A Customized GIS Application to Create and Analyze Drought Characteristics using Geoinformation Technologies

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Abstract
In this study, different drought indices have been analyzed with the aim of deriving Normalized Difference Vegetation Index (NDVI), Aridity Index (AI), and Standardized Precipitation Index (SPI) using remotely sensed and meteorological data. The indices are derived using mean temperature, precipitation, vegetation, and evapotranspiration (ET0). MODIS NDVI product for the drought year 2002 and drought free 2005 has been acquired from the archives of GODDARD Space Flight Center. NDVI is used to calculate the vegetation index, AI is computed to analyze the temperature and rainfall, and SPI are calculated to quantify the precipitation deficit. Drought indices are analyzed on monthly basis through spatial maps generated using Geographical Information System and geostatic environment. The study reveals that the state is having diverse drought conditions in 2002 when compared with 2005. Particularly the Rayalaseema region suffers more droughts due to poor and delayed monsoon and insufficient water. Telangana region also has some effect of drought due to abnormal rainfall. The drought is also found in part of north Andhra region. The spatial maps of these indices are customized using MapObjects in Visual Basic Environment (VBE) with user-friendly tools.

1. Introduction

Drought is defined as an extended period, a season, a year or more of deficient rainfall relative to the statistical multiyear average of a particular region (Murthy and Sesha Sai, 2009). A drought measures accumulated precipitation deficit, or accumulated departure from normal. In India about 68% of the country is prone to drought in different levels. The major drought years in India were 1877, 1899, 1918, 1972, 1987 and 2002. Droughts lead to the loss of rural employment, starvation, loss of human life due of lack of revenue, and even suicide due to the stress. It has been reported that Andhra Pradesh, Maharashtra, Karnataka, and Madhya Pradesh have together seen 89,362 farmer's suicides between years1997 and 2005 (Hindu, 2007). In Andhra Pradesh alone there were 16,670 deaths between 1997 and 2005. Andhra Pradesh was the first State in India to appoint a commission to go into the agrarian crisis. There are number of parameters for estimating and analyzing the drought. Precipitation can be considered to be the carrier of the drought signal, while temperature, relative humidity, stream flow and ground water levels can be considered to be the last indicators of the occurrence of a drought (Hare, 1987 and Klemes, 1987). The World Meteorological Organization defines a drought index as an index that is related to cumulative effects of a prolonged and abnormal moisture deficiency. There are several indices that measure drought using different input parameters. These indices provide useful information than raw data values in decision making. Over the years, various indices have been developed to study the drought and all these indices have strengths and weakness. In the beginning, drought is quantified from a deficiency of precipitation that results in water shortage for an activity. Some other criteria are i) fifteen consecutive days with no rain; ii) twenty one days or more with precipitation less than one third of normal; iii) annual precipitation that is less than 75 percent of normal; iv) monthly precipitation that is less than 60 percent of normal; and v) any amount of rainfall less than 85 per cent of normal (Richard, 2000). Friedman (1957) used these criteria to quantify the drought index in a study of Texas. Palmer (1965) formulated a drought index for use in US Great Plains, based on a simplified water balance. Because of the inadequacies in the Palmer model, Shear and Steila (1974) proposed an alternate approach of using water budget analysis to identify moisture anomalies. This process accounts for precipitation, potential evapotranspiration, and soil moisture. Another index is that Surface Water Supply Index (SWSI) (Schafer and Dezman, 1982) formulated for use in mountainous areas where snowpack plays a significant role. NDVI values are useful for drought monitoring, made for the natural differences in vegetative type associated with background climate. McQuigg (1954) and Waggoner and O'Connel incorporated both the amount and timing of precipitation in their Antecedent Precipitation Index (API). In 1993, McKee et al., (1993) developed a new index, the Standardized Precipitation Index (SPI) to improve operation water supply monitoring in Colorado. Vergni and Todisco (2011) carried out a spatio temporal variability of precipitation, temperature and agricultural drought indices in central Italy using SPI and Standardized Deficiet Index (SDI). These two indices were analyzed with reference to different periods. The results obtained for SPI and SDI are in accordance with the tendencies of non-standardized indices. Bhuiyan et al., 2012 used Standardized Precipitation Index (SPI) has been used to quantify the precipitation deficit in Rajasthan, India. Standardized Water-Level Index (SWI) has been developed to assess ground-water recharge-deficit. Vegetative drought indices like Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) and Vegetation Health Index (VHI) have been computed using NDVI values obtained from Global Vegetation Index (GVI) and thermal channel data of NOAA AVHRR satellite. The study reveals that comparison to hydrological stress, vegetative stress in the Aravalli region is found to be slower to begin but quicker to withdraw (Bhuiyan et al., 2010). Steven et al., (2003) carried out a study on an evaluation of agricultural drought indices for the Canadian prairies. A series of curvilinear regression-based crop yield models were generated for each of the 43 crop districts in the study region based on four commonly used measures of agricultural drought (Palmer Drought Severity Index, Palmer's *Z*-index, Standardized Precipitation Index, and NOAA Drought Index). The analysis indicated that Palmer's *Z*-index is the most appropriate index for measuring agricultural drought in the Canadian prairies. The model evaluation indicated that the *Z*-index is best suited for predicting yield when there is significant moisture stress. Rhee et al., (2010) used remote sensing for monitoring agricultural drought for arid and humid regions using multi-sensor data. Scaled Drought Condition Index (SDCI), for agricultural drought monitoring in both arid and humid regions using multi-sensor data. This index combines the land surface temperature (LST) data and the Normalized Difference Vegetation Index (NDVI) data from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, and precipitation data. Ghulam et al., (2010) applied a Modified perpendicular drought index (MPDI) introducing vegetation fraction that takes into account both soil moisture and vegetation growth. To validate the drought indices Enhanced Thematic Mapper Plus (ETM+) and MODerate Resolution Imaging Spectrometer (MODIS) images from different times registered over different eco-systems with various drought conditions are used to calculate the Perpendicular Drought Index (PDI) and MPDI over ground measuring points. MPDI demonstrates a much better performance in measuring vegetated surfaces since it takes into account both soil moisture and vegetation growth in the modeling process. Narasimhan and Srinivasan (2005) carried out Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for gricultural drought monitoring. The developed drought indices showed high spatial variability (spatial standard deviation +_ 1.00) in the study watersheds, primarily due to high spatial variability of precipitation. The present study envisaged to derive and analyze the drought indices using remotely sensed data in conjunction with meteorological data for the year 2002 and 2005. The study also incorporates to develope a customized application for computation and visualization of drought indices in GIS environment.

