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Mapping of Agriculture Drought using Remote Sensing and GIS

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Abstract: **Agriculture drought occurs when moisture level in soils is insufficient to maintain average crop yields. Initial consequences are in the reduced seasonal output of crops & other related production. An extreme agricultural drought can lead to a famine, which is a prolonged shortage of food in a restricted region causing widespread diseases and deaths from starvation. Agriculture drought is mainly dependent on low rainfall which results in agricultural production.**

This study demonstrates the use of Remote Sensing and GIS in the mapping of drought. In the present work, an effort has been made to assess drought condition using temporal images from Landsat TM, ETM+ in Jodhpur District, particularly where the occurrence of drought is high. The Landsat-7 ETM+ and Landsat-5 TM satellite sensor data were used for calculating Brightness Temperature (BT), Land Surface Temperature (LST). Correlation and regression analysis was performed between Normalized Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Food Grain Anomaly.

BT was converted to the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI), which are useful indices for the estimation of vegetation health and agriculture drought. The yield and production analysis of crops analysis was carried out for a period of 21 years (1991–2011). On the basis of the satellite-based indices, the study area was divided into several drought categories; moderate, mild, no drought using GIS software. It was found that in years 2000, 2002 and 2010, the entire study area was affected by moderate drought with greater intensity.

KEY WORDS: Drought Indices, Remote Sensing and GIS, Crop yield and Production

1. INTRODUCTION

Drought is a climatic anomaly, characterized by deficient supply of moisture, resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of the entire factors (Bhalme and Mooley (1980). The escalating impact of drought has increasingly drawn the attention of scientists, planners and society. The vulnerability to drought in relation to the increasing needs of the growing population has become a point of great concern, especially at the food front. Drought is considered the most complex but least understood of all natural hazards, affecting more people than any other hazard. Drought is a normal feature of climate and its recurrence is inevitable (Mishra and Desai 2005).

Different definitions of drought have been proposed from time to time depending on the moisture needs for specific human activities and subject of interest. In current hydrological literature, devising a suitable universal definition of drought has become a difficult task (Yevjevich 1967; Dracup et al., 1980b). Cole (1933) has defined drought as a period of at least 15 consecutive days none of which had rainfall of 2.5 mm or more. According to Hoyt (1936), there is a drought when annual rainfall is less than 85% of normal. Ramdas (1960) has defined drought as a situation when rainfall is deficient by twice of its mean deviation. Konstantinov (1968) believed that drought should be studied using an analysis of deficit of evapotranspiration, which defined as the difference between the potential and the real evapotranspiration. Palmer (1965) has defined drought at a given location, as a period of time, lasting months or years, during which the actual moisture supply consistently falls short of the climatically expected moisture supply. Dracup et al. (1980a) has defined drought as a period of time (month/year) with rainfall/runoff below a mean truncation level which is derived from long term rainfall/runoff series. Variables which are used either alone or in combination for defining drought are rainfall, temperature, humidity, evaporation from free water, transpiration from plants, soil moisture, wind, stream flow and wind conditions. Drought is difficult to detect and monitor for three reasons: (1) it develops slowly, and the onset and end are indistinct; (2) it is precisely and universally defined and (3) its impact is non-structural and often spreads over a very large area (Wilhite 2000).

The global climate change is characterized by increase in surface temperatures to the tune of 0.6±0.2°C over the twentieth century and with a projected rise in the range of 13.5°C by 2100 (Houghton et al. 2001). Climate change is expected to change the existing vulnerability profile of India (O'Brien et al. 2004). The studies on the past climate indicated an increase in the temperatures to the tune of 0.57°C per 100 years (Kumar et al. 1994; Singh et al. 2001). Some studies identified decadal departures above and below the long time average rainfall alternatively for three consecutive decades

(Kothyari and Singh 1996). The most notable climate change implication for the vulnerable India is the frequent occurrence of drought. It is therefore important for scientific community to carry out enhanced preparedness with due emphasis to the community based preparedness planning, review the existing monsoon and drought prediction methodologies, and establish drought monitoring and early warning systems in association with a matching preparedness at the input level.

Arid Rajasthan is characterized by limited seasonal precipitation with erratic distribution, high atmospheric temperature that has large diurnal and seasonal variation, strong insolation and persisting wind regime. Consequently, there are high crop water requirements. The weather conditions remain too dry, even in normal years, for most part of the year and are inhospitable for successful crop growth (Rao, 2009).

