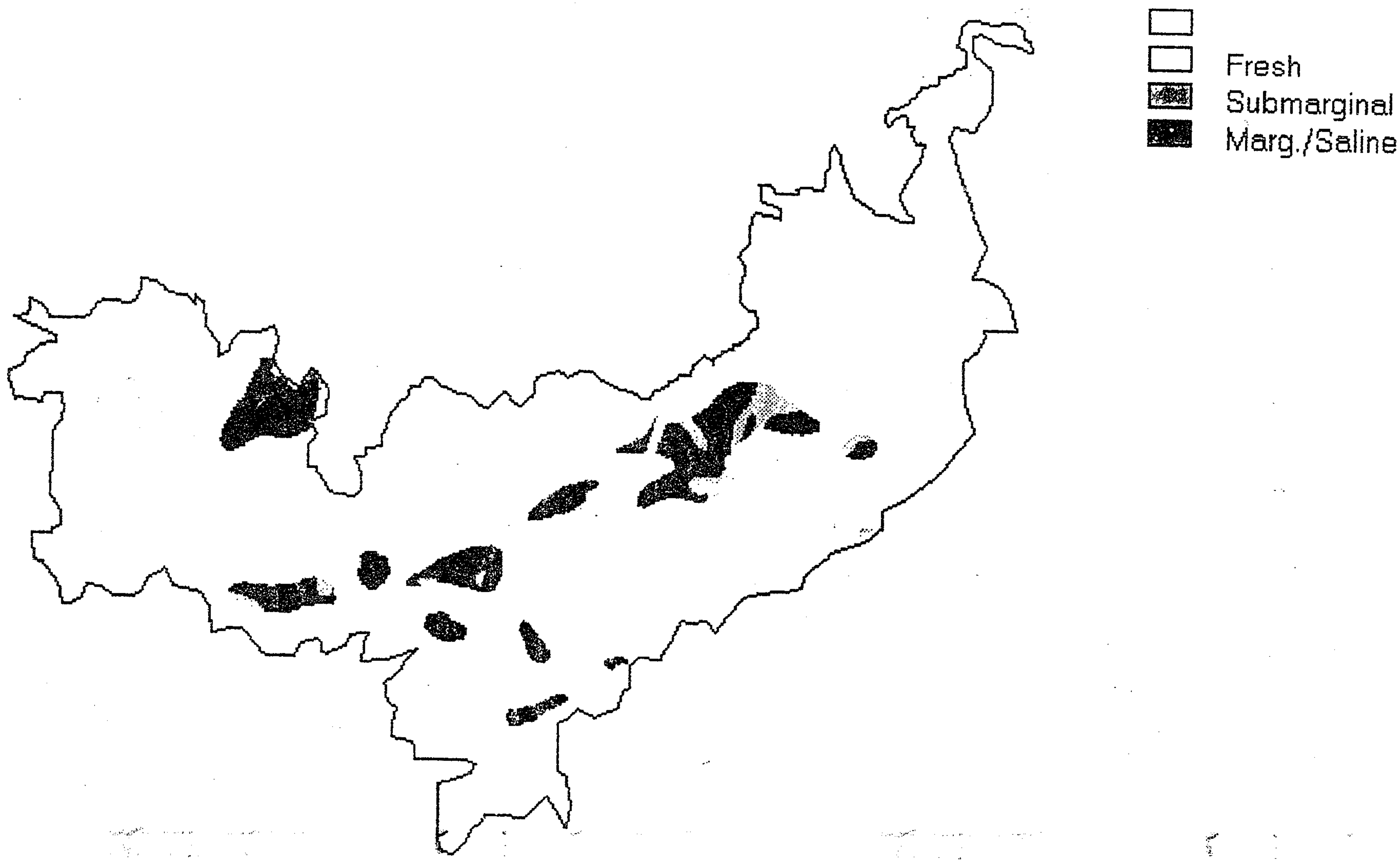

Fresh
Submarginal
Marg./Saline

Table 1 : Multidate Satellite Coverage During 1995-96 Rabi Season

Date of satellite overpass	Status of crops
21/22 Nov 1995	Beginning of rabi season - Oilseed crops already sown some early sown wheat.
04 Jan 1996*	Oilseeds and early sown wheat in growing stage.
26/27 Jan 1996	Oilseeds and other crops in peak greenness stage. Wheat in active vegetative phase.
17/18 Feb 1996	Wheat in peak greenness-other crops in flowering / senescence.
10/11 Mar 1996 **	Wheat in peak greeenness-other crops in senescence / harvested.
01/02 Apr 1996	Wheat in senescence-other crops harvested.

* 5 th Jan data not available.
** Cloudfree only over 40% of command area approximately.

Table 2 : Summary of Spaticial and Non-Spatial Data

Sl No	Source	Data	Type	Pixel Size	Map Scale	Remarks
1	NRSA	Crop type	raster	30 metres		Every pixel within the command classified into wheat, oil seeds, other crops or no crop.
2	NRSA	Wheat yield	raster	30 meters		Wheat yield in quintal/ha
3	NRSA	Soil	Vector		1:250,000	Saline, saline sodic and sodic classes, and of 3 severity levels and 3 areal concentrations derived from satellite data of 1986.
4	HSMITC/GWD	Ground water quality	Vector		1:500,000	Four quality classes (fresh, sub-marginal, marginal and saline) extracted from State map.
5	HSMITC/GWD	Ground water depth	Vector		1:500,000	Contours of depth to ground water in June 95, Oct. 95 and June 96 extracted from state map.
6	HSMITC/GWD	Long term ground water trend	Vector		1:500,000	Positive and negative changes in ground water depth during 1974 to 1995 extracted from State map.
