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Comparison of remote sensing based indices for drought monitoring in Anantapur

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Abstract
Drought is one of the most widespread and least understood natural phenomena. Drought can be monitored using the climatic variables like rainfall and temperature. In developing countries like India, maintenance and operation of climatic stations is laborious and costly. The application of remote sensing technology for monitoring drought make the process easy and simple. The potential contribution of easily accessible satellite data to the detection and quantification of regional droughts, in the absence of reliable meteorological data, is the objective of this study. In the present study, remote sensing technology is used for monitoring drought for Anantapur district which is second driest region in the country. For this study remote sensing images from the Landsat satellite from 2005 to 2010 were used. The Normalised Difference Vegetation Index (NDVI) and Normalised difference water index (NDWI) which are most widely used vegetation indices in recent years that measure and monitor plant growth and vegetation cover from multi-spectral satellite data are computed for Anantapur region for monitoring drought. The conclusion of this study is NDVI index successfully monitored the drought conditions can be used to assess drought conditions instead meteorological indexes.

Keywords: Drought, Drought assessment, Remote sensing, NDVI, NDWI.

Introduction

Drought is a deficiency of precipitation from expected or “normal” that, when a season or longer period of time extended over, is insufficient to meet demands. This may result in economic, social, and environmental impacts. It should be considered a normal, recurrent feature of climate. Drought is a relative, rather than absolute, condition that should be defined for each region. Each drought differs in intensity, duration, and spatial extent (Knutson *et al*., 1998) [33]. Drought is recognized as part of the climate cycle with wet periods and sometimes floods separating two dry periods. Drought, however, has different impacts on people and production systems because of the underlying conditions interacting with different vulnerabilities (Wilhite, 2000) [30]. The impacts of drought are sometimes not clearly demarcated; it stretches over larger geographical areas than most other natural hazards and it is largely non-structural (Sivakumar & Wilhite, 2004) [34]. Wilhite (2000) [30] reports that the onset and end, as well as severity are often difficult to determine. Drought ranked as the first among all natural hazards (Bryant, 1991) [4]. Drought is not only confined to arid and semi-arid regions but often visits potentially good rainfall areas. There is no universally applicable and acceptable definition for drought as yet. Numerous attempts to define drought have led to several definitions of the term (Nagarajan, 2003) [22]. The UNDP (2008) [29] defines drought as the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels causing serious hydrological imbalances that adversely affect land resources production systems.

Drought gives an impression of the water scarceness attributable to insufficient precipitation, high evapotranspiration, and the over exploitation of water resources or a combination of these parameters (Bhuiyan, 2004) [35]. Unlike other natural hazards like floods, hurricanes and tsunamis that develop quickly and last for short time, drought has a creeping or insidious nature. It evolves and builds up across a vast area over a period of time and its effect lingers for years even after the end of drought (Narasimhan, 2004) [36]. This complex nature of drought makes it least understood of all natural hazards. Drought has many facets in any on single region and it always stars with the lack of precipitation, and many (or may not, depending how long and severe it is) affect soil moisture, streams, ground water, ecosystems and human beings. This leads to the identification of different types of droughts. They are 1) meteorological drought 2) hydrological drought 3) Agricultural drought 4) Socio-economic drought.

Meteorological drought is a situation when there is a significant decrease in rainfall from the normal over an area. Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period (WMO, 2005; Schuman, 2007) [31, 28]. Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater). Meteorological drought, if prolonged, results in hydrological drought. Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Agricultural drought occurs when soil moisture and rainfall are inadequate to support crop growth to maturity and cause extreme crop stress leading to the loss of yield.

Droughts of varying severities are regular occurrences in Anantapur district with a climate that varies from sub-tropical in the east to semi-arid in the west with a mean and highly variable precipitation of nearly 553 mm for the district as a whole. The assessment of drought become more important with increased population and demand for food (FAO, 2009) [9].

Drought Indices (DIs) have been most commonly used to assess drought conditions around the world, since they are more functional than raw data in decision making. Drought indices assimilate thousands of bits of data on rainfall, snow pack, stream flow, and other water supply indicators into a comprehensible big picture. These DIs were used to trigger drought relief programs and to quantify deficits in water resources to assess the drought severity. Also, they were used as drought monitoring tools. Most of the drought indices are not precise enough in detecting the drought conditions (Bhuyan and Wilhite, 1990) [3].

