HYDROLOGICAL DROUGHT INDICES

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OUTLINE

- Hydrological drought
- Monitoring and evaluation of hydrological drought
- Different hydrological drought indices
- Case studies

Hydrological Drought

HYDROLOGICAL DROUGHT

Hydrological drought is defines as a significant decrease in the availability of water in all its forms appearing in the land phase of the hydrological cycle (Nalbantis 2009).

Forms of water

- **Surface water**
- **Stream flow (snowmelt and springflow)**
- **Lake and reservoir level**
- **Ground water**
- **Ground water level**

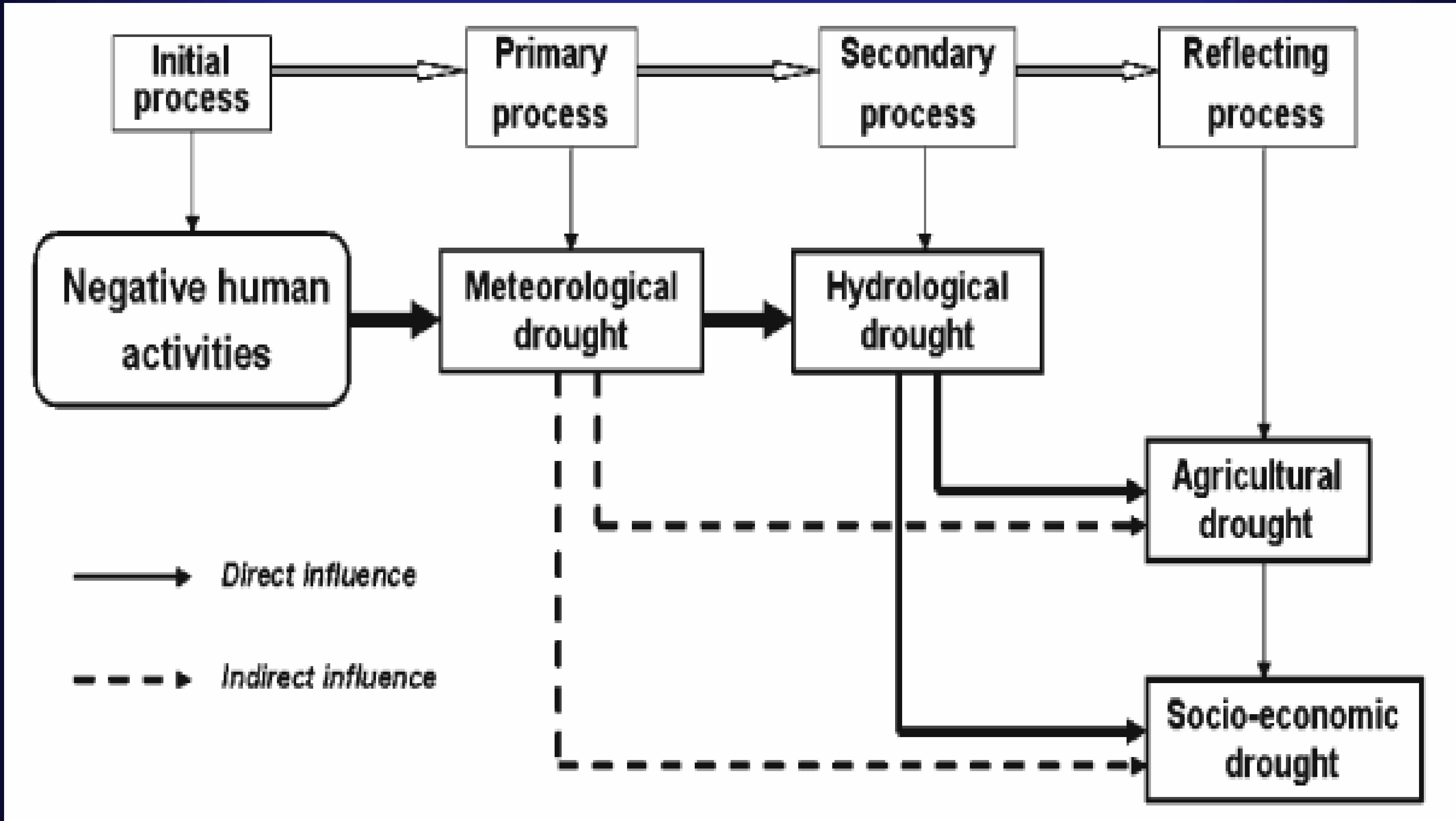
HYDROLOGICAL DROUGHT

Hydrological drought is described as a sustained and regionally extensive occurrence of below average natural water availability (Tallaksen and van Lanen, 2004)

Hydrological drought as period of time below the average water content in streams, reservoirs, groundwater aquifers, lakes and soils. The period is associated effects of precipitation (including snowfall) shortfall on surface and subsurface water supply, rather than with direct shortfall in precipitation (Yevjevich et al., 1977) .

