Remote sensing based drought indicator

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Abstract: Large area worldwide is affected by drought affecting millions of people. Drought is caused by spatial and temporal variability in rainfall. Deficit in rainfall in crop growing season may impact the crop growth and yield. Indicators are used for identification and quantification of drought. The indicators could be based on hydrometeorological data e.g. rainfall, reservoir storage, soil moisture. On other hand, remote sensing data could also be utilized for monitoring of the drought. Crop vigor influence the signature in the remotely sensed data in visible and near infrared atmospheric windows. Crop stress due to moisture deficit, crop deceases causes reduction in infrared reflectance and increase in red reflectance from the crop canopy. It is monitored using an index, namely Normalized Difference Vegetation Index (NDVI) computed using these two bands. Stressed crops show reduction in NDVI. Thus, the index could be used in monitoring the drought situation. Rainfall is widely used in drought monitoring. Standardized Precipitation Index (SPI) is based on precipitation and negative value of the index, in particular lower than -1 is indicative of drought. In the study, rainfall data for Haryana subdivision of IMD's Homogeneous Indian Monthly Data Sets (1871-2012) are used for computing SPI. Drought conditions were detected in monsoon months for the 2009, 2002, 2007, 2004 and 2006 in decreasing magnitude based on monthly SPI. MODIS data (8-day composite) are used to compute NDVI for June to October 2007. District wise mean NDVI was computed. NDVI value dropped in July 2007 in most of the districts except Panipat and Karnal. SPI in the subdivision is negative in months of July to September 2007. This indicates that NDVI may be useful indicator for drought conditions and there by its impact on vegetation.

Keyword: Drought, SPI, NDVI, MODIS, Haryana

1.0 Introduction:

Drought is caused due to significant deficit in water including that stored in soil vadose zone. Water is a renewable natural resource with precipitation as main source of renewable water. A significant deficit for a time step may signify drought in entire period of the deficit rainfall. If subsequent rainfall is unable to wipe out accumulated deficit, drought prolongs. Drought situation is only averted when large rainfall occurs. Drought impacts all form of life including crops and vegetation. Human population depends on food grains for survival and any crop failure resulted due to drought affect them. Drought situation is routinely monitored through rainfall information. Departure from normal precipitation is used as drought indicator. In case of drought onset and persistence, necessary steps are required to be taken to alleviate the problem.

Crop condition is easily monitored using remote sensing. Crop health and growth is effected due to various factors e.g. disease, water stress etc. Crop growth is monitoring using crop reflectance in red and NIR bands and the several indices e.g. Normalized Difference Vegetation Index (NDVI) derived using these bands. For stressed crops, red reflectance increases and NIR reflectance reduces. This causes NDVI to reduce for these crops. NDVI increases with crop growth. Near crop senescence to harvest period, NDVI values reduces. Thus, using NDVI crop growth and health may be monitoring. This in turn may be indicative of the drought situation. Since these may be short term affects, frequent spatial data coverage of the area may be required. This may be achieved by medium to coarse resolution data e.g. MODIS, AVHRR etc.

2.0 Drought indices:

It is difficult for decision maker to interpret reflectance or digital number in the original satellite data, hydrometeorological times series data etc. Data sets may either be suitably transformed or number may be derived from these data which may point towards certain desired property of the system. These derived data typically represent deviations from representative statistics derived from the historical data. Several indices e.g. Percent of Normal, Standardized Precipitation Index (SPI), Palmer Drought Severity Index, Crop Moisture Index, Surface Water Supply Index, Reclamation Drought Index, Decile etc. [2] based of hydrometeorological data are used as drought indices. SPI detects drought earlier compared to Palmer Index and thus has been adopted by National Drought Mitigation Centre (NDMC) of USA.