Sowing rains have also been found to occur at times as early as 1st week of June in the eastern part and 2nd week of June in the western part. Such early or late commencement of sowing rains lead to large variability in year to- year crop productivity. The assured crop growing period in western Rajasthan varies from 25 to 90 days under shallow soils and 35 to 105 days under deep soils (Rao *et al.*, 1994).

Relative humidity in the region is often less than 30% during summer months, but gradually increases to 80% by monsoon and then decreases from October onwards, following the withdrawal of the monsoon. Low humidity, combined with strong wind regime, leads to advection, a phenomenon that causes evaporation loss more than the energy actually available through solar radiation. (Rao, 2009).

2. VARIOUS VEGETATION INDICES

Monitoring and assessment of drought through remote sensing depends on the factors that cause drought and the factors of drought impact. An extensive survey of the definition of droughts by WMO found that droughts are classified on the basis of: (i) rainfall, (ii) combination of rainfall with temperature, humidity and or evaporation, (iii) soil moisture and crop parameter, (iv) climatic indices and estimates of evapotranspiration, and finally (v) the general definitions and statements (Ungani et al., 1998).

Among various satellites-derived indices, the Normalized Difference Vegetation Index (NDVI) has evolved over a period of time as a primary tool for monitoring vegetation changes and interpretation of the impact of climatic/weather events of the biosphere. For example, Kogan (1995) has developed the Vegetation Condition Index (VCI) using the Advanced Very High Resolution Radiometer (AVHRR) thermal bands images. NDVI was first suggested by Tucker (1979) as an index of vegetation health and density. The expression for calculating NDVI is given as follows:

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

Where, NIR and R are near infrared and red part of the optical spectrum.

Other commonly used Vegetation indices associated with remote sensing data are Soil Adjusted Vegetation Index (SAVI), Vegetation Condition Index (VCI), Transformed Vegetation Index (TVI), Green Vegetation Index (GVI), Stress Related TM based Vegetation Index. A few of the vegetation indices are defined below (Reed, 1993). SAVI is computed as:

$$SAVI = \frac{(R_i - R_r)}{(R_i + R_r + L)} \times (1+L) \quad (2)$$

Where, R_r is the reflectance in red part of the optical spectrum, R_i is the reflectance in the near infrared, L is the parameter to take account of density of vegetation (0.5) and λ is the slope of soil lines (assumed constants).

VCI and TCI have been developed further using the following equations:

$$VCI = 100 * \left[\frac{(NDVI - NDVI_{min})}{(NDVI_{max} - NDVI_{min})}\right] \quad (3)$$

$$TCI = 100 * \left[\frac{(BT_{max} - BT)}{(BT_{max} - BT_{min})}\right] \quad (4)$$

Where NDVI, $NDVI_{min}$, and $NDVI_{max}$ are the seasonal average of smoothed weekly NDVI, its multiyear absolute minimum and its maximum respectively; BT, BT_{min}, and BT_{max} are similar values for brightness temperature (Kogan, 2001).

The relationship between NDVI and rainfall is known to vary spatially, notably due to the effect of variation in properties, such as vegetation type and soil background (Farrar et al. 1994). Many studies have focused on the relationship between the NDVI and rainfall. NDVI shows patterns of vegetative growth from green-up to senescence by indicating the quantity of actively photosynthesizing biomass on a landscape (Burgan 1996).

The digital number (DN) of thermal infrared band of Landsat can be converted to spectral radiance (L_λ) using the equation given in Landsat User's Handbook (2000) (Kumar et. al, 2012).

$$L_\lambda = \left\{\frac{Lmax - Lmin}{QCALMax - QCALMIN}\right\} * DN - 1 + Lmin \quad (5)$$

Where L_{max} = the spectral radiance that is scaled to *QCALMAX* in W/(m^2 * sr * µm)
Lmin = the spectral radiance that is scaled to *QCALMIN* in W/(m^2 * sr * µm)
QCALMAX = the maximum quantized calibrated pixel value (corresponding to *Lmax*) in DN = 255
QCALMIN = the minimum quantized calibrated pixel value (corresponding to *Lmin*) in DN = 1

Lmax and Lmin are obtained from the Meta data file available with the image, and are given in the Table 1.