Hydrological drought may be the result of long term meteorological droughts that results in the drying up of reservoirs, lakes, streams, rivers and a decline in groundwater levels (Rathore 2004).

HYDROLOGICAL DROUGHT



Shaban 2009

HYDROLOGICAL DROUGHT

Characterization

- Its severity expresses by a drought index
- Its time of onset and its duration,
- Its areal extent and
- Its frequency of occurrence.

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Operational requirements

- Easily understood
- Carrying physical meaning
- Sensitive to wide range of drought conditions
- Independent of area of application
- Reveal drought with short lag after its occurrence and
- Based on the data which are readily available

HYDROLOGICAL DROUGHT INDICES

Data and Instrumentation

- Rainfall gauges in several representative sites
- Hydrographs and flow meters on rivers and springs water courses, outlets of watershed
- Scale levels to measure water levels in lakes, reservoirs, ponds etc
- Remote sensing data (RADARSAT, NOAA, MODIS etc.) to monitor snow coverage and areal extent of lakes and wetlands
- Piezometers to measure groundwater levels
- Available equipments and laboratory for soil moisture

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Indices Based on Precipitation

Standardized Precipitation Index (SPI)

Used in South Asia

To quantify the precipitation deficit in the monsoon and non-monsoon periods

$$SPI = (X_{ij} - X_{im})/\sigma$$

Where X_{ij} is the seasonal precipitation at the i^{th} rain gauge station and j^{th} observation, X_m is the long term seasonal mean and σ is standard deviation.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Precipitation

Effective Drought Index (EDI)

It is an intensive measure which considers daily water accumulation with weighting function for time passage.

Advantages

- **It calculates daily drought severity.**
- **Rapid detection and precise measurement of short term drought.**
- **Indicates current level of available water resources.**
- **it is able to diagnose prolonged droughts that continue for several years (because: It calculates the total precipitation period)**

HYDROLOGICAL DROUGHT INDICES

Indices Based on Precipitation

Effective Drought Index (EDI)

Steps to calculate EDI

- ✓ **Calculate the daily EP**

$$EP_i = \sum_{i}^{n=1}\left[\left(\sum_{n}^{m=1} P_m\right)/n\right]$$

Where i=365 is the period over which precipitation is summed. P_m denotes precipitation m days ago.

- ✓ **Calculate 30 year mean EP (MEP) for each calendar year**

- ✓ **Calculate the DEP, which is the difference between EP and MEP**

- ✓ **When DEP is negative, it signifies dryer than average, add the days of prolonged dryness to the existing period (*i=365*) and**

- ✓ **Recalculate MEP and DEP**

- ✓ **Divide the DEP for each calendar day by standard deviation of DEP over the past 30 years. This will results in EDI.**

HYDROLOGICAL DROUGHT INDICES

Indices Based on Precipitation

Effective Drought Index (EDI)

Definition of states of drought with EDI

Drought classes	Criterion
Extreme drought	EDI ≤ 2.0
Severe drought	-2.0≤ EDI ≤-1.5
Moderate drought	-1.5≤ EDI ≤-1.0
Near normal	-1.0≤ EDI ≤1.0

HYDROLOGICAL DROUGHT INDICES

Indices Based on Streamflow

Streamflow Drought Index (SDI)

This index $SDI_{i,k}$ requires streamflow volume values $Q_{i,j}$ where *i* denote the hydrological year and *jth* month within a hydrological year. We can obtain $V_{i,k}$ cumulative streamflow volume for the *i-th* hydrological year and *k-th* reference period

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \qquad i = 1, 2, \ldots, \quad j = 1, 2, \ldots\ldots 12, \quad k = 1, 2, 3, 4$$

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V_k}}{s_k}$$

Where V_k and s_k are respectively the mean and standard deviation of the cumulative streamflow volumes for the *k-th* reference period.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Streamflow

Streamflow Drought Index (SDI)

