CHAPTER 11

SUMMARY AND CONCLUSIONS

11.1 INTRODUCTION

Indian economy is largely agriculture based as more than 70% of the total population depends on agriculture for their livelihood. In spite of significant advances since independence to bring more area under sustainable irrigation and the development of new high yielding crop varieties, Indian agriculture has remained highly dependent on monsoon rainfall. Owing to the abnormalities in monsoon precipitation in terms of both spatial and temporal distribution, drought is a frequent phenomenon in many parts of the country. Out of the net sown area of 142 Million Hectares about 68% of the area is reported to be vulnerable to drought conditions. About 50% of the drought prone area, where frequency of drought is regular, is classified as severe.

Conventionally, the drought condition in the country is monitored by both state and central government including Group of Ministers, the Chief Minister of States and the Prime Minister at political level and constant monitoring by Group of Secretaries including agriculture, relief, revenue, water resources, rural development at state and central government level. The basic parameters monitored are: (i) The daily rainfall observed by India Meteorological Department from a sparse network of rain gauge stations and (ii). The crop and seasonal conditions report generated by the State departments of Agriculture and Revenue based on limited survey. However, most of the time the drought information is inadequate and unreliable as the assessment is mostly biased and based only on rainfall without taking into account the temporal distribution of amount, intensity and duration of rainfall, soil type, crop type and stage of the crop etc. Besides the government has been spending huge amount of money for the long term drought mitigation programme such as development of Drought Prone Area Programme (DPAP), Desert Development Programme (DDP) and for drought relief, the real time drought management strategies are carried out with inadequate scientific data.
For the effective drought management, the main requirement is spatial and reliable observation of not only the rainfall but the weather, soil moisture and crop condition etc. Further, the information generated should be made available in near real time so that effective and appropriate measures can be taken up for the drought management. Space based remote sensing of earth observation provides such information with the required accuracy and reliability at frequent intervals.

The present day remote sensing is capable of monitoring environment parameters that cause drought at various scales. India is one of the world leaders in the launch and application of Earth resources, Meteorological and Communication satellites to address the national priorities such as natural resources management, disaster management, management of ocean resources and education for sustainable development (Rao, U.R., 1991, Kasturirangan, K., 1995). In case of Drought Management, The National Remote Sensing Agency (NRSA) with co-operation from other Department of Space (DOS) centers carried out the following national program for long term drought mitigation (Rao, D.P.,2000): 1) Under Drinking Water Technology Mission, groundwater potential maps were prepared at district level using multi spectral satellite data. This has helped in identification of better well sites for ground water extraction. 2) Under Integrated Mission for Sustainable Development (IMSD), action plans are provided at water shed level based on resources available and the socioeconomic requirement of the region. Though the result of these programs helps for taking up drought mitigation activities, because of the frequent changes both in the agriculture and water resources, there is a need for real time drought information for taking up effective drought management.

The real time monitoring of agricultural drought condition was taken up under the National Agricultural Drought Assessment and Monitoring System (NADAMS), which was established at NRSA, of DOS in 1988 and has issued biweekly drought bulletins periodically (1989-91) using coarse spatial resolution (1 km) NOAA AVHRR data (Thiruvenkadachari et al 1991). Though the methodology was able to provide spatial variation of drought condition using satellite based vegetation index data, the issue of bulletin takes 20 to 30 days time to reach the user mainly because the satellite data processing was carried out at different place and the manual interpretation method followed.

For the real-time drought management, timely and reliable information on the extent, the state and the distribution of drought severity as well as their temporal
variations are essential for decision-making. With the advancement in the remote sensing technology to observe other parameters such as rainfall, surface temperature, surface wetness or soil moisture in addition to improvement in the vegetation index methods, there is a need for investigations of these parameters for real time drought monitoring. To reduce the turn around time in issue of biweekly bulletin and to cover more number of states for drought monitoring, there is a need for automation in the drought monitoring procedure. To improve the quality of drought assessment, there is a need for development of various spatial and temporal assessment models and development of early warning procedures. To improve spatial assessment within the district and specific to crop area there is a need for the development and operational utilisation of high spatial resolution (188 m) IRS WiFS data. To improve the drought assessment through historic vegetation index which involves different satellite sensor and varying atmospheric condition, there is a need for assessing atmospheric effect and the satellite data normalisation. Due to continued development activities carried out over drought prone area in the country during last two decades, there is a need to identify the current status of drought prone area of the country.

11.1.1 Study Objective
In the light of issues mentioned above, a research plan has been worked and implemented to develop real time drought management strategies at district level in the country. The detailed scientific objectives are

- To investigate and validate the methods available for estimating the drought parameters such as rainfall, surface temperature, surface wetness and vegetation condition amenable to remote sensing and their utility for real time drought monitoring.
- Development of automated district level drought monitoring procedure using Course resolution data for the country and development of district level drought monitoring procedure using better spatial resolution data to reduce the turn around time.
- Improvement in the drought assessment in terms of development of spatial and temporal assessment model, early warning model and the crop specific sub district drought assessment at district level.
- Study of atmospheric impact on NDVI and the development of satellite data normalization for temporal comparison
Identification of current status of drought prone area through remote sensing
Based on the results, the constraints and the future satellite program to bring out the recommendations for further study.

11.1.2 Scope

The scope of the study is to evaluate the various global products on rainfall, surface temperature, surface wetness and vegetation index to assess its utility and to develop procedure for real time monitoring.
To develop automated procedure for satellite data processing and drought assessment not only to reduce the turn around time in issue of drought information but also to improve the quality of drought assessment.
To develop and validate improved drought assessment at district level for the country and at sub district level for few states.
To develop method to identify the current drought prone area and to bring out methodologies to assess atmospheric effect on vegetation index for real time drought monitoring.

11.1.3 Review of Literature

A comprehensive review of the reported research work relevant to the needs as discussed above was carried out. The critical review of the literature survey is organised in two parts
1. Remote sensing based methods for drought parameters estimation and the earlier work on drought monitoring
2. The theoretical background on the basic concepts of drought, conventional drought management practices and the theory behind the satellite based estimation of drought parameters.

