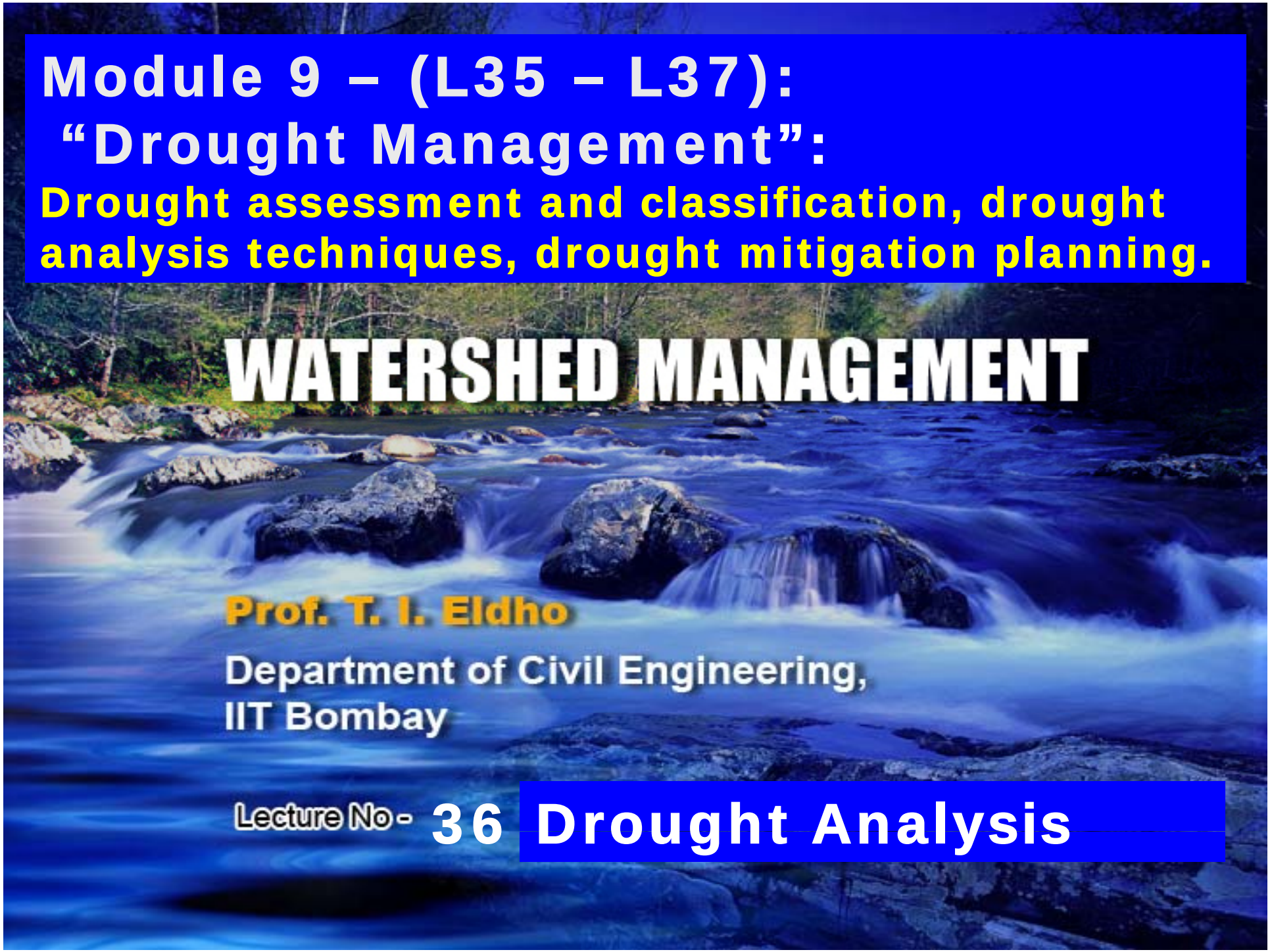
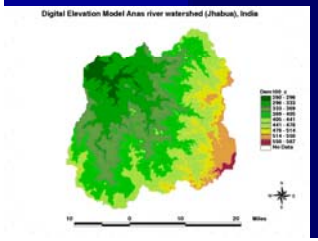
Module 9 – (L35 – L37): "Drought Management":

Drought assessment and classification, drought analysis techniques, drought mitigation planning.