Definition of states of drought with SDI

Description of state	Criterion
Non drought	SDI≥ 0.0
Mild drought	-1.0 ≤ SDI < 0.0
Moderate drought	-1.5 ≤ SDI < -1.0
Severe drought	-2.0 ≤ SDI < -1.5
Extreme drought	SDI < -2.0

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Indices Based on Streamflow

Surface Water Supply index (SWSI)

This index integrate reservoir storage, streamflow and two precipitation types (snow and rain) at high elevations into a single index. The *SWSI* is given by

$$SWSI = \frac{aP_{snow} + bP_{prec} + cP_{stream} + dP_{resv} - 50}{12}$$

Where *a, b, c, d* = weights for snow, rain, streamflow and reservoir storage respectively (*a* + *b*+ *c*+ *d*= *1*) and *P*= the probability (%) of non-exceedence for each of these four water balance components. *The estimation is carried out with a monthly time step. In winter months, SWSI is computed using snowpeck, precipitation and reservoir storage. In summer, streamflow, precipitation and reservoir storage data are used.*

The range of SWSI is similar to PDSI as -4.2 to + 4.2.

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Indices Based on Low Flows

(WMO 1974) defines low flow as a flow of water in a stream during prolonged dry weather.

Droughts include low-flow periods, but a continuous seasonal low-flow event does not necessarily constitute a drought, although many researchers refer to a continuous low-flow period in one year as an Annual drought.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Low Flows

- A number of consecutive time intervals where the selected flow variable (a discharge or flow volume) has lower values than a reference flow level indicate the *duration of a drought* event.

- For each such event, the sum of deviations of a flow variable from the reference level represents the cumulative flow-deficit amount *(drought severity).*

- This deficit divided by the duration is the measure of *drought intensity.*

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Indices Based on Low Flows

Definition of Water Shortages

- ✓ ***A deep shortage*** **-when annual runoff is lower than the mean, by at least one standard deviation.**
- ✓ ***A continuous shortage*** **-when annual volumes are lower than the mean, during at least 4 consecutive years.**
- ✓ ***An extended shortage*** **-when a deep or continuous shortage extends over the entire region under consideration.**

Drought indices and definitions based solely on low flow or reservoir storage are normally designed for reservoir operation and are seldom (if at all) used as triggers for drought relief, or for drought monitoring over vast territories.

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Index Based on runoff

Steps for defining the Drought Index

- **Normalization of runoff**

  Runoff data should be fit in to follow normal distribution or other type of distribution.

- ***Normalizing runoff would convert the probability density function of Pearson type III distribution into the standard normal distribution as function of Z.***

- **Define the runoff anomaly percentage. For *e.g.* The categories of runoff are separated into 5 according to their percentage anomalies.**

HYDROLOGICAL DROUGHT INDICES

Index Based on runoff

Definition of states of drought index based on runoff

Runoff anomaly percent, Δ	Corresponding category	Runoff status
$\Delta < -30\%$	-2	Low
$-30\% \leq \Delta \leq -10\%$	-1	Lower
$-10\% \leq \Delta < 10\%$	0	Normal
$10\% \leq \Delta < 30\%$	1	Higher
$\Delta > 30\%$	2	High

HYDROLOGICAL DROUGHT INDICES

Index Based on runoff

Definition of states of drought index based on runoff

- Define the runoff denoted drought index and its categories.
- Develop a set of standards for classifying runoff levels (water deficiency or abundance) in the rivers to indicate the associated drought/flood categories.
- Based on the Z value calculated for normal distribution, drought/flood categories could be defined.

Category	AF	Z value	D/F	TFD
1	>95%	$Z > 1.6448$	Flood	5%
2	70%–95%	$0.5244 < Z \leq 1.6448$	Light flood	25%
3	30%–70%	$-0.5244 \leq Z \leq 0.5244$	Normal	40%
4	5%–30%	$-1.6448 \leq Z < -0.5244$	Light drought	25%
5	<5%	$Z < -1.6448$	Drought	5%

* AF = accumulation frequency, D/F = drought or flood, and TFD = theoretical frequency distribution.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Groundwater Levels

Standardized Water Level Index (SWI)

Standardized Water Level Index has been developed by to scale ground water recharge deficit. The *SWI* expression is given by

$$SWI = (W_{ij} - W_{im})/\sigma$$

W_{ij} is the seasonal water level for the i^{th} well and j^{th} observation. W_{im} is the long term seasonal mean and σ is standard deviation.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Groundwater Levels

