ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Satellite based irrigation performance monitoring : case study over upper Tapi irrigation command, India

A. T. JEYASEELAN, A. V. SURESH BABU, M. SHANKER, K. CHANDRASEKAR
Water Resources Group , National Remote Sensing Agency, Department of Space, Government of India, Balanagar, Hyderabad -500 037, India

Abstract
Remote sensing technology is increasingly being applied in various water resources development and management activities. In irrigation water management, remote sensing is used as a tool for both performance evaluation of already developed schemes or the schemes under development for monitoring through the season. The current capabilities of satellite data with improved spatial resolution and high repetitive coverage can regularly provide objective information on the irrigation status from main and branch canal to distributaries, minors and field channels. The Centrally sponsored Command Area Development (CAD) programme was initiated in 1974-75 with the objective of bridging the gap between creation and utilisation of irrigation potential and optimising the productivity and production. In order to make quick evaluation on the implementation of the CAD programme, Ministry of Water Resources, Govt of India has selected 14 irrigation commands on a pilot basis using satellite remote sensing technique. Upper Tapi irrigation command is one of the 14 irrigation commands selected.

The satellite based irrigation performance monitoring is carried out over Upper Tapi irrigation command using Indian Remote Sensing Satellite(IRS LISS II &III with 36 m and 23 m spatial resolution) data of 1997-98,1990-91 and 1988-89. Crop wise area for each of the distributaries and minors was estimated using hierarchical classification procedure using multi spectral data. The normalised difference vegetation index (NDVI) derived from satellite data was related for crop condition assessment and to develop crop yield model by using crop yield observed at crop cutting experiment sites identified through Global Positioning System (GPS) survey. Using the crop yield model and the NDVI, the cropwise condition was assessed for years between 1988-89, 1990-91 and 1997-98 to monitor irrigation performance of Upper Tapi command along with cropwise area variations. The results of the study indicated changes in the cropping pattern wherever command is developed and all around improvement in terms of crop area, productivity and well irrigated area, better communication network and economic growth within the command.

INTRODUCTION

Performance monitoring requires quantitative and repetitive analysis of regular irrigation management process to reach the targeted maximum utilization potentials of irrigation from the designed canal network and for better crop productivity. Knowledge of the performance indicators within and among irrigation schemes can help policy makers and managers to wisely allocate funds for interventions and rehabilitation. Among the performance indicators, irrigation intensity, productivity, yield per water supplied are the major indicators in addition to soil salinity and water logging. The advantage of using remote sensing determinants is that they are based on standard international diagnostic techniques which provides realistic information. The time series measurements obtained from repetitive satellite images can be used for performance evaluation between different years. The current capability of satellite data due to improved spatial resolution and availability of gallery of computing and analysis capabilities, the cost and time effective and accurate evaluation of irrigation performance is possible at disaggregated level within a command.

The Centrally Sponsored Command Area Development programme was initiated in 1974-75 with the objective of bridging the gap between the creation and utilisation of irrigation potential and for optimising the productivity and production. The programme mainly involves on farm developmental works like construction of field channels and field drains, levelling and shaping and conjunctive use of surface and ground water. The programme has now been in operation for more than two decades. The conventional evaluation studies indicated due to inadequate and poor maintenance of data, there was difficulty in assessing the impact of CAD programme. In order to make quick and realistic evaluation of CAD programmes , Ministry of Water resources , Govt. of India has selected 14 irrigation commands on a pilot basis using satellite remote sensing techniques by National Remote Sensing Agency. In this article, the methods followed and the results from satellite based evaluation of Upper Tapi irrigation command is presented.

Satellite use for Irrigation Performance

Irrigation is the largest consumer of water withdrawals in India . As water scarcity becomes more acute , better irrigation management is required to achieve greater efficiency. But we lack accurate information on the conditions of irrigation systems, making performance hard to quantify(Molden 1997). And as a result water management are carried out based on qualitative and subjective information. Moreover, field data can become outdated because changes in land and water management occurs frequently. Consequently, remote sensing data from space, which can regularly provide objective information on the agricultural and hydrological conditions of large irrigated areas as well as small ones. Spectral radiance measured by satellite do not directly indicate the irrigation condition at the ground. Between satellite spectral radiance and irrigation performance evaluation to several levels of interpretation that must be made. Vegetation indices are better related with biophysical parameters of crop, crop productivity estimated using vegetation indices is used as another important parameter for performance evaluation.