L36– Drought Analysis

- **Topics Covered**
- Drought analysis, Indices, Standardized precipitation index, Palmer Drought Index (PDI), Normalized Difference Vegetation Index
- Keywords: Drought analysis; Indices



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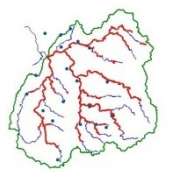


Drought Analysis - Introduction

- Drought – Complex, least understood natural hazards
- Large historical datasets- required to study drought
- Involves complex inter-relationship between climatological & meteorological data
- Not possible to avoid droughts - But management of Drought impacts & preparedness is possible
- Success depends on how drought characteristics are quantified
- Drought indices - Assimilate thousands of bits of data on rainfall, snowpack, stream flow, & other water supply indicators
- Ex: Standard Precipitation Index (Popular method)

Drought Analysis - Introduction

- Drought analysis - Interdependence between climatic, hydrogeologic, geomorphic, ecological & societal variables
- Very difficult to adopt a definition that fully describes the drought phenomena & respective impacts
- Concept of Drought - Varies among regions of different climates
- Conceptual definitions of drought- lack to provide the specifics about the severity, duration & extent of drought.
- Operational definitions of drought - typically require quantification of "normal" or "expected" conditions within specified regions & variations in societal conditions
- Operational definitions – Formulated in terms of Drought Indices

Drought Analysis

- Hydrological Drought Analysis- through hydrological models – water balance models, evapo-transpiration studies, groundwater & surface water flow models
- Onset, duration and deficit volumes – analyzed from simulated hydrographs
- Physically based models – more effective
- To explore the impact of man-induced changes on droughts
- Existing models - still need some improvement if a very accurate simulation of low flows and associated droughts is required.

Drought Analysis -Procedure

- 1- Diagnosis of meteorological anomaly causing reduction of the major water input to the hydrological system – precipitation;
- 2 – Analysis of the basin hydrological dynamics responsible for water retention, transport, and storage, in terms of its availability for human use (supply analysis);
- 3 – Analysis of the potential & effective use of water by society (demand analysis), & social and economic impacts of such scarcity;
- 4 – Assessment of methods & models of social & political organization used to react to and mitigate such impacts, seeking the most appropriated and effective ones in the reduction of societal vulnerability.

Droughts Indices

- Drought Index – A Single number useful for decision making
- Drought Indices- measure different drought-causative & drought-responsive parameters, & identify & classify drought accordingly
- Used for drought warning & lead time assessment
- Summarize different data on rainfall, snowpack, streamflow, and other water supply indicators
- PDI/PHDI, SPI, CMI, SWSI, VHI – Different Drought Indices
- Water supply planners find it useful to consult one or more indices before making a decision

Droughts Indices

- Palmer indices take precipitation, evapotranspiration & runoff into consideration:
- Palmer Drought Index (PDI): A long-term meteorological drought index run on a weekly or monthly basis.
- Strength: First comprehensive drought index in U.S.
- Limitations: Slow to detect rapidly changing conditions - Not as well-suited for inhomogeneous regions- Not as effective in winter –snowpack not considered - Used to Quantify Drought
- **Crop Moisture Index (CMI):** A short-term weekly index designed to reflect quickly changing soil moisture conditions for agricultural applications.
- Limitation: Used mainly during growing season