2. Materials and Methods

2.1 Description of the Study Area

Andhra Pradesh state is located in the southern part of India. It borders Maharashtra, Chhattisgarh and Orissa in the north, the Bay of Bengal in the East, Tamil Nadu to the south and Karnataka to the west (Figure 1). The state is also called as called the '*Rice Bowl of India*' because of the large production of rice. Rice, sugarcane, cotton, Chili pepper, mango, and tobacco are the local crops. The state is India's fourth largest state by area and fifth largest by population has 24 districts with rural and urban population 75,727,000 and covering an area of about 275045 km². This area is bounded between 12°41' and 22°N latitude and 77° and 84°40'E longitude. The state is composed of the eastern half of the Deccan plateau and the plains to the east of the Eastern Ghats. It is divided into three regions, northern part of the plateau is the Telangana region and the southern part is known as Rayalaseema and third region is Coastal Andhra. Monsoons play a major role in determining the climate of the state. The state receives heavy rainfall from Southwest Monsoon during these months. About one third of the total rainfall in Andhra Pradesh is brought by the Northeast Monsoon. Summers last from March to June.

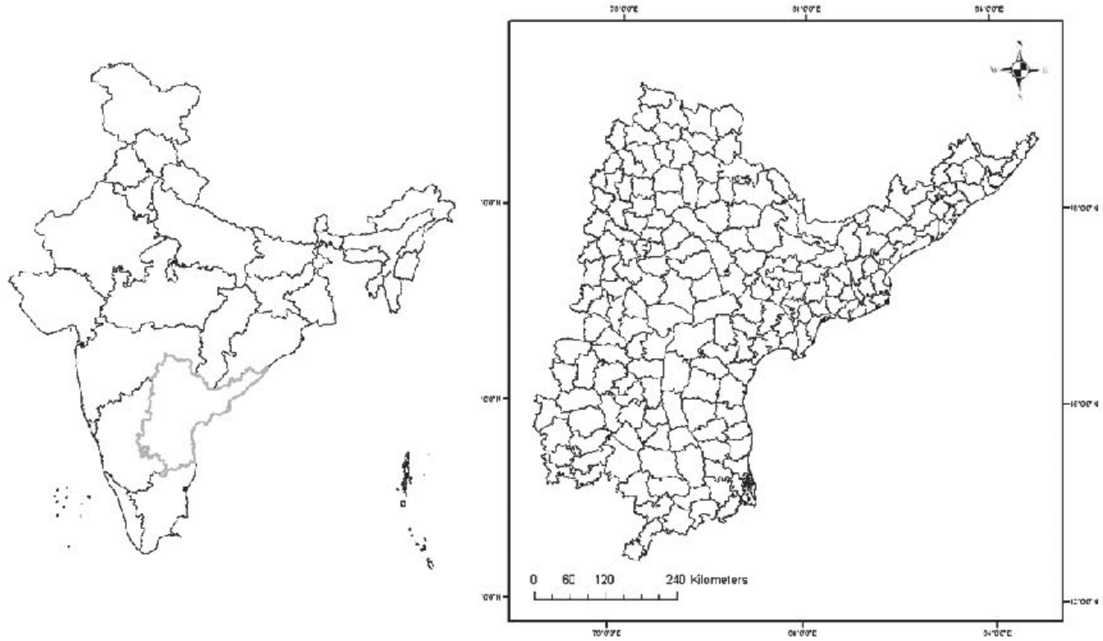

Figure 1: Location map of the study area

In the coastal plain, the summer temperatures are generally higher than the rest of the state, with temperature ranging between 20 °C and 41 °C. The primary reason for selecting the study area is that the state of Andhra Pradesh is frequently affected by drought conditions. The most recent was the drought of 2002, that ranked fifth in terms of magnitude but is unique when examined in overall terms of magnitude, spacing, dispersion and duration. In July 2002, rainfall deficiency dropped to 51%, surpassing all previous droughts. Particularly the districts namely Anantpur, Chittoor, Cuddapah, Hyderabad, Karnool, Mehboobnagar, Nalgonda, Prakasam are severely affected by the drought. Unfortunately the state is also affected with excess rainfall and regular floods. Kurnool, Mahbubnagar, Krishna and Guntur are the worst flood affected districts. Overall, at least 1.8 million people in nearly 400 villages of Andhra Pradesh have been affected by the floods. Therefore, the state is more vulnerable to both insufficient and excess rainfall. Hence it is meaningful to study and analyze the drought condition in Andhra Pradesh particularly in the drought year of 2002, and the indices are compared with non-drought year of 2005. The state is having good rainfall during some of the years (except drought years) having good ground water recharge with major rivers falling in the states. But in the recent years the state is again frequently hit by drought. Some of the drought effected districts in year 2010 have given up hope on the kharif crop as rainfall has been very low and there is no possibility to sow seeds (IMD, 2010). Therefore it becomes more meaningful to study on the drought situation to implement alternative methods to tackle the crisis.