The estimation of the drought parameters such as rainfall, evapotranspiration, soil moisture and vegetation condition by both conventional and remote sensing methods of observation or estimation are critically reviewed for its usefulness for real time monitoring of drought.

The review of the operational drought monitoring developed prior to this study indicated that the methodology followed in the real time drought monitoring using remote sensing was based on the manual interpretation of vegetation index profile and its comparison with the previous year's profile of the corresponding period at district
level. The methodology resulted in qualitative information mainly by use of coarse resolution NOAA AVHRR data and by the manual interpretation method followed. Further the issue of periodic biweekly drought bulletin used to take 20 to 30 days to reach the user and covers only 6 states till 1990

11.1.4 Theoretical Background

Extensive survey by Jeyaseelan and Thiruvengadachari, 1986(a), 1986(b) on conventional drought monitoring mechanism indicated that the ground observation of agricultural conditions by the State Departments of Agriculture and Revenue are exhaustive but involves a significant amount of subjective judgments and mostly biased based on rainfall.

The critical review on concepts of drought (Wilhite and Glantz, 1985), conventional drought management strategies in India (www.ndmic.in , Sinha et al., 1987, Thapliyal, 1990 and Das, 2000) and drought prone area program (Govt. of India, 1984) was made. The theory behind the satellite based estimation of rainfall, evapotranspiration, soil moisture and vegetation index are reviewed from the referred article was discussed.

The review of their study suggests that the accuracy of rainfall forecasts is needed to be improved. The network of rainfall observations are found inadequate for the varying rainfall conditions. Most of the satellite based rainfall estimation was based on the correlation with the ground observed rainfall and are still in experimental stage.

In case of evapotranspiration (ET), the network of ET observation in the country was found inadequate. In the remote sensing based ET estimation depends on the surface temperature observation, the surface temperature using thermal and microwave infrared method was complicated because of varying effect of atmospheric and emissivity conditions.

The soil moisture observations are limited in the country which provide point information and cannot be extrapolated for spatial variations in the soil moisture. The remote sensing based method using thermal and microwave sensors provide information on surface wetness in top surface layer of few centimeters depth.

The remote sensing based vegetation was comprehensive which reflects the biophysical characteristics of the vegetation owing to rainfall, soil moisture, crop stage and type and weather factors. The evolution of vegetation indices and their
relation with drought monitoring indicate NDVI was found adequate over other vegetation indices developed in recent years.

11.2 RESEARCH APPROACH

The research approach includes

1. The utilization of coarse spatial resolution, high revisit, satellite of NOAA AVHRR sensor's visible, near infrared and thermal infrared data, INSAT CCD data in visible and near infrared and DMSP SSM/I based microwave data for investigation of real time monitoring of rainfall, surface temperature, surface wetness and vegetation index based drought assessment.

2. Using Fortran compiler, the spatial modeler and the image analysis package available in the computer system the improvements in the automated drought assessment at district and sub district level was planned using NOAA AVHRR and IRS WiFS data.

3. The improvements in the drought monitoring methodology at district level using the coarse spatial resolution data over Andhra Pradesh and Karnataka state and the validation of sub district level drought assessment was carried out over Andhra Pradesh state by comparing with ground information on rainfall and crop yield at district level and with water budgeting parameters at sub district level.

4. The study of atmospheric (volcanic aerosol) impact on satellite data was assessed for the entire country during 1991-92 and the satellite data normalization study was taken up for improved drought monitoring.

5. Using the historic vegetation index data the identification of the drought prone area district level in the country is planned.

11.3 RESULTS AND DISCUSSION

11.3.1 Evaluation Of Satellite Based Rainfall Estimation For Real Time Drought Monitoring

In this investigation the following three case studies were selected to study the utility of remote sensing based rainfall estimation.

11.3.1.1 Validation of NOAA AVHRR Thermal Infrared Based Rainfall

The first case study to evaluate the thermal infrared based Precipitable water index (PWI) product generated using the NOAA AVHRR of 1 sq.km and compared
with the NOAA AVHRR global data product. The PWI from global AVHRR data (16.5 km²) for the week ending June 19th 2001 was acquired from NOAA website. The Precipitable water index was computed by taking the difference of brightness temperature from band 4 and band 5 using high spatial resolution AVHRR data (1 km) acquired on 21st June 2001. The PWI values are suitably grouped with every increase of 0.35 PWI from -2.0 to +5.0 and by assigning the similar color through density slicing procedure so that the PWI image generated using local area AVHRR data can be compared with the global PWI product. The procedure was developed to acquire the station wise daily rainfall data acquired from the Global summary of meteorological data and acquired the station wise rainfall of 21st June 2001. By knowing the station wise location in terms of geographic coordinates, the ground observed rainfall was overlaid on the geo corrected PWI data for its comparison.

From the analysis of precipitable water index from global and local area data of NOAA AVHRR indicates that PWI from LAC is reasonable and comparable with the ground observed rainfall. Though there is a general correspondence with the location of rainfall and the PWI, but the amount of rainfall and the PWI does not relate proportionately. Though the PWI can be estimated in real time i.e. on a daily basis, since the coverage is limited to one time observation, it can not give a good estimate for the day's rainfall. In such case the PWI generated from the geostationary satellite may be more close to the ground observed rainfall as it can integrate every 30 minutes data.

11.3.1.2 Validation of DMSP SSM/I Microwave Based Rainfall

In the second case study, the evaluation of passive microwave based rain rate estimates from DMSP SSM/I was evaluated using ground observed taluk wise rainfall over Karnataka state. The rain rate product covering Indian region of 6° N to 40° N and 65° E to 100° E was acquired from the NOAA web site for the period from 1st of June 2002 to 31st August 2002. The weekly rain rate was estimated from the SSM/I data over Karnataka state during June, July and August month. The ground reported rainfall at monthly interval obtained for each taluk over Karnataka state was compared with the SSM/I based rain estimate image at taluk level for the three month’s period. The result of the present study indicated that, in spite of using all the available data from the entire DMSP vehicle's SSM/I, the spatial distribution of
rainfall is not accounted in many taluks mainly because of its limited swath near equator. And hence it can not be used for real time monitoring in India.

