STUDIES ON ASSESSMENT OF VULNERABILITY TO DROUGHT

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HYDROLOGIC EXTREMES: Two opposite faces of same coin

Circumstances when there is

FLOODS
excess water that causes damage

DROUGHTS
deficit of water that causes scarcity in sustaining usual activities and life
HYDROLOGIC EVENTS

- Truncation Level: Mean or Median

- Time Unit: Day, Months, Years, Time Unit

- Flood

- Low Flow

- High Flow

- Drought
Drought differs from other natural hazards

- Slow-onset, creeping phenomenon (early warning systems, impact assessment, response)
- Absence of universal definition (leads to confusion and inaction)
- Severity is described through multiple indicators and indices
- Impacts are non-structural and spread over large areas
- **RESULTS**: Slow scientific advancement of drought early-warning, forewarning, vulnerability and preparedness systems
Critical issues in drought mitigation

We are lacking in:

• Data networks and Data sharing
• Early warning system and preparedness
• Drought forecasting
• Drought monitoring tools
• Integrated drought/climate/water supply monitoring
• Impact assessment methodologies
• Reactive to proactive response systems
Drought vulnerability scenario in India

- 120 million ha
- 185 districts in southern and western India
- 1173 development blocks
- 28 drought years in India, during 20th Century
- Seasonal rainfall deficits cause droughts and often lead to migration of people and livestock
### Occurrence, population affected and damage from droughts in India 1900-2002


<table>
<thead>
<tr>
<th>Date</th>
<th>State, region or district</th>
<th>Population Affected (#)</th>
<th>Loss/ Deaths (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2002</td>
<td>13 states</td>
<td>300 million</td>
<td>41000 million</td>
</tr>
<tr>
<td>May 2001</td>
<td>4 states</td>
<td>--</td>
<td>20 deaths</td>
</tr>
<tr>
<td>Nov. 2000</td>
<td>5 districts in Chattisgarh</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>April 2000</td>
<td>6 states</td>
<td>90 million</td>
<td>26500 million</td>
</tr>
<tr>
<td>March 1996</td>
<td>Rajasthan</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>March 1993</td>
<td>8 states</td>
<td>1.2 million</td>
<td>--</td>
</tr>
<tr>
<td>July 1987</td>
<td>Orissa</td>
<td>--</td>
<td>110 deaths</td>
</tr>
<tr>
<td>1987</td>
<td>6 States + 4 UT</td>
<td>300 million</td>
<td>300 deaths</td>
</tr>
<tr>
<td>April/1983</td>
<td>3 states</td>
<td>100 million</td>
<td>--</td>
</tr>
<tr>
<td>1973</td>
<td>Central India</td>
<td>100 million</td>
<td>2500 million</td>
</tr>
<tr>
<td>1972</td>
<td>Central India</td>
<td>100 million</td>
<td>2500 million</td>
</tr>
<tr>
<td>Aug. 1964</td>
<td>Mysore</td>
<td>166 million</td>
<td>--</td>
</tr>
<tr>
<td>1964</td>
<td>Rajasthan, Central India</td>
<td>0.5 million</td>
<td>--</td>
</tr>
<tr>
<td>1942</td>
<td>Kolkata, Bengal region</td>
<td>-</td>
<td>15 lakh deaths</td>
</tr>
<tr>
<td>1900</td>
<td>Bengal</td>
<td>-</td>
<td>13 lakh deaths</td>
</tr>
</tbody>
</table>
Drought management scenario in India

Rainfall Monitoring

Crop Weather Watch Group

1. IMD
2. Revenue Department

MoA, Govt. of India
IMD, CWC, ICAR, MoP, Ec & St. and others

District collector monitors the district

Revenue Tahsil, mandal, district

Drought watch at state level
State Relief Commissioner

Estimation of Losses

Responsibility of State Govt.