Standardized Water Level Index (SWI)

Definition of states of drought with SWI

Drought Classes	Criterion
Extreme drought	SWI > 2.0
Severe drought	SWI > 1.5
Moderate drought	SWI > 1.0
Mild drought	SWI > 0.0
Non drought	SWI < 0.0

Positive anomalies correspond to drought and negative anomalies correspond to no-drought or normal condition.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Groundwater Levels

Groundwater Resource Index (GRI)

A groundwater resource index has been developed by Mendicino *et al.* (2008) to quantify groundwater detention for the assessment of drought condition. The index is given by

$$GRI_{y,m} = \frac{D_{y,m} - \mu_{D,m}}{\sigma_{D,m}}$$

$GRI_{y,m}$ and $D_{y,m}$ are respectively the values of the index and of the groundwater detention for the year y and month m. $\mu_{D,m}$ and $\sigma_{D,m}$ are respectively the mean and standard deviation of groundwater detention for the month m in a defined number of years.

HYDROLOGICAL DROUGHT INDICES

Indices Based on Water Balance

Palmer Drought Severity Index (PDSI)

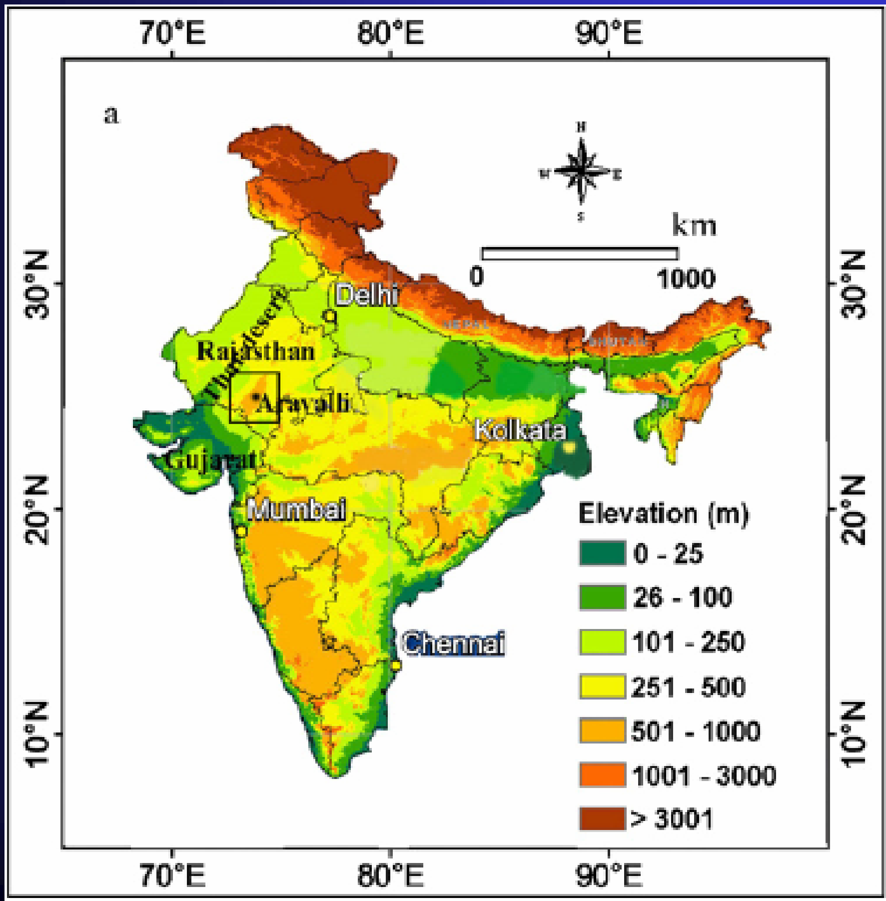
Palmer (1965) developed soil moisture algorithm which uses precipitation, temperature data and available water content of the soil. This model relates regional soil moisture conditions to the normal using a water balance model. PDSI indicates standardized moisture conditions and allows comparisons to be made between locations and between months. PDSI values are normally calculated on a monthly basis.