Droughts Indices

- Palmer Hydrological Drought Index (PHDI): A monthly index - quantifies long-term hydrological impacts. Limitation: Responds more slowly to changes than PDI
- Standardized Precipitation Index (SPI): A monthly probability index considering only precipitation.
- Calculated for a variety of time-scales (from 1 to 60 months).
- Strengths: Recognizes drought on many time scales Anticipates long-term drought cessation
- Limitation: Only considers precipitation
- Satellite Vegetation Health Index (VHI): A satellite-derived index reflecting a combination of chlorophyll & moisture content in vegetation and changes in thermal conditions at the surface (NDVI).
- Limitation: Used mainly during growing season

Droughts Indices

- Objective Blended Drought Index Percentiles (OBDI): A weekly index averaging PDI, soil moisture and 30-day precipitation ranking percentiles.
- Strength: Incorporates both long and short term indices
- Limitation: Opposite-phased long and short-term conditions may offset in final product

- Other useful drought indices include: % of Normal Precipitation; USGS Streamflow Percentiles; USDA/NASS Soil Moisture Measurements (SCAN); SNOTEL Measurements; Surface Water Supply Index (SWSI)** Used in the West and primarily during the snow season Drought

Palmer Drought Severity Index

- **PDSI:** Computation of the PDSI (PDI) incorporates a water balance model using historic records of monthly precipitation, potential evapotranspiration & simple 2-layer soil moisture reservoir
- Upper layer is assumed to contain 1 inch (25.4 mm) of available moisture at field capacity
- Underlying layer has an available capacity that depends on the soil characteristics of the site
- Moisture cannot be removed from the lower layer until the top layer is dry
- Runoff (RO) is assumed to occur when both layers reach their combined moisture capacity.

Palmer Drought Severity Index.

- Potential values required: Potential evapotranspiration (PE), Potential recharge (PR) - the amount of moisture required to bring the soil to field capacity, Potential loss (PL) - The amount of moisture that could be lost from the soil to evapotranspiration provided precipitation during the period was zero, Potential runoff (PRO) - the difference between the potential precipitation and the PR
- Climate coefficients are computed as a proportion between averages of actual versus potential values for each of 12 months
- Climate coefficients are used to compute the amount of precipitation required for the Climatically Appropriate for Existing Conditions (CAFEC)

Palmer Drought Severity Index..

- Difference (d) between the actual (P) and CAFEC precipitation (^P) is an indicator of water deficiency for each month

$$d = P - \hat{P} = P - (\alpha \cdot PE + \beta \cdot PR + \gamma \cdot PRO + \sigma \cdot PL)$$

$$\alpha = \bar{ET}/\bar{PE}, \beta = \bar{R}/\bar{PR},\ \gamma = \bar{RO}/\bar{PRO} \text{ and } \sigma = \bar{L}/\bar{PL} \text{ for 12 months}$$

- ET, R, RO and L are actual evapotranspiration, recharge, runoff & loss respectively)
- A Palmer Moisture Anomaly Index, Z, is defined as Z = K.d
- K is a weighting factor - to adjust departures from normal precipitation such that they are comparable among different areas & different months
- Palmer suggested empirical relationships for K. By plotting Z versus duration for the worst drought episodes

Palmer Drought Severity Index…

- Linear relationship obtained for drought severity is

$$PDSI_t = \varphi \cdot PDSI_{t-1} + \epsilon \cdot Z_t$$

φ and ϵ are coefficients

- PDSI of the initial month in a dry or wet spell is equal to $\epsilon \cdot Z_t$
- Z index indicates how wet or dry it was during a single month without regard to past precipitation anomalies

Classification of drought and wet conditions as defined by Palmer (1965) for PDSI

PDSI/PHDI Value	Scale
Above +4.00	Extreme wet spell
3.00 to 3.99	Severe wet spell
2.00 to 2.99	Moderate wet spell
1.00 to 1.99	Mild wet spell
0.50 to 0.99	Incipient wet spell
-0.49 to +0.49	Near normal
-0.99 to -0.50	Incipient drought
-1.99 to -1.00	Mild drought
-2.99 to -2.00	Moderate drought
-3.99 to -3.00	Severe drought
Below -4.00	Extreme drought