2.2 Remote Sensing and Ancillary Data

The Normalized Difference Vegetation Index (NDVI) data product derived from bands 1 and 2 of the Moderate-resolution Imaging Spectroradiometer (MODIS) on board NASA's Terra satellite is used for the year 2002 and 2005 (Carrol, 2003). The ortho-rectified MODIS satellite data (UTM/WGS 84 projection) provided by Global Land Cover Facility was used). Monthly series of NDVI observations were used to examine the dynamics of the drought in the region. In order to compare the images, the original images were resampled to the resolution of the actual values. Monthly precipitation, mean temperature data are taken from India Meteorological Department, India. These data sets are validated data sets which are further processed to generate the spatial surfaces of the state. Spatial surfaces of monthly mean temperature and rainfall are generated using krigging interpolation technique (New et al., 2002). Around 30 ground stations (IMD) for rainfall and temperature were used for the study.

2.3 Image Classification

Two independent resources (Survey of India topo sheets and ground truth data) were used to classify NDVI. The satellite imageries were classified and different land use and land cover categories are delineated on the basis of NDVI values namely water, bare soils, fallow land, agriculture, vegetation. Ground truth collected during field visit was used for the accuracy assessment. The aim of this study is to analyze the different drought indices of the region and to obtain more knowledge on drought monitoring by deriving the indices. The study addresses on NDVI, AI and SPI. For estimating these indices the study takes an integrated approach by using satellite remote sensing data together with meteorological data sets. During the period of drought conditions, physiologic changes within vegetation are very prominent. NDVI is very easy to use readily available indices because; satellite sensors have the capability to distinguish such changes within vegetation for a larger region. The visible and near infrared (IR) bands on the satellite multispectral sensors allow monitoring of the greenness of vegetation. MODIS data NDVI product is obtained for the physiologic changes within vegetation of the state. Otherwise NDVI is defined as:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Equation 1

Aridity Index (AI) derived by Blaney- Cridle is about quantifying degree of dryness of a climate in the region (Huschke, 1970). This index is more predominant on temperature data to identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of the land for such activities as agriculture or stock-farming.

$$AI = \frac{P}{ET_O}$$

Equation 2

P - is the cumulative monthly precipitation

ET_O - is the monthly potential evapotranspiration

$$ET_0 = p * (0.46 * T_{mean} + 8)$$

ET_0 - is the monthly potential evapotranspiration

T_{mean} – is the mean daily temperature

p –is the mean daily percentage of annual daytime hours

Colorado State University developed a new drought index called, the Standardized Precipitation Index (SPI) (McKee et al., 1993) to improve operation water supply monitoring in Colorado.

The SPI works more on the precipitation factor, designed for any location based on the long term precipitation for a desired period (one month, three months, six months, year, etc). SPI is:

$$x_i = \frac{X = X}{S_x}$$

Equation 3

Where: X_i -is the monthly RF_{mean}

$\overline{X}$ - is the monthly RF

s_x - Standard deviation of monthly RF_{mean}

All the above indices give accurate results only when the input data used in the formula are accurate. MODIS NDVI product for the year 2002 and 2005 are classified into 5 major classes namely, water, bare soils, fallow land, agriculture, vegetation. AI and SPI were computed using equations (2) and (3) with the input of monthly mean temperature and rainfall. GIS and geostatic modules were used for the computation. Monthly surfaces of mean temperature and rainfall are generated by using kriging interpolation algorithm. Later these surfaces are used as inputs in AI and SPI computations. Later these final indices are customized using Map Objects in Visual Basic Environment. The indices derived from remote sensing data and weather data were used to quantify the drought over the study area. Table 1 suggests the classification scale for different drought indices. These drought indices are having their own suitability with respect to the region and climate. In general, from agricultural point of view, a drought is not merely a deficiency of rainfall, but a deficiency of water available for the use of growing crops. In addition to the above drought indices satellite imagery has been used to derive different drought indices.

3. Results and Discussions

The year 2002 was declared as severe drought year in India. The value of the total loss in agricultural production during the major drought years ranged from Rs 9,289 crore in 1972-73 to Rs. 37,382 crore in 2002-03 (PACS, 2008). The state of Andhra Pradesh was also severely affected with drought condition in 2002. The state has officially declared as a drought year affecting majority of districts namely, districts Anantapur, Chittoor, Cuddapah, Hyderabad, Kurnool, Mehaboobnagar, Nalgonda, and Prakasam.