11.3.1.3 Validation of TRMM based Rainfall

The TRMM based microwave instrument (TMI) and precipitation radar (PR) combined product was acquired on 6th July, 2004. This includes both ascending and descending orbits. Each orbit has 760 km swath and 5 km horizontal resolution. Both orbits data was digitally mosaic. The ground observed rainfall over the Indian region was extracted from the global summary of daily weather data for the 6th July 2004. Based on the station's location, the 5 stations rainfall was compared with the TRMM based rainfall. The result indicates that there was a trace of high intense rain rate over the region. However, the ground rainfall indicated high rainfall of 34mm over Dehradun, but no trace of rain rate was observed. This may be due to difference in the time of rainfall event and the time of satellite coverage. But in most cases of ground observed rainfall can be compared with the spatial rain rate information from the TRMM combined product.

11.3.2 Investigation on Remote Sensing based Surface Temperature Estimation for Real Time Drought Monitoring

To assess the utility of surface temperature estimated using thermal infrared and microwave sensor for real time drought monitoring, the following four experiments were conducted:

1. As the Landsat Thematic Mapper has 7 spectral bands in visible, near infrared, mid infrared and thermal region of electromagnetic spectrum, the utility of thermal sensor was evaluated along with vegetation index and infrared index during the cloud free period for drought assessment.

2. Use of weekly time composite data of NDVI and surface temperature from the long record of NOAA AVHRR based Global Vegetation index product at 16 sq. km resolution, the utility of surface temperature data during monsoon season was evaluated.

3. Use of microwave based surface temperature is evaluated by comparing the surface temperature anomaly derived from SSM/I data and compared with the ground observed rainfall anomaly during drought and non drought year.
4. Methodology was developed to estimate surface temperature using 1km resolution of NOAA AVHRR data.

11.3.2.1 Investigation of Landsat TM Based Thermal Data

Since the Bijapur district went through severe drought in 1988 and got good production in the year 1999, The Bijapur district was selected for the study. In order to get the cloud free satellite data from TM, the Rabi season (i.e. from November to January) was selected. The TM data covers the one quarter scene of 145-49 (path-row) of LANDSAT 5 acquired on 11th December 1988 and 14th December 1989. The normalized difference Vegetation index, infrared index were computed. 45 sample sites covering at least 4 or 5 in each NDVI class range were selected and the comparison between NDVI, Infrared index and thermal count were made during drought and non drought year.

The comparison of Infrared index between drought year (1988) and non drought year (1989) over the sample sites selected over different NDVI ranges indicate that in general larger reduction over lower NDVI samples, moderate reduction over high and medium NDVI sample sites and less reduction over non vegetation NDVI classes during the drought year in comparison with the non drought year were observed.

The comparison of NDVI between drought year (1988) and non drought year (1989) over the sample sites selected over different NDVI ranges indicate larger reduction over high (NDVI greater than 0.4) and medium (NDVI between 0.2 to 0.4) level and less reduction over low (NDVI between 0.1 to 0.2) NDVI classes during drought year in comparison with non drought year was observed.

The comparison between NDVI and Infrared index indicate both are linearly related with increase of NDVI corresponds to increase of Infrared index. The comparison between NDVI and thermal counts indicate that both NDVI and thermal bands are inversely related with higher the NDVI, lower was the thermal counts. Further each type of vegetation like the forest and agricultural crops has different relations.

11.3.2.2 Investigation of GVI Based Surface Temperature

GVI product consists of vegetation index and the surface temperature (TS) over Indian region was acquired from 1985 to 1997. Each weekly average NDVI and
TS for each district of Andhra Pradesh was generated. The weekly average NDVI and TS are added through the Kharif season for each district and for each year as Integrated NDVI (INDVI) and Integrated TS (ITS) respectively. The monthly rainfall data from June to September for all the districts of Andhra Pradesh state was collected and the seasonal rainfall for each district was computed for each year from 1985 to 1997. The year wise variations of weekly NDVI and TS and the relationship between them are studied. The result of the study indicates in almost all the districts maintained similar trend in NDVI profiles without much variations between the districts. There was a better correlation with inverse relationship was obtained between NDVI and TS in most of the districts indicated for higher vegetative cover, higher will be the evapotranspiration rate and lower will be the Ts. The NDVI, Ts and rainfall relations at different region indicate strong influence on the relationship between the type of vegetative cover and monsoon rainfall.

11.3.2.3 Investigation on Microwave Based Surface Temperature

The monthly temperature anomalies maps for June to September over South west Asia region covering major part of India during 2002 and 2003 was acquired and the temperature anomaly maps over Indian region was extracted. The monthly rainfall anomaly maps published by India Meteorological department for the period during June to September 2002 and 2003 was considered for comparison during drought year (2002) and during non drought year (2003). The result indicated during June, July period, the deficient rain with late sowings resulted in rise in temperature, whereas the deficient rain with early sowing region does not show increase in temperature. During the peak vegetative season, the drought condition is reflected by at least 2 to 4 degree rise in surface temperature when compared to drought free conditions. Therefore, it can be used as one of the indicators for real time monitoring.

11.3.2.4 Estimation of NOAA AVHRR Based Surface Temperature

The operational procedure was developed for estimating surface temperature using high spatial resolution (1 km) NOAA AVHRR data. The initial procedure was based on the Price (1984) method where the fixed emissive value was used. AVHRR data acquired during 19th November 1995, 6th December 1995, 4th January 1996, 19th February 1996, 26th March 1996 and 26th April 1996 from NOAA 14 satellite was processed. The comparisons between NDVI and surface temperature over
Rajasthan state indicated that the slope of regression line does not show much variation during December, January and February. Subsequently the procedure was developed based on the method proposed by Uliveri et al. 1994 which uses varying emissive based on NDVI. The land surface temperature was estimated from each day’s satellite coverage of NOAA AVHRR during July 2nd and July 4th week of 2002 and compared with the global temperature anomaly and the rainfall anomaly. The result of the study indicated spatial variation in surface temperature and reflected well with the dry spell and the sowing activity.