Drought assessment is a challenging task for drought researchers and professionals because it is very difficult to determine its onset and end, as well as its severity (Wilhite, 2000) [30]. Many drought indices are developed regionally, they cannot be used directly to assess the drought conditions in other regions without prior evaluation (Shishutosh Barua *et al*., 2011) [37]. Now a days scientists acknowledge the fact that drought assessment cannot be done by looking at precipitation, evaporation and transpiration alone (Wilhelmi, 2002; Wisner *et al*., 2004; Gbetibouo & Ringler, 2009) [38]. There was much confusion exists amongst scientists and policymakers about the characteristics of drought and this confusion explains the lack of progress in drought preparedness in most drought affected countries (Sivakumar and Wilhite, 2004) [34].

Therefore it is necessary and useful to consider several indices, examine their sensitivity and accuracy, and evaluate them. The present study was motivated by the fact that no such study has been carried out in the case study area which is driest inhabited region in Andhra Pradesh.

Accordingly the objectives of present study are framed. They are

1) Quantification of drought in Remote sensing contexts.
2) Evaluating the performance, strength, weakness and limitations of drought indices.
3) To determine which type and combinations of drought indices are best.

In the present study, Normalised difference vegetation index (NDVI) and Normalised difference water index (NDWI) are selected as a remote sensing based drought indices. These drought indices are selected because of their popularity and different approach in characterising the drought.

All the drought indices are evaluated using the evaluation criteria (Keyantash and Dracup, 2002) [14]. This is the first study conducted in the Anantapur region to evaluate the suitability of existing drought indices for drought management. The following sections describes the study area details, computation and evaluation of drought indices and risk analysis and development of composite drought index.

Study Area

The area of investigation in this research study is the Anantapur district, Andhra Pradesh, India. Anantapur district lies in between 13040’ and 15015’ North latitude and 760 50’ and 780 30’ East longitude. The district is bounded by Y.S.R Kadapa and Chitoor districts towards east, Kurnool District towards north and Karnataka State towards south and west. The total geographical area of the Anantapur district is 19,225k.m2. Monsoons also evades this part due to its unfortunate location. Being far from the East coast, it does not enjoy the full benefits of North East monsoons and being cut off by the high western Ghats, the South West Monsoon are also prevented from penetrating and punching the thirst of these parched soils. The normal rainfall of the district is 553.0 mms. The normal rainfall for the South West Monsoon period is 338.0 mms. The rainfall for North East monsoon period is 156.0 mms.

The normal daily maximum temperature ranges between 31.7 C to 38.9 C. Anantapur's history will reveal that the district has been subjected to severe droughts and famines right from 14 century. The whole district lies within the famine zone, with very scanty rainfall, poor soils and precarious irrigation sources exposing the district to famines. The drought assessments might not have been carried out in any of such identified places using scientific methods. This might be due to lack of proper drought assessment methods. Hence, historical analysis of droughts (both qualitative and quantitative) using a systematic scientific methodology will help in identifying the drought proneness of a region and helps the policy makers to decide the mitigation measures for the reason.