Many studies have been carried out to estimate irrigated area using satellite technique. Visser(1989),Vidal and Barqi (1995) has used supervised classification procedures and found that it performed better than the principal component analysis or simple infrared and red ratio methods. Van Dijk and Wijdeveld (1996) used four images covering a complete annual cycle to discriminate irrigated agriculture from rainfed agriculture in the Tihama basin in Yemen. Azzali and Menanti(1996) used temporal variation in NDVI to distinguish irrigated from non irrigated agriculture. The crop type discrimination are generally carried out by using supervised classification procedure with extensive ground data support. Gang and Howarth(1992), Curran(1987), Vidal et al (1996) used SPOT images to identify major land cover classes. Thiruvengadachari et al (1997) used multi date IRS data to classify wheat, oilseed , or other crops in Bhakra command by combining supervised and un supervised procedures. Jeyaseelan et al (1998) used biweekly normalised difference vegetation index data from NOAA AVHRR data and identified wheat and oil-seed based on the duration of the NDVI response for each crop. Further many studies have been reported within India and other countries by using both optical and microwave data for crop classification Ahmed et al (1996), Janssen and Molenaar(1995). The accuracy of crop type classification reported so far (Bastianssen,1998) indicated an average accuracy of 86% if extensive field data support the classification procedure. Because productivity is the focal point for evaluation of irrigation management , periodic monitoring of command areas using satellite data has helped in evaluating the performance of major irrigation systems leading to initiation of corrective measures. Inadequate irrigation due to improper distribution of water and salinity and water logging due to excess irrigation which affects the productivity from year to year. Biophysical crop parameters like fractional vegetation cover , leaf area index and photo synthetic active radiation play a major role in the description of vegetation development, crop yield and crop Evapotranspiration. Most of these bio physical parameters are important for irrigation management as they reflect water and production issues.

The present study is focussed on the estimation of the total irrigated area, area under major crops/crop groups and to assess the condition of major crops/crop groups at disaggregated level during the three selected rabi seasons in the recent decade. Identification of poorly performing canals/distributaries through various performance indicators such as irrigation intensity, percentage area under different crops and major crop condition/productivity was studied. In addition to this relationship is established between satellite derived vegetation index and major crop yield to estimate the crop productivity at disaggregated level for the above mentioned rabi seasons.

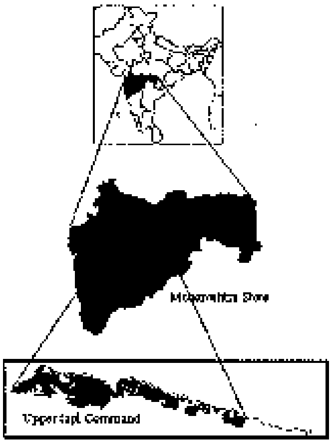

Figure 1. Location of the study area.

STUDY AREA

The location of the study area (Figure.1) of Upper Tapi irrigation command lies between the latitudes 21^o 05' and 21^o 10' North and longitudes 75^o 5' and 75^o 55' East falling in Jalgaon district of Maharashtra State in India. The command is being developed along the river Tapi which is downstream of Hatnur reservoir project. The Hatnur reservoir project was constructed just 8 km after the major tributary Purna has its confluence with Tapi in Jalgaon district. Out of the total catchment area of 62395 sq.kms, 49595 sq.kms falls in Maharashtra State which is 79.7% of the total catchment area of the Tapi river. A canal on the right bank from Hatnur head works site starts and was run for a length of 96 km upto Aner to obtain a gross command of 70592 ha. But currently, the project has a Gross Command Area(GCA) of 59,124 ha, Culturable Command Area(CCA) of 50,450 ha (85 percent) and designed to irrigate i.e. ultimate irrigation potential or Irrigable Command Area (ICA) 37,838 ha (64 percent) which include 14,740 ha (39 percent) by lift irrigation and 23,098 ha (61 percent) by flow irrigation. The proposed irrigation intensity (ie ICA over total cropped area) is 68 percent and cropping intensity (ie total cropped area over ICA) is 146 percent.

The proposed typical cropping pattern and crop calendar in Upper Tapi command indicates that the crops are grown in all the three season. The Kharif season starts in June and goes till October and the major crops grown in terms of per cent of CCA are groundnut(20%), pulses(30%), jowar(20%) and green manure (12%). The rabi season starts by mid of October and goes upto end of February and the major crops in the rabi season are jowar(19%), wheat(10%) and green peas(1%). The hot weather starts by end of January and goes till mid of may and the major crops in hot weather are groundnut(10%) and peas(1%). In addition the perennials like sugarcane (6%) which starts in January or June or October and stands for 15 months. The other perennial is banana (6%) which starts in June or October and stands for 14 months. Further the two seasonal crops such as cotton (4%) starts in June or July and goes till end of February. The land in the Upper Tapi river track is comparatively plain and lies in the rainfall zone of 762 mm to 1260mm.

SATELLITE DATA USE

Satellite data for the study year of 1997-98 was obtained from IRS-1D LISS III data of 23 m spatial resolution in December, February and March period. The satellite data for the historic year of 1988-89 and 1990-91 was obtained from IRS 1A LISS II data of 36 m spatial re4solution during the similar period of December, February and March. To differentiate hot weather crop and perennial crop additional satellite data during May also was obtained.