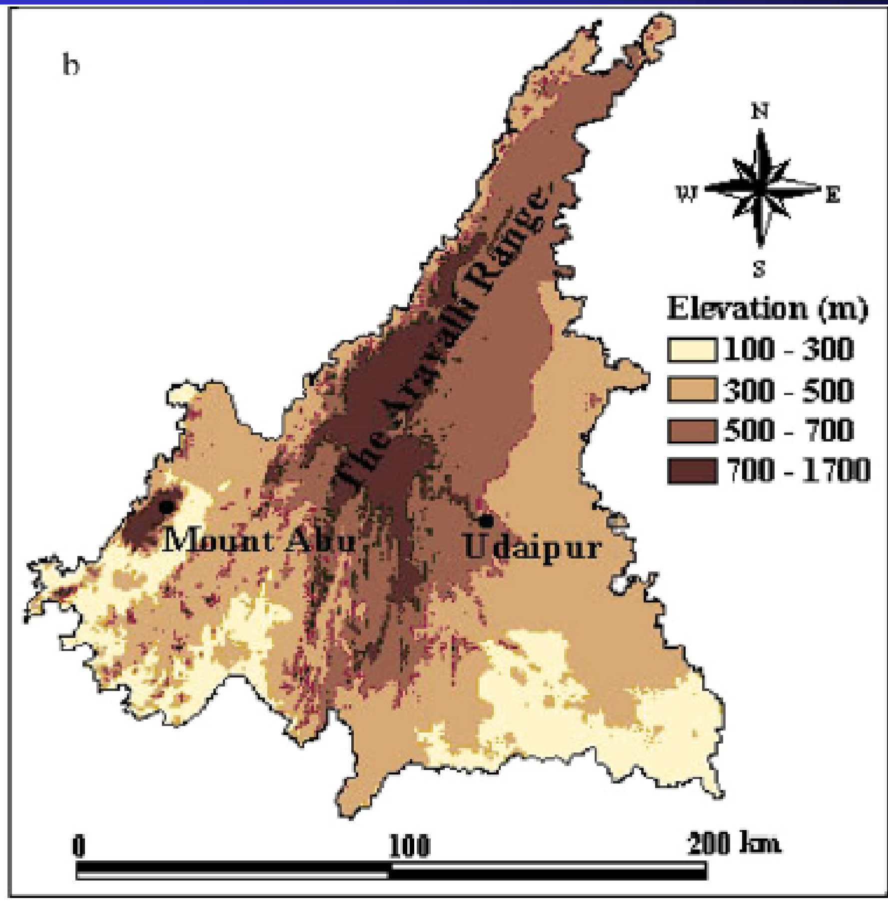
The major problem associated with using PDSI is that its computation is complex and requires substantial input of meteorological data. Its application in Asia, where observational networks are scarce, is therefore limited.

Applications of Hydrological Drought Indices in Asia

Drought dynamics in Aravali regions of Rajasthan, India

A study carried out by Bhuiyan et al. (2006) analysed the seasonal drought dynamics in the Aravali region of Rajasthan State of India. The study identified the spatio-temporal patterns in Hydrological drought.