Ref: Awass, 2009

Droughts Indices - SPI

- Standardized precipitation index (SPI) -based on an equi-probability transformation of aggregated monthly precipitation into a standard normal variable (See Fig)
- Computation of the index requires fitting a probability distribution to aggregated monthly precipitation series (e.g. k= 3, 6, 12, 24 months, etc)

(Ref: Awass, 2009)

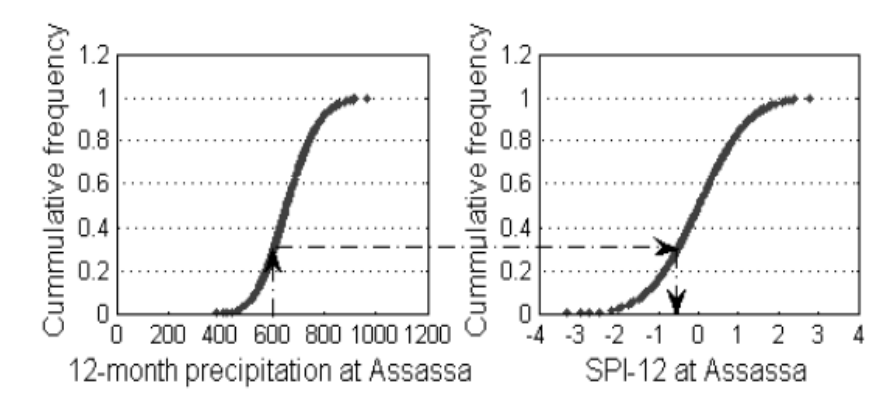


Fig: Equi-probability transformation from fitted gamma distribution of monthly precipitation aggregated at 12 month to standard normal distribution at Assassa Station

Droughts Indices – SPI..

- Computing the nonexceedance probability related to such aggregated values and defining the corresponding standard normal quantile as the SPI
- SPI has advantages of statistical consistency, & ability to describe both short-term & long-term drought impacts through the different time scales of precipitation anomalies
- Relies on one input – Limitation
- Temporal variability of SPI at different time scales
- Developed for the purpose of defining & monitoring drought

U.S. National Drought Mitigation Centre

- Uses the SPI to monitor current states of drought
- SPI can track drought on multiple time-scales
- SPI with 5 running time intervals, i.e. 1, 3, 6, 9, & 12-months

Droughts Indices – SPI…

- Computation of the SPI - fitting a Gamma probability density function to a given frequency distribution of precipitation totals for a station
- Estimation of parameters of gamma probability density function for given frequency (1, 3, 6, 9, & 12 months)
- SPI index is flexible with respect to the period chosen
- The Gamma distribution is defined by its frequency or probability density function

$$g(P) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} P^{\alpha-1} e^{-P/\beta} \quad \text{for} \quad P > 0,$$

- α, β are shape & scale parameters, P – Precipitation amount, Γ(α) – Gamma function, Maximum likelihood solution for optimal estimate of α, β

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \quad \beta = \frac{\overline{P}}{\alpha},$$

$$A = \ln\left(\overline{P}\right) - \frac{\sum \ln(P)}{n},$$

- n-number of observations

Droughts Indices – SPI….

- Cumulative probability (H(P)) of an observed precipitation event for the given month and time scale for the station – Using resulting parameters
- g(P) is undefined for P = 0, Hence

