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RESEARCH ARTICLE

CRITICAL APPRAISSAL OF METEOROLOGICAL DROUGHT INDICES: A CASE STUDY ON THE ANANTHAPUR DISTRICT.

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Abstract

Drought is one of the major threat to the sustainable development of India. The Ananthapur district is particularly vulnerable to droughts and there is need to take up the drought mitigation measures. The first phase in the development of drought mitigation measures is the drought assessment. Drought assessment is carried out by drought indices and it was found that drought indices are developed regionally and no drought index is superior to other in characterising drought. This research work illustrates the complexity of drought assessment and holistic approach of evaluating drought indices. In the case of this research drought assessment is carried out using meteorological drought indices and evaluated using decision criteria to find the suitability of existing drought indices to case study area. Risk analysis was also carried out to find out the drought risk in the case study area.This study reveals that 1) Percentage of departure along with Percent of normal are most suitable drought indices in characterising drought in study area. 2) Standardised precipitation index and Reconnaissance drought index are least suitable and shows high temperamental characteristic in nature. 3) Risk analysis reveals that the chance of occurrence of mild drought in the study area is 99% and return period is 2.6 years. 4) It is essential to utilize the percentage of departure along with percent of normal for development of drought policy.

Introduction:-

Drought is generally defined as a deficiency of precipitation from expected or normal that when over a season or a long period of time extended, is insufficient to meet demands. Drought is 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). There is no universal applicable and acceptable definition of drought. Numerous attempts to define drought have led to several definition of term (Nagarajan, 2003).

The UNDP (2008) defines drought as the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levelscausingserioushydrological imbalances that adversely affect land resources production systems. Drought has many facets in any facets in any single region and it always starts with lack of precipitation and affects soil moisture, streams, ground water, ecosystems and human beings. This led to identification of different types of drought. They are 1) Meteorological drought 2) Hydrological drought 3) Agricultural drought 4) Socio economic drought(Whilite et al., 1985).

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).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 meteorological or hydrological drought to agricultural impacts focussing 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 (Glantz et al., 1985).

Socio economic drought associates the supply and demand of some economic good with elements of meteorological, hydrological and agricultural drought (Whilite et al., 1985). Droughts results insocial, economical and environmentally impacts. Economic impacts are those impacts of drought that cost people’s money. Environmental impacts are those which effects plants and animals, it shrinks their food supply and damage their habitat. Social impacts of drought are ways that affects people’s health and society. The impacts of drought are sometimes not clearly demarcated, it stretches over larger geographical areas than most other natural hazards and its largely non-structural characteristic (Sivakumar and Wilhite, 2004).

Droughts of varying severities are regular occurrences in Ananthapur 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). 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).
There was much confusion exists among drought researchers and professionals about characteristics of drought and this confusion explains the lack of progress in drought preparedness in most drought affected countries (Sivakumar, 2004).

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. Most of the drought indices are not precise enough in detecting the drought conditions (Bhuyan and Wilhite, 1990). 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).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.
- Quantification of drought in meteorological context.
- Evaluating the performance, strength, weakness and limitations of drought indices.
- To determine which type and combinations of drought indices are best.
- To determine risk percentage of drought in study area using risk analysis.

In order to achieve the objectives, Ananthapur district is selected as a study area. The following sections describes the study area details, computation and evaluation of drought indices.

Study Area:-

The area of investigation in this research study is the Ananthapur district, Andhra Pradesh, India. Ananthapur district lies in between $13^0$40’ and $15^0$15' North latitude and 76^0 50' and 78^0 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 Ananthapur district is 19,225 k.m^2. 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 38.9^0 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.

Data collection:-

Different data sets were used to fulfill the intended purpose of the project.

Meteorological Data:-

Data required for this project to compute the drought indices were rainfall and potential evapotranspiration. Monthly mean rainfall and potential evapotranspiration data of Ananthapur district for the period 1901 to 2013 was collected from the Indian Meteorological Department (IMD).