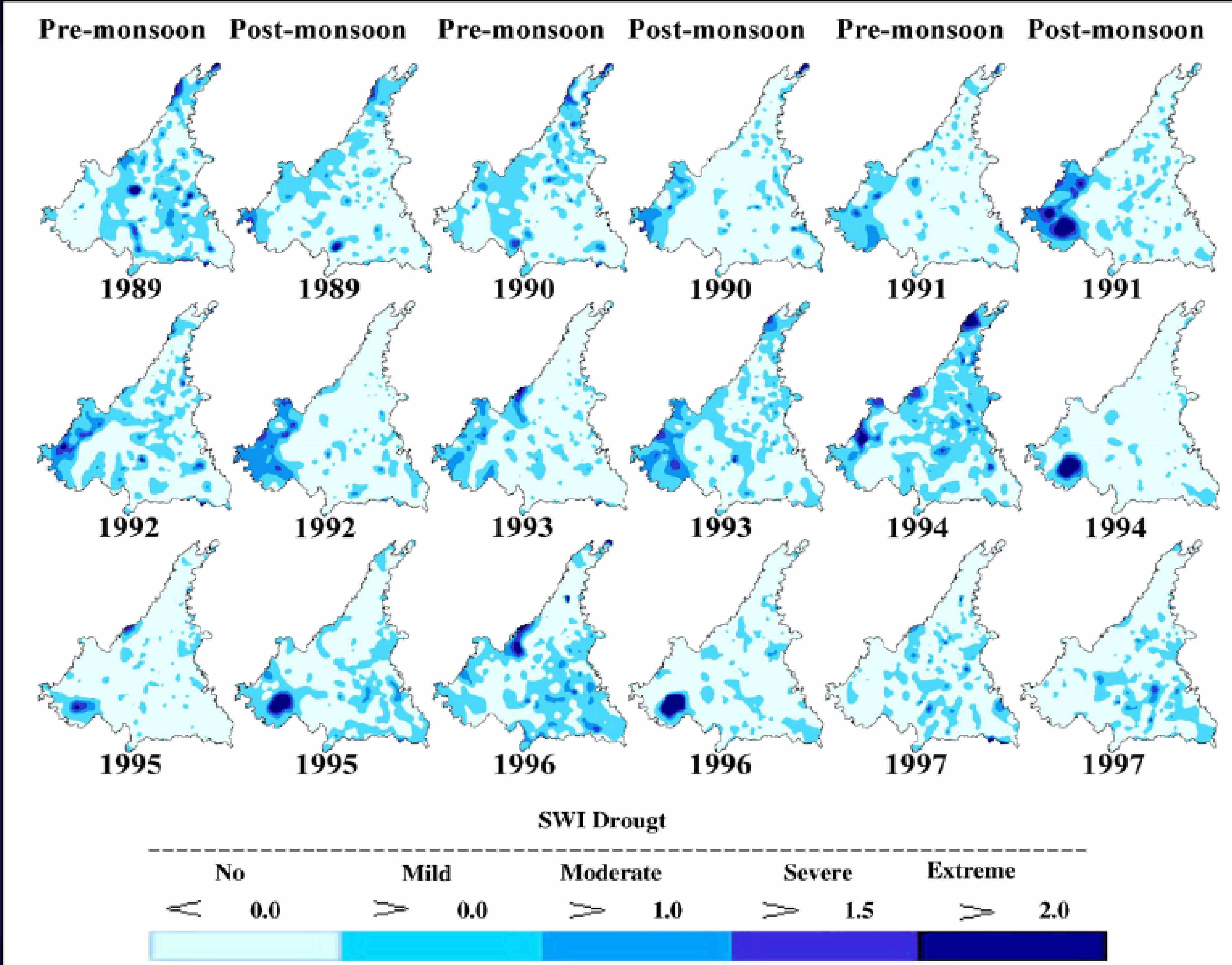


(b)