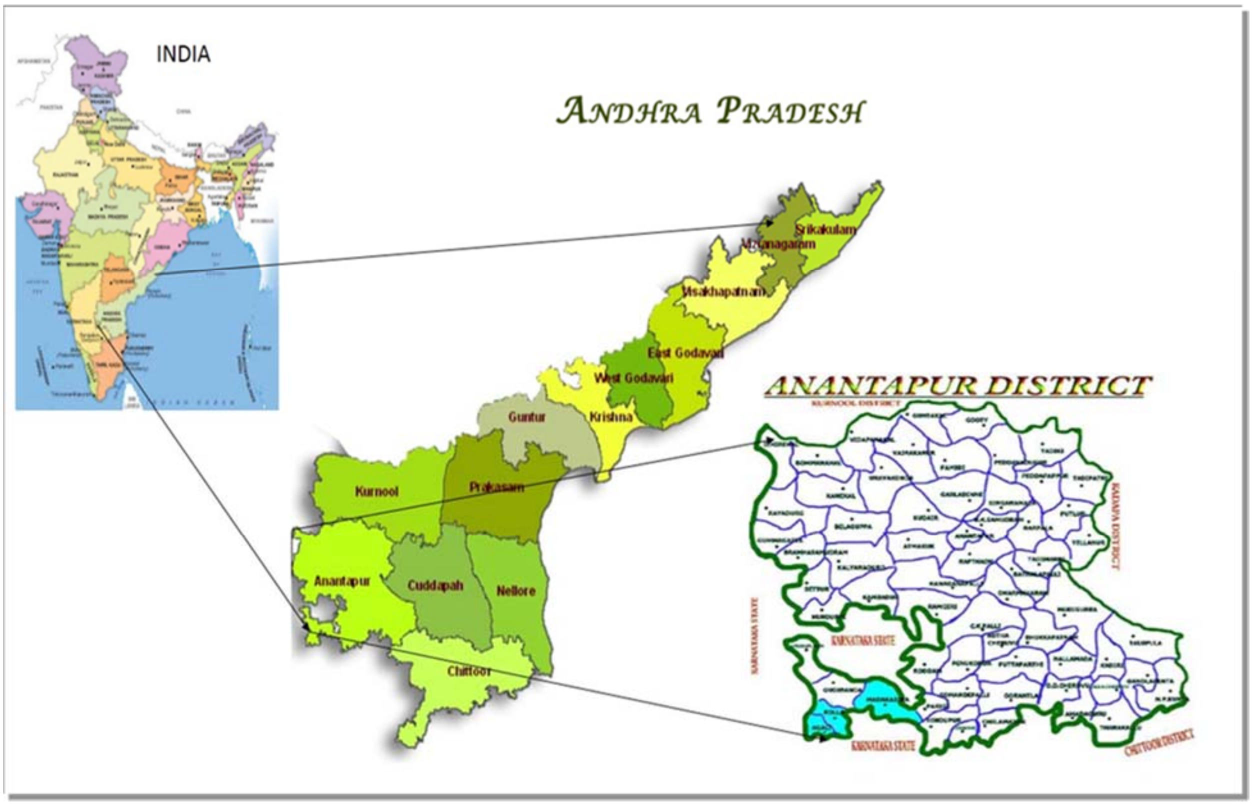

Fig 1: Location Map of Study Area

Data Collection

Remote Sensing Data

The remote sensing data used in this study was Landsat 4-5 TM Satellite images. The satellite images spanning from 2006-10 of month September from Landsat-4-5 were obtained from the USGS National Center for Earth Resources Observation and Science (http://glovis.usgs.gov/). Two sensors offer 30 m spatial resolution and a large spectral window through the addition of several bands in the blue-visible, infrared and thermal spectrum.

Methodology

Drought assessment is carried out by using the following indices because of their popularity and different approach in characterising the drought.

Remote sensing based drought assessment

Remote sensing drought assessment is carried out using the following indices

Normalised Difference Vegetation Index

Tucker first suggested NDVI in 1979 as an index of vegetation health and density (Thenkabail and Gamage *et al*. 2004). The normalized difference vegetation index (NDVI) is the most commonly used vegetation index and is based on differences in absorption and reflectance in the visible and near-infrared (NIR) spectrums, respectively. It varies from +1 to -1. NDVI values of 0.1 and below corresponds to barren areas of rock and sand. Moderate values of (0.2-0.3) represent shrub and grass lands. High values of (0.6 – 0.8) indicate temperate and tropical rainforests.

The Normalized Difference Vegetation Index (NDVI) is a satellite data driven index measures chlorophyll absorption in the red portion of the spectrum relative to reflectance or radiance in the near infrared. The NDVI is a measure of greenness or vigour of vegetation. When sunlight strikes a plant, most of the red wavelengths in the visible portion of the spectrum (400 -700 nm) are absorbed by chlorophyll in the leaves, while the cell structure of leaves reflects the majority of NIR radiation (700-1100 nm). NDVI was computed by using the following equation

$$\mathrm{NDVI} = \frac{\mathrm{NIR}-\mathrm{RED}}{\mathrm{NIR}+\mathrm{RED}} \qquad (1)$$

In ArcGIS10.1 software, the coordinate system of all images were defined into GCS_WGS_1984 and projected into UTM_44N, which is a coordinate system used for Anantapur. NDVI was computed for each image using bands 3 and 4 as input to detect vegetation density. NDVI is calculated by raster calculator tool provided in spatial analyst extension in Arc Gis10.1 by using the following equation

$$\mathrm{NDVI} = \frac{\mathrm{Band4}-\mathrm{Band3}}{\mathrm{Band4}+\mathrm{Band3}} \qquad (2)$$

For Landsat TM this NIR corresponds with band 4, and Red with band 3.The NDVI images generated were reclassified for monitoring drought. The study area of interest was extracted by overlaying the shape file over NDVI image generated. The NDVI images generated are shown in figures 10.1 – 10.5.