2.1 Standardized Precipitation Index (SPI):

SPI is useful for early warning of drought. It is less complex than indices e.g. Palmer Index. SPI is computed at several time scales e.g. weekly, fortnightly, monthly, 3-, 6- monthly, yearly etc. The method is based on fitting suitable probability distribution to time series of the data. With the rainfall data, Gamma probability distribution is usually fit. Parameters of the distribution may be computed using Thom's approximation. For any rainfall, the probability of occurrence is computed using the distribution. For this probability value, standard normal variate (Z value) or SPI is estimated from standard normal distribution. For estimation of parameters of the Gamma distribution, zero values in the rainfall time series are replaced by small rainfall amount (usually one hundredth of a mm). Based on SPI, drought magnitude and period may be defined. Deficit period is defined as one where all consecutive SPI values are negative with positive value before and after the period. When at any time step, SPI value is equal to or less than -1 in the deficit period, the period is termed as drought period. Drought magnitude is positive sum of SPI during drought period. Drought duration is length of the drought period (http://drought.unl.edu/ranchplan/DroughtBasics/WeatherDrought/MeasuringDrought.aspx) [4]. Drought magnitude is nearly equal to drought duration. Drought types are categorized as mild or near normal, moderate, severe and extreme based on SPI ranges of 0 to -1, -1 to -1.5, -1.5 to -2 and beyond respectively.

2.2 Normalized Difference Vegetation Index (NDVI):

NDVI is estimated as ratio of difference in near infrared and red reflectance to sum of both. Its value varies between -1 and +1. NDVI for healthy vegetation is always higher than zero. NDVI depends on leaf area index (LAI), chlorophyll content and leaf cell structure (in turn on photosynthetic activities) and percent ground cover. Due to dependency of the NDVI on LAI, NDVI will change with crop growth. For vegetation, reflectance is high in near infrared (NIR) band and low in red band. High reflectance from healthy green leaves in NIR band is caused due to cell structure of the leaves. Low reflectance in red band is caused due to large absorption of light by chlorophyll. NDVI is calculated using different band for various sensors. NDVI for NOAA Advanced Very High Resolution Radiometer (AVHRR) and MODIS is calculated using bands 1 (Visible) and 2 (NIR). Deviation in the normal NDVI profile is indicative of stress in the vegetation.

NDVI for a location are influenced by factors other than vegetation. These factors are extent of vegetative cover, atmospheric aerosols, viewing angle, sensors degradations, spatial extent of vegetative cover etc. In early growth stages, the vegetative cover is small. In such case reflectance is received from soil and vegetation both, reducing the NDVI value. Soil may affect NDVI up to 20%. The reflectance properties of soil will differently affect the NDVI values. At vegetative cover greater than 75%, soil effect is small. Higher aerosol presence in atmosphere reduces NDVI. Scattering effect is more in red band and it increases red reflectance and in turn reducing NDVI. Short period aerosol effects are offset by using Maximum Value Composite (MVC). At nadir view, underneath soil has more visibility. Off nadir view has more atmospheric attenuations. Thus, off nadir views do not provide correct information for crops. In general, off nadir view of more than 40° are not used. Deterioration of sensors may also reduce NDVI values and require corrections. In coarse resolution data, the crop areas will be mixed with other land use and cover types e.g. roads, built up, perennial vegetation etc. At the end of crop season, decrease in NDVI values could also correspond to crop stress or wilting, rather than harvest. Crop calendar could be useful in interpreting NDVI profiles. Cloud presence obscures the view of land and thus composites are often used. This limits the availability of NDVI information for shorter periods e.g. less than 8 to 10 days.

2.3 Vegetation Condition Index (VCI):

Value of the average NDVI during particular period of the year will vary year to year depending on crop stress, sowing period, crop type sown etc. The condition of crop may be assessed in various ways e.g. comparing average NDVI value with the corresponding value in a normal year or a long term average, normalizing the NDVI value etc. NDVI value is normalized with respect to historical range of values for the corresponding period. The normalized index is called VCI. The period for VCI could be week, season etc. VCI value increases with increasing NDVI from historical minimum to maximum. Zero VCI occurs at minimum NDVI.

2.4 Standardized Vegetation Index (SVI):

SVI is derived from NDVI for a give time period. SVI assumes normal distribution for NDVI values at a location for given time period and is Z- value (standard normal variate) corresponding to NDVI value. Mean and standard deviation of NDVI for a location and time period are required for computing SVI. Zero SVI corresponds to historical mean NDVI value. Negative value indicates stress condition.