Table 1: Classification of SPI, AI and NDVI values

Drought Classes	SPI (McKee et al,1993)	AI (Blaney Criddle, 1950)	NDVI
Extreme dry	-2 and less	0.001	0.02 to 0.09
Severe dry	-1.5 to -1.72	0.001 to 0.30	0.10 to 0.12
Moderate dry	-1.0 to -1.49	0.30 to 0.50	0.125 to 0.140
Mild dry	-0.21 to 0.28	0.50 to 0.75	0.145 to 0.20
No dry	0.28 to 1.31	> 0.75	> 0.205

Rainfall in July, 2002 (most important for agriculture) was 49 per cent 'deficient'. The last time maximum deficit in rainfall recorded below 45 per cent was in the year 1911. Coastal Andhra Pradesh and Rayalseema fall short of 31 per cent below normal rainfall.

Vegetation Index: The remote sensing can be used to assess the rainfall, soil moisture, and vegetation/crop conditions, which are helpful in delineating agricultural drought (Steven et al., 2003). Among the various vegetation indices Normalized Difference Vegetation Index (NDVI) is widely used for drought assessment. The NDVI is easy to calculate, easy to interpret, also availability of satellite imagery. From the NDVI images it is inferred that during august to September, 2002 the state shows good vegetation. The period January to July, 2002 the vegetation experienced stress and loss of vegetation health. Abnormally May 2002 also show good vegetation. The region was affected by drought owing to poor rainfall during the monsoon particularly in the areas of Rayalaseema, the northern Andhra districts, and part of Telangana region. The state was almost drought free during the year 2005 compared to 2002. NDVI values are significantly less than normal, particularly in the districts of Adilabad, Nizamabad, Rangareddy, Mehaboob nagar, Kurnool, Cuddpah etc. indicating the loss of vegetation in 2002 compared to 2005.

3.1 Aridity Index

An Aridity Index (AI) is a numerical indicator of the degree of dryness of the climate at a given location. The AI time series for the monthly data of 2002 are quantified. AI makes it possible to quantity the degree of dryness of a climate in the region. AI makes it possible to quantify the dryness by taking the temperature as input condition for a specific month and time. The temperature value plays a major role in estimating the index. The series of temperature shows a positive behavior from 2002 to 2005. There are also positive trends for the month from January to March and negative behavior from July to December months.

Monthly spatial distribution of mean monthly temperature (Tmean) was acquired from the IMD dataset. Monthly spatial distribution of temperature difference was calculated as the difference between average monthly maximum and minimum temperature, both available from IMD dataset. Monthly potential evapotranspiration (ET_O) is calculated for estimating the AI subsequently using Blaney- Cridle equation. In figure 2a-b annual values of AI in 2002 and 2005 are presented. The value closer to the index one shows the more arid areas which is easier to identify the drought regions and severity of the drought. The drought situation is diverse in the state, for example districts Adilabad, Karimnagar, Warnagal, Khammam, Prakasam, and Srikakulam are severely affected with drought in 2002. The rainfall in this region is normal but ground water levels and the temperatures are bit high in these regions. The index shows lower value in the scale of 0-1 for the server drought prone areas. Interestingly year 2005 also witness a drought for the part of state. The southern part of the state shows a severe drought in 2005.

3.2 Standardized Precipitation Index

The time series of rainfall of the state shows a positive behavior from 2002 to 2005. There are positive trends for all the month from January to December except November. Especially the months during June to October having good rainfall compared with 2005 shows good vegetation (NDVI). Analysis of SPI for Andhra Pradesh was done for 12 months for both of years 2002 and 2005. Particular attention was given to the 12 months of 2002 as the year is drought year in the state. The SPI values for 2001 ranges from -1.1 to 0.8 where as the SPI values in the year 2005 ranges from -1.1 to 1.3. The values quantify the precipitation anomaly with respect to the scenario in 2005 which is drought free year. Figure 3a-b shows the SPI dynamics in the state for 2002 and 2005.It is evident from these indices that majority part of Andhra Pradesh is affected with drought because of the less rainfall.