Table 1: *Lmax* and *Lmin* values of Landsat data

Band No	Satellite/Sensor	L_{max}	L_{min}
6.1	Landsat7 /ETM+ High gain	12.65	3.2
6.2	Landsat7 /ETM +Low gain	17.04	0.0

The effective at-sensor brightness temperature (TB) also known as black body temperature is obtained from the spectral radiance using Plank's inverse function.

$$T_B = \frac{K_2}{\ln(1+\frac{K_1}{L_\lambda})} \text{ (Unit: Kelvin)} \quad (6)$$

The calibration constants K_1 and K_2 obtained from Landsat Data User's Manual (2000) are given in the Table 2 below.

Table 2: Calibration constants for thermal band

Sensor	K_1	K_2
Landsat7 /ETM+	666.09	1282.71
Landsat-5 TM	607.76	1260.56

The Land Surface Temperature (LST) is estimated by the following equation (7).

$$LST = \left(\frac{T_B}{1+\left(\lambda+\frac{T_B}{\rho}\right)*\ln\varepsilon}\right) \text{ (Unit: Kelvin)} \quad (7)$$

Where, λ is the wavelength of the emitted radiance which is equal to 11.5µm. ρ = h.c/σ, σ = Stefan Boltzmann's constant which is equal to 5.67 x 10^{-8} Wm^{-2} K^{-4}, h = Plank's constant (6.626 x 10^{-34} J Sec), c = velocity of light (2.998 x 10^{8} m/sec) and ε is the spectral emissivity. In this study spectral emissivity coefficient is taken as unity. Satellite images can be used to detect the early stages of drought events as anomalies in a time series manner. These images allow monitoring the drought event during the time of occurrence while the forces are in full swing. The remote sensing data provide a database from which the evidences left behind by drought impact that have occurred before can be interpreted, and combined with other information drought maps can be derived. It can assist in damage assessment and aftermath monitoring, providing quantitative base for relief operations (Manikiiam, 2003).

3. STUDY AREA

The study has been carried out in Bhopalgarh Tehsil which is one of the promising and drought prone Tehsils among nine Tehsils of Jodhpur district. It lies between 26°28'22″ and 26°42'21″N and between 73°10'30″ and 73°26'40″E catchment covering an area of about 273 km^2. The topography of the area is undulating. The climate in the region is characterized by a significant dry season from November to May, which sometime extends in dry years up to June. The average temperature experienced by the State is January to March is 5-25°C, April to June is 35-45°C, July to September is 30-40°C and October to December is 20-30°C (www.mapofindia.com).

The area has semi-arid climate, comprising of undulating terrain, dry land cultivation (mostly rained) and barren (scrub) land to a larger extent, fallow and degraded grazing lands. The average rainfall is 320 mm based on 1901-2010 years rainfall data. In contrast, the average annual rainfall in the study area for the period from 2000 to 2002 was only 202 mm. This area is prone to water scarcity and thus, drought-like conditions prevail. The major land use/land cover includes mixed cropland which are rain fed, water tanks, vegetation which includes outcropped and plantation, barren land consisting of poor to no vegetative cover and rocky surface. The majority of irrigation wells got dried up and groundwater is over-exploited.

4.0 METHODOLOGY

The data required for the study has been procured from various sources. Topographic features were extracted from topographic map sheets of the Survey of India (SOI) (45 F/2, 45 F/3, and 45 F/6) at a scale of 1:50 000. Table 3 shows pre-processed multi-temporal satellite images from the Landsat-7 and sensor ETM+ sensor. Crop area, production and yield of Jodhpur are in Table 4 and Table5.

Table 3: Satellite images from the LANDSAT-7 and ETM+ sensor (www.earthexplorer.usgs.gov)

S. No.	Satellite	Sensor	Path-Row	Dates
1.	LANDSAT-7	ETM+	149-42	20.04.2000
2.	LANDSAT-7	ETM+	149-42	29.10.2000
3.	LANDSAT-7	ETM+	149-42	12.05.2002
4.	LANDSAT-7	ETM+	149-42	03.10.2002
5.	LANDSAT-7	TM	149-42	11.06.2010
6.	LANDSAT-7	TM	149-42	02.11.2010
7.	CARTOSAT	PAN	149-42	05.06.2010

Table 4: Crop area, production and yield of 20 years (Source:www.krishi.rajasthan.gov.in/Departments/Agriculture)

Years	Area (Hectare)	Production (Tones)	Yield (Kg/Hectare)
2000-01	536590	65967	276
2001-02	652067	58577	230
2009-10	708420	52273	225

Process of different operations of meteorological data, satellites data and ancillary topography map is presented in Fig. 1. Software used to carry out different image processing operations includes ERDAS 9.1 and ARC GIS 9.3.