$$H(P) = q + (1 - q)\,G(P)$$

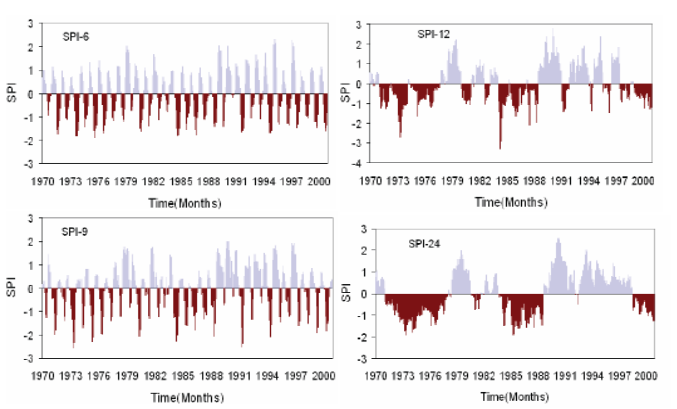
- q is the probability of a zero & G(P) the cumulative probability of the incomplete gamma function
- q=m/n, m = no of zero precipitations
- Cumulative probability, H(P), after its computation, is transformed to the standard normal random variable z with mean equal to zero & variance of one, which is the value of the SPI

Droughts Indices – SPI….

- Weather Classification by SPI values & corresponding example : event probabilities

SPI value	Category	Probability (%)
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
–0.99 to 0.99	Near normal	68.2
–1.49 to –1.00	Moderately dry	9.2
–1.99 to –1.50	Severely dry	4.4
–2 or less	Extremely dry	2.3

Ref: Awass, 2009



Loukas and Vasiliades(2004)

Normalized Difference Vegetation Index

- NDVI - Based on Spatial & temporal variability of vegetation
- Utilizes reflectance spectra of healthy green vegetation -characteristically high in the near infrared
- 0.73-1.10µm in the case of the NOAA Advanced Very High Resolution Radiometer (AVHRR)

Before NDVI Computation, following conversations are necessary

- ✓ For computation there is a need to geo-locate the pixels from satellite data & remap to chosen projection
- ✓ Sensor calibration of individual channels- implemented & digital numbers converted to spectral reflectances to enable NDVI calculation
- ✓ Atmospheric corrections & employ a method to screen for clouds

Normalized Difference Vegetation Index.

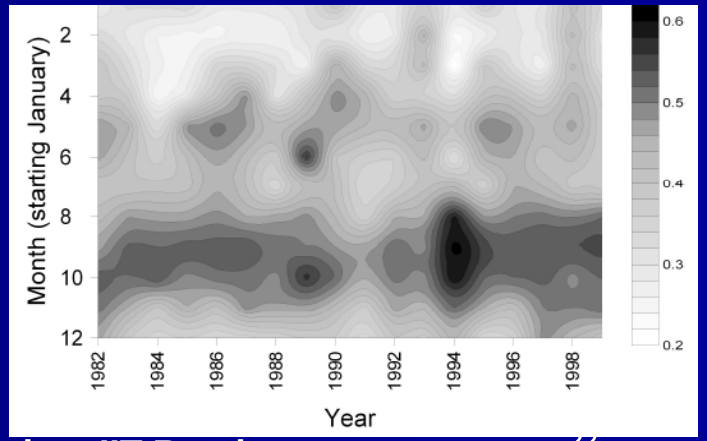
$$NDVI = \frac{NIR - RED}{NIR + RED}$$

- NIR is reflectance in the near infrared
- RED is the red waveband reflectance
- Differential reflectance in these bands provide- means of monitoring density & vigour of green vegetation growth using spectral reflectivity of solar radiation
- Green leaves commonly have larger reflectance in the near infrared than in the visible range
- Leaves under water stress- become more yellow – reflect significantly less in the near infrared range

Normalized Difference Vegetation Index.