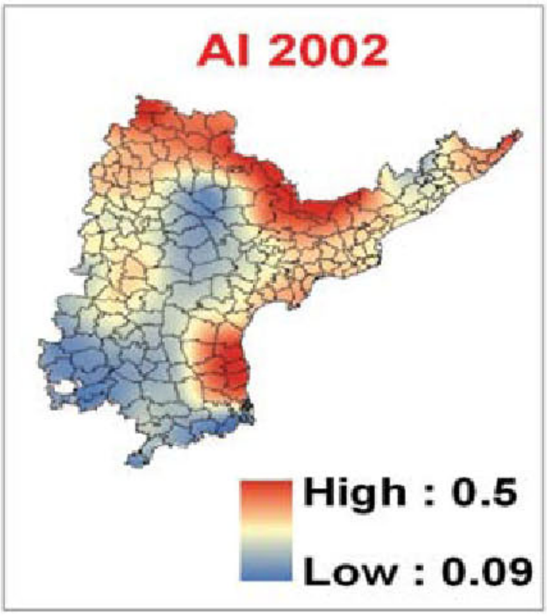

Figure 2a: AI values of the state in 2002

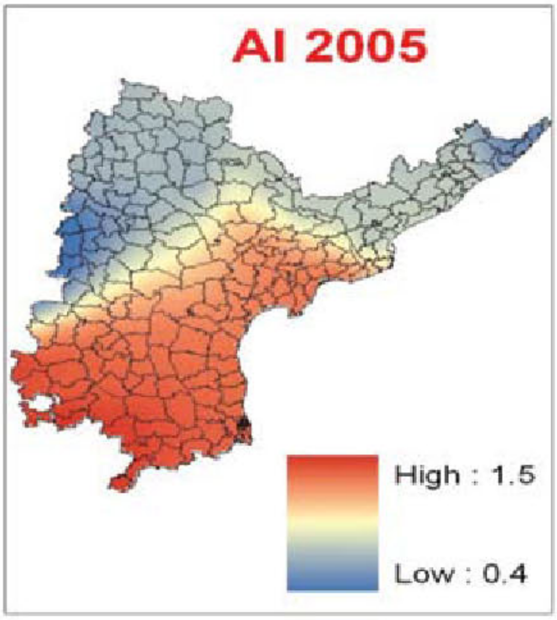

Figure 2b: AI values of the state in 2005

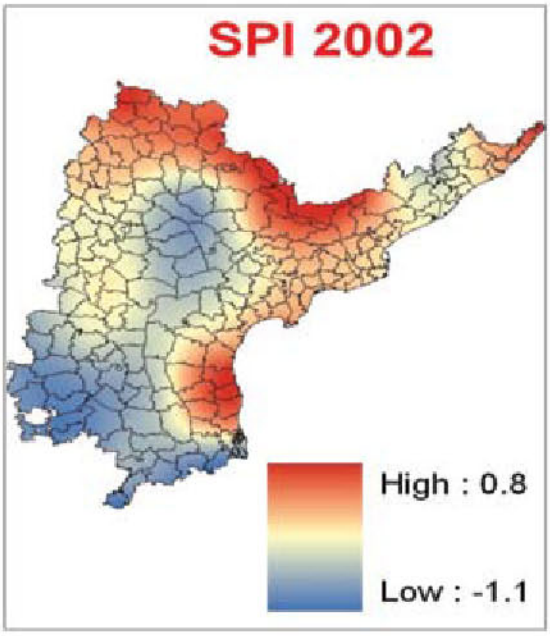

Figure 3a: SPI values of the state in 2002

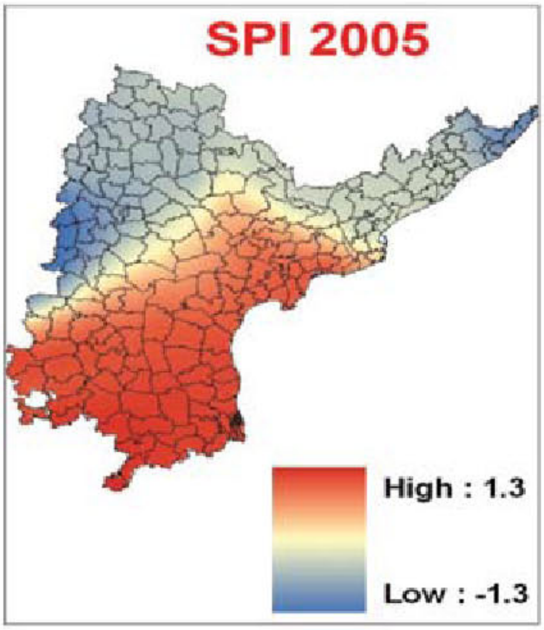

Figure 3b: SPI values of the state in 2005

The SPI values for the most of the regions are between -0.1 to 0.8, which indicates the scenario of severe drought to mild drought. However the values in the 2005 are between -1.3 to 1.3 which is an indicative of comfortable situation compared to that of year 2002. Although, SPI is a typical meteorological drought index, the short time scales (monthly) chosen for the analysis are suitable for detecting the presence which is important indicators particularly from an agricultural view of point. During the beginning of 2002 the SPI values are less (almost close to zero) during January to April. From May the drought began with a very dry August, and then September to December the SPI values are nominal. The monthly SPI values reveal that it is easier to identify the drought regions and severity of the drought.