11.3.3 Investigation on Remote Sensing Based Soil Moisture and Vegetation Index for Real Time Drought Monitoring

Two case studies for drought assessment one by using ERS SAR data and the other using the passive microwave SSM/I based soil wetness anomaly and the vegetation index anomaly was carried out. In the third case study the utility of CCD a unique payload available in INSAT platform was evaluated for real time drought monitoring

11.3.3.1 Investigation of ERS Data

In 1992, it was reported by the government of Andhra Pradesh state that there was significant delay and less sowings in Cuddapah district. The rain fed groundnut sowings were taken up during late August to early September, irrigated groundnut crop and the paddy crop sowings were reported by end of July to September first week. In order to assess the delay in sowings the following three dates of ERS data during the growing season was acquired: 17th June, 26th August and 10th October 2002. As the interpretation of crop area from individual ERS data was difficult due to the mix of surface roughness and speckle in the images, after removing speckles using median filter and by selecting the temporal data for false color composites, the interpretation has improved. The results of the study indicated the area of early sowing and delayed sowings. With the help of image classification using IRS data in the optical region, the crop wise sown area was estimated. However, due to poor revisit of 35 days swath, it can not be used for real time monitoring.
11.3.3.2 Investigation of Surface Wetness and Vegetation Index Anomaly

Surface wetness anomaly product generated monthly at a spatial resolution of 30 km derived from Special Sensor Microwave Imager (SSMI) from Defense Meteorological Satellite Program (DMSP) was evaluated for its use in drought monitoring. The methodology was based on comparison between surface wetness and vegetation index anomalies and with the vegetation and temperature condition index during each month from June to September during drought (2002) and non drought (2003) years. The result of the study has indicated that,

1. The surface wetness anomaly product provided by SSM/I compares well with the vegetation index anomaly maps and vegetation and temperature condition maps generated from NOAA AVHRR data during drought and non drought years.

2. As cloud cover is the limitation in case of vegetation index anomaly and vegetation and temperature condition images during monsoon period, the microwave based surface wetness anomaly can be used as an alternative and will be helpful in monitoring at shorter interval than a month. However, due to very coarse spatial resolution of 30 km compare to 1 km and 188m spatial resolution from NOAA AVHRR and IRS WiFS based vegetation index, the SSM/I based wetness anomaly cannot be useful for district level monitoring, but it can be useful for regional level studies.

3. During early part of monsoon, when there is no crop emergence, both surface wetness anomaly and vegetation and temperature condition relate better with the rainfall and temperature conditions.

4. After the crop emergence during the monsoon season, the vegetation index anomaly respond well with drought conditions than the rainfall anomaly. The surface wetness anomaly and vegetation and temperature condition estimates shows higher severity than the vegetation index anomaly during August and September month suggests fine tuning the limits for assessment of dry or stressed condition.

5. Though the SSM/I based surface wetness anomaly is found to be useful tool, the non availability of information close to the coast is another limitation for its use for drought monitoring.

11.3.3.3 Investigation of INSAT CCD Based Vegetation Index

INSAT 3A CCD data evaluation for Drought application was attempted with the following objectives.
Utility of INSAT CCD NDVI in comparison with NOAA AVHRR based NDVI for drought monitoring

Utility of frequent INSAT CCD data for cloud removal in drought monitoring

### 11.3.3.1 Comparison of INSAT CCD with NOAA AVHRR

One cloud free INSAT CCD image covering entire India with all three bands of 24th April 2003 acquired at 14.00 hrs for comparison with NOAA AVHRR data obtained on the same day at 14.30 hrs. After development of INSAT CCD data processing procedure for vegetation index the corresponding date's vegetation index from NOAA AVHRR data was compared between individual bands and between the NDVI over different land cover classes. The result indicated good correlation between them. However, the response from the visible band from CCD is comparatively lower than the NOAA AVHRR resulting in higher NDVI from CCD.

### 11.3.3.2 Utility of Temporal INSAT CCD

The 2 hourly data from 8.30 hrs to 14.30 hrs during the depression period of 20 to 23rd June over North eastern part of India with 80 to 90 percent of the area under cloud cover. The results of time composite within a day and with three days indicate considerable reduction in cloud cover permitting for drought monitoring even at shorter interval of week compared to fortnight or monthly monitoring using NOAA AVHRR and IRS WiFS. Further due to similar bandwidths and sensor technologies are available at INSAT CCD, IRS WiFS and LISS, the compatibility of drought information at national/regional level to district and taluk level is possible.

### 11.3.4 Development of Real Time Drought Monitoring Package at District Level

#### 11.3.4.1 Improvement in the NOAA AVHRR Based Drought Monitoring

The initial NOAA data processing method developed followed the First generation GVI product procedure (NNRMS, 1988). The drought information was provided based on the earlier developed procedure took about 20 to 30 days for issue of bulletin and the drought information was based on the district average condition. The improvement in the data processing package developed has the following advantages

- Better quality in the data processing is achieved by Use of calibrated data rather than the digital number for generation of NDVI
Working with original 10 bit data instead of 8 bit truncated data
Automating the command and minimizing the manual entry of commands and input
Providing quality checks at different levels of processing
- The processing time was considerably reduced to improve the turn around time to 2 to 3 days
- Drought assessment is carried out digitally to avoid manual errors in the analysis.
- Statistics extraction, NDVI comparison and the report generation including map and report generation procedure are automated

The step wise processing method was developed so that most of the commands are run for the specific area rather than for entire image. This has helped to reduce processing time and generation of statistics from 2 days to 5 hours for the entire country. Improvement in the geometric correction procedure with quality check has lead to generation of high spatial accuracy of less than 1 km compared to 4 to 5 km accuracy achieved earlier. The improvements in color maps generation and the report generation on spatial and temporal comparison of NDVI through the development of software/model for drought assessment has helped in providing the quantitative assessment.

11.3.4.2 Development of IRS WiFS Based Drought Monitoring
Though the coarse resolution NOAA satellite data is able to provide regional drought assessment at district level in terms of general vegetation condition, but the detailed drought assessment over smaller areal units and for specific themes such as crop area need use of better spatial resolution data such IRS WiFS. After the launch of IRS-1C in 1995 with the initial study on its evaluation for drought monitoring by comparing with the NOAA AVHRR data, the development of operational drought monitoring package was discussed.