Table 5: Kharif and Rabi Production of 20 years data of Jodhpur (Source:www.krishi.rajasthan. gov.in/ Departments/Agriculture)

Years	Kharif (Tones)	Rabi (Tones)	Total (Tones)
2000-01	1308911	118303	1427214
2001-02	1169870	136087	1305957
2009-10	1109775	158645	1268420

4.1 Geo-referencing of Satellite Data

Landsat satellite data have been checked for radiometric error, and are georeferenced with respect to the Survey of India topographic maps. Pre-processing, such as geometric and radiometric correction were necessary before the analysis, in order to reduce the radiometric distortion in multi-date images. Second order polynomial transformation was used to achieve higher accuracy in georeferencing. This polynomial requires 6 or more ground control points (GCPs) for geometric rectification of satellite data. To ensure better geometric fidelity of the images minimum of 20 GCPs, well distributed spatially, have been used for each satellite image. UTM North 84 projection system and UTM zone 43 (Range 72˚E–78˚E) have been used for geo-referencing of Landsat satellite images.

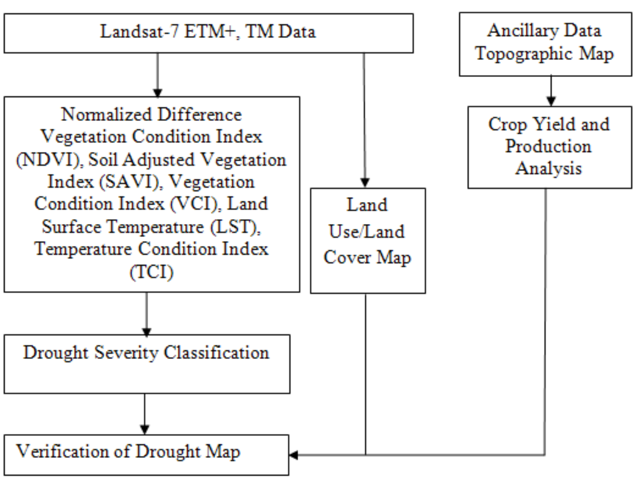

Figure 1: Flow chart of steps of methodology

4.2 Development of Land Use/Cover Map

All 7 bands have been used to obtain land use classes by adopting supervised classification using ERDAS Imagine software. Land use maps were generated by maximum likelihood method. Since the study area has a mixed cropping pattern, only crop land is identified in particular. Water and moistened water body are also very distinctly identified. Barren land has a limited ability to support life, and therefore it is also easily identifiable. The rocky outcrops and vegetation cover are mixed. The five classes considered for the study area are; Built-up area, Waste/Barren land, Agriculture, Sandy and Water. Classification accuracy assessments was done with field knowledge, visual interpretation and also referring the Google Earth Images.

4.3 Generating Vegetation Indices

A number of vegetation indices based on remote sensing data have been used to monitor vegetation, with the most widely adopted being the normalized difference vegetation index (NDVI) (Tucker, 1979).

(A) Derivation of NDVI and SAVI Images

From geo-referenced images, a series of new data are generated viz., Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI). NDVI calculation was performed to extract vegetation index values, which were used as the main indicator for determining drought impact. For this study, NDVI images were generated for each of pre and post-monsoon images. The data used in compiling the NDVIs closely related to the radiation absorbed and reflected by vegetation in the photosynthetic processes. Green and healthy vegetation reflects much less solar radiation in the visible (red) compared to those in the near-infrared (NIR). More importantly when vegetation is under stress, the band red value may increase and the band NIR value decrease.

(B) Derivation of VCI Image

The Vegetation Condition Index (VCI) is a measure of the amount and vigor of vegetation at the surface. The reason VCI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. Green leaves have a reflectance of 20 % or less in the 0.5 to 0.7µm range (green to red) and about 60 % in the 0.7 to 1.3µm ranges (near infrared).

(C) Land Surface Temperature

Land surface temperature was computed for each pixel following steps given in Fig. 2.