3.0 Review:

Plant density (PD) i.e. stems per unit area was measured during growing period at 10 day interval during 1985 to 1994 for wheat crop. It is a measure of vegetation density and productivity (both biomass and grain yield). PD values were normalized by the range with zero value at the median. At observation sites, average NDVI was computed for a window of 3 X 3 GVI (Global Vegetation Index) pixels. NDVI and VCI were computed for two year namely 1991 and 1992. For dry condition lower values of VCI were observed compared to wet conditions, in particular values were very low during middle of the season. There was also drop in the NDVI value of dry season compared to wet season. Agreement in temporal variation in plant density deviation (PDD), i.e. normalized PD and VCI was seen in both normal and stressed conditions [3].

SVI maps in western USA were compared to weekly Drought Monitor (DM) products prepared from climatic, water resources data and expert feedback. Weekly NDVI for year 1989 to 2000 is obtained from AVHRR data by finding MVC. For most of the data 14-day composite was interpolated to obtain weekly composites. DM and SVI maps are broadly in agreement. Difference occurs due to variation in the sowing dates for the crops compared to normal sowing dates. SVI was found to respond to short term weather changes [5].

National Agriculture Drought Assessment and Monitoring System (NADAMS) is operation at National Remote Sensing Centre (NRSC), Hyderabad since 1989. Near real time agriculture drought related information from satellite data are generated for 13 states at state/ district/ sub district levels. For 11 states, daily NOAA AVHRR data are used. For four states namely Andhra Pradesh, Karnataka, Haryana and Maharashtra, district and sub district level drought information and fortnightly/ monthly reports are generated using AWiFS and WiFS data (http://www.dsc.nrsc.gov.in/DSC/Drought/index.jsp).

4.0 Study area:

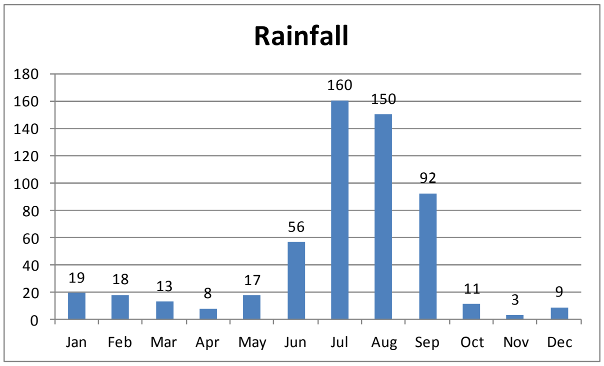


Fig. 1 Average monthly rainfall (in mm) for Haryana meteorological sub division

Haryana, a state in north India, is situated between 27° 37' and 30° 35' latitude and 74°28' and 77°36' longitude. Altitude of the state varies from 200 to 1200 m. Geographic features in the state are Yamuna-Ghaggar plain, Shiwalik hills, semi- arid desert plain and Arawali hills. Yamuna River flows in the eastern margin. Ghaggar is main seasonal river. Markanda and Sahibi are other rivers of the state. Area of the state is 44,212 sq. km. Nearly 80% of the rainfall occurs from July to September (http://en.wikipedia.org/wiki/Haryana). Average annual rainfall in the meteorological sub division Haryana comprising of Haryana, Chandigarh and Delhi is 617 mm (Fig. 1).

5.0 Data:

5.1 MODIS (MOD09A1):

The Moderate-resolution Imaging Spectroradiometer (MODIS) is a payload scientific instrument launched into Earth orbit by NASA on board the Terra (EOS AM) and Aqua (EOS PM) in 1999 and 2002 respectively. The instruments capture data in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km). The MODIS bands 1 to 7 are centered at 648 nm (Red), 858 nm (near infrared), 470 nm (Blue), 555 nm (Green), 1240 nm (Near infrared), 1640 nm (SWIR), and 2130 nm (SWIR), respectively.