METHODOLOGY

The general methodology followed for irrigation performance evaluation of Upper Tapi irrigation command is given in Figure.2. Initially the current year satellite data corresponding to rabi season starting from November 1997 to March 1998 from three overpass dates in December, February and March from IRS-1D LISS-III was taken up for analysis. The satellite data analysis can be grouped into (i) preliminary analysis covering geometric rectification, radiometric calibration and NDVI generation (ii) crop classification analysis and (iii) yield modelling. The methodology finalised in the study year analysis of crop classification and yield modelling are validated with the ground truth information collected during the field visit. Same methodology was adopted for analysing 1990-91 and 1988-89 satellite data for further performance evaluation .

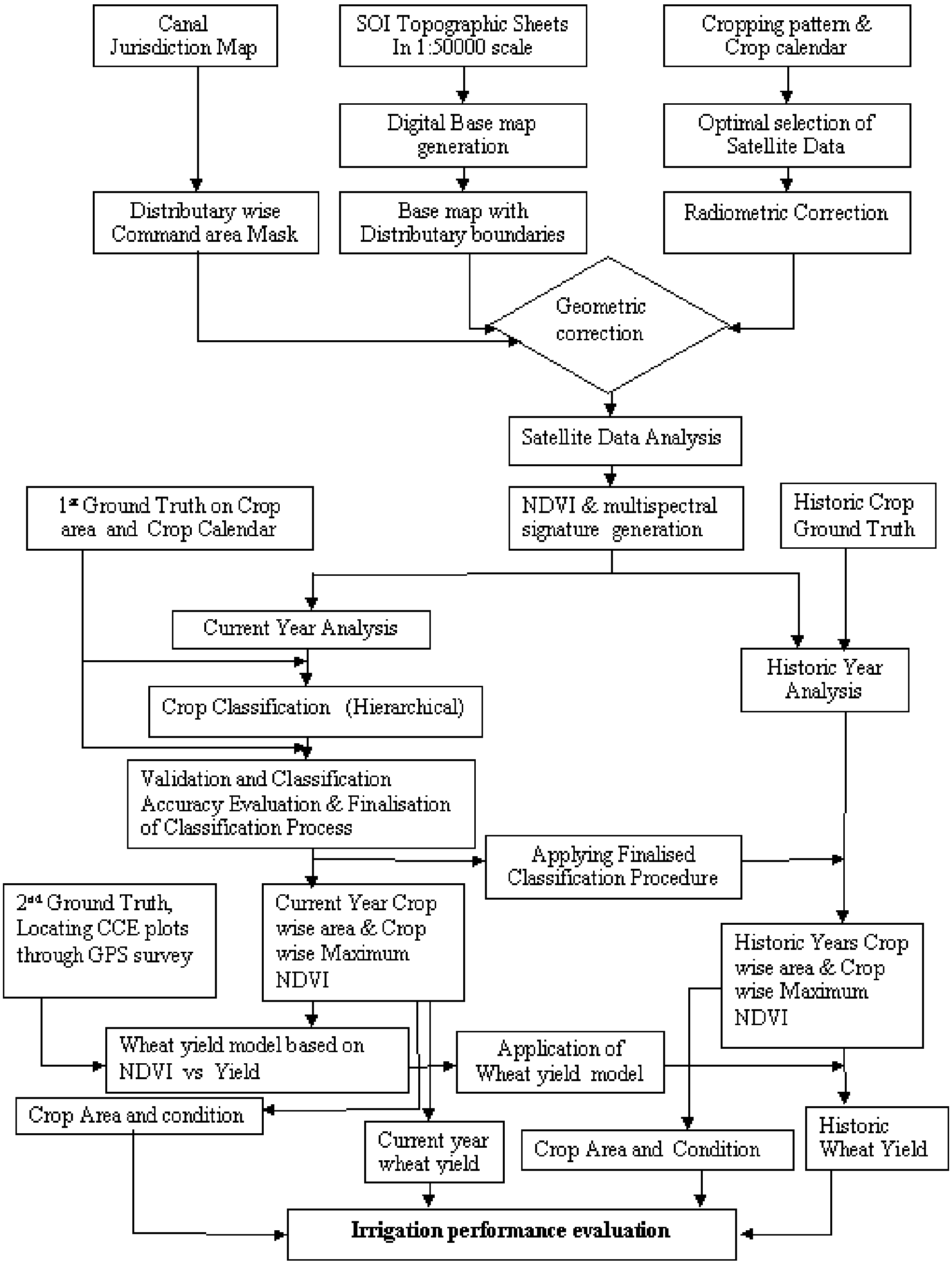

Figure 2. Flowchart on the methodology on performance evaluation.

Satellite data Analysis

The Survey of India topographic maps on 1:50,000 scale covering Upper Tapi command area are collected and a digital base map with polyconic projection is created with 30 m. by 30 m. pixel resolution. The command area features like main canal, branch canals/

distributaries and other canals and overall command boundary are digitised using topographic maps and command area index maps supplied by the Upper Tapi Irrigation Division office. The un-command portions are delineated and an area mask for the entire command was made so that satellite data analysis will be carried out within the command mask.