Normalized Difference Water Index

The Normalized Difference Water Index (NDWI) was first proposed by McFeeters in 1996 to detect surface waters in wetland environments and to allow for the measurement of surface water extent. NDWI is a measure of liquid water molecules in vegetation canopies that interacted with the incoming radiation. This index is calculated by the equation

$$\mathrm{NDWI} = \frac{\mathrm{NIR}-\mathrm{SWIR}}{\mathrm{NIR}+\mathrm{SWIR}} \qquad (3)$$

The Normalized Difference Water Index (NDWI) (GAO, 1996) is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content (Ceccato et al. 2001). NDWI is known to be strongly related to the plant water content. Its usefulness for drought monitoring and early warning has been demonstrated in different studies. It is less sensitive to atmospheric scattering than NDVI. NDWI is an independent vegetation index and not a substitute for NDVI (GAO, 1996). NDWI values are positive for green vegetation and negative for dry vegetation. Computation of NDWI index is similar to that of NDVI. The Landsat imagery was imported into ARCGIS raster data set. The projection toolbar was used to project the image data. Values of NDWI were calculated from the Landsat image using Equation (13) in the Raster Calculator tool in the Spatial Analyst extension in ArcGIS 10.1.

$$\text{NDWI} = \frac{\text{Band 5} - \text{B and 4}}{\text{Band 5} + \text{Band 4}} \qquad (4)$$

The result was a single band file that was color-coded to facilitate analysis. The study area image were extracted by using the “EXTRACT MASK” tool in ARC GIS 10.1 by projecting the boundary shape file of study area onto NDWI image. NDWI images generated are shown in the figures 10.6 to 10.10. By glancing through the results, it was observed that in the all years NDWI values falls under the negative values indicating severe water stress in vegetation canopies and low vegetation water content.