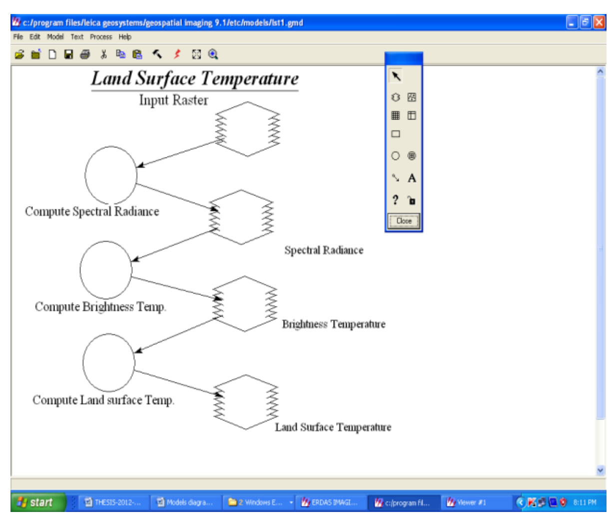

Figure 2: Process to determine Land Surface Temperature using ERDAS Imagine software

For all the calculations at pixel level, models were developed using Spatial Modeler module of ERDAS Imagine. Vegetation affects the latent thermo flux of the surface intent to the atmosphere through the evapotranspiration. Lower LST (except water bodies) is usually measured in areas with higher NDVI values

(D) Temperature Condition Index

Temperature condition index images are generated by procedure given in Fig. 3.

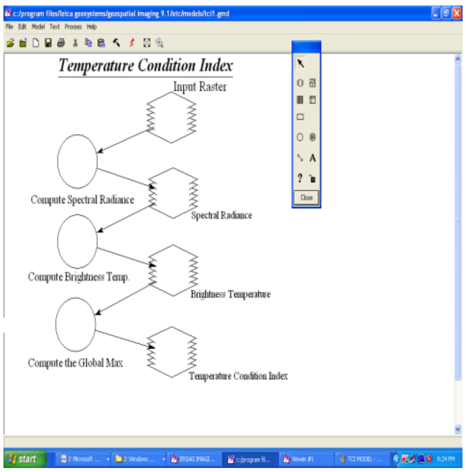

Figure 3: Procedure to determine Temperature Condition Index

4.4 Generation of Drought Severity Map

Systematically procedure of generate drought map of drought year is shown in Fig. 4. It is necessary that the thematic layers be ranked depending upon the importance of the parameter that influence drought. In order to overcome the difficulty of subjectively and biasness with respect to ranking of parameters by direct methods, Saaty's pair-wise comparison method which uses statistical concept is used.

Table 6: Pair wise comparison matrix

Option matrix for criterion of drought							
Pair wise Comparison of Option Against Criterion	NDVI	SAVI	VCI	LST	TCI	Geometric Mean of Rating Against Criterion	Option Priority Vector for Criterion
NDVI	1	1.5	0.5	2	2.5	1.5	0.22
SAVI	0.67	1	0.33	1.33	1.66	0.998	0.147
VCI	2	3	1	4	5	3	0.443
LST	0.5	0.75	0.25	1	1.25	0.75	0.11
TCI	0.4	0.6	0.2	0.4	1	0.52	0.076

Total						6.768	

The pair-wise comparison method consists of generation of pair-wise comparison matrix, criteria ranking and estimation of consistency ratio. Table 6 gives pair-wise comparison matrix (6*6) of the criterion parameters. Pair-wise comparison method allows the more important criteria to always come before the less important criteria to provide ease in finalizing intensity of importance.

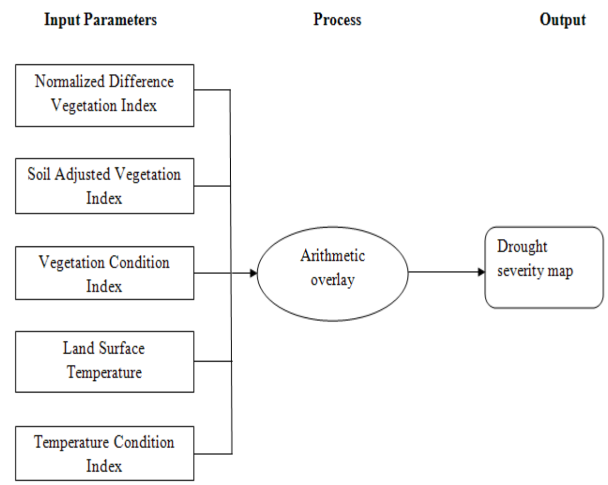

Figure 4: Schematic diagram of generation drought severity map

5 RESULTS

5.1 Land use /Land cover map

Land use land cover classes of study area of pre and post-monsoon are shown in Table 7.