7	IMD	Annual potential evapotranspiration (PET)	Vector		1:2.5 million	Annual PET contours in mm extracted form the state map.
8	IMD	Rainfall	Vector		1:2.5 million	Contours of rainfall during year, July-Sept., April-June and October extracted for command area from state map.
9	Irrigation Dept. of Govt. of Haryana	Canal network	Vector		1:50,000	Showing branch canals, distributaries and minors.
10	Irrigation Dept., of Govt. of Haryana	Distributary/minor command	Vector		1:50,000	Area commanded by distributary/minors.
11	Irrigation Dept. of Govt. of Haryana	Canal discharge	Non-spatial data			Rabi season discharge measured selectively at distributary offtakes
12	NRSA	Crop related statistics	non spatial data			Crop area, area under wheat, oilseeds, other crops, wheat yield.

Table 3: Overview of Irrigated Area Statistics Across the Command Area

Sr No	Circle	GCA in ha	CCA		Crop Area					Irrigation intensity %	Wheat Yield t/ha	Wheat Production (tons)
			in ha	% of GCA	Wheat ha	% Crop area	Oil seed ha	Others ha	Total ha			
1	Ambala	94,236	85,680	91	61,903	80	10,055	5323	77280	90	4.10	254,077
2	Kaithal	381,485	343,262	90	271,156	86	37,412	7549	316177	92	4.36	1,181,393
3	Hisar 1	294,650	244,217	83	94,368	54	59,398	20613	174379	71	3.73	351,668
4	Hisar 2	254,614	206,257	81	155,824	75	33,868	17030	206722	100	4.20	653,967
5	Sirsa	482,875	385,798	80	163,309	58	86,438	31593	281340	73	3.76	613,630
	Total	1,507,860	1,265,215	84	746,560	71	227,172	82107	1,055,838	83	4.09	3,054,735