MODIS MOD 09 products are derived from MODIS Level 1B land bands 1 through 7 (http://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=09). The product contains spectral reflectance values. The product MOD09A1 provides 8- day composite at 500 m resolution (https://lpdaac.usgs.gov/products/modis_products_table/mod09a1). The composite is derived by selecting observations from MODIS daily L2G products based on several factors e.g. maximum observation coverage, low view angle, absence of cloud or its shadow, aerosol loading etc. The accompanying data have quality assessment, day of observation, solar azimuth, and view and zenith angles information. The version-5 product is validated Stage-2 product. It has been validated spatially and temporally through ground truth etc. The data is recommended for scientific use. Data is available in tiles of size 10° in HDF-EOS format. The file size is 2400 X 2400. The product is gridded level- 3 product and has sinusoidal map projection.

5.2 Districts GIS layer:

District vector layer of Survey of India digital data set was used.

5.3 Rainfall:

Homogeneous monthly rainfall data are available for meteorological sub division in India (ftp://www.tropmet.res.in/pub/data/rain/iitm-subdivrf.txt) for period between 1871 and 2012. Data are developed by Indian Institute of Tropical meteorology (IITM), Pune. Using data of 306 raingauge stations, monthly rainfall for 30 meteorological sub divisions were developed (ftp://www.tropmet.res.in/pub/data/rain/iitm-imr-readme.txt).

6.0 Software:

6.1 MODIS Reprojection Tool (MRT):

The product is developed for use with higher level MODIS raster (gridded) data products e.g. MOD09A1 available in HDF- EOS data format with Sinusoidal projection. Mosaicking, sub setting (spatial and spectral), reprojection and format change may be done using both command line and GUI interfaces. The product is available on multiple Operating Systems. Output formats supported are raw binary, HDF-EOS and GeoTIFF. Input data of 8, 16 and 32 bit signed/ unsigned integer and 32 bit float are supported. Output data type is same as input. Several projections e.g. LCC, UTM, Albers equal area, geographic etc. are supported. Resampling may be done using nearest neighbour, bilinear or cubic convolution techniques. When multiple input files are selected, these are mosaiced. In GeoTIFF output format, separate output files are created for individual band [1].

7.0 Methodology:

7.1 Reprojection:

A tile of MOD09A1 products available in HDF- EOS data format was reprojected using MODIS Reprojection Tool (MRT). The bands 1 and 2 were selected. Projected coordinate system selected was Lambert Conformal Conic (LCC). Two standard parallels are 12.472944444°N and 35.172805555556°N. Central meridian and parallel are 80.0 and 24.0 respectively. False Eastings and Northings are both 4000000.0. Datum is WGS84.

7.2 NDVI:

NDVI was computed using MODIS band 1 and 2 reflectance values in ERDAS Imagine. NDVI values were computed from 4th June 2007 to 2nd October 2007. Zonal statistics (average) for the district is computed for the NDVI values in ArcGIS.

7.3 SPI:

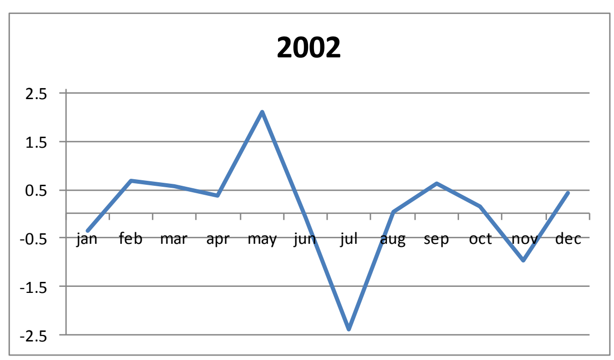
SPI values were computed for time scale of 1-, 3-, 4- months and 1- year using a computer program downloaded from site http://drought.unl.edu/monitor/spi/program/spi_program.htm. The program was written in C++. The precipitation values were entered in one hundredths of mm (i.e. multiply precipitation values in mm by 100). Zero precipitation was replaced by one- hundredth of mm (smallest denomination). This was needed as zeros are taken as missing values by the program.