11.3.4.2.1 Initial Evaluation of IRS WiFS data
The evaluation of IRS WiFS data was made in comparison with NOAA AVHRR of same date over Andhra Pradesh state, studied the NDVI sensitivity to vegetation dynamics. The result of the study indicated that IRS WiFS based monitoring would be better for the following reasons: (i) in spite of 7 bit information of WiFS data the radiometric response of vegetation and land category is better in
WiFS than NOAA AVHRR data (10 bit). (ii) The sharp NDVI difference between vegetation and non-vegetation category in WiFS data for better discrimination of cropped area (iii) the better dynamic range of NDVI response in WiFS for more number levels (iv) The narrower band width specific to vegetation response and better spatial resolution helps in better vegetation discrimination and condition monitoring by use of WiFS data.

11.3.4.2.2 Development of Operational Methodology

The generalized operational procedure was developed using the ERDAS Imagine package was developed initially for Andhra Pradesh and extended to cover additional two states of Karnataka and Orissa. The procedure was developed using the spatial modeler option and by generating separate models for different processes such as cloud mask, radiometric correction, NDVI generation, time composition, map composition, statistics generation and report generation. The details of the methodology developed were discussed in detail.

11.3.5 Improvement in Real Time Drought Monitoring and Validation of Methodologies

With the development of real time drought monitoring package at NRSA campus after 1990, the turn around time was reduced from 20 to 30 days to 2 – 3 days and the area of the study was increased from 6 states to 11 states. Considerable time reduction was achieved not only with the automation of satellite data processing but also by automation of drought interpretation methods.

11.3.5.1 Development of District wise Drought Assessment Model at National Level

The development of drought assessment model at national level includes development of temporal assessment model, development of spatial assessment model, and development of drought assessment model using 1987 to 2002 NDVI data by comparison with crop yield and rainfall data at state, district and sub district level for Andhra Pradesh and Karnataka states. The development of early warning models, using NDVI and the rainfall relations and by comparison of NDVI profile with crop yield studied over Andhra Pradesh and Karnataka state and the use of forest area mask has helped in crop area specific assessment.
11.3.5.1.1 Temporal Assessment Model

The drought assessment in any reporting two weekly or monthly period is developed based on comparison of district NDVI profile up to that period to the seasonal profiles of the normal year. Profile anomalies are interpreted in terms of moisture stress conditions and relative severity level. False alarms due to excessive rainfall/flooding, cloud contamination, poor time composition, difference in seasonal growth cycles are appropriately identified and discarded. The relative drought severity level (normal, mild, moderate and severe) is assessed on the following criteria: 1.) Delay in vegetation growth (1 fortnight, 2 fortnights, 3-4 fortnights and more than 4 fortnights) and 2.) The VI anomaly compared to normal year in percentage (up to 10% low, 10-25 % low, 25-50% low and more than 50% low).

11.3.5.1.2 Spatial Assessment Model

The fortnight vegetation index image generated over India is overlaid with state boundary image. The state wise NDVI images are overlaid with district boundary images. The standard color lookup table generated for color NDVI image generation is applied automatically through command procedure, using image analysis software. The spatial variation in NDVI for each fortnight is provided in terms of vegetation condition map. The comparative crop condition map is also generated automatically through command procedure using image analysis software. The crop condition map is obtained by estimating the percentage deviation of the current season vegetation index with the previous reference seasons vegetation index for each fortnight / month. The comparative crop conditions are grouped into five classes namely, 1.) Better condition for the percentage deviation of vegetation index is greater than 10 % and assigned with a cyan color, 2.) Comparable condition when the percentage deviation of vegetation index is from -10% to 10% and assigned with a green color, 3) Slightly low condition when the percentage deviation is between -10% to -20% and assigned with yellow color, 4) Moderately low condition when the percentage deviation of vegetation index is between -20% to -40% and assigned with pink color and 5) Severely low when the percentage deviation of vegetation index is less than -40% and assigned with the red color. Both the vegetation condition and comparative crop condition maps are generated at national, state and district level.
11.3.5.1.3 Drought Assessment Model Based on Yield Relations

The district average vegetation index integrated through the crop season (June to October) is correlated with major crop yield at district level. The major crop is identified based on the higher acreage of the crop in each district. The district wise rainfall, crop area and crop yield data were acquired for the year 1987 to 1992 from Bureau of Economics and statistics and Agriculture departments of Andhra Pradesh and Karnataka state. The relationship between NDVI and yield and rainfall and yield was carried out using the district average NDVI with the vegetation response threshold of 0.05 and above to represent the vegetation is considered. The district level regression coefficients ($R^2$) between the district's major crop's yield with seasonal integrated NDVI and seasonal rainfall are carried out for Andhra Pradesh and Karnataka state.

The result of the relations in Andhra Pradesh indicates the NDVI has a better correlation coefficient with major crop's yield than with the rainfall in 20 out 22 districts. However, the regression between NDVI and yield was found to be low ($R^2=0.6$) in three districts namely Krishna, Visakapatnam and West Godavari. In these districts paddy growth period goes beyond October, where as the NDVI from June to October only was considered. The low regression coefficient in Mahabubnagar district is due to the multiple cropping followed in the district. Though Jowar has slightly more area than other crops, but the district has considerable areas under cotton, castor, groundnut and paddy crops also.

The result of the relations in Karnataka state indicates the NDVI has a better correlation coefficient with major crop's yield in all the districts. However, the regression between NDVI and yield is found to be slightly low ($R^2 < 0.6$) in Bijapur, Tumkur and Kodagu districts where the NDVI response from other crops in Bijapur and Tumkur and from the forest in Kodagu has reduced the relations.

11.3.5.1.4 Drought Assessment at State, District and Sub District Level

The fortnightly NDVI image over Andhra Pradesh and Karnataka state were Integrated through the season for the year 1987 to 1992. The state average NDVI was related with the major crop's yield in the state, the average NDVI over major crop growing districts was related with the major crop's yield in the state and the district average NDVI was related with major crop yields and by considering only those crop growing mandals average NDVI in case of Andhra Pradesh and by considering only
those crop growing taluks in case of Karnataka are related with the major crop's Yield at district and sub district level. The result indicated better correlation coefficient for both Karnataka and Andhra Pradesh state at sub district level than district, major crop growing districts and at state level.