Declaration

Verification by Central Team

Relief & Rehabilitation
Response to Drought in India

- Efforts have been largely on recovery from drought rather than proactive mitigation
- Strategies may be characterized as ad hoc, short-term and superficial: knee-Jerk reaction
- Response is too little, too late
RISK OF DROUGHT

Drought risk involves two major components:

- Hazard (natural event)
- Vulnerability (Physiographic & social factors)

Climatology:
- Population growth and shifts
- Urbanization
- Technology
- Soils and land use practices
- Environmental degradation
- Water use trends
- Government policies
- Awareness
OBJECTIVES

• Strengthening R & D
• Identify and characterize the drought indicative parameters -- meteorology, hydrology, agriculture and social in realizing drought and preparedness
• Prepare drought vulnerability scenario under different conditions at macro and micro levels (watershed or district / mandal / villages)
• Capacity building in understanding / realizing the preparedness and vulnerability
INPUT DATA

• Temporal satellite images of IRS, NOAA & INSAT
• Long term precipitation data (50-100 years)
• Stream flow data
• Ground water levels
• Cropping system, crop coverage area, yield, and soil characteristics
• Human and cattle population and other water demanding activities, etc.
APPROACH

• Indicators of onset of drought
  – Prevalent (meteorological, hydrological, agricultural and social) conditions
  – Reported / experienced drought events
• Analysis and identification of pattern and critical parameters
• Monitoring of present day conditions
• Evaluation of threshold of critical parameters
• Deriving a drought susceptibility map and ground reality
• Assessing runoff storages and possibilities of enhancing runoff conservation
• Preparing geographically referenced systems for regional information base
Plan of Work

Technology Transfer

- Characterization of drought susceptibility (Defining various Groups)
- Threshold for various indicators

Time Series
- Event Evaluation
- Storage Potential
- Agril., human Cattle & Industry, etc

- Rainfall
- Runoff
- Demand Assessment
- Deficit Computation
- Satellite Data Analysis

Instrumentation
- Monitoring

Data Collection

Different rainfall scenario
- Cropped area vegetation
- Reservoir pond spread

Assessment
- Deficit Computation

Rainfall Runoff Demand Assessment Deficit Computation Satellite Data Analysis Instrumentation Monitoring Data Collection
Location of Study Sub-basins in different states

- **Lanth Sub-Basin** in Bolangir, Orissa
- **Sonar Sub-Basin** in Damoh/Sagar, M.P.
- **Manar Sub-Basin** in Nanded, Maharashtra
- **Don Sub-Basin** in Bijapur, Karnataka
- **Sarala Sagar Sub-Basin** in Mahboobnagar, A.P.
<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Name of sub-basin selected for study</th>
<th>Name of major river system</th>
<th>Geographical location (Districts/States)</th>
<th>Catchment area (Sq Km.)</th>
<th>Mean Annual Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sonar sub-basin</td>
<td>Ken River (A tributary of River <em>Yamuna</em>)</td>
<td>Damoh/Sagar districts in M.P.</td>
<td>6550.0</td>
<td>1186.0 (Dry sub-humid)</td>
</tr>
<tr>
<td>2</td>
<td>Don sub-basin</td>
<td>Krishna River</td>
<td>Bijapur in Karnataka and Sangli district in M.S.</td>
<td>2486.0</td>
<td>643.0 (Semi arid)</td>
</tr>
<tr>
<td>3</td>
<td>Lanth sub-basin</td>
<td>Tel River (a tributary of River <em>Mahanadi</em>)</td>
<td>Bolangir in Orissa</td>
<td>1562.0</td>
<td>1443.0 (Sub-humid)</td>
</tr>
<tr>
<td>4</td>
<td>Manar sub-basin</td>
<td>Godavari</td>
<td>Nanded and Latur districts in Maharashtra</td>
<td>2423.0</td>
<td>896.0 (Dry Sub-humid)</td>
</tr>
<tr>
<td>5</td>
<td>Pedda Vagu up to Sarala Sagar Dam site</td>
<td>Krishna River</td>
<td>Mahaboobnagar in A.P.</td>
<td>1225.0</td>
<td>674.0 (Semi arid)</td>
</tr>
</tbody>
</table>
Status of drought at different sites during 2006 & 2007