8.0 Results and discussion:

8.1 SPI:

SPI values for the Haryana meteorological sub division (Fig. 2) indicates drought (at monthly scale) in decreasing order of magnitude for year 2009, 2002, 2007, 2004 and 2006. In computing magnitudes, months from July to September were considered. In year 2007, drought condition exists in July, where as August and September are having deficit rainfall. Thus, period from July to September is treated as drought period. SPI of 3-, 4- months and 1- year time period indicate that year 2006 is drought affected in all the time periods. SPI of 3- months (Jul- Sep) indicates drought in year 2006 and 2007. SPI of 4- month (Jun- Sep) and 1- year indicates drought in years 2006 and 2009. For these longer periods, drought is not indicated in years 2002 and 2004. For short term (1- month duration), condition of extreme and severe drought exists in years 2002 and 2004 respectively. In 2006 and 2007 moderate drought condition exists in a month. In 2009, moderate drought condition exists in two months. Considering various time scales and magnitude of drought, 2002, 2009 and 2006 could be have more pronounced drought conditions compared to other years 2004 and 2007.

One- month SPI based drought magnitude for period July to September indicated very high magnitude in years 1877, 1899, 1938, 1939, 1941, 1987 and 1989 (greater than 2.5). Years arranged in decreasing order of magnitude are 1877, 1987, 1899, 1938, 1939, 1941 and 1989. In 1877, SPI indicates extreme drought In July and August. In 1899, moderate drought is indicated in July and September and extreme drought in August. Year 1938 had moderate drought in July to September. In 1939, drought was moderate and severe in July and August respectively. In 1941, extreme drought occurred in July. Year 1987 saw extreme, close to moderate and moderate drought in July to September. Year 1989 had moderate drought in July.



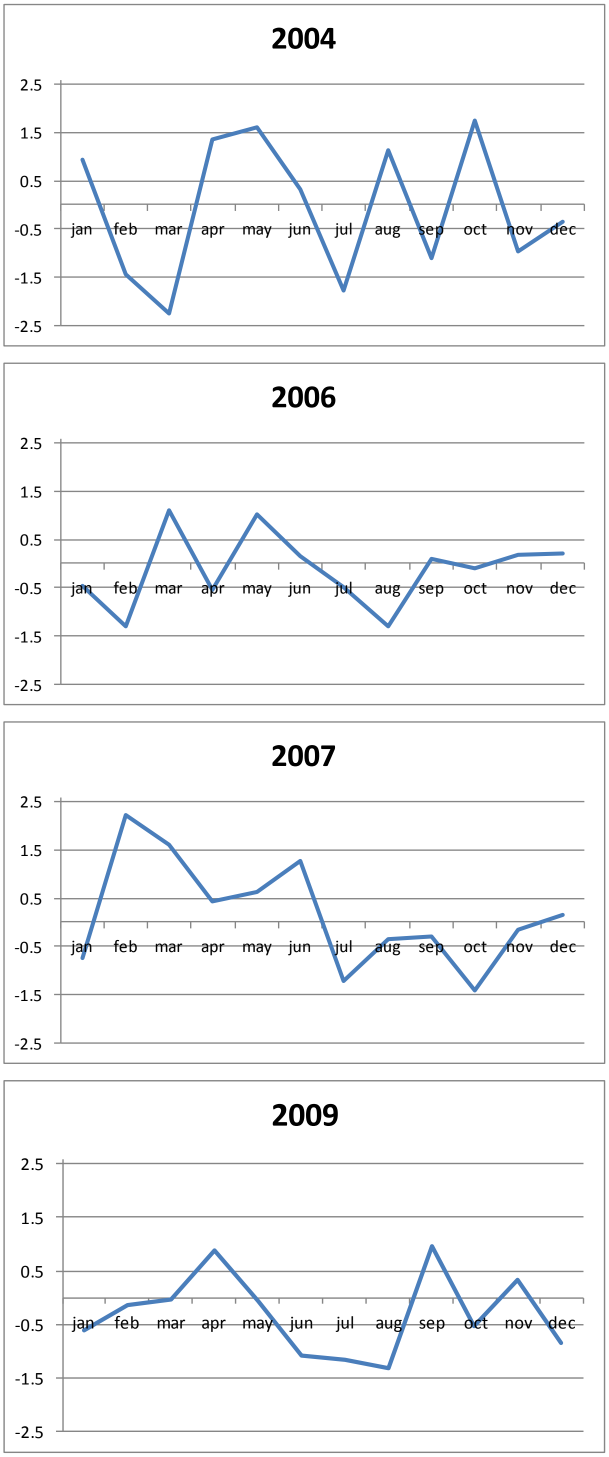
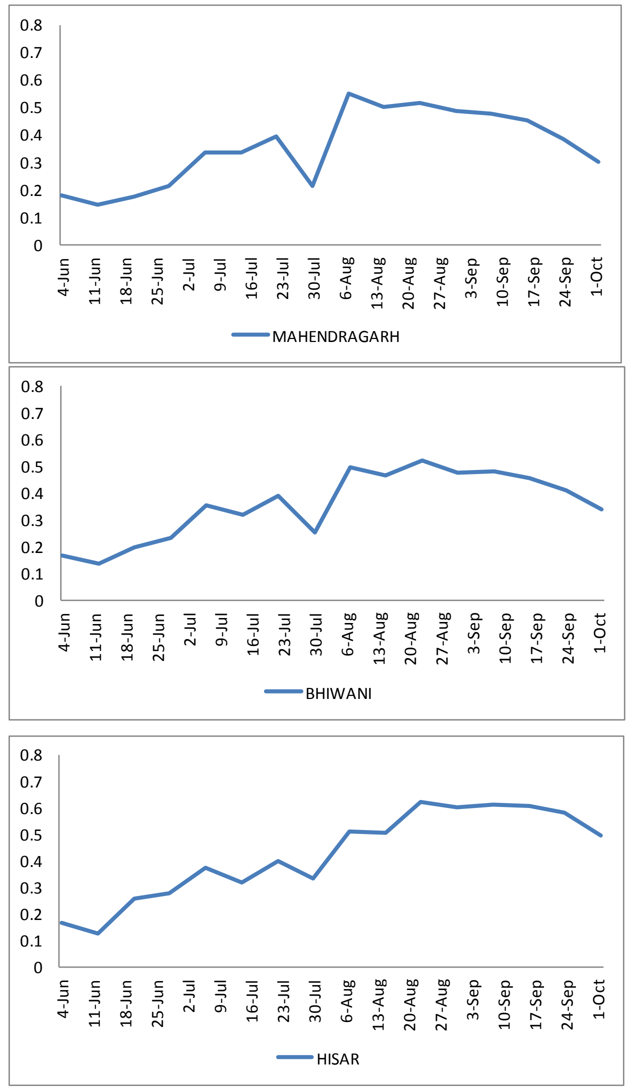