- Vegetation NDVI typically ranges from 0.1 up to 0.6
- With higher values associated with greater density and greenness of the plant canopy
- Regions of high variability in NDVI depict regions which are either highly variable in precipitation regime
- Identify agricultural droughts

Ref: Awass, 2009



Droughts Indices - Comparison

S.No	Index	Pros	Cons	Citation
1	PDSI/ PHDI	Non-dimensional, Widely accepted especially in USA	Arbitrary threshold, may lag emerging droughts by several months less well suited for mountainous or of frequent climatic extremes	Palmer 1965
2	SPI	Identifies emerging droughts months sooner than the PDSI, Limited data input	Arbitrary threshold,	McKee et al. 1995
3	CMI	Identifies potential agricultural droughts.,	not a good long-term drought monitoring tool	Palmer 1965

Ref: Awass, 2009

Droughts Assessment Tools

- **U.S. Drought Monitor:** A multi-agency weekly drought assessment product which depicts drought conditions of different time scales and of varying impacts using a blend of drought indices and local expert input.
- **Drought Termination and Amelioration:** A web tool used to quantify how much precipitation is needed and the probability of receiving such precipitation to end or ameliorate a PHDI drought of specified intensity (PHDI values of -2 to -6) on 1 to 6-month time scales.
- **Main Federal Partners:** Joint Agricultural Weather Facility (USDA and DOC/NOAA)
- Climate Prediction Center (DOC/NOAA/NWS)
- National Climatic Data Center (DOC/NOAA) **Academic Partner:**
- National Drought Mitigation Center (University of Nebraska-Lincoln)

Drought Severity Classification

- Drought Monitor - Categories of drought magnitude

Category	Name	Percentile Chance*
D0	Abnormally Dry	21-30
D1	Drought - Moderate	11-20
D2	Drought - Severe	6 – 10
D3	Drought - Extreme	3 – 5
D4	Drought - Exceptional	2

**percentile chance is for any given year out of 100 years.*

- Primary Indicators - for categories include: PDI, CPC Soil Moisture Model Percentiles, USGS Weekly Streamflow Percentiles, Percent of Normal Precipitation, SPI & VHI.

Drought Situation in India

- Drought Prone Areas of the Country – Criteria (MOWR)
- When the annual rainfall is less than 75% of the normal in 20% of the years examined.
- Less than 30% of the cultivated area is irrigated.
- The Irrigation Commission, 1972, National Commission on Agriculture, 1976, Drought Area Study & Investigation Organization of C.W.C., 1978
- Out of total geographical area of the country (329 M. ha) about 1/6th is drought prone.