Table 4 : Distributaries/Minors of Poor Wheat Productivity

Sl. No.	Circle	Division	Distributaries/Minors
1.	Ambala	Ambala Kurukshetra	Panjokra minor and Dangheri, Garnala,Tandla subminor Nil
2.	Kaithal	Kaithal Pundri Narwana	Nil Badhana minor and 2R Badhana minor 1R Badhana minor, Songri minor. Bithmara minor, Tail branch Sudhkan 1L, 2L,3L and 4L Barsola minor, 1-R Barsola minor, Surban distributary.
3.	Hisar-1	Adampur Hisar-1	Jagan sub-minor, Dabra minor, Gorchi sub-minor, New Sarsana sub-minor, Basra sub-minor[1], Dhansu minor, Dhansu sub-minor, Gaushala minor. Deosar feeder, Chirod minor, Chandarywas minor, Daha sub-minor, Gawar minor, Garanpura minor, Haritha minor, Nalauli minor and Nalauli sub-minor, Shikarpur minor and Talwandi minor, Siwani minor.
4.	Hisar-2	Tohana Fatehabad	Nil Manawali minor, Old Mochiwala minor, Ding minor, Kheri distributary. Bhattu minor, Khabra minor, Dhabi minor, Chuli minor, Jogiwala minor.
5.	Sirsa	Sirsa Rori Neharana Gaggar	Kishangarh minor, Nathour minor, Phaggu distributary. Jandwala sub-minor. Kutiyana distributary, Jamal minor. Baruwali sub-minor, Salapur sub-minor, Kishanpura minor.

Note: Distributaries/minors having less than 90 percent of divisional average wheat yield are considered poor performance.

Ground Water Quality	Percentage of rabi irrigated area 1	Percentage of wheat area 2	Percentage of what area with yield < 4t/ha 3	Percentage command area with low Q/A 4	Percentage of area with falling ground water trend 5	Percentage area with groundwater depth > 10 6
Fresh	37	49	33	70	49	51
Sub-marginal	42	38	48	19	12	45
Marginal/Saline	21	17	43	9	10	47
Total command area			43	35	25	48

Note : low Q/A = less than 150 mm canal supply per unit command area.

Column 1 = Percentage based on total irrigated area
Columns 2 to 6 = Percentage based on irrigated area under each ground water category

Branch	Wheat Yield		Wheat Intensity		Cropping Intensity		Surface Supply		Predominant GW Depth	G.W. Quality	G.W. Level Fluctuation
	Mean	Variation	Mean	Variation	Mean	Variation	Mean	Variation			
Narwana	41.3	Constant	75	Constant	93	Increase	69	Constant	3-10 m 10-20 m	Fresh	Moderate falling
Sirsa	41.9	Decreases	71	Constant	88	Constant	150	Increases	3-10 m < 3 m	Fresh/ sub-marg.	Moderate raising
Barwala	37.8	Slight decrease	43	Steep decrease	65	Decrease	157	Decrease	3-10 m < 3 m	Marg./Saline	Moderate raising
Fatehabad	38.7	Steep decrease	54	Steep decrease	90	Decreases	207	Constant	3-10 m < 3 m	Marg./Saline	Fast raising
Bhakra Main	39.30	Steep decrease	62	Steep decrease	87	Decrease	193	Increase	10-20 m 3-10 m < 3 m	Marg./Saline	Fast raising

Table 7 : Multiple Regression Analysis

Varaibles :

WHYLD	=	Wheat yield (quantals/ha)
CPCCA	=	Cumulative percent of CCA (%)
SWMM	=	Surface water supply (mm)
GWDL3	=	Percent of CCA with ground water, water depth < 3m (%)
GWQS	=	Percent of CCA with saline water quality (%)
WTCG10	=	Percent of CCA with water table change > 10m (%)

Multiple Regression Results :

Explanatory Variables	Dependent Variable : Wheat Yield	
	Coefficient	T-Value
Constant	42.9105	4397[a]
CPCCA	-0.0853	-8.63[a]
GWDL3	-0.0419	-3.28[a]
WTCG10	-0.0308	-4.24[a]
GWQS	-0.0129	-0.83
SWMM	0.0005	0.94
R^2		0.69

a : Significant at 5% Confidence Level.