11.3.5.1.5 Development of Early Warning Model

As there is a time lag between the vegetation development and the rainfall or the soil moisture conditions, the prediction of subsequent vegetation development can be assessed based on the current rainfall or soil moisture conditions. In the present study the district wise current rainfall information acquired was integrated with the current vegetation condition to provide early on the subsequent vegetation development.

As drought is finally assessed based on the reduction in crop yield, time integrated NDVI at monthly interval through the season is related with crop yields to assess the scope for early warning. The vegetation index profile and the crop's yield from major crops in each district during 1987 to 1992 over Andhra Pradesh and Karnataka states were considered. The simple linear regression model was developed between the integrated NDVI and the Yield, the coefficient of determination or the regression coefficient ($R^2$) which describes the strength of their relation between the two. By monitoring through the season depending on how early in the season the better relation is achieved indicate the scope for early warning.

The result of the study over Andhra Pradesh indicates by end of August, 12 out of 22 districts have shown better correlation coefficient of 0.65 indicates prediction of crop yield based on Integrated vegetation index is possible by end of August. In September, the correlation has improved in 16 districts and by October the correlation was further improved to 20 out of 22 districts with better correlation coefficient indicates scope for early warning with improved accuracy from September onwards over Andhra Pradesh state.

The result of the study over Karnataka state indicates by end of August, 8 out of 19 districts have shown better correlation coefficient. In September, the correlation has improved in 16 districts and by October the correlation was further improved to 17 out of 22 districts with better correlation coefficient. The result of this study indicates scope for early warning based on monthly time integrated NDVI by the end
of August and with improved accuracy from September onwards over Karnataka state.

**11.3.5.1.6 Improvement by Use of Forest Area Mask**

The initial study using NDVI alone and NDVI and DEM combined method does not give the accurate forest area map. The forest area map generated using the high resolution satellite data at state and national level by the Forest Survey of India was used for generation of forest mask. The extracted forest mask is used in the vegetation index image to eliminate forest area for crop area monitoring. This has further improved the accuracy in the drought assessment in the country.

**11.3.5.2 Development and Validation of IRS WiFS Based Drought Assessment**

The monthly seasonal condition report for each state is generated by providing spatial information on crop status at state level by superposing districts boundary, and at district level by superposing mandal boundaries for Andhra Pradesh, taluk boundaries for Karnataka state and Block boundary for Orissa state. Each report contains the following information generated through spatial Modeling option available in ERDAS imagine software:

- Monthly time composite of False Colour Composite (FCC) image wherein vegetation appears in red colour, the increase of red colour from May through each month indicate increase of crop coverage.

- Monthly time composited vegetation index map with various colours from orange, yellow to light, medium and dark green , red and purple indicate increase in vegetation vigour and condition.

- Crop area map obtained through comparing vegetation index map of each month with previous months vegetation index images including pre monsoon months (May) image after masking forest area.

- The crop condition map obtained by comparing the current season vegetation index with the previous reference seasons vegetation index of similar period. The vegetation condition at each month is indicated as better /excess when the vegetation index deviation is greater than 10 %, comparable (normal, green color) when VI deviation is -10 to 10%, slightly low (yellow colour) when VI deviation is -10 to -20%, moderately low (red colour) when VI deviation is -20 to -40% and severely low (purple colour) when VI deviation is less than -40%. 
The tables indicating mandal/taluk/block wise crop area, condition assessment and early warning for each districts of Andhra Pradesh, Karnataka and Orissa state.

11.3.5.3 Validation of Drought Assessment over Andhra Pradesh

As district is too large a unit with varying covers, soil types, and crop types etc., the sub district level assessment in terms of smaller administrative unit has been considered for validation study using IRS WiFS data during the Kharif season for the years 1998 and 1999 in Cuddapah district. The methodology followed was

1. **By identifying the reduction in crop sown area.** The total crop sown area was estimated after eliminating area under forest, barren land and perennial vegetation using temporal Normalised Difference Vegetation Index (NDVI) data during 1999 and 1998 and compared with the sown area reduction. By identifying the NDVI threshold over predominantly mono crop growing regions, crop wise area was identified.

2. **By assessing the crop condition.** Based on the crop cutting experiments result obtained from the district authorities on crop yield, model was developed between NDVI and crop yield and estimated the reduction in crop yield over paddy and groundnut cropped areas in 1999. Further the moisture deficit was estimated from the daily water budgeting procedure and compared with NDVI profile of 1998 and 1999 to validate the crop condition assessment.

The result of the study indicated reduction in crop area observed in 1999, when compared with 1998 which was confirmed with the prolonged dry spell that occurred in the month of July-August 1999 and is critical for the crop sowings. In comparison with 1998, the 1999 crop condition was found to be much lower in most of the areas except in the forest region where comparable vegetation levels are seen. The NDVI and crop yield model developed over paddy and groundnut areas for 1998 was applied to 1999 NDVI to forecast the expected crop yield in the spatial domain. The result indicated more than 40 % yield reduction in 1999, which indicates severity of drought condition in Cuddapah district.

To verify the changes in the vegetation condition weighted average NDVI and water deficit values obtained from daily water budgeting procedure based on climatic data for both paddy and groundnut crops are compared. The result indicated good comparison of water deficit period with the reduction in NDVI period in most of the mandals.
11.3.6 Investigation on Atmospheric Effect and Satellite Data Normalisation

In spite of using time composite NDVI for drought assessment, the sudden eruption of Mt Pinatubo volcanic has affected the NDVI and disrupting the drought monitoring activity during 1991. In this section, the assessment of volcanic aerosol impact during 1991 and the persistence of the impact were studied for entire India. Further satellite radiometry is affected by change of satellites or sensors, orbital drift, sensor degradation etc. In order to compare the values across the time period there is a need for satellite data normalization. The results of the normalization study undertaken for drought monitoring activity were also discussed.