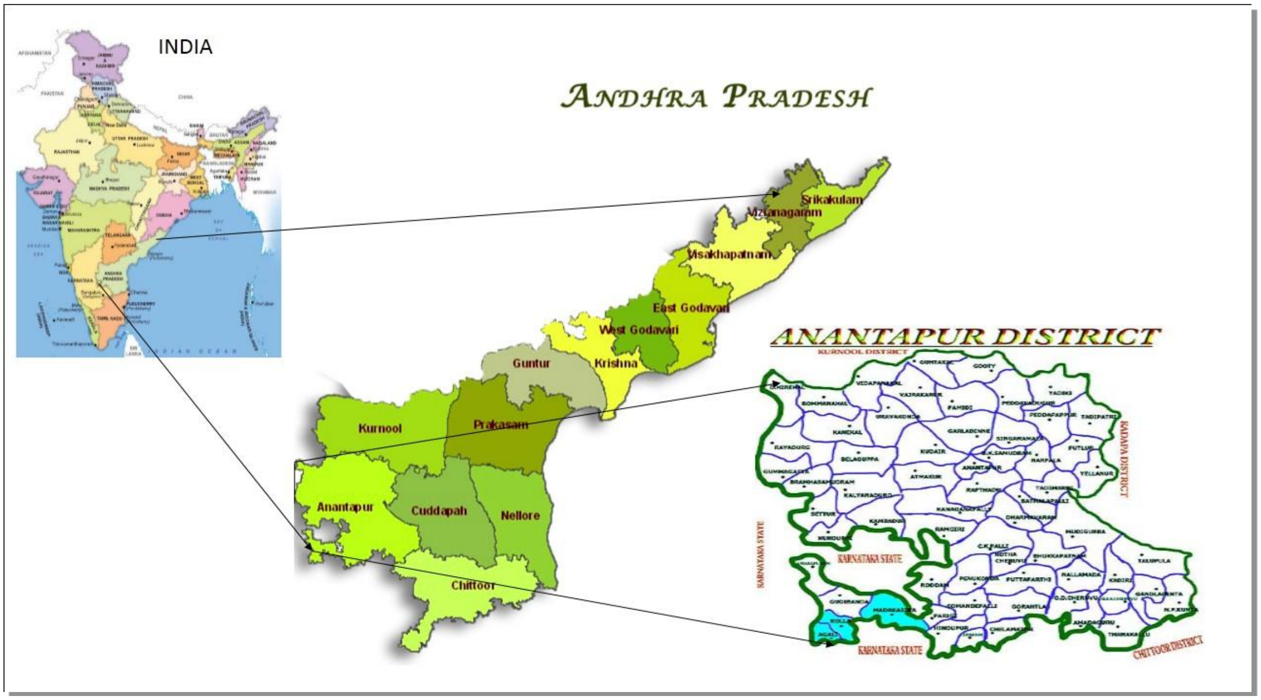

Figure 1: Location Map of Study Area

Methodology:-

Meteorological drought is usually defined by a precipitation deficiency threshold over a predetermined period of time. This is a reduction in rainfall supply compared with a specified average condition over a specified period of time. Metrological drought identify periods of drought on the basis of the number of days with precipitation less than some specified threshold. Drought assessment is carried out by using the following indices because of their popularity and different approach in characterising the drought.

Percentage of departure (P_d):-

In this method, drought is assessed on the basis of percentage deviation of annual rainfall from the long term annual mean rainfall.This index is estimated by using the following equation.

$$\mathbf{P_d = \frac{P_i - \overline{P}}{\overline{P}} * 100} \qquad (1)$$

Where Pi is the annual rainfall in the year i; and $\overline{P}$ is the long term annual mean rainfall. The classification of drought intensities based on Percentage of departure is shown in the table 1.

Table 1: P_d classification.

Percentage of departure	classification
≥0	No drought
0 to -25	Mild drought
-26 to -50	Moderate drought
≥-50	Severe drought

The percentage of departure was computed for Ananthapur region using monthly rainfall data as per Equation 1 and historical drought events were identified as per the classified values presented in the Table1. Percentage of departure plot for the period 1901 -2013 was shown in Figure 2.