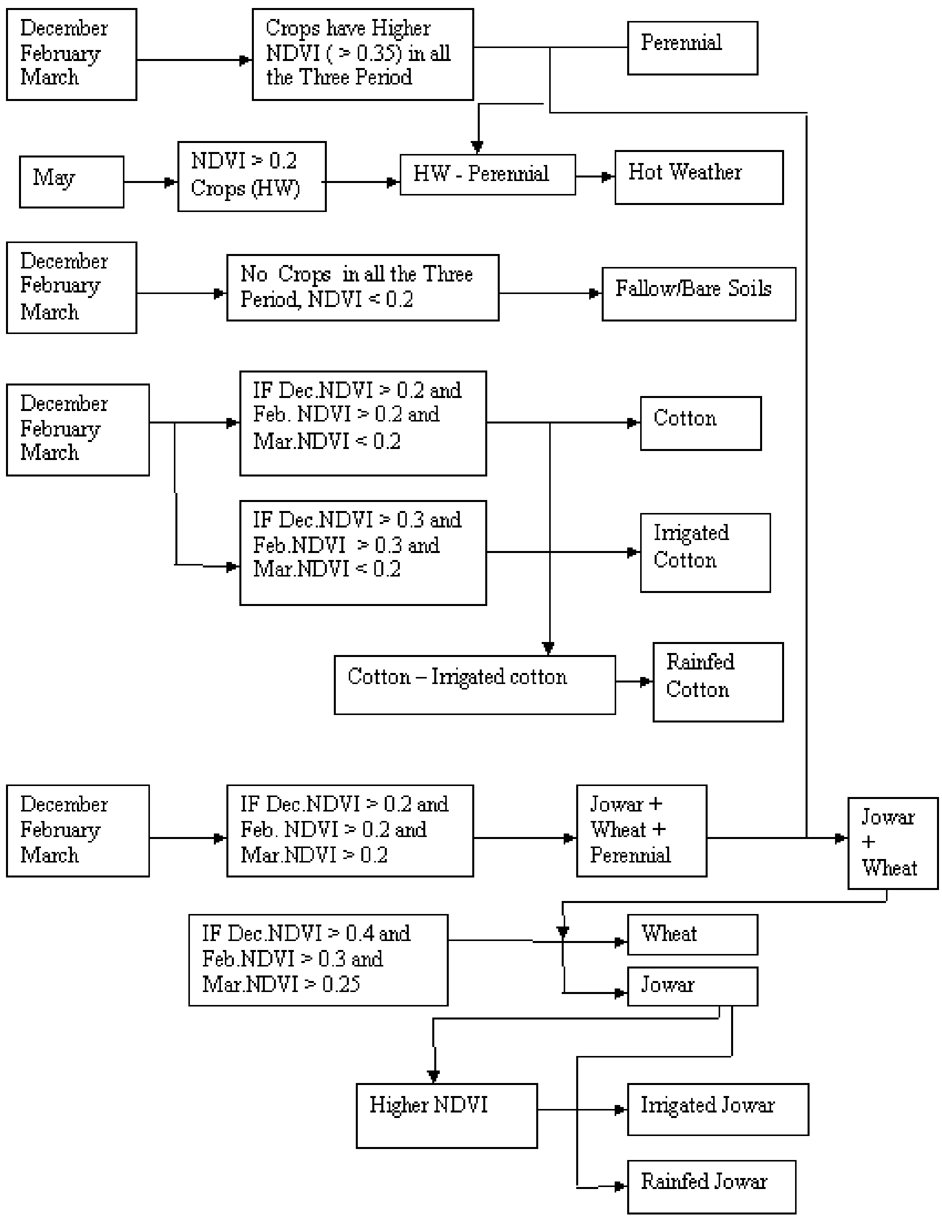

Figure 3. Flowchart on hierarchical crop classification.

All the three satellite data selected for the current study year, 1997-98 from IRS-1D LISS- III sensor and all the satellite data selected for the years 1990-91 and 1988-89 from IRS -1A LISS II A/B data are converted into radiance using the corresponding pre launch calibration coefficients provide by NRSA data centre to convert satellite digital data into radiance. Pixel-wise NDVI image was computed from each of the radiometrically calibrated satellite data of December, February and March was used using the following relation and scaled with the gain of 200, so that crop response on NDVI is enhanced to arrive at scaled NDVI (SNDVI).

SNDVI= 201-200* (Band 4- Band 3)/(Band 4+ Band 3)

Analysis for Crop classification

Training sites identified during the field visits were transferred onto the geometrically rectified satellite data with help of base map. In the first stage, individual data of December, February and March was used and spectral signatures were generated for each of the crop and other land use classes by using 3 spectral bands viz. Green, red and infrared wavelengths and NDVI. The signature statistics were then examined for separability amongst the various crop groups and found that except for perennial crop, poor separability between the rabi crops is noticed. Then keeping the crop calendar in view and the crop wise NDVI signature extracted at different satellite over pass period, a hierarchical classification scheme was worked out. The crop area statistics obtained based on hierarchical classification scheme was compared with ground information. The hierarchical classification model was finalised based on better accuracy with ground reports on crop area. The procedure followed in the hierachial crop classification of satellite data of all the three years is given in Figure.3.