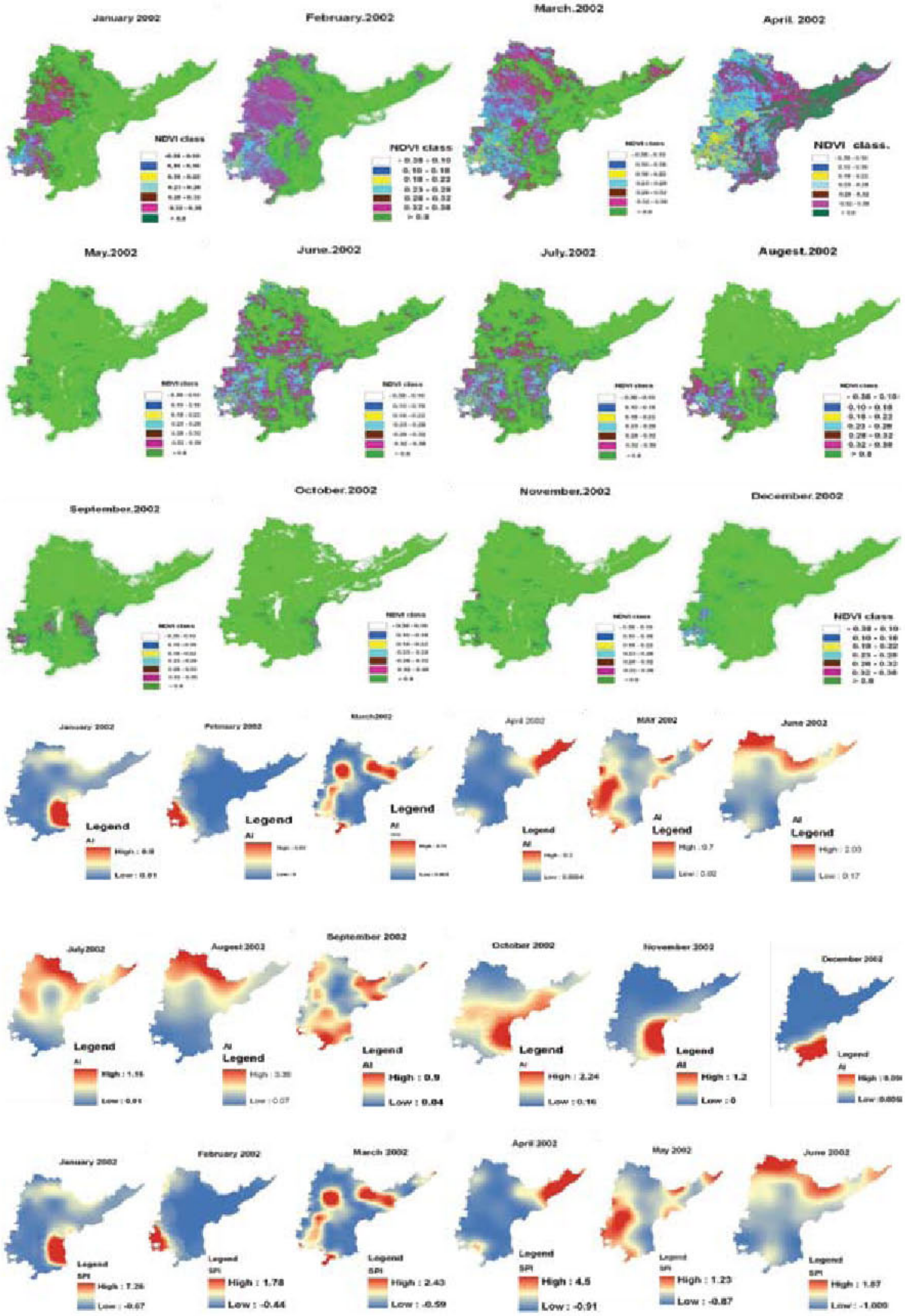

Figure 4a: Good correlation between NDVI, AI and SPI in 2002 (contd.)