2006 & 2007, Meteorological-DROUGHT PREVAILED

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Name of the site</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bijapur</td>
<td>Near Normal</td>
<td>Near Normal</td>
</tr>
<tr>
<td>2</td>
<td>Bolangir</td>
<td>Near Normal</td>
<td>Near Normal</td>
</tr>
<tr>
<td>3</td>
<td>Nanded</td>
<td>Near Normal</td>
<td>Near Normal</td>
</tr>
<tr>
<td>4</td>
<td>Damoh</td>
<td>Drought prevailed</td>
<td>Drought prevailed</td>
</tr>
<tr>
<td>5</td>
<td>Mahboob-nagar</td>
<td>Drought prevailed</td>
<td>Drought prevailed</td>
</tr>
</tbody>
</table>
EP and Pa variation in India

Western Rajasthan (Very low rainfall)
\[ P_a = 100 - 450 \text{ mm} \]
\[ E_p = 2000 - 2500 \text{ mm} \]

North eastern region
\[ P_a = 6400 \text{ mm} \]
\[ E_p = 1000 - 1200 \text{ mm} \]

Central India
\[ P_a = 800 - 1550 \text{ mm} \]
\[ E_p = 1500 - 2000 \text{ mm} \]

South India (Low Rainfall)
\[ P_a = 450 - 700 \text{ mm} \]
\[ E_p = 1600 - 2000 \text{ mm} \]
Relationship of av. Drought Frequency with the $E_p/P_a$ ratio (sub-humid, semi-arid and Arid)
At Y = -25% deviation ---- Pae/PET ratio is 0.6.

Where X is Pae/PET and Y is SPI at X=0.6, the value of SPI = -0.66. However, in original SPI classification, SPI up to -0.99 represents normal condition.

Revised Index value w.r.t. IMD criteria

<table>
<thead>
<tr>
<th>X= Pae/PET</th>
<th>(^aY=) % Rainfall deviation</th>
<th>(^bY=) SPI index</th>
<th>(^cY=) EDI index</th>
<th>Drought Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.60 to 0.50</td>
<td>-24% to -37%</td>
<td>-0.66 to -1.20</td>
<td>-0.75 to -1.11</td>
<td>Mild</td>
</tr>
<tr>
<td>0.50 to 0.40</td>
<td>-37% to -43%</td>
<td>-1.20 to 1.87</td>
<td>-1.11 to -1.47</td>
<td>Moderate</td>
</tr>
<tr>
<td>0.40 to 0.35</td>
<td>-43% to -59%</td>
<td>-1.87 to 2.28</td>
<td>-1.47 to -1.65</td>
<td>Severe</td>
</tr>
<tr>
<td>Below 0.35</td>
<td>-60% and below</td>
<td>-2.28 and below</td>
<td>Below -1.65</td>
<td>Extreme</td>
</tr>
</tbody>
</table>

At X = 0.6, the EDI i.e. Y= -0.75, close to the original classification value of EDI

Where, X is Pae/PET, and Y is EDI
### Comparison of Drought Indices

#### Revised Index value w.r.t. IMD criteria

<table>
<thead>
<tr>
<th></th>
<th>X = Pae/PET</th>
<th>(^a)Y = % Rainfall deviation</th>
<th>(^b)Y = SPI index</th>
<th>(^c)Y = EDI index</th>
<th>Drought Type</th>
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<td>-2.28 and below</td>
<td>Below -1.65</td>
<td>Extreme</td>
<td></td>
</tr>
</tbody>
</table>