Percent of normal (P_n):-

Percent of Normal (P_n) is expressed as the actual rainfall in percentage compared to the normal rainfall (Hayes, 2003; Morid et al., 2006). Usually the long-term mean or median rainfall value has been considered as the normal (Smakhtin and Hughes, 2004). It can be used to compare precipitation in a single region or season, but it is also easy to misinterpret the results (Hayes, 2011).

$$P_n = \frac{P}{P_{30}} * 100 \qquad (2)$$

where P is annual precipitation in the year, P_{30} is 30 year mean precipitation.

P_n can be calculated in a variety of time scales ranging from a single month to a group of months representing a particular season, calendar year or water year. However, P_n in this study was calculated using the annual time step. No threshold ranges had been published for this drought index. Usually, lower P_n (P_n<100%) values indicate dry circumstances. Percent of normal was arrived by using the Equation2 and historical drought events were identified as per the threshold values and presented in the Figure 3.

Deciles:-

Deciles is a meteorological drought measurement tool which uses rainfall. The deciles index provides an accurate statistical measurement of precipitation provided that long climatic data is available.In calculating Deciles, the long-term monthly rainfall records from 1901-2013 were first ranked from highest to lowest to construct a cumulative frequency distribution. This distribution was then split into ten parts (or deciles) based on equal probabilities (Gibbs and Maher, 1967).

The threshold ranges of Deciles used to define drought conditions are presented in the Table 2 (Gibbs and Maher, 1967).

Table 2: Decile classification.

Class	Period
Decile 1-2	Much below normal
Decile 3-4	Below normal
Decile5-6	Near normal
Decile 7-8	Above normal
Decile8-9	Much above normal

In this study decile 1-2 and decile 3-4 were considered as a drought events. Deciles were computed for the long historical rainfall data of 113 years over Ananthapur district and historical drought events were identified which falls under the deciles 1-2 and 3-4.The results were presented in the Figure 4.

Standardised Precipitation Index (SPI):-

The SPI was formulated by Tom McKee, Nolan Doesken and John Kleist of the Colorado Climate Centre in 1993 to give a better representation of wetness and dryness than the Palmer index (McKee et al., 1993). The SPI is globally the preferred index to be used for drought risk assessment (WMO,2009). The SPI was developed to quantify a precipitationdeficitfordifferent time scales and for different locations. It was designed to be anindicatorofdrought that recognizes the importance of time scales in the analysis of wateravailabilityand water use (McKee et al., 1993; 1995; Keyantash & Dracup, 2002; Moreiraetal.,2008).

The advantage of the SPI is that one can relatively easily analyse drought or anomalouslywet periods at a particular time scale for any location in the world with daily precipitationrecords (McKee, 1995; Moreira et al., 2008).Technically, SPI is the number of standard deviations that the observed value would deviate from the long-term mean for a normally distributed random variable.This index based on the probability of rainfall for any time scale.In the present study SPI was computed using spi_sl_6.exe programme which was developed by National drought mitigation centre (NDMC). The classification of drought intensities based on SPI is shown in the Table 3.

Table 3: SPI Classification.

Spi values	Class
>2	Extreme Wet
1.5 to1.99	Very Wet
1 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Extremely Dry
<-2	Severely Dry

SPI values arrived were presented in the Figure 5. Historical drought events were identified as per threshold values presented in the Table 3.

Reconnaissance drought index (RDI):-

Reconnaissance drought index (RDI) is a multivariate drought index that considersthe precipitation and evapo transpiration. RDI is more sensitive and suitable in case of changing environment (G.Tsakiris, 2007). The index is computed by the following equations.

$$\boldsymbol{\alpha_0 = \frac{\sum_{j=1}^{12} P}{\sum_{j=1}^{12} PET_{ij}}} \qquad (3)$$

$$\mathbf{y_{i=ln(\alpha_0)}} \qquad (4)$$

$$\mathbf{RDI = \frac{Y_i - \bar{y}}{\sigma_y}} \qquad (5)$$

where P= Precipitation,

PET= Potential Evapotranspiration,

$\bar{y}$ = Mean ofy_i,

σ_y= Standard deviation

The classification of drought intensities based on RDI is shown in the Table 4.