Table 7: Land use land cover area of pre and post-monsoon

		Pre-monsoon Area (Km^2)			Post-monsoon Area (Km^2)		
S. No	**Class**	**2000**	**2002**	**2010**	**2000**	**2002**	**2010**
1	Build up area	2.2	2.32	3.01	2.322	2.45	3.71
2	Sandy area	141.6	230	154.84	196.4	169.19	138.1
3	Waste/Bare area	122.6	34.87	111.0155	43.3	70.432	106.2
4	Agriculture area	6.2	5.9	2.8891	28.02	26.5234	21.1
5	Water	0.12	0.66	0.76	2.3	3.72	3.21

From this table, it is seen that waste land and sandy area is increasing whereas water and agriculture areas are decreasing. Drought is also found to have more intensity in year 2010 as compared to other years.

5.2 Normalized Difference Vegetation Index (NDVI)

Normalized difference vegetation Index (NDVI) of Landsat ETM+ and TM satellite images of pre and post monsoon of 2000, 2002 and 2010 years were generated. Variations of NDVI are shown in Fig. 5.

NDVI value range has been divided into four categories (i) -1 to -0.5 for severe drought, (ii) -0.5 to 0.0 for moderate drought, (iii) 0.0 to +0.5 mild drought and (iv) +0.5 to +1 no drought. Accordingly, NDVI values between -0.3617 to 0.6 of study area has been classified as moderate drought, mild drought, and no drought, respectively.

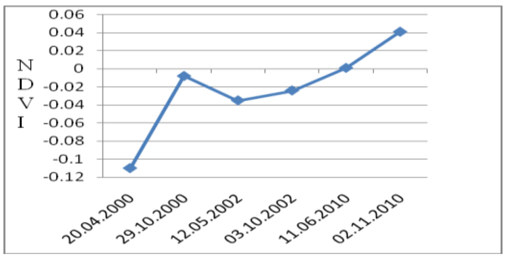

Figure 5: Mean values of NDVI

5.3 Difference of pre and post-monsoon images

The next step was to calculate the difference between NDVI acquired for each pre and post-monsoon for years, 2000 and 2002. The purpose was to detect NDVI change between normal and drought conditions. If difference values are positive then area is less affected by drought, if value is zero then there is no change in drought condition and if value is negative then there is significant change in drought conditions. Difference of NDVI of pre-monsoon is shown in Fig. 6 and post-monsoon shown is in Fig. 7.

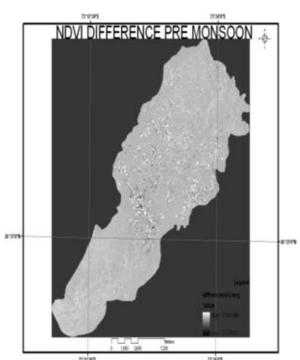

Figure 6: Difference of NDVI Images of Pre-Monsoon (2000-2002)

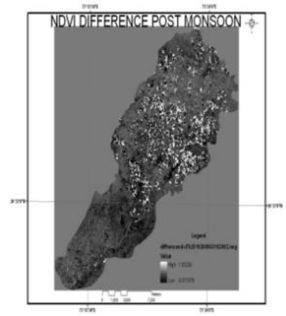

Figure 7: Difference of NDVI Images of Post-Monsoon (2002-2002)

5.4 SAVI Images

Range of SAVI values computed from satellites images are shown in Table 8.

Table 8: SAVI values of Landsat images

Date	Min	Max	Mean
20.04.2000	1.1692	1.5659	1.391
29.10.2000	1.14	2.108	1.492
12.05.2002	1.3428	1.868	1.465
03.10.2002	1.243	2.5	1.496
11.06.2010	1.193	2.1	1.499
02.11.2010	1.27	1.9695	1.541

5.5 Vegetation and Temperature Condition Indices

VCI is derived from NDVI images and TCI from brightness temperature. It shows a relationship between temperature and vegetation.

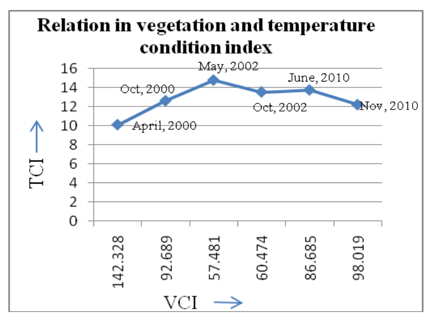

Figure 8: Relation in VCI and TCI

VCI value is high where TCI value is low, it means dense vegetation helps to lower down the temperature. Variations in TCI and VCI value over three years are shown in Fig. 8 indicate that both are reciprocal to each other.