Analysis of yield modelling and condition assessment

Based on the ground truth information on crop area, it was found that Wheat is the main cereal crop irrigated by canal during the rabi season in the command and hence crop condition assessment for wheat through Crop Cutting Experiment information supplied by CADA is attempted. During the second field visit, the location of survey number of the plot where crop cutting experiments were conducted was visited and observed the geographic coordinates i.e. latitudes and longitudes through GPS Survey. However due to scattered nature of the wheat crop area in the command, with less than a hectare area in most of the locations instead of 5 x 5 or 7 x 7 pixels average NDVI directly obtained from CCE plot location is considered. There was about 30 CCE plots for 1997-98 covering both well irrigated and canal irrigated wheat area through random sampling technique covering the entire command. However due to practical difficulties in taking GPS survey and redundancy in the yield, only a total of 27 CCE plots are selected for model development. The wheat yield corresponding to each CCE plot and the corresponding pixel=s maximum NDVI obtained between December through March is related. The linear relationship obtained between CCE plots NDVI and yield for the year 1997-98 was applied to all wheat pixels within the command to estimate wheat productivity. The same relationship is extended to other historic years of 1990-91 and 1988-89.

Performance evaluation

The performance evaluation of Upper Tapi command is made by extracting distributary/minor wise cropped area for 1997-98, 1990-91 and 1988-89. The comparison of crop area changes between the years is considered as one of the parameters of performance. The crop productivity is estimated for wheat area for the current year and historic years. The comparison of productivity changes over the years is considered as another performance indicator. In case of other crops satellite derived maximum NDVI comparison was made between the study year and the historic years to assess the changes in the crop condition. Further, the poorly performing distributary/minor through various performance indicators such as irrigation intensity, percentage area under different crops and crop condition and productivity were identified.

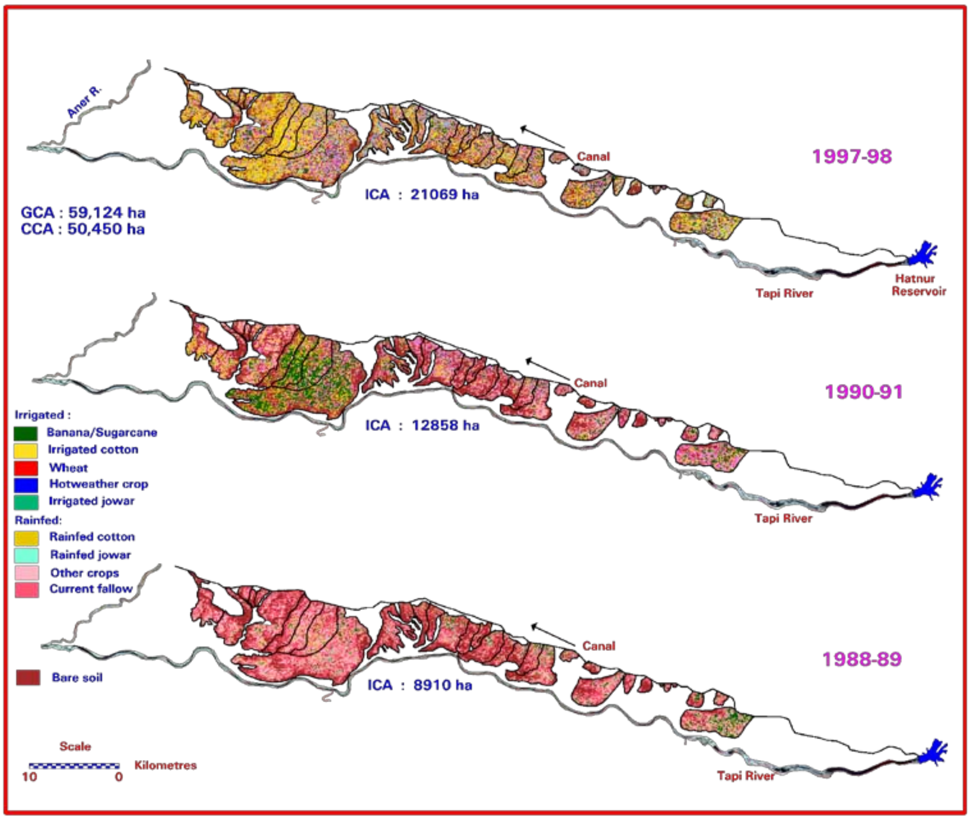

Figure 4. Spatial cropping pattern (Rabi crops) in upper Tapi irrigation command.

RESULTS AND DISCUSSION

Using the multi-temporal NDVI data the cropwise classification was made for the study year. The crop area statistics at distributary/minor level and at the command area level is extracted and compared with the crop area statistics supplied by project authority and also with the ground truth information obtained during field visit. The comparison of cropwise area statistics obtained from 1997-98 satellite data analysis and from project authorities (Table 1) confirm the validation of hierarchical classification.