### Original Classification of SPI & EDI

<table>
<thead>
<tr>
<th>S.N.</th>
<th>SPI-index value</th>
<th>Classification of Drought</th>
<th>EDI-index value</th>
<th>Classification of Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.99 to 0.99</td>
<td>Near normal</td>
<td>-0.7 to -0.99</td>
<td>Mild drought</td>
</tr>
<tr>
<td>2</td>
<td>-1.0 to -1.49</td>
<td>Moderate</td>
<td>-1 to -1.49</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>-1.5 to -1.99</td>
<td>Severe</td>
<td>-1.5 to -1.99</td>
<td>Severe</td>
</tr>
<tr>
<td>4</td>
<td>-2.0 or less</td>
<td>Extreme</td>
<td>-2 or less</td>
<td>Extreme</td>
</tr>
</tbody>
</table>
ASSESSING VULNERABILITY TO DROUGHT

1. **Static factor of vulnerability** (*Physiographic factors: w.r.t. space*)
   - Topographic factors (General Slope and drainage etc.)
   - Soil (Soil water holding capacity)
   - Climatic components (Precipitation & ET),

2. **Semi-static factors of vulnerability** (*w.r.t. space and long-term temporal variability*)
   - Irrigation support
   - Status of surface water storage availability
   - Status Ground water availability
   - Population density (Population concentration, industrial/ commercial activities)
   - Land use
   - Regional cropping system
   - Region-specific activities (like cattle farming/wildlife preservation etc)

3. **Variable factors of vulnerability** (*w.r.t. space and time*)
   - Rainfall (monthly/seasonal/annual)
   - Stream flow
   - Storages (if any)

--- Classification and spatial representation of drought vulnerability using geographic processing techniques

--- Evaluation of weight of the factors that contribute to drought risk / vulnerability.
## Assessing vulnerability to Drought (Weighing Scheme)

<table>
<thead>
<tr>
<th>Vulnerability factor</th>
<th>Vulnerability</th>
<th>Drought Vulnerability class’s score (weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach location</td>
<td>Lower</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Upper</td>
<td>4</td>
</tr>
<tr>
<td>Probabilities of seasonal crop moisture deficiency(%)</td>
<td>Less than 30 (low)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>30-50 (Moderate)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>50-70 (high)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>More than 70 (very high)</td>
<td>5</td>
</tr>
<tr>
<td>Soil root zone water holding capacity (mm)</td>
<td>More than 200</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>150-200</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>100-150</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Less than 100 (low)</td>
<td>4</td>
</tr>
<tr>
<td>Land use types</td>
<td>Forestland</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cropland/habitation</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Water bodies/swamp/wetland</td>
<td>-20</td>
</tr>
<tr>
<td>Irrigation Support (canal)</td>
<td>Complete irrigation</td>
<td>-20</td>
</tr>
<tr>
<td></td>
<td>Tank/Lift irrigation</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Unirrigated</td>
<td>5</td>
</tr>
<tr>
<td>Population concentration</td>
<td>Less than average</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Near average</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>More than average</td>
<td>5</td>
</tr>
<tr>
<td>Status of Groundwater</td>
<td>Safe</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Semi critical</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Critical</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Over exploitation</td>
<td>5</td>
</tr>
<tr>
<td>Status of surface water storages in tanks, lakes etc.w.r.t. domestic/cattle and other drinking water demand</td>
<td>Deficit</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Moderately deficit</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Surplus</td>
<td>4</td>
</tr>
</tbody>
</table>
Integrated drought vulnerability Index (DVI)  
(Proposed)

\[ DVI = \frac{\sum w_i}{kN} \]

DVI = Drought Vulnerability Index  
N = Number of indicators under consideration  
w_i = Weights of drought vulnerability indicators, \( \text{(where, } i = 1, 2, \ldots, N) \)  
k = Upper limit of vulnerability weights \( \text{(Say, range = 0-}k\text{, where, } k \text{ is highest value of } W_i) \)