Table 4: RDI Classification.

RDI values	Class
>2	Wet
1.5 to 1.99	Very wet
1 to 1.49	Moderate wet
-0.99 to 0.99	Normal dry
-1 to -1.49	Severely dry
-1.5 to -1.99	Extremely dry

The Reconnaissance Drought Index (RDI) is calculated in three stages: initial value of RDI (α_0), log value of α_0 and standardized RDI (RDIst). RDI values that are computed were presented in the figure 6. By glancing at the Figure 6, it was observed that severe dry condition was observed in the years in the years 1923 and 1976 with RDI values -2.52 and -2.15. It was observed that RDI generally responds in similar fashion to that of SPI.

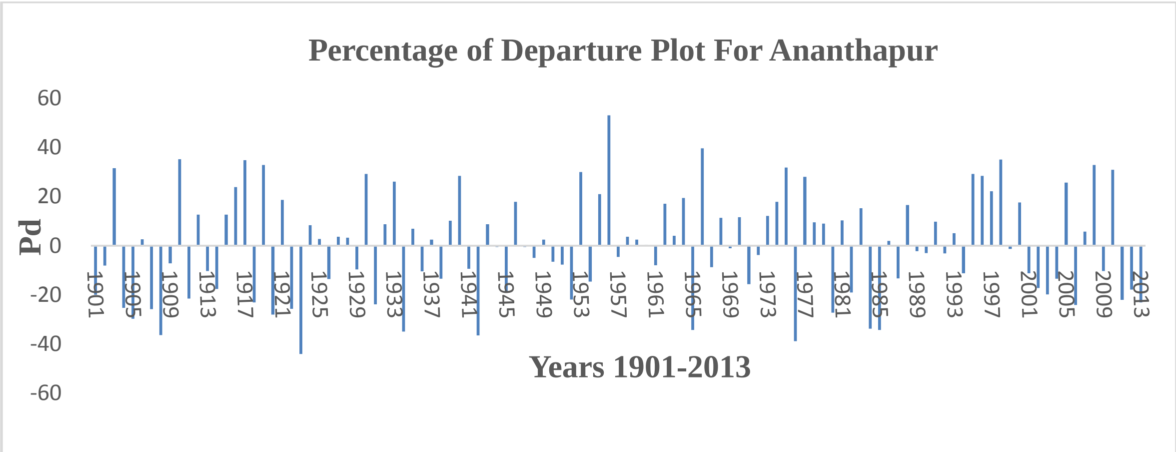

Figure 2: Time Series Plot of Percentage of Departure.

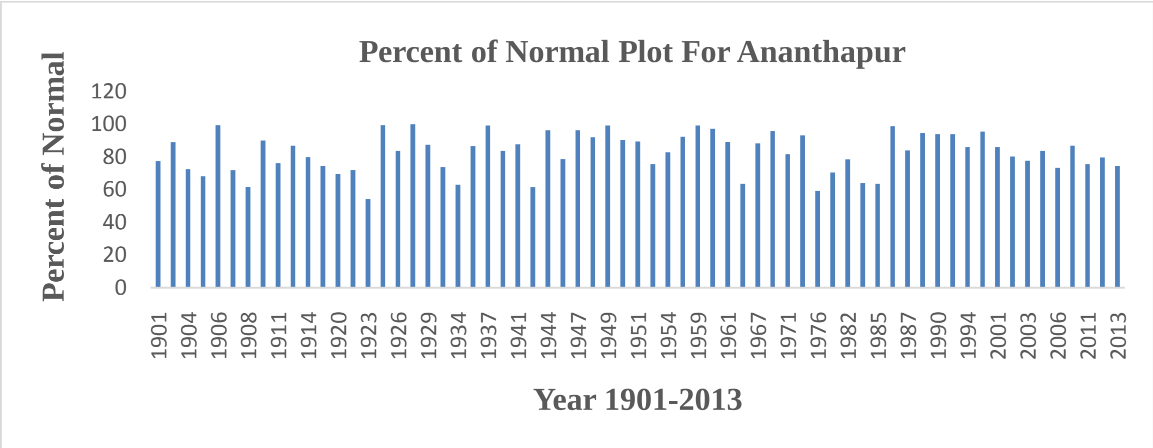

Figure 3: Time Series Plot Percentage of Normal.