Drought dynamics in Aravali regions of Rajasthan, India

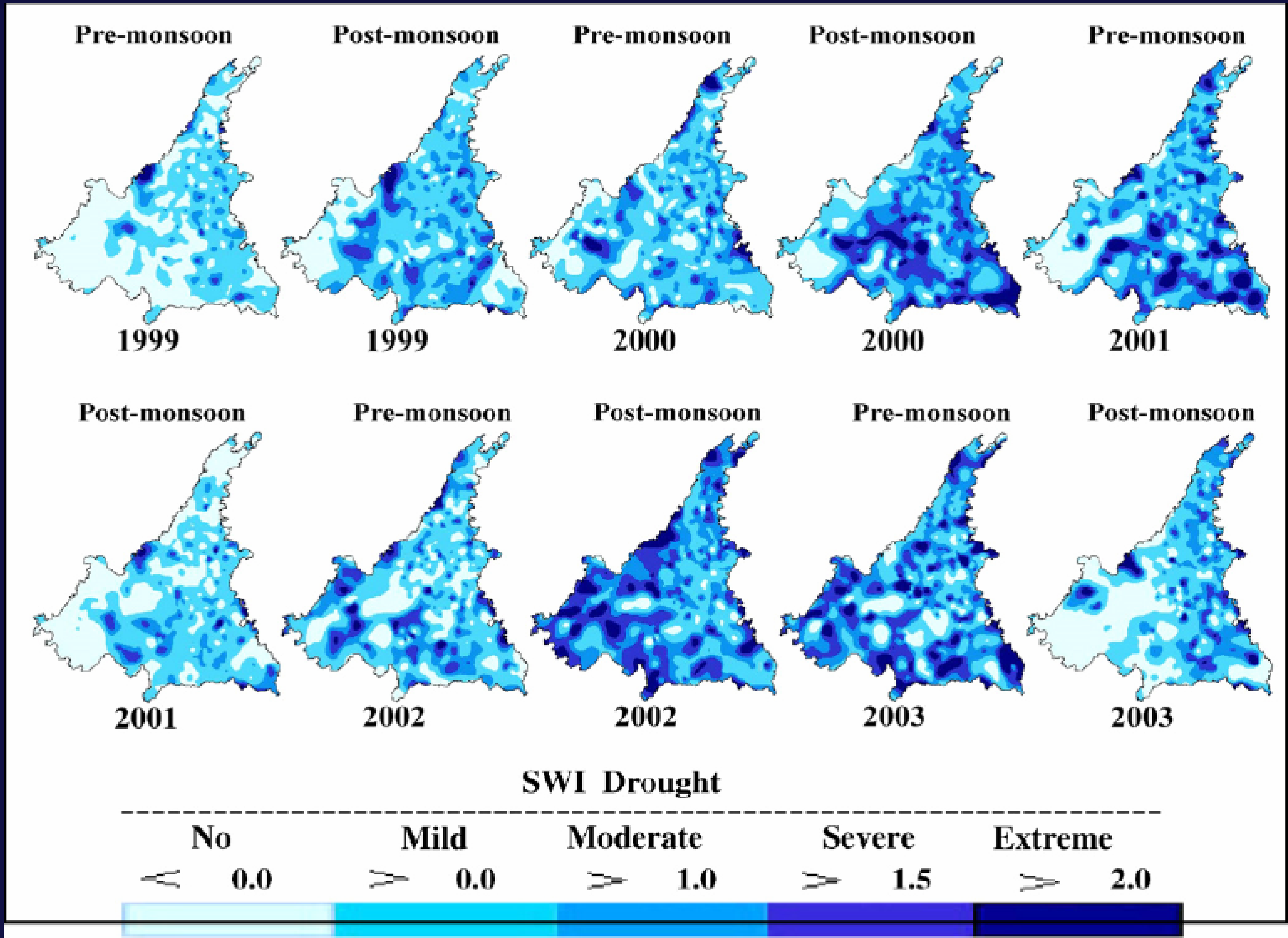
The study focused on drought during the monsoon and non monsoon periods. For hydrological drought analysis, *Standardized Water Level Index (SWI)* was used. The data used were of groundwater levels of 541 wells of the region. SWI was calculated using the mean seasonal water levels of 20 years (1984-2003). SWI values of the wells were interpolated using spline interpolation technique in a GIS environment to generate SWI maps of the region.