Classification of DVI

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Values of DVI</th>
<th>Vulnerability Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 0.2</td>
<td>Least vulnerable</td>
</tr>
<tr>
<td>2</td>
<td>0.2 – 0.4</td>
<td>Mild vulnerable</td>
</tr>
<tr>
<td>3</td>
<td>0.4 – 0.6</td>
<td>Moderately vulnerable</td>
</tr>
<tr>
<td>4</td>
<td>0.6 – 0.8</td>
<td>Severely vulnerable</td>
</tr>
<tr>
<td>5</td>
<td>&gt;0.8</td>
<td>Critically vulnerable</td>
</tr>
</tbody>
</table>
Integration of physiographic factors

Grid Size --- 100 m x 100m
Integration with rainfall departure

Legend
- Damoh (-28 %)
- Hatta (-48 %)
- Sagar (-50 %)

Legend
- Least Vulnerable
- Moderately Vulnerable
- Severely Vulnerable
- Critically Vulnerable

Scale
0 10 20 Kilometers
Integrated vulnerability to drought (October-2007)

<table>
<thead>
<tr>
<th>Vulnerability Class</th>
<th>Area (km²)</th>
<th>% Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least</td>
<td>51.590</td>
<td>0.78</td>
</tr>
<tr>
<td>Moderate</td>
<td>1779.88</td>
<td>26.76</td>
</tr>
<tr>
<td>Severe</td>
<td>4516.48</td>
<td>67.89</td>
</tr>
<tr>
<td>Critical</td>
<td>304.640</td>
<td>4.58</td>
</tr>
</tbody>
</table>
Components of Integrated Drought Management System (Proposed)

- Nodal Unit (Decision Making)
  - Scientific Community
  - Stake Holders
  - Water Managers (site units)
  - Drought Partnership
    - Data: historical, real time (monitoring)
    - Tools: forecasting, predictions
    - Drought Watch System
    - Drought Management
Drought Partnerships

Purpose: to improve the coordination of drought related activities in India.

- Partnership would act as a platform to initiate and discuss scientific inputs with multidisciplinary experts and it would insure exchange of information.
- Develop regional real time monitoring system to identify progression and critical areas vulnerable to drought, based on precipitation, river flows and groundwater data.
- Identify gaps in knowledge and coordinate research activities.
- Develop analytical tools for estimating drought severity, extent and frequency.
- Support harmonization of methods for drought analysis.
- Share experiences in drought planning and management.
- Establish best practice guidelines for drought monitoring, forecasting, prediction and mitigation to support operational drought management.
- Improve mobility of operational and research staff.
- Develop links with international programmes and national drought activities inside & outside India.
- To carry out specific research projects, e.g. estimation event frequency from non-stationary data, impact or climate change on drought and medium-range drought forecasting.
- Develop and implement training activities.
- Communicate with stakeholders and the public.
Summary of Project activities

- Field investigations, historical data/information collection, processing and analysis etc. of hydro-meteorological data.
- Analysis of occurrence of dry spells, seasonal, and annual rainfall departure.
- Application of Departure analysis, SPI, EDI and Decile Index for monthly, seasonal and annual time scale.
- Establishing of revised Index values for SPI and EDI in reference to our field conditions.
- Interim report- prepared & submitted
- Remote Sensing and GIS data processing, analysis and NDVI estimation.
- Formulation of vulnerability assessment criteria using combinations of static (physical) and variable factor.
- Proposed an index for integrated assessment of vulnerability to drought
- Formulating guidelines to facilitate development of drought early warning systems, preparedness plans for vulnerability reduction and Mitigation.
OUTCOME OF THE STUDY

• Study evolved a methodology for integrated assessment of vulnerability to drought.
• Proposed revised index values for application of SPI and EDI in different study areas/regions.
• Proposed functional guidelines for the possible monitoring and management of drought situation.
• It is hoped that this study may contribute as an important input of early warning and preparedness to the National Action Plan for drought mitigation.
Thank You