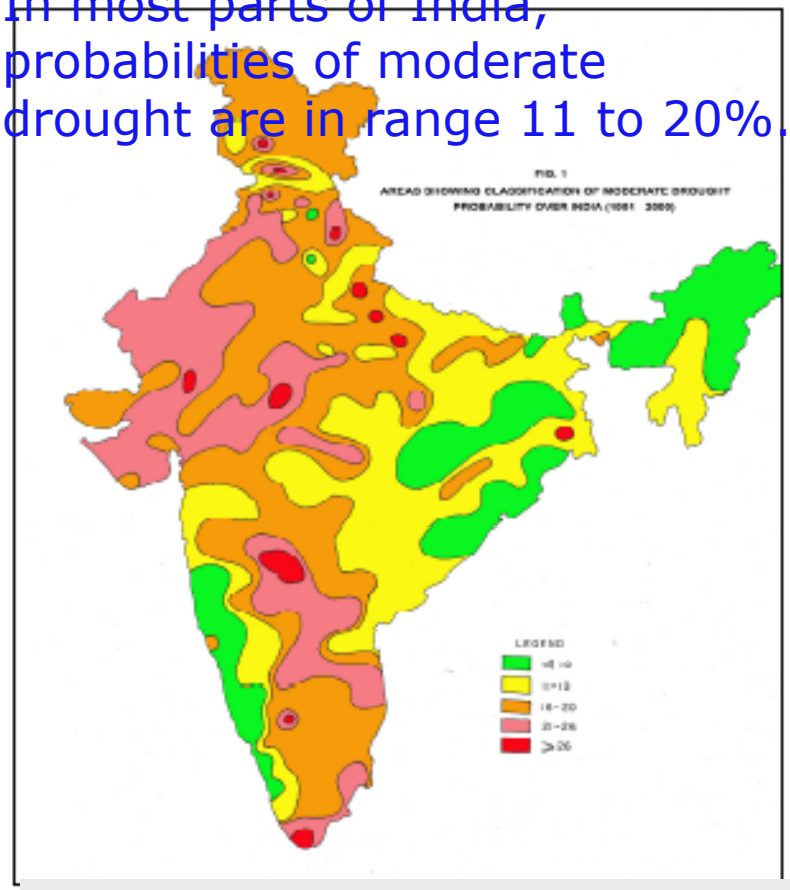
Drought Areas in India

- Mapping of Drought Areas Over India (2010) – NCC Research Report, P.G. Gore, T. Prasad, H.R. Hatwar, IMD, Pune
- Data & methodology: daily rainfall data of different stations for the period 1901 to 2000 for selected districts with long rainfall data series have been considered.
- Drought criteria :- A meteorological drought over an area is defined as a situation when rainfall over that area is less than 75% of the climatological normal.
- Further, when deficit of rainfall is in between 26 to 50%, moderate drought is defined. When deficit of rainfall is more than 50%, severe drought is defined.

Drought Areas in India

	Region	Sub-divisions
1.	Northwest India	Haryana, Chandigarh and Delhi, East Rajasthan, West Rajasthan, Gujarat Region, Saurashtra & Kutch and Punjab.
2.	West Central India	East Madhya Pradesh, West Madhya Pradesh, Konkan and Goa, Madhya Maharashtra, Marathwada, Vidarbha, Telangana and North Interior Karnataka.
3.	Peninsular India	Coastal Andhra Pradesh, Rayalaseema, Tamilnadu and Puducherry, Kerala, Coastal Karnataka, South Interior Karnataka.
4.	Central Northeast India	Jharkhand, Bihar, Orissa, East Uttar Pradesh, West Uttar Pradesh.
5.	Northeast India	Assam and Meghalaya, Nagaland, Manipur, Mizoram and Tripura, Sub-Himalayan West Bengal and Sikkim and Gangetic West Bengal.
6.	Hilly region	Jammu and Kashmir, Himachal Pradesh, Uttarakhand.

In most parts of India, probabilities of moderate drought are in range 11 to 20%.



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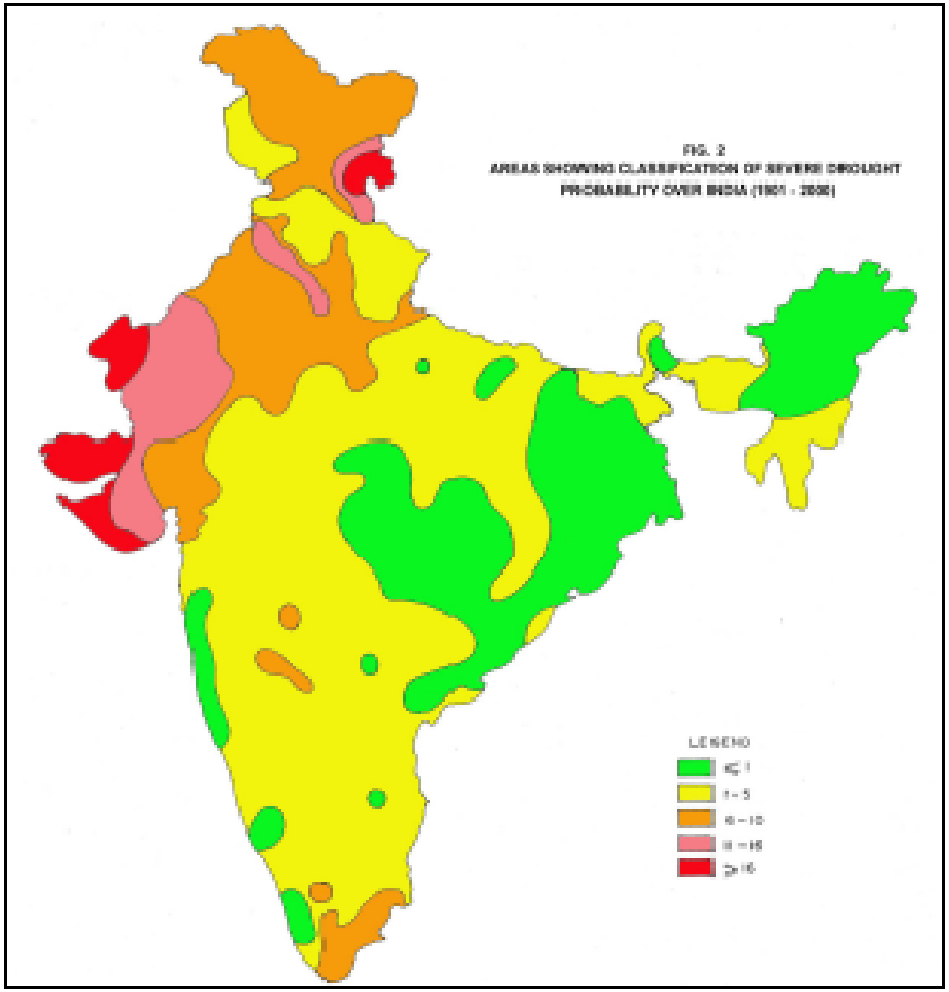
Drought Areas in India