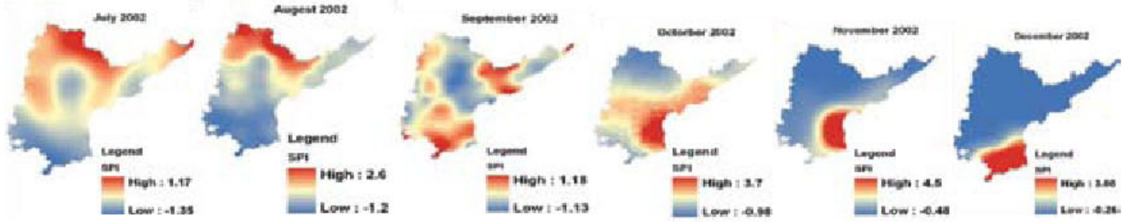

Figure 4a: Good correlation between NDVI, AI and SPI in 2002

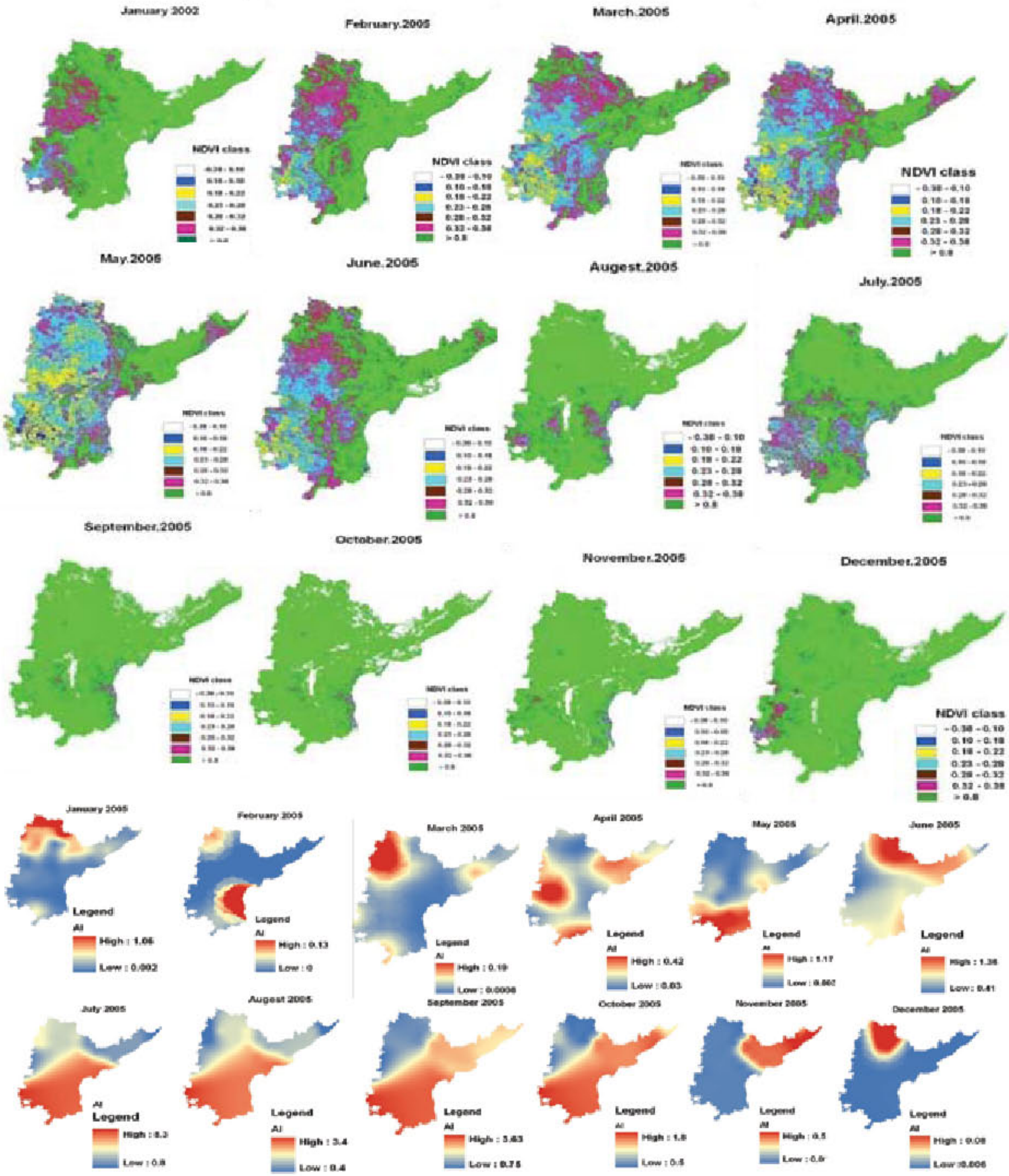

Figure 4b: Good correlation between NDVI, AI and SPI in 2005 (contd.)