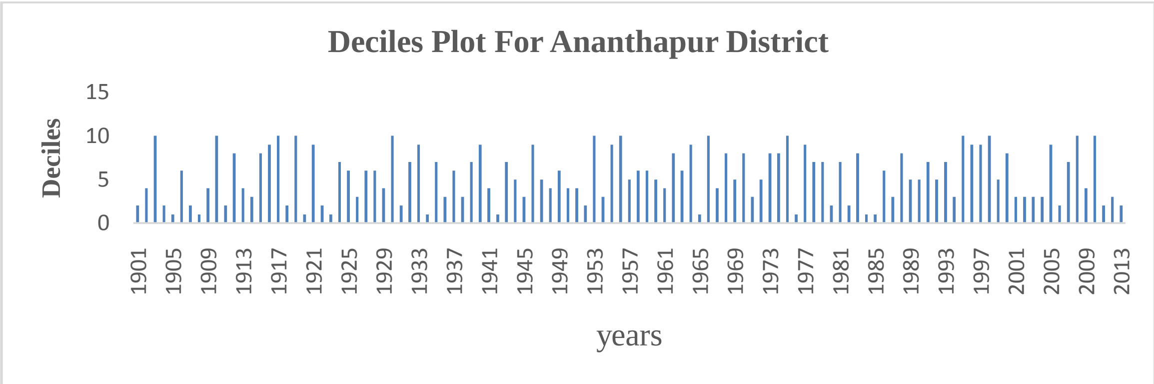

Figure 4: Time Series Plot of Deciles.

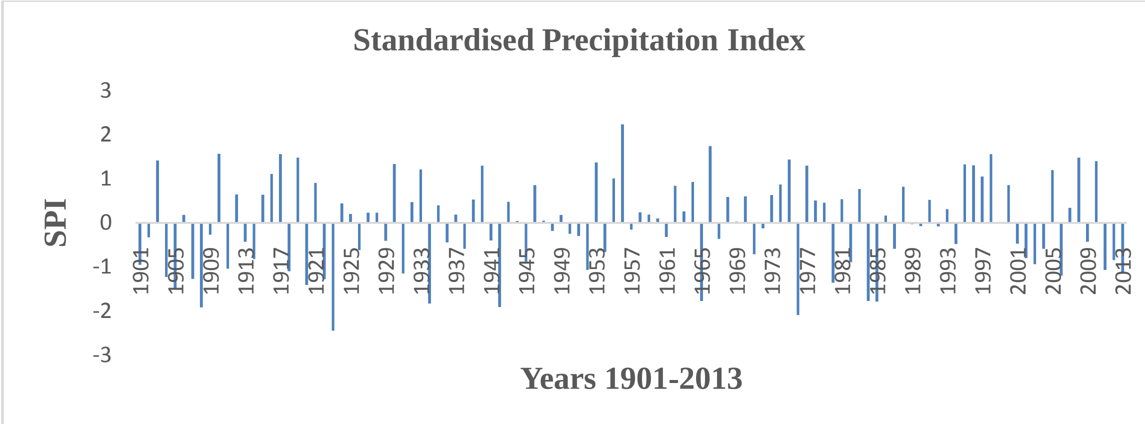

Figure 5: Time Series Plot of SPI.