Table 1. Comparison of Satellite and Ground Based Crop Area for 1997-98.

Crop	Crop area supplied by project authorities (Ha)	Crop area estimated from satellite analysis(Ha)
Perennial	2142	1978
Cotton	6678	6484
Irrigated cotton	2641	3650
Jowar	3907	4830
Irrigated Jowar	474	451
Wheat	678	531

Crop Classification Analysis

The procedure followed in 1997-98 hierarchical crop classification model is adopted for 1990-91 and 1988-89 data. In 1990-91 February data and in cloud, the cloud affected area in February is very thin and transparent, separate lower threshold in hierarchical classification is applied. In March data, the clouded area is thick, the clouded area is re-placed by February satellite data. Hence in those cloud affected area, crop wise area over the few distributaries, the crop classification and condition assessment needs continuos evaluation. The crop wise area classified from satellite data of three years of 1997-98,1990-91 and 1988-89 is given in Figure.4. The distributary wise cropped area for three years indicates that the total cropped area estimated in 1997-98 is 20,816 ha, in 1990-91 is 14,272 ha and in 1988-89 the total cropped area is 8705 ha. Among the crop wise area , the cotton area was more in 1997-98. In 1988-89, and in 1990-91 in spite of less area are reported under irrigation, more crop area was seen from the satellite data and most of the crops are of rainfed nature.

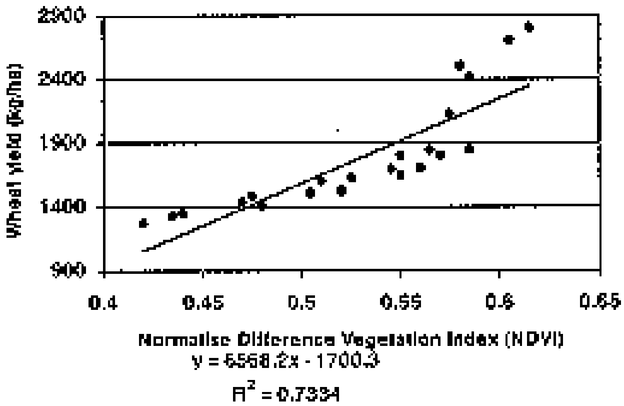

Figure 5. Graph showing the relationship between Wheat yield and NDVI.

Crop Condition Assessment and Yield Modelling

The scatter plot of CCE plots yield versus NDVI indicates linear relations between them (Figure 5). The linear regression model obtained between wheat crop yield and NDVI is as follows:

Wheat yield in kg/ha= 6568.2*NDVI-1700.3 with regression coefficient is (r^2) 0.7334 . By using the NDVI yield model for wheat crop , the pixel wise yield over wheat area was computed for 1997-98. Similarly, by using the same model, the pixel wise crop yield was computed. Since there is negligible wheat crop is observed in 1988-89, the wheat yield for 1988-89 was not computed over wheat crop classified area in 1990-91. The distributary / minor wise average yield for 1997-98 and 1990-91 was estimated and compared. Though the distributary wise weighted area average wheat productivity estimated from satellite data by using CCE plots information in 1997-98 is 18.54 quintals/hectare, where as the CCE plots average productivity reported by the project authority is 14.72 quintals/hectare. This indicate the CCE plots selected through random sampling does not reflect the average conditions of productivity in the command.

In 1990-91 the satellite based average productivity for the entire command is 11.46 quintals/hectare where as the CCE plots average productivity reported over canal supplied wheat is 18.99 qunitals/hectare and over well is 23.17 quintals/hectare. Since there are more variations in distributary wise crop productivity more CCE plots need to be identified to reflect average condition in the filed. The evaluation of crop condition across the year was carried out using the maximum vegetation index observed for each year. Based on the current year analysis, it was observed that the maximum vegetation index occurs during December. Though it is required to have more satellite over pass during peak vegetative stage to accommodate differential crop calendar within command, only available well with the crop yield , the maximum vegetation index, mainly derived from December data for the three years of 1997-98,1990-91 and 1988-89 is used for crop wise condition evaluation. The comparison of maximum NDVI images over the study period (Figure.6) indicate better condition in 1997-98 than the previous years of 1990-91 and 1988-89 in most of the crops.