Major parts of India show Probability of severe drought in the range 1 to 5%.

Ref: Mapping of Drought Areas Over India (2010) – NCC Research Report, P.G. Gore, T. Prasad, H.R. Hatwar, IMD, Pune

Drought Management In India

- Larger thrust for watershed development under Drought Prone Area Programme.
- Dry land farming & water resource development
- Dovetail Crop production activities into the watershed project along with soil conservation activities.
- Take up large scale dry land farming demonstrations.
- Undertake Research on the efficacy and economics of sprinkler and drip irrigation systems.
- Construction of suitable water harvesting structures-conservation & optimal use of surface water and recharge of underground aquifers
- Afforestation and Pasture Development
- Animal Husbandry and Fodder Development.
- People's participation in drought proofing

References

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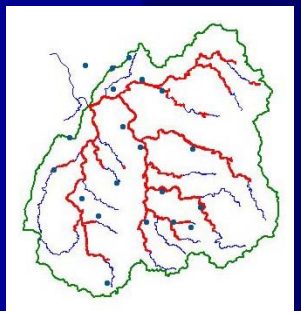
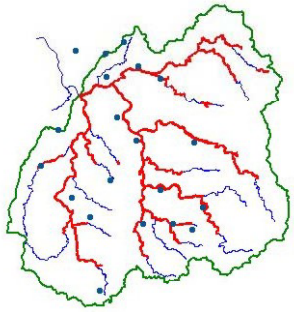
- Mapping of Drought Areas Over India (2010) – NCC Research Report, P.G. Gore, T. Prasad, H.R. Hatwar, IMD, Pune

Tutorials - Question!.?.

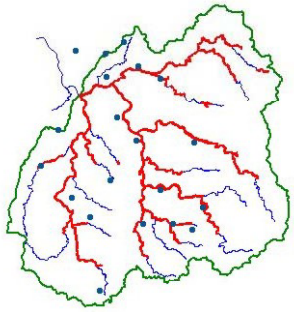
- Critically study the various drought indices and compare each with advantages & limitations.
- From the literature, identify the most suitable drought index for Indian conditions.





Self Evaluation - Questions!.

- Why drought analysis is required for drought mitigation?
- What is the role of drought index in drought mitigation?.
- Discuss Standardized Precipitation Index (SPI) with all details.
- Describe the drought assessment tools with important features.



Assignment- Questions?.

- What is drought index?.
- Explain Palmer drought severity index with all features.
- Illustrate Normalized Difference Vegetation Index.
- Discuss drought severity classification.

WATERSHED MANAGEMENT

THANK YOU

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