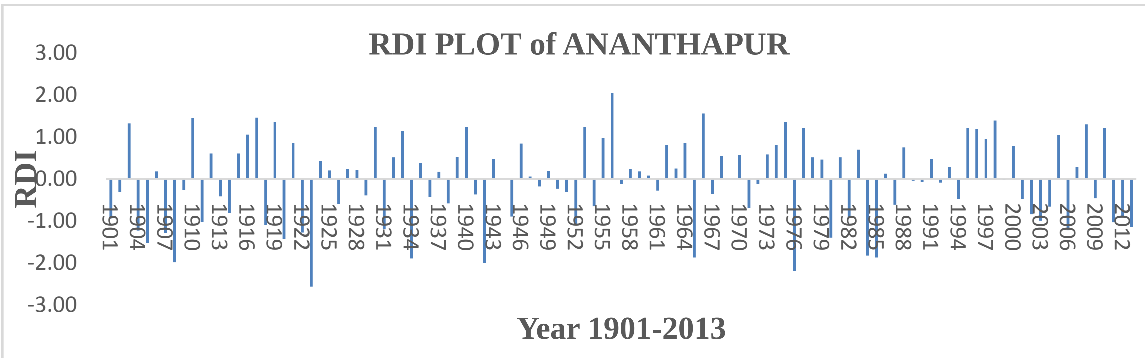

Figure 6: Time Series Plot of RDI.

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 nature of the drought phenomena, the different hydro-climatic conditions of area and different catchment characteristics (Redmond, 2002; Smakhtinand Hughes, 2007; Mishra and Singh, 2010). In this chapter, drought indices (DIs) that were analyzed for the Ananthapur 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). 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 Ananthapur 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 Ananthapur region in this study.Therefore, the maximum possible total weighted score any DI could have is 25.

In the present studyit is considered that each decision criteria has equal importance for the evaluation.

Robustness:-

Robustnessrepresents 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). Percentage of departure (P_d)index is quite response as well as it was not temperamental in detecting historical drought conditions. It detected all historical droughts except the event 1997 (Table 5). It can be applied to wide range of physical conditions with long term rainfall data. Therefore, a raw score of 4 was given for robustness criterion to the percentage of departure. Percent of normal (P_n) also showed good agreement with percentage of departure in detecting historical droughts. However it failed to identify the 1997 drought and correctly identified the other drought events. Hence a raw score of 4 was given. Deciles as a meteorological drought index failed to identify 1997 and 1999 droughts in the period of 1995-2013 (Table 5).

Hence the robustness score fordeciles was given as 3. The SPI index showed poor robustness characteristics than P_d and P_n (Table 5). SPI failed to identify 1997 drought event and overestimated 2000 and 2007 years as drought events. Therefore, the robustness score of 1 was assigned to SPI. Reconnaissance drought index (RDI) have shown similarity to SPI in detecting historical droughts (Table 5). RDI also failed to identify 1997 drought event and overestimated 2000 and 2007 years as drought events. RDI showed high temperamental characteristic in nature. Therefore, a score of 1 was assigned.

Table5: Drought Events.

Percentage of Departure	**Percent of Normal**	**Deciles**	**Standardised Precipitation Index**	**Reconnaissance Drought Index**	**Actual Drought Events (A.P Drought memorandum-(2013)**
1999	1999		1999	1999	1997
2001	2001	2001	2000	2000	1999
2002	2002	2002	2001	2001	2001
2003	2003	2003	2002	2002	2002
2004	2004	2004	2003	2004	2003
2006	2006	2006	2004	2006	2004
2009	2009	2009	2006	2007	2006
2011	2011	2011	2007	2009	2009
2012	2012	2012	2009	2011	2011
2013	2013	2013	2011	2012	2012
			2012	2013	2013
			2013		

Table 6: Robustness Score.

Drought index	**Score**
Percentage of Departure	4
Percent of Normal	4
Deciles	3
Standardised Precipitation Index	1
Reconnaissance Drought Index	1

Tractability:-

Tractabilityimplies the practical aspect of the drought index. A tractable index requires less number the of numerical computations, less number of input variables and less extensive data base with historical (Keyantash and Dracup, 2002). Percentage of departure (P_d) requires simple computations, use only rainfall data as input variables and requires less extensive data base with historical data. Hence a score of 5 was given for tractability criteria to the percentage of departure.