The distributary/minor wise crop area estimation for major crops which includes fallow during rabi 1997-98, 1990-91 and 1988-89 indicate that the bare soil and fallow land in 1988-89 is about 67 per cent has reduced to 45 percent in 1990-91 and 20 percent in 1997-98 which indicate significant increase in cropped area from 1988-89 to 1990-91 and 1997-98. The main reason for increase in cropped area is due to continuous progress in the development of command which is still in progress. The comparison of crop wise area indicate that the major increase in cropped area is from jowar and cotton. The jowar cropped area was 1 percent in 1988-89 has increased to 9 percent 1990-91 and 19 percent in 1997-98. The cotton cropped area was 5 percent in 1988-89 has increased to 13 percent in 1990-91 and 39 percent in 1997-98. The comparison of crop wise irrigated area indicate a) the irrigated wheat and irrigated jowar area was nil during 1988-89 has increased to 1 percent in 1990-91 and 2 percent in 1997-98 b) The irrigated cotton area was 1 percent in 1988-89 and 1990-91 and increased to 14 percent in 1997-98. The lower percent of irrigated cotton in 1990-91 was due to good rainfall received in kharif and in rabi c) The area under perennials are also increased from 5 percent in 1988-89 to 8 percent in 1997-98. In 1990-91 more area under perennials was seen due to good monsoon received. The maximum NDVI through the season is extracted over satellite derived cropwise area. The distributary/minor wise average NDVI for the year 1997-98,1990-91 and 1988-89 for jowar, perennial, cotton and wheat indicate that in most of the distributory the crop condition was slightly lower in 1988-89 and increased in 1990-91 and further increased in 1997-98.

Water logging and Soil Salinity/Alkalinity

Due to improper management of soil and water resources in the command area, the land degradation problems specially Water logging and soil salinity and alkalinity will arise.

The study consists of visual interpretation of satellite data and the soil survey on physical and chemical properties indicate that there are no symptoms of development of salinity and alkalinity and Water logging problems.

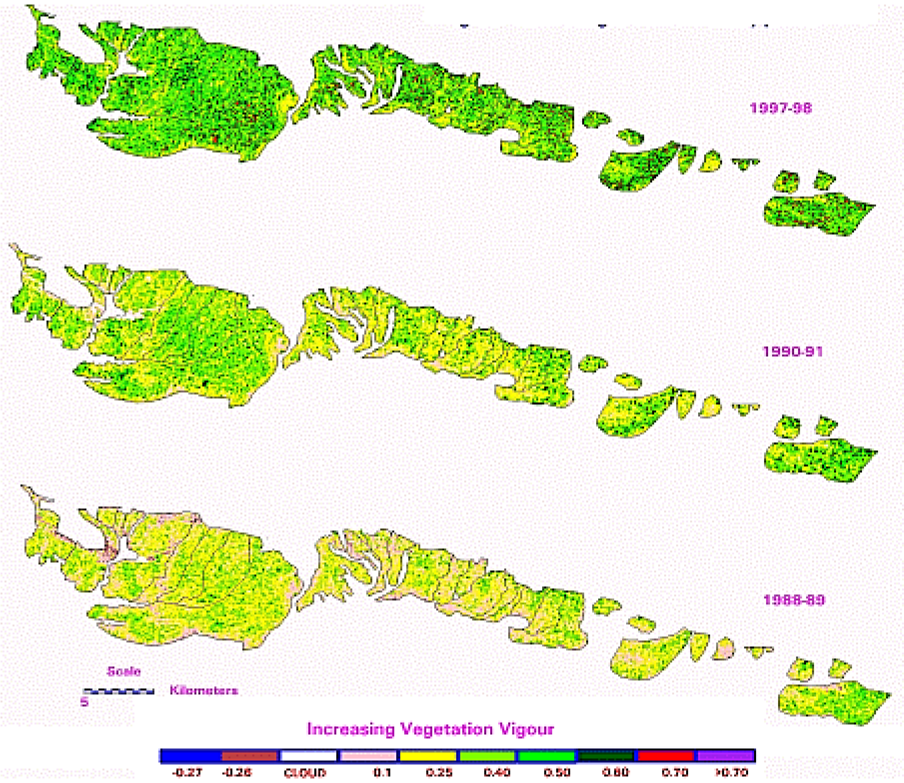

Figure 6. Maximum NDVI over the study period.

Other Field Informations

The indirect benefit of ground water recharge due to canal operation has led to increase of number of wells and increase of crop area under wells. The comparison of year wise progress of well irrigated area and number of wells in the command since 1985-86 to till 1997-98 indicate that the number of wells in 1985-86 was 580 in number and wells has increased to 2000 in 1997-98. The total crop area under wells has increased from about 1000 ha in 1985-86 to 7000 ha in 1997-98. The field report on season wise potential created versus utilised for few years indicate that there is significant increase in potential created from 1985-86 to 1997-98 in the order of 6000 ha to 25000 ha where as utilisation figure shows marginal increase of about 1000 ha in 1985-86 to 2000 ha in 1997-98. The field enquiry reveals that less utilisation is due to lesser demand from the farmers.