5.6 Land Surface Temperature

Land surface temperature values of study area were computed from satellites images. Variation of mean LST values is shown in Fig. 9

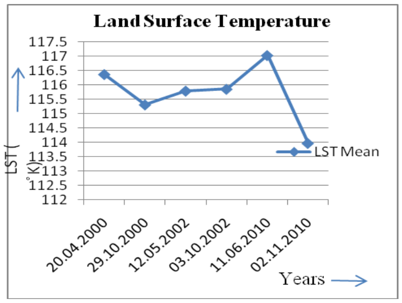

Figure 9: Variation of Land Surface Temperature index values

More than 200 points are selected randomly on the LST image and corresponding NDVI values are obtained to find the correlation between LST and NDVI. The correlation coefficient so obtained between LST and NDVI is found as -0.79. This clearly indicates that the LST is strongly and negatively correlated with NDVI. Hence areas with least vegetation cover are expected to experience more temperature and more drought condition.

5.7 Drought Severity Map

Drought severity map of pre-monsoon of year 2000, 2002 and 2010 are shown in Figs. 10, 11 and 12, respectively.

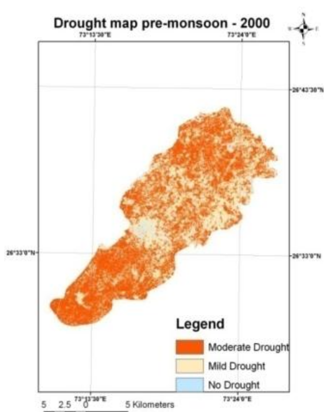

Figure 10: Generated drought severe map of pre-monsoon of year 2000

These maps are generated by arithmetic overlay process already described in Figure 4. Area of various drought classes is shown in Table 9.

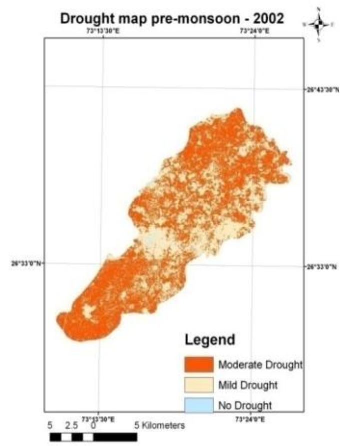

Figure 11: Generated drought severe map of pre-monsoon of year 2002

Relationships of drought (Moderate and Mild) with crop production, yield and land use land cover for year 2000, 2002 and 2010 are shown in Figs. 13, 14 and 15, respectively.

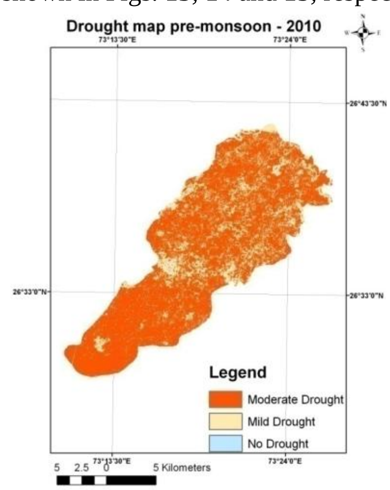

Figure 12: Generated drought severe map of pre-monsoon of year 2010

Table 9: Area of drought classes of pre-monsoon

S.No.	Drought Category	Year-2000 Drought Area (Km^2)	Year-2002 Drought Area (Km^2)	Year-2010 Drought Area (Km^2)	Changes in area of 10 years (Km^2)
1.	No Drought	6.51	4.24325	2.037	-4.4
2.	Mild Drought	117.65	113.1	61.14	-56.