Percent of normal (P_n) also requires simple numerical computations, use only rainfall data. But requires extensive database of 30 years rainfall data. Therefore a score of 4 was assigned to percent of normal. Deciles index showed good agreement to percent of departure in computations and data requirement. Therefore, a score of 4 was given.

Standardised precipitation index (SPI also requires only rainfall as input variable but computations are complex than P_d andP_n

Therefore a score of 3 was assigned. Reconnaissance drought index (RDI) requires rainfall and potential evapotranspiration as parameters for its computation. The level of computation is also difficult when compared to deciles and percent of normal. Hence a score of 3 was assigned.

Table 7: Tractability score.

Drought Index	Score
Percentage of Departure	5
Percent of Normal	4
Deciles	4
Standardised Precipitation Index	3
Reconnaissance Drought Index	3

Transparency:-

Transparency represents the clarity of the objective and rationale behind the drought index (Keyantash and Dracup, 2002). 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. Percentage of departure (P_d) is understandable to both general public and scientific community. Therefore, a score of 5 was assigned. Percent of normal (P_n) is also transparent in nature and easily understandto both general public and scientific community. Hence a score of 5 was assigned. Deciles in general understandable to both the scientific community and the general public but less transparent when compared to the percent of normal and P_d. Therefore a score of 4 was assigned. Standardised precipitation index (SPI) is not relatively easy to understand by the general public, but it is understandable by drought researchers and professionals. Therefore, a score of 2 was given for transparency criterion.

Reconnaissance drought index (RDI) is quite difficult for the general public to understand. The level of understandability seems to be the better than SPI. Therefore a score of 3 was assigned.

Table 8: Transparency score.

Drought Index	Score
Percentage of Departure	5
Percent of Normal	5
Deciles	4
Standardised Precipitation Index	2
Reconnaissance Drought Index	3

Sophistication:-

Sophisticationconsiders the conceptual merits of the drought characterization approach (Keyantash and Dracup, 2002). 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.

Standardised precipitation index (SPI) and Reconnaissance drought index (RDI) are less transparent and tractable in nature. But RDI considers the precipitation and potential evapotranspiration variables for their computation which are main factors of causing drought. Therefore a raw score of 5 was assigned. SPI fits the data to gamma distribution in its calculation which reduces sensitivity in data. Therefore a score of 4 was assigned. Percentage of departure, percent of normal and deciles are more transparent and tractable in nature but they cannot be appreciated in special perspective. Therefore, scores of 1, 1, and 2 were assigned respectively.

Table 9: Sophistication score.

Drought Index	Score
Percentage of Departure	1
Percent of Normal	1
Deciles	2
Standardised Precipitation Index	4
Reconnaissance Drought Index	5

Extendability:-

Extendability corresponds to the degree to which the DI may be extendedacross time to alternate drought scenarios (Keyantash and Dracup, 2002).For example, all DIs evaluated in this study use basic measureddata (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 datawill be available. When long records of future data will be available, they can be used to update the classification thresholds.

Percentage of departure, percent of normal and Deciles indices use only rainfall data. They can be comfortably extended for future time if rainfall data is available. The future calculations are very easy for these indices. Therefore, a score of 5 was assigned.Standardised precipitation index (SPI) also requires only rainfall data for its extendability but it requires high level of computations. It is very difficult to extend it for future scenario. Therefore, a score of 3 was assigned.

Reconnaissance drought index (RDI) is a complex variable as it requires precipitation and potential evapotranspiration. These two variables are needed to be extend for future and level of computations are also difficult when compared percent of normal and deciles. Therefore, a score of 2 was given.

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 shows lowest scores. Therefore, this study shows that Pd and Pn are better in quantifying drought conditions for Ananthapur region. The Pd and Pn were the most stable DIs having smooth transistional characteristics during the droughts as well as other periods.

Table10: Extendability Score.