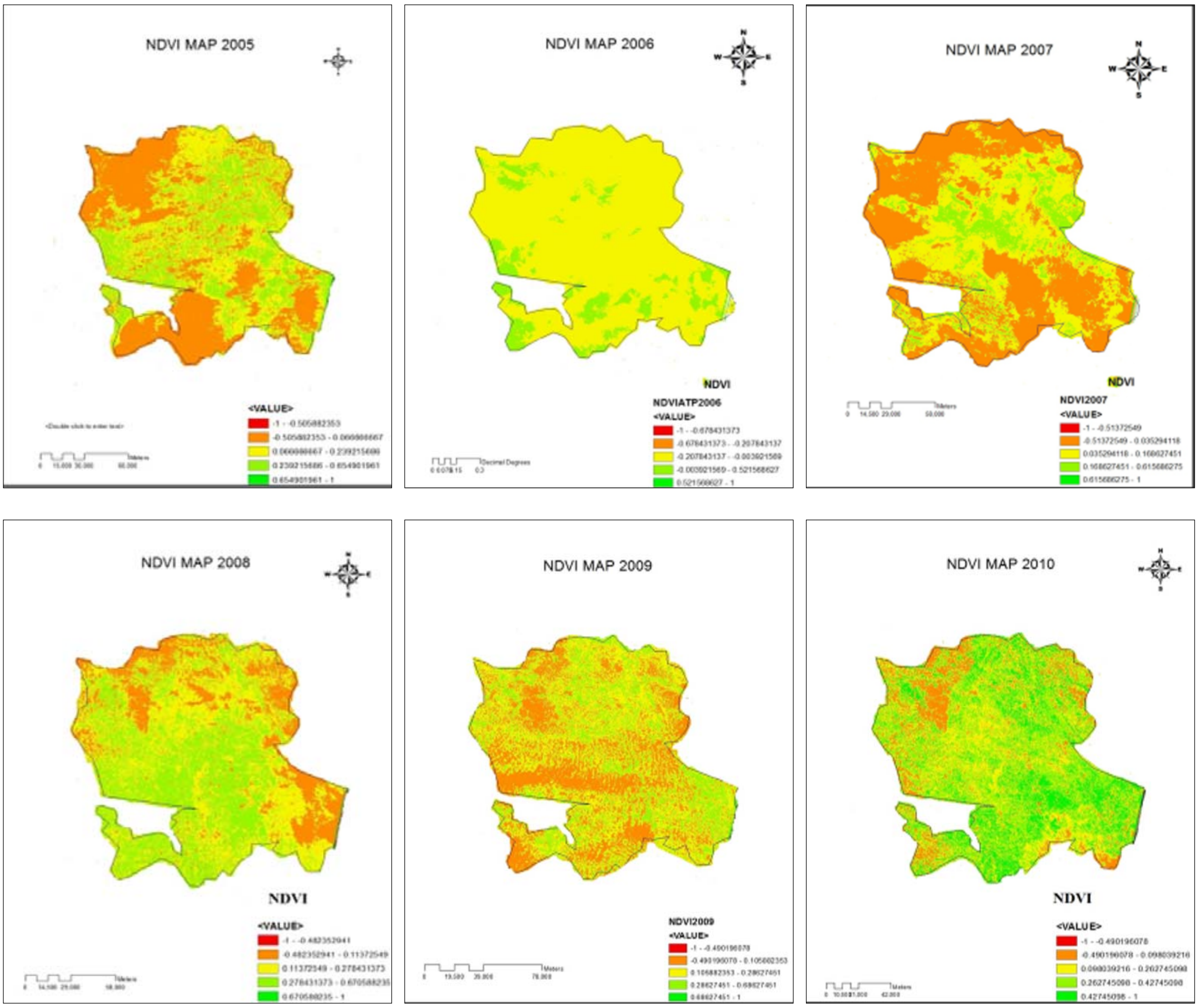

Fig 10.1-10.5: NDVI IMAGES

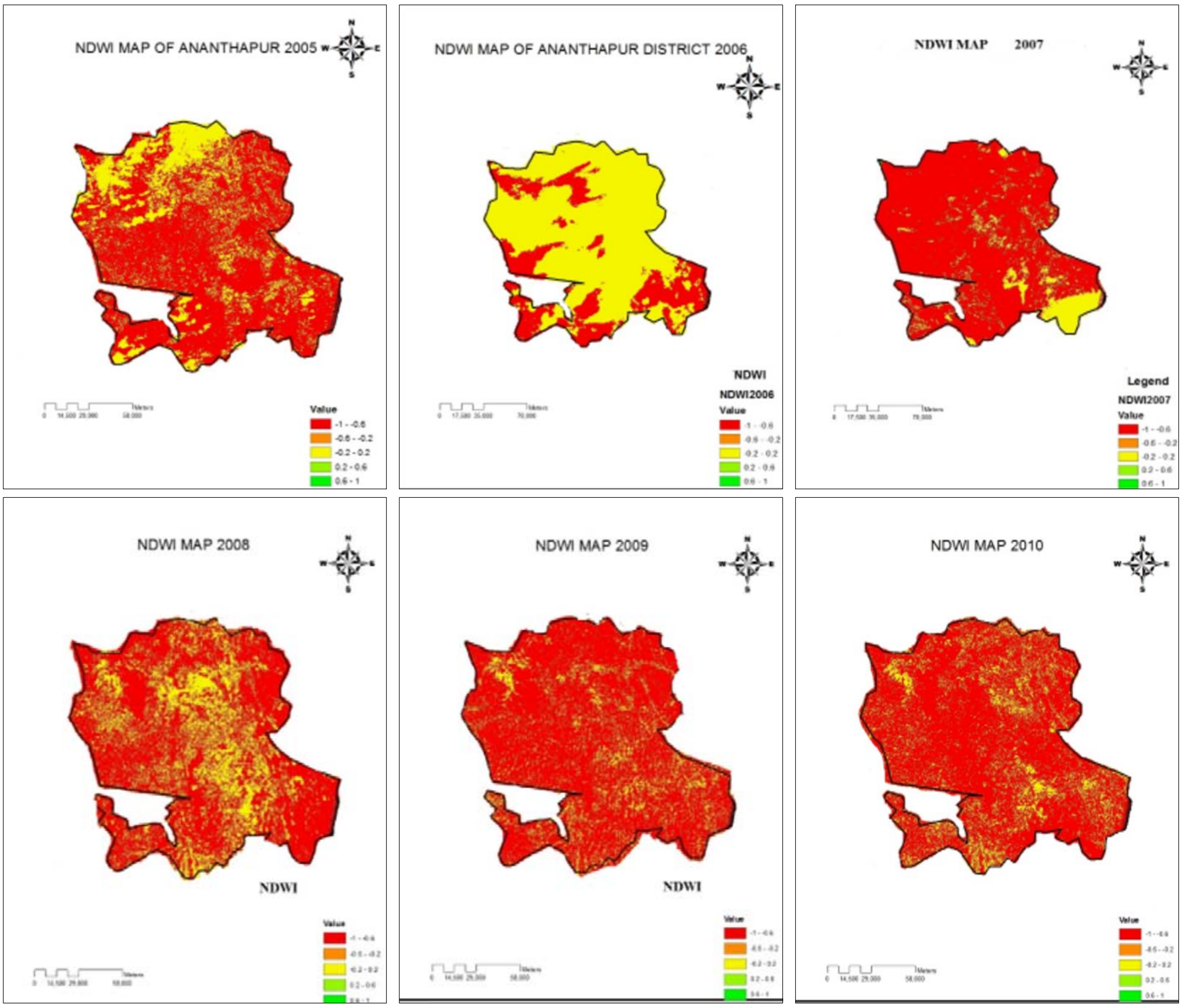

Fig 10.6-10.10: NDWI IMAGES

Evaluation of Drought Indices

In most cases, DIs were developed for a specific region, and therefore they may not be directly applicable to other regions due to inherent complexity of the drought phenomena, different hydro-climatic conditions and different catchment characteristics (Redmond, 2002; Smakhtin and Hughes, 2007; Mishra and Singh, 2010). In this chapter, drought indices (DIs) that were analyzed for the Anantapur district were evaluated to investigate how they satisfied desirable properties of a good DI and how they could be useful for this region.

Evaluation criteria

In judging the overall usefulness of the DIs, five decision criteria namely robustness, tractability, sophistication, transparency and extendability are used (Keyantash and Dracup; 2002; Shishutosh Baruva; 2011) [37]. A range of raw scores from 1 to 5 (5 being the most desirable) were assigned to each of the five selected decision criteria to evaluate the DIs for the Anantapur region. The raw scores were given based on the qualitative and quantitative assessment of DIs. The qualitative assessment are based theoretical and computational aspects of DIs. The quantitative assessment is based on how well these DIs modelled the historical droughts (Drought memorandum released by A.P. government for the period 1995-2013). Historical droughts were considered for the period 1995-2013. The sum of the weighted scores of each criterion (i.e., raw scores multiplied by relative importance factor) was the total weighted score for each index. These total weighted scores were used for comparative evaluation of DIs for the Anantapur region in this study. Therefore, the maximum possible total weighted score any DI could have is 25.

Robustness