					5
3.	Moderate	147.93	154.78	208.99	61.06
Drought area		265.58	267.88	270.14	4.56
Total area		272.1	272.12	272.17	00

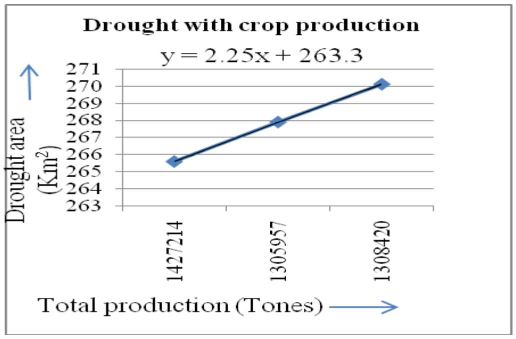

Figure 13: Variation of crop production with drought

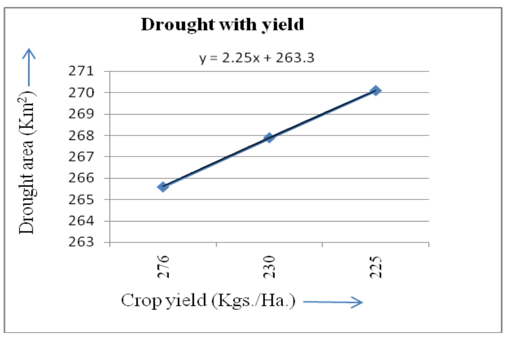

Figure 14: Variation of yield production with drought

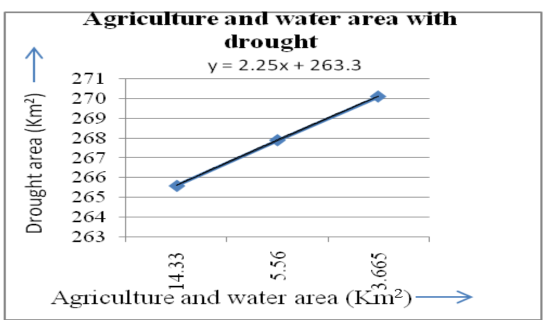

Figure 15: Variation of agriculture and water with drought

6. DISCUSSIONS

(i) The analysis of Landsat images of pre and post-monsoon of years 2000, 2002 and 2010 revealed that land use and land cover of the catchment of study area has changed over 10 years.

(ii) The results of drought and NDVI study illustrate that vegetation condition can be used as indicator for drought condition of an area. NDVI can be used as the main indicator to evaluate drought.

(iii) Difference images of NDVI show drought conditions. In these images, if difference values are positive then area is less affected by drought, if difference values are zero the area is not affected by drought, and if difference values are negative then the area has affected by drought.

(iv) VCI and TCI are inversely proportional to each other. Values of VCI are very low in post monsoon of 2002 and very high TCI in pre-monsoon of 2002.

(v) From the LST image it was observed that highest temperatures of about 302˚K exist in urban built up areas and other impervious areas, and lowest temperatures of about 289˚K exist in vegetative areas.

(vi) Indices derived from the thermal bands, such as LST and the TCI have a higher sensitivity to drought conditions than indices derived from the visible bands, such as the NDVI, VCI and SAVI.

(vii) From LST images, it is clearly understood that surface temperature is more in urban area as compared to rural areas. Also the study shows that the LST is strongly and negatively correlated with NDVI.

(viii) Low rainfall is usually the cause of drought, but high temperatures may also be involved. Drought as related to precipitation may be a result of several growing days without precipitation, low seasonal precipitation, or abnormally low annual precipitation approximately 303 and 198 mm for year 2000 and 2002, respectively.

(ix) Drought with crop production, production of Kharib and Rabi seasons crops of years 2000, 2002, and 2010 decreases with an increase in drought area.

(x) In drought area map, mild drought is high in 2000 and less in 2010, Area of moderate drought in 2010 is high and low in 2000 and total area affected by drought is more in 2010.

7. CONCLUSIONS

The following are the significant conclusions that have been drawn by way of having achieved the overall objectives of this research study.

(i) Area of drought is less in 2000 more in 2010 value of difference is 4.56 km^2. It means intensity of drought has increased in ten years.

(ii) Land surface temperature values of build up area, sandy area, waste land, agriculture, water have been found in decreasing order.

(iii) Sandy and waste land area has increased 1.655 km^2 and agriculture and water area is decreased 2.671 km^2

in 10 years from 2000 to 2010.

RECOMMENDATIONS FOR FUTURE WORK

The study has identified an approach by which drought can be identified using remote sensing and GIS. The drought maps are of great importance as they can be used subsequently for preparing action plan for providing relief measures to drought affected areas. Thus, the future direction of research can be enumerated as follows:

- **a.** Prioritization of critical parameters related to drought condition.
- **b.** Preparation of short and long term action plans
- **c.** Definition of a well defined drought classification based on numeric indices

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