11.3.6.1 Assessment of Mt. Pinatubo Volcanic Aerosol Impact

The comparison of biweekly district NDVI profiles during May-December period between 1991 and previous four years indicate a lowering of NDVI values especially over Southern India in 1991

11.3.6.1.1 Study of NDVI over Latitudinal Belts

The biweekly NDVI data sets over India were compiled into monthly values averaged over each one degree latitude belt starting from 8°N to 35°N over India. To minimise problems of cloud contamination and to eliminate water pixels, the NDVI values of only vegetation pixels were averaged. The latitudinal NDVI profiles for May to September 1991 between 8°N-35°N indicate the decrease in NDVI value beyond 15° N latitudes from July to September. In order to ascertain the impact due to aerosol the following study was taken up.

11.3.6.1.2 Comparison of NDVI and Rainfall Anomaly

The biweekly district wise NDVI averaged over vegetation pixels (NDVI>.05) of 1991 was compared with the corresponding biweekly NDVI of previous four years (1987-1990) average to generate vegetation index anomaly. This was compared with the rainfall anomaly obtained from IMD at meteorological subdivision level. The result of the study indicates in spite of better monsoon over major part of India, the low NDVI may be due to the aerosol impact.
11.3.6.1.3 Comparison of NDVI and Production

In order to confirm the result, the comparison of district wise NDVI and production deviation of 1991 data with 1989 over few drought affected and drought free states at different latitude region was taken up. The result indicates in spite of better production over drought free states, the lower NDVI was observed. Over drought affected states the loss in production with larger reduction of NDVI was indicated.

11.3.6.2 Persistence of Aerosol Impact

The persistence of aerosol impact was studied by comparing the District wise NDVI anomaly during 1992 January to December in comparison with the 1989 NDVI and the rainfall anomaly observed over Meteorological subdivisions over India. The result of the study indicated gradual reduction in the severity till May 1992 and no impact could be seen beyond August 1992.

11.3.6.3 Satellite Data Normalisation

For quantitative comparison between different satellites and different processing methods there is a need for normalizing the values. During drought monitoring for the historic data analysis the data normalization was carried out for the following reasons: 1.) To compare with the different processing methods between GVI and LVI, 2.) For change of satellites from NOAA 9 to NOAA 11, 3.) For orbital drift and sensor degradation of NOAA 11, 4.) For aerosol effect, 5.) For extending drought to other satellite sensors.

11.3.7 Historic NDVI Analysis for Drought Prone Area Identification in The Country

In the present study, significant work has been carried out to identify the drought prone areas using recent year's satellite based vegetation index data of 1 km spatial resolution. The method involves identification of area of low vegetation development with large year-to-year variation and its occurrence over more number of years.
11.3.7.1 Estimation of Vegetation Activity Types

NOAA AVHRR based 1Km spatial resolution fortnightly NDVI data generated over India during June to October was time composites for each year from 1986 to 1999. The time composites NDVI image represents the maximum vegetation development during monsoon season. Out of the total study period of 15 years from 1986 to 1999, the first 10-year period from 1986 to 1995 was considered. The mean and standard deviation of vegetation development for each of the pixels of 1km by 1km for entire country was computed for the reference period of 1986 to 1995. Based on the combined effect of both mean and standard deviation of NDVI, six types of vegetation activity were derived. The first type of vegetation activity is identified with low vegetation development (low mean NDVI) and moderate to high standard deviation NDVI, the second type of vegetation activity is identified with low mean NDVI with low deviation. In these two types most of the arid regions and part of semi arid regions are covered. The third type of vegetation activity is identified with moderate vegetation development with high standard deviation. The fourth type of vegetation activity is identified with moderate vegetation development and moderate standard deviation. The fifth type of vegetation activity is identified with average to high vegetation development and low to moderate deviation and the sixth type of vegetation activity is identified with better vegetation development and moderate to low deviation.

11.3.7.2 Estimation of Frequency of Low NDVI

In order to assess the severity of reduction in vegetation index, the three levels between mean and minimum NDVI was computed with 25%, 50% and 75% of mean minus minimum. Year-wise changes in the vegetation development from 1986 to 1999 with respect to the average condition were carried out. Based on the total years of low NDVI, the areas having 1-2 years frequency, 3-4 years and more than 4 years of frequency was identified.

11.3.7.3 Estimation of Drought Proneness

The vegetation activity type based on mean and standard deviation and the frequency of low NDVI are combined to classify the following three types of drought prone area namely: Severely drought prone area, moderately drought prone area and low drought prone area.
11.3.7.4 Comparison of Drought Prone Area

The comparison of the district wise drought prone areas identified by the Irrigation commission 1972 with the drought prone area identified based on the current study was made. The results of the study indicate that drought prone areas have reduced over the already identified drought districts. This was mainly due to the development activities carried out by the Government of India since 1970s through DPAP and DDP programmes. The study also indicates that additional areas need to be identified as drought prone in most of the states.

11.4 CONCLUSIONS

Based on the analysis of results and discussions, the following conclusions are drawn.
1. A review of conventional drought management practices in India suggests that though India has very good mechanism established right from drought prone area identification to prediction, early warning, monitoring, damage assessment and implementation of drought management practices, but the basic data it has relied was only rainfall that too with limited network of observatories.
2. The thrust of India’s Space programme to address the national priorities includes its application for drought management. National programs were initiated for long term drought mitigation under Drinking water technology mission and Integrated Mission for sustainable development. For real time drought monitoring, the National Agricultural Drought Assessment and Monitoring System was developed.
3. The gap in the remote sensing based drought monitoring suggests the need for monitoring the entire country, reduced turn around time, quantitative assessment, early warning, spatial assessment within district and identification of the latest drought prone areas which forms the objective of the present study.
4. The investigation on the rainfall estimation through remote sensing suggests that from the analysis of precipitable water Index from global and local area data of NOAA AVHRR indicates that PWI from LAC is reasonable and comparable with the ground observed rainfall. Though there is a general correspondence with the location of rainfall and the PWI, but the amount of rainfall and the PWI does not relate proportionately. Though the PWI can be estimated in real time i.e. on a daily basis, since the coverage is limited to one time observation it can not give a good estimate for the day’s rainfall. In such a case the PWI generated from the geostationary...
The satellite may be more close to the ground observed rainfall as it can integrate every 30 minutes data.