Robustness represents the usefulness of the DI over a wide range of physical conditions. Ideally a DI should be responsive, but not temperamental (Keyantash and Dracup, 2002 Shishutosh Barua, 2011) [37]. Normalised difference vegetation index (NDVI) can be applied to wide range of physical conditions as satellite can cover over a large area. NDVI was quite responsive as well as it was not temperamental in detecting drought conditions. NDVI successfully detected low vegetation content in the drought years 2006 and 2009. Therefore, a robustness score of 4 was assigned.

Normalised difference water index (NDWI) developed as a remote sensing based index showed good agreement with NDVI in robustness criteria. NDWI identified low water content in the drought years 2006 and 2009. Therefore, a score of 4 was assigned.

Table 10: Robustness Score

Drought index	Score
Normalised Difference Vegetation Index	4
Normalised Difference Water Index	4

Tractability

Tractability implies the practical aspect of the drought index. A tractable index requires low level of numerical computations, less number of input variables and less extensive database with historical data (Keyantash and Dracup, 2002) [14].

Normalised difference vegetation index (NDVI) and Normalised difference water index (NDWI) requires only satellite images as input data for their computation. The level of computation is also quite simple. Therefore, a score of 5 was given.

Transparency

Transparency represents the clarity of the objective and rationale behind the drought index (Keyantash and Dracup, 2002) [14]. A DI is considered to be transparent if it is understandable by both the scientific community and the general public, and therefore transparency may represent general utility.

Normalised difference vegetation index (NDVI) and Normalised difference water index (NDWI) less transparent in nature. They relatively not easily by general public. The level of understandability is difficult. They are understandable only by drought researchers and professionals. Therefore, a score of 2 was assigned for transparency criteria to NDVI and NDWI.