Fig. 2 SPI for drought affected years computed using Haryana meteorological sub division rainfall data

8.2 NDVI:

NDVI profiles (Fig. 3) with values at 8-days interval indicate that mid- August to mid September is peak vegetative period. A dip in average NDVI value was observed in the month of July for the district in Haryana. This may be due to deficit rainfall in the month of July. After July, NDVI profile was restored. This may be due to near normal though deficit rainfall in the period August and September 2007. Relatively small deficit in later months in the monsoon season may have lead to recovery of NDVI values. NDVI images are show in Fig. 4.



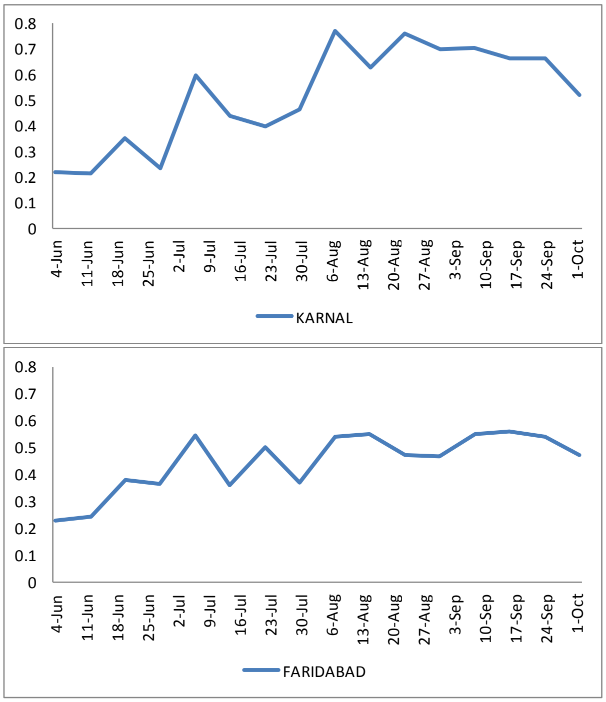
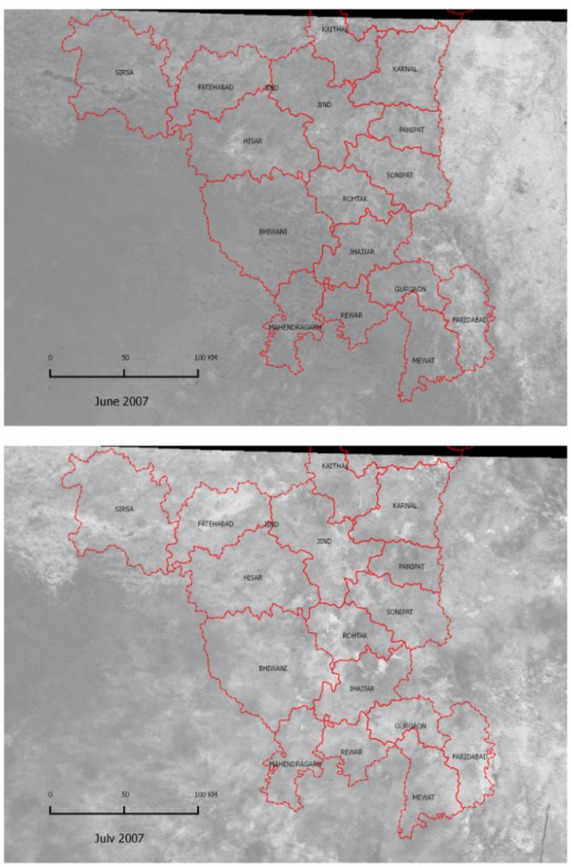


Fig. 3 District wise average NDVI computed from MOD09A1 data



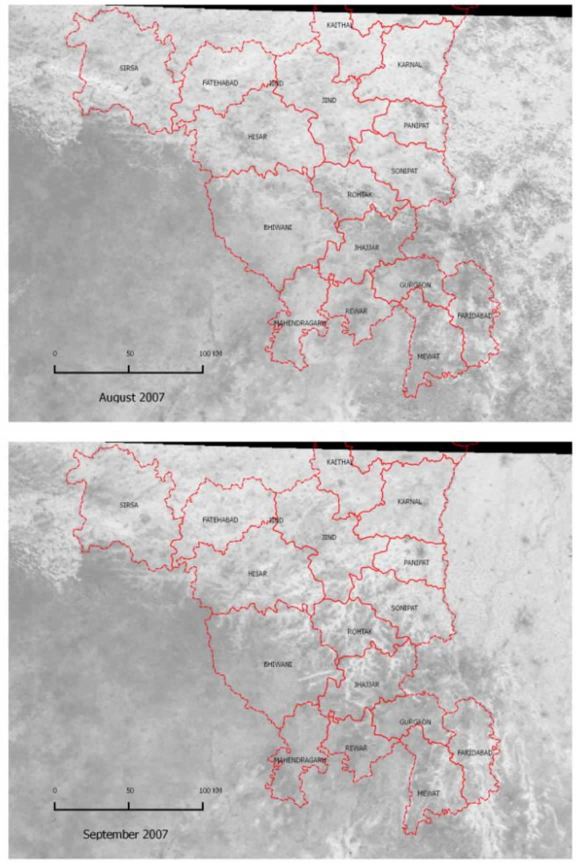


Fig. 4 NDVI of part of Haryana using MOD09A1 data

9.0 Conclusions:

For Haryana, year 2009 and 2002 were found to be having higher drought magnitude. Year 2007 was found to have high drought magnitude. Drought in 2002 and 2004 was short term drought (1- month duration). Considering drought conditions in various time scales and drought magnitude (1- month time scale), year 2002, 2006 and 2009 have more pronounced drought condition compared to years 2004 and 2007. In the MODIS based NDVI values, drop in NDVI value was observed in July month for districts in Haryana. During July 2007, SPI value for the meteorological sub division is also lowest in the monsoon season of the year.

10.0 References:

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