5. The rain rate estimate from DMSP SSM/I data was found inadequate because of the large footprints with narrow swath and poor revisit, though compares well with taluk average rainfall.

6. Due to limited swath and twice coverage in a day by the TRMM based TMI and PR data, the rainfall estimate from these products can not be operationally used as an independent source. However, due to the better accuracy of the observation, the estimation from this sensors information is combined with other sensor's rainfall estimation.

7. The utility of thermal data using LANDSAT Thematic Mapper data suggests its potential for drought assessment during cloud free period. The use of Global surface temperature using NOAA AVHRR relates well with seasonal NDVI and rainfall amount. The investigation of Microwave based surface temperature anomaly with monthly rainfall anomaly compares well indicating its scope for utilization at regional level due to its coarse spatial resolution. The utility of surface temperature using NOAA AVHRR data at 1 km spatial resolution provides good comparison of dry spell and drought condition and can be used for operational drought monitoring in addition to NDVI.

8. The multi temporal ERS SAR data acquired at different time within the season to accommodate the differential crop calendar can be useful for identification of sowing progress, but due to its poor revisit of 35 days and difficulty in discriminating the crop type, its use for drought assessment is limited.

9. The comparison of Microwave based surface wetness anomaly with the vegetation index anomaly during drought and non drought year suggests that, in spite of cloud cover, the surface wetness anomaly reflects drought condition.

10. The comparison of INSAT CCD based vegetation index with NOAA AVHRR based vegetation index suggests that, due to less response in the red region, the NDVI from INSAT CCD was higher than NOAA AVHRR. The utility of frequent data from INSAT during heavy cloud period suggests that its scope for reducing the present level of monthly drought monitoring to weekly monitoring.

11. The development of satellite data processing takes into account radiometric calibration, better geometric correction, statistics generation, and vegetation
comparison in an automated manner to reduce the turn around time and improvement in the quality of processing.

12. The utility of IRS WiFS with 188 m spatial resolution was proved to provide sub district level assessment and further generation of drought monitoring package using IRS WiFS data helps providing detailed drought monitoring within district for few states in the country.

13. Improvement in spatial and temporal assessment helps in reducing the turn around time. The development of crop condition model based on NDVI and yield over Andhra Pradesh and Karnataka state indicates better relation at sub district level than at district and at state level. The study also indicated the scope for providing early warning from August month onwards with improved accuracy from the subsequent months. The use of forest mask improves crop area specific drought monitoring.

14. Development of district wise drought assessment using IRS WiFS data is provided with the detailed spatial as well as quantitative assessment in terms of sown area, crop condition and early warning at district and sub district level.

15. The validation of sub district assessment using IRS WiFS over Cuddapah district of Andhra Pradesh with crop area, yield reduction and water deficit gave improved assessment of drought situation.

16. The Mt.Pinatubo’s volcanic aerosol in combination with dry spell has affected the drought interpretation in 1991. The comparison of NDVI anomaly with agricultural production over selected states in different latitude belts confirmed to aerosol impact over India. The study also revealed that its impact on NDVI was persisted till August 1992.

17. Since no evaluating or monitoring mechanism exists to know the impact of various drought ameliorative measures taken up by the Government over the drought prone areas, the present study using historic NDVI data analysis has shown great potential to identify the current drought prone area as well as to monitor the impact of drought ameliorative measures in a more scientific way.

11.5 RECOMMENDATIONS FOR IMPLEMENTATION

As the space technology has tremendous potential not only for drought monitoring but also to provide early warning with better accuracy but need the ground truth support to develop and validate the methodology in real time. Therefore the
drought monitoring programme carried out at the Decision Support Centre of NRSA, established under Disaster Management System of Department of Space need to be strengthened as a nodal agency and with the participation of India Meteorological Department and Indian Council of Agriculture Research Institutions for ground truth support. The continuous monitoring and early warning should be made available to the public in website.

The detailed drought assessment using high resolution WiFS/ AWiFS data can be studied by the state government with the help of State Remote sensing centre or the NGOs within the state to carry out independent assessment on the drought conditions at sub district level. The technology developed in the present research can be easily adopted for both district and sub district level drought monitoring in the country.

11.6 RECOMMENDATIONS FOR FURTHER RESEARCH

1. There is a need to combine INSAT based rainfall estimate with the rainfall estimate from other space agencies with the good network of ground observations for the spatial rainfall estimates over India.

2. As there was good relation between satellites based surface temperature both in infrared and microwave with the drought condition. Further research should address its daily variation with other climatic factors, so that it can be used operationally for drought monitoring.

3. Further research is required to utilize the frequent data from INSAT VHRR with other satellite data from DMSP-SSM/I, NOAA-AVHRR, TERRA/AQUA-MODIS thermal data to study evapotranspiration.

4. The present study on INSAT CCD suggests that due to its better geometric accuracy, high revisit of every 30 minutes and comparable vegetation index than NOAA AVHRR, the further research study to correct for different sun and look angle for making it for operational drought monitoring.

5. The present NOAA AVHRR data processing the precision geometric correction is carried out by manual method of identifying the ground control points for rectification. Further research is needed for development of automatic GCP selection algorithm to reduce further processing time.
6. The present study suggests that there is a significant effect of aerosol on NDVI, further development of atmospheric correction algorithm to be developed for day to day use.

7. For the drought prone identification, since the present study with the coarse resolution NOAA AVHRR data of 1km resolution provides encouraging result at regional level over different states, the use of high resolution IRS WiFS based historic data can be further studied to estimate the drought proneness under each watershed for further developing management strategies.

8. As there is a time lag between the rainfall and the NDVI, further research is needed to find the relation between soil moisture and NDVI, which will give better early warning than the rainfall.

9. IRS P6 (Resourcesat) AWiFS provides better spatial resolution to identify crop types, there is a need to develop mathematical models by relating NDVI with agro-meteorological parameters and the productivity to study the drought impact.