Table 11: Tractability score

Drought Index	Score
Normalised Difference Vegetation Index	5
Normalised Difference Water Index	5

Table 12: Transparency Score

Drought Index	Score
Normalised Difference Vegetation Index	2
Normalised Difference Water Index	2

Sophistication

Sophistication considers the conceptual merits of the drought characterization approach (Keyantash and Dracup, 2002) [14]. Sometimes, the computational technique of the DI is complex and the DI itself might not be quite understandable (i.e., neither tractable nor transparent), but it may be sophisticated and appreciable from the proper perspective.

Normalised difference vegetation index (NDVI) and Normalised difference water index (NDWI) are more tractable in nature but less transparent. But they able to characterise the drought intensity and severity and can be applied to wide area. In the absence of reliable hydro-meteorological data, NDVI and NDWI can be applied to wide area. They are more sophisticated in nature. Therefore, a score of 4 given.

Table 13: Sophistication score

Drought Index	Score
NDVI	4
NDWI	4

Extendibility

Extendability corresponds to the degree to which the DI may be extended across time to alternate drought scenarios (Keyantash and Dracup, 2002) [14]. For example, all DIs evaluated in this study use basic measured data (e.g., rainfall, stream flow and storage volume), and therefore were constructed for the period where historical data were available. They are extendable for future, provided these data will be available. When long records of future data will be available, they can be used to update the classification thresholds.

Normalised difference vegetation index (NDVI) and Normalised difference water index (NDWI) are less extendable when compared to other drought indices. They require satellite images for their computation which are very difficult to project into future. Therefore, a score of 1 was assigned.

Table 14: Extendability Score

Drought Index	Score
Normalised Difference Vegetation Index	1
Normalised Difference Water Index	1

Sensitivity of Raw Scores on Ranking

It should be noted that a significant effort has been spent in this study to assign raw scores in some objective form to each of the decision criterion, based on the results of past studies and modelling of historical droughts for the DIs that were investigated (in this study). However, the researchers and professionals may select nearby raw scores compared to the current scores in Table 5.7, which might give a different ranking. Therefore, a sensitivity analysis was conducted using the Monte Carlo simulation (Mooney, 1997) technique. Monte Carlo simulation technique is widely used technique in the probability analysis of engineering systems. This technique is used for the validation of analytical methods. In the sensitivity analysis method, 10,000 possible raw score combinations were randomly generated for each of the 5 decision criteria of each DI. The total weighted score was computed for each combination of 5 criteria of each DI. Number of failures of N_f obtaining a score as per Table 5.7 is counted. Then, the probability of failure was found out using the following formula

$$\mathbf{P_f} = \frac{\mathbf{N_f}}{\mathbf{N}} \qquad (15)$$

Where N_f = Number of failures
N= Number of samples
$\mathrm{P_f}$= Probability of failure

The number of samples (N) was chosen to be 10,000.The probability of failure was estimated to be 0.0031-0.0069 for all the drought indices. This means that the subjective nature of assigning raw scores did not have any impact in the overall ranking of the DIs investigated in this study.

Overall Evaluation

According to Table 15, remote sensing based drought indices NDVI and NDWI shows same ranking of 16. Therefore, this study shows that the NDVI and NDWI are better in quantifying the drought conditions for Anantapur region. The NDVI and NDWI was the most stable DIs having smooth transitional characteristics during the droughts as well as during other periods.

Table 15: Scores of Drought Indices

Drought Index	Robustness	Tractability	Transparency	Sophistication	Extendability	Total Score
NDVI	4	5	2	4	1	16
NDWI	4	5	2	4	1	16

Conclusions

Drought has been occurring in Anantapur district for the last one century. It is essential to come out with most appropriate techniques to assess drought in a better way and map the mild, moderate and severe droughts. From the present study, the following conclusions are drawn:

1. Quantification of drought for the period 2005 to 2010 reveals that the study area affected by drought continuously.
2. Satellite data based drought analysis is the most effective technique for spatial analysis and near real time drought assessment. NDVI and NDWI represented the drought conditions accurately.
3. Overall evaluation of drought indices based on evaluation criteria reveals that NDVI and NDWI are most suitable drought index in identifying drought conditions. It is stable and has the smooth transitional characteristics.
4. It is essential for policy makers to use NDVI and NDWI for remote sensing based drought assessment in the case of hydro meteorological data.

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