Drought Index	Score
Percentage of Departure	5
Percent of Normal	5
Deciles	4
Standardised Precipitation Index	3
Reconnaissance Drought Index	2

was computed for each combination of 5 criteria of each DI, Number of failures(N_f) obtaining a score as per Table 11 is counted.ofThenthe probability of failure was found out using the following formula.

$$\mathbf{P_f = \frac{N_f}{N}} \qquad (6)$$

where N_f= Number of failures

N= Number of samples

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 11, the Percentage of departure and percent of normal shows high overall weighted scores of 20 and 19 respectively. The indices SPI and RDI shows ranking of 13 and 14 respectively. The index deciles has score of 18. Among the meteorological drought indices SPI and RDI The percent of departure (P_d) and P_n has modelled the characteristics of historical droughts better than any other DI.

Table 11: scores of drought indices.

Drought Index	Robustness	Tractability	Transparency	Sophistication	Extendability	Total Score
P_d	4	5	5	1	5	20
P_n	4	4	5	1	5	19
Deciles	3	4	4	2	5	18
Spi	1	3	2	4	3	13
Rdi	1	3	3	5.	2	14

The SPI and RDI has produced the lowest total score within the group of drought indices (DIs) considered. This is because of the complexity of SPI calculations and relative difficulty in understanding the SPI and RDI by the general public.

Risk Analysis:-

Hydrologic systems are impacted by extreme events such as floods and droughts, which cause severe damage to natural environments and human lives. Extreme hydrologic events are usually expressed by return periods. When the concept of return period is applied to drought-related variables, the return period will be the average time between the occurrence of events with a certain magnitude or less (Haan, 2002). The objective of risk analysis is to relate the magnitude of extreme events to their frequencies of occurrences through the use of probability distribution. It is usually assumed that the variables being analysed are independent and identically distributed (Chow et al., 1988). In the present study a methodology is introduced for estimating the return periods of droughts in Ananthapur region using risk analysis. By the evaluation criteria it was found that Percentage of departure was most suitable index for quantifying the drought in Ananthapur region. Therefore P_d index is used for risk analysis for determining the return period of droughts.

Computation of Return Period:-

Risk analysis of drought is important in drought management.Risk analysis is used to predict how often certain values of a drought phenomenon may occur and to assess the reliability of the prediction. It is a tool for determining drought mitigation measures.

The return period of an event in any observation is the inverse of its exceedance probability.

$$\mathbf{T = \frac{1}{P}}$$

where

T= Return period

P= Probability of exceedance

n= number of successive years

The exceedance of probability is given by

$$\mathbf{P = \frac{m}{N}}$$

where

m is number of occurrences and N (113) is total number of events.

The risk of occurrence of drought is calculated by $R = (1- q^n)$

where q= (1-p)
R= probability of risk

The above procedure was applied to the index percentage of departure given in the Table 12.

Table 12: Risk analysis.

S.no	Category	No of occurrences (m)	Probability (m/N)	Return Period
1	Mild Drought	43	0.38	2.6
2	Moderate Drought	11	0.10	10.3

Historical droughts occurred in the Ananthapur region are evaluated based on risk analysis. The analysis reveals that the return period of mild drought is 2.6 years. The chance of occurrence of mild drought in next 10 years is 99 %. The return period of moderate drought is 10.3 years. It means that year after 10 year is a moderate year. The risk of occurrence of moderate drought in next 10 years is 65 %.

Conclusions:-

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

- Quantification of drought for the period 1901 to 2013 reveals that the study area affected by drought continuously.
- For meteorological data based drought analysis, Percentage of departure, percent of normal and deciles characterised the historical droughts accurately. Standardised precipitation index and reconnaissance drought index shows temperamental characteristics in detecting historical droughts.
- Overall evaluation of drought indices based on evaluation criteria reveals that Percentage of departure is most suitable drought index in identifyingdrought conditions. It is stable and has smooth transitional characteristics.
- It is essential for policy makers to use Percentage of departure index for rainfall based drought assessment.
- 5.The risk analysis reveals that the chance of occurrence of mild drought in next 10 years is 99% and moderate drought is 65%. The return period of mild drought is 2.6 years and moderate drought is 10.3 years.

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