CONCLUSION

There is significant improvement in crop area and crop condition from 1988-89 to 1990-91 and 1997-98 in most of the crops especially in Cotton, Jowar, Wheat and perennials mainly due to continuous progress in the development of command. The field reports on irrigated crop area are in general confirms with the satellite derived cropped area for most of the crops, except for cotton, where the field reports indicated lesser for earlier years. The satellite derived wheat yield model using CCE plots yield and the corresponding locations identified using GPS survey on the maximum NDVI relates well with each other with r^2 =0.73.The weighted average productivity estimated by the model developed between the satellite based NDVI and the CCE for the year 1997-98 shows higher productivity than the CCE average productivity. The lower yield estimated by CCE indicate that there is a need for more CCE plots to represent average productivity condition of the command. The analysis on cropping pattern indicates, after commencement of the project, there is significant improvement in cropped area especially during rabi and hot weather season. Further ,the cropping pattern has also changed from rainfed jowar to commercial crops of cotton, perennials and wheat over the years. In most of the distributaries, the crop wise condition was slightly lower in 1988-89 and increased in 1990-91 and further increased in 1997-98 which indicates good performance. Due to improvement in the ground water recharge, more number of wells and the area under wells has increased over the years.Due to command area development, all around improvement in road network, communication and better economic growth in the area is reported by farmers. In spite of significant potential created over the years there is moderate utilisation of canal water is reported so far and needs more improvement.

Acknowledgement

The authors acknowledges with great appreciation the progressive steps taken by the Ministry of Water Resources (MOWR), Government of India in entrusting the present study of satellite remote sensing based evaluation of 14 selected irrigation projects covered under CAD programme. Shri. L.K. Joshi, IAS, Joint secretary and the then Commissioner (CAD), Ministry of Water Resources initiated the study which is being very ably supported by Dr. V.S. Dinkar, present Commissioner (CAD), Shri. D.K. Kaushik, Joint Commissioner (CAD), Ministry of Water Resources is providing valuable support from the day of the initiation of the study. Grateful thanks are due to Dr. D.P. Rao, Director and Prof. S.K. Bhan, Dy. Director (Applications) and Shri. A.K. Chakraborti, Group Head, Water Resources, National Remote Sensing Agency (NRSA) for their valuable guidance and support. The authors sincerely acknowledge to the valuable help and cooperation recieved from Secretary (CAD), Irrigation Department, Govt. Of Maharastra, Superindent Engineer, Jalgaon Irrigation Circle, Executive Engineer, Hatnur Project and other officials of Irrigation Department, Hatnur Project in providing field and office data and other logistics support during the field visits. The cooperation and help received from other colleagues of Water Resources Group and the help recieved by NRSA data centre are acknowledged.

References

Ahmad,M.D.,J.Jamieson,S.Asif, and P.Strosser. (1996), AUse of satellite imagery for land use mapping and crop identification in irrigation systems in Pakistan≅, Paper A-2 in Proceedings of the 17th Asian Conference on Remote sensing. Colombo: Survey Department.9p.

Azzali, S., and M.Menenti. (1996), AFourier analysis of temporal NDVI in the Southern African and American continents≅, Report 108, Wageningen, Netherlands:DLO-Winand Staring Centre. 149p.

Bastiaanssen, W.G.M. (1998). ARemote sensing in water resources management: the state of the art≅, International Water Management Institute, Colombo, Sri Lanka.

Curran, P.J. (1987), ARemote Sensing in agriculture : An introductory review≅, Journal of Geography 86:147-156.

Gong,P., and P.J.Howarth. (1992), ALand-use classification of SPOT-HRV data using a cover frequency method≅ . International Journal of Remote Sensing 13(8):1,459-1,471.

Jeyaseelan, A.T., Chandrasekar. K. and Thiruvengadachari, S.T. (1997), A Satellite (NOAA) based monitoring of Bhakra Irrigation Command, ISPRS- Workshop on Application of Remote sensing and GIS for Sustainable Development , 24-25 November, 1997. Hyderabad, India.

Janssen,L.F., and M.Molenaar.(1995), ATerrain objects, their dynamics and their monitoring by the integration of GIS and remote sensing≅, IEEE Transactions on Geoscience and Remote Sensing 33(3):749-758.

Molden, D.J. (1997), AConceptual frame work for water accounting≅, Technical report, International Irrigation Water Management Institute, Colombo.

Thiruvengadachari, S., and R.Sakthivadivel. (1997), ASatellite remote sensing techniques to aid irrigation system performance assessment: A case study in India≅, Research Report 9. Colombo: International Irrigation Management Institute. 23p.

Van Dijk, A., and T.Wijdeveld. (1996), AWater Management and remote sensing≅, Land and Water International 84:12-15.

Vidal, A and Baqri, A. (1995). Management of large irrigation projects in Morocco. In use of Remote sensing techniques in irrigation and drainage, ed. A. Vidal and J.A. Sagardoy, 99-105. Water Reports 4. Rome : FAO.

Vidal, A., P.Maure, H.Durand, and P. Strosser, (1996), A Remote sensing applied to irrigation system management: Example of Pakistan≅, In EURISY Colloquium: Satellite Observation for Sustainable Development in the Mediterranean Area, 132-142. Paris: Promotion of Education and Information Activities for the Advancement of Space Technology and its application in Europe.

Visser, T.N.M. (1989), AAppraisal of the implementation of water allocation policies≅, ICW note, Wageningen, Netherlands. 54p.