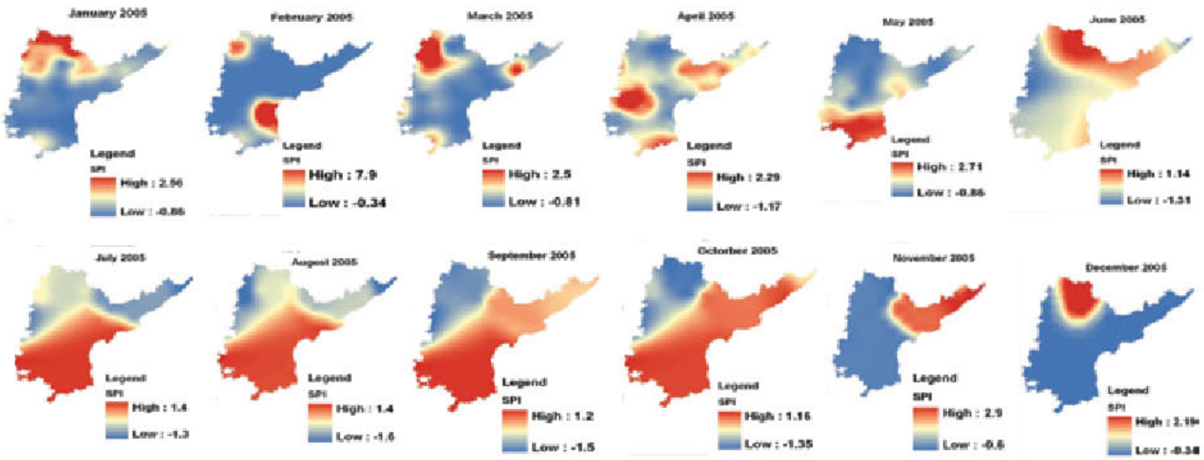

Figure 4b: Good correlation between NDVI, AI and SPI in 2005

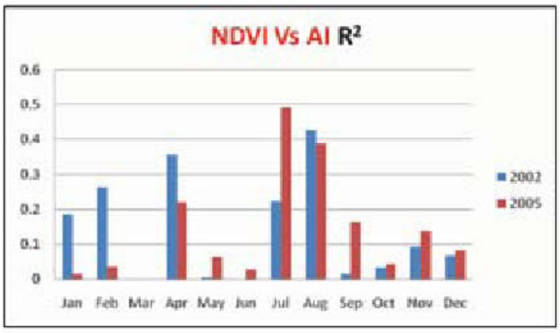

Figure 5a: Regression between NDVI Vs AI

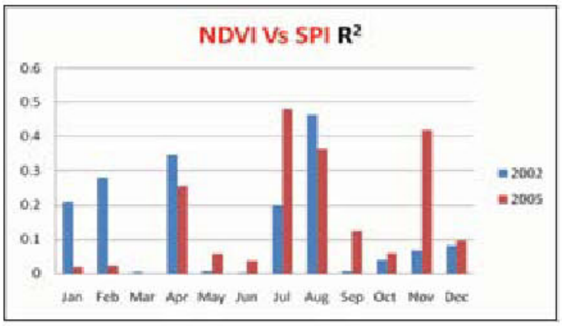

Figure 5b: Regression between NDVI Vs SPI

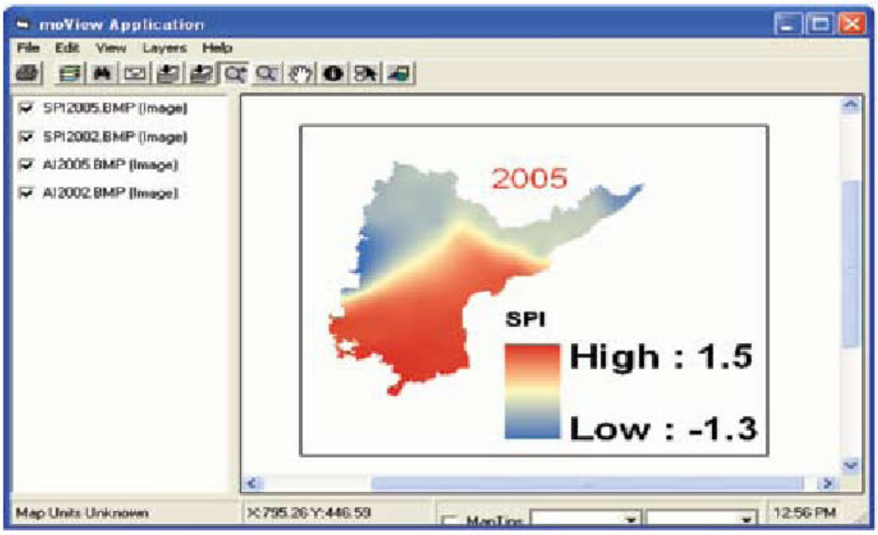

Figure 6: Appearance of drought indices in the customized tool

The drought situation is diverse in the state, for example districts Adilabad, Karimnagar, Warnagal, Khammam, Prakasam, and Srikakulam are severely affected with drought in 2002. The rainfall in this region is normal but ground water levels and the temperatures are bit high in these regions. Interestingly the year 2005 also witness a drought for the part of state. The southern part of the state shows a severe drought in 2005.

4. Relative Drought Dynamics

Calculation of SPI for the study is based on the long term precipitation record for the year 2002 and 2005. This precipitation field in the database was fitted to a probability distribution (Krigging) which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). As per SPI values there is a severe drought in 2002 during June to August. Majority of the districts are affected with drought. Similarly the AI value also reveals that the same districts are affected with drought which is also comparable with NDVI results. The three indices namely NDVI, AI, and SPI indicate that meteorological drought in the Andhra Pradesh appears randomly during January to December (Figure 4a-b). There is a severe drought during June to August in 2002. September and October are having moderate drought issues when compared to the early months in the year. However, certain regions northern state is suffered from drought for a long duration irrespective of good or poor rainfall. These indices show uniform results estimating the drought condition in Andhra Pradesh and hence are very useful for the monitoring and management. Good correlation is observed between NDVI, AI, and SPI during the months January to July. However, the NDVI results show that there is vegetation during August to December 2002. Vegetation consists of forest, plantations, shrubs, etc and which is not able to quantify the meteorological drought. In order to quantify this anomaly AI and SPI plays an important role in understanding the drought. In this case NDVI has not proven to provide information in quantifying the meteorological drought. However, the time series maps of these three indices reveal a good correlation among the meteorological and vegetative droughts in the state of Andhra Pradesh. 90 percent of the drought values coincide with the derived three indices showing that there is a good match between these drought indices. The analysis of these three indices shows that AI values are more closure to SPI values though they are derived from different weather parameters temperature and precipitation respectively. The results of the indices are derived from remote sensing images (NDVI) and meteorological data (AI, SPI). A good correlation is observed between all the three indices derived in the study. However, the regression results AI and SPI are the important indices to explain the drought phenomenon. The seasonal values of NDVI are being compared to AI and SPI values (Figures 5a and 5b). The 12 month values of the NDVI are in close agreement with an error of 10-12% that of AI and SPI of years 2002 and 2005.

5. Customization of Drought Indices in Visual Basic Environment

The drought application has been customized using ESRI's MapObjects 2.1 in the Microsoft's Visual Basic Environment (VBE). The tool is powered with user friendly interactive forms for each command. All forms consist of labels, textboxes, command buttons and pictures for guiding the end user to effectively handle the tool. The user friendly toolbar has been added with zoom in, zoom out pan, identity, full extent, spatial query, print, spatial selection. All most all features of generic GIS functions also been added for advanced representations. The main features of tool are:

a) User friendly tool bar: All the interfaces of the application are fully user friendly with rich look and feel.
b) Add/Remove layer menus.
c) Search option.
d) Rendering option to reveal the attribute information.
e) Symbolization.
f) Class breaker analysis.
g) Feature selection with retrieval the attribute information.

The application is developed with a Visual Basic from end forms for easy to use environment. The application GUI has File, Edit, View, Layers, Help menus with utility tool box (Figure 6).

6. Conclusions

Drought is a difficult and uncertain phenomenon to define, detect, and measure. Researchers are trying to develop different indices for quantifying them. These indices are helpful for compare current conditions with past conditions. The indices provide a simple, quantitative assessment of drought characteristics namely intensity, duration, and spatial extent (Hayes et al., 2000). The indices are useful for monitoring and management of the drought affected areas. SPI, AI, and NDVI maps indicate that meteorological drought appears in the state of Andhra Pradesh during 2002 and some part of the state in 2005. Different drought indices reveal linear correlation over the period. The spatial maps of AI and SPI are having very good correlation in all the time period. However, the NDVI results showing vegetation vigor during August to December 2002 does not match with the indices of AI and SPI. This vegetation may be forest, plantations, shrubs, etc which is not able to quantify the meteorological drought.

In order to quantify this anomaly this AI and SPI plays an important role in understanding the drought. Hence to quantify the meteorological drought NDVI is not much useful technique. However, the time series maps of AI and SPI indices reveal a good correlation among the meteorological droughts in the state of Andhra Pradesh.

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