Drought dynamics in Aravali regions of Rajasthan, India



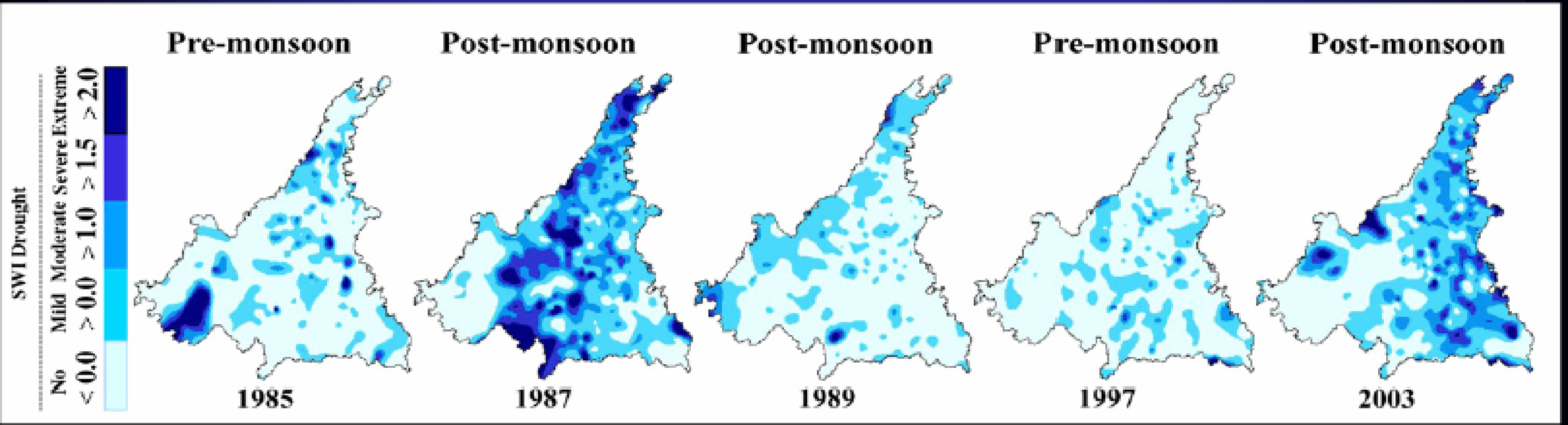
Water table depletion zones

Drought dynamics in Aravali regions of Rajasthan, India



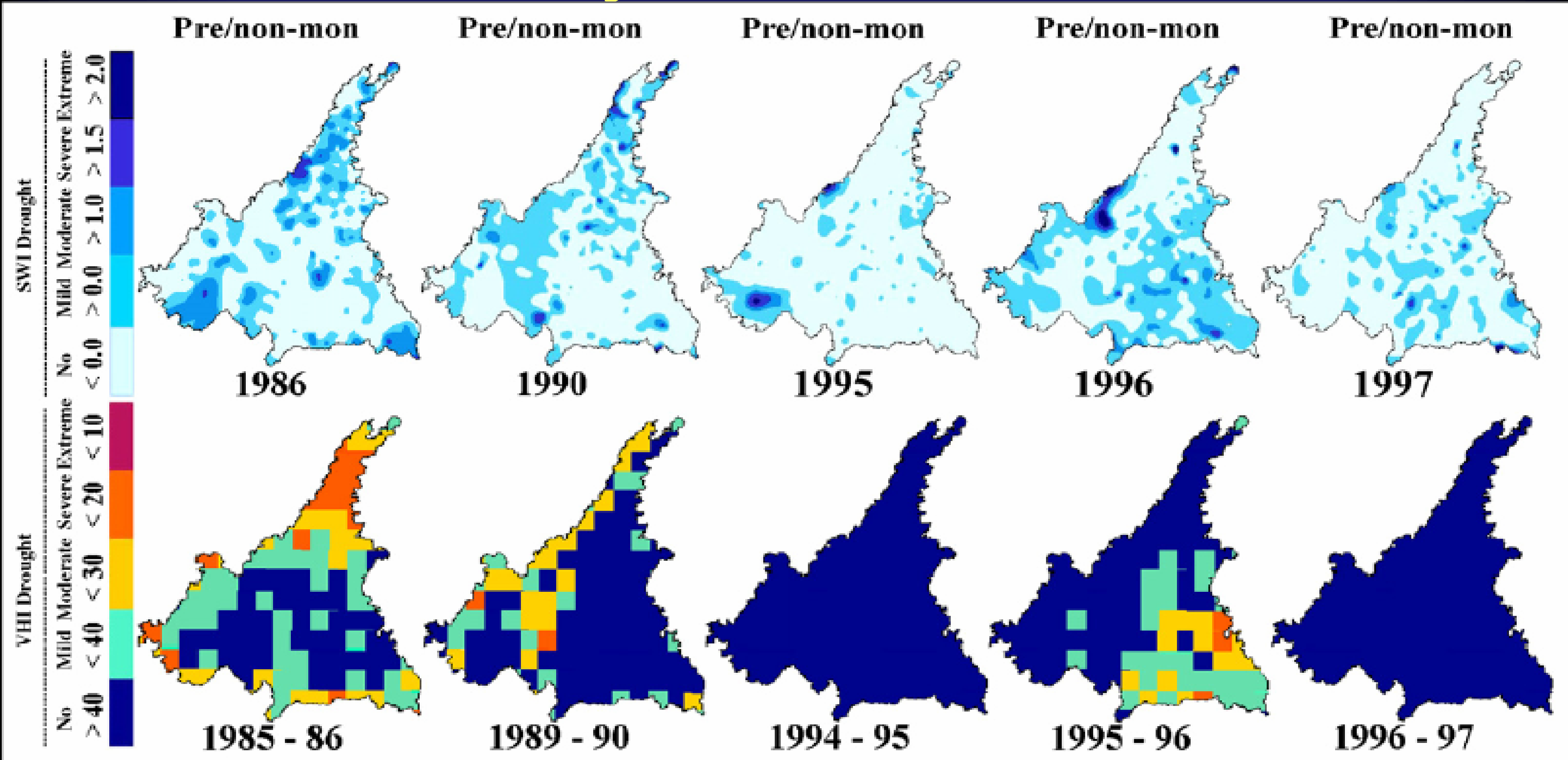
Years of continuous Hydrological Drought

Drought dynamics in Aravali regions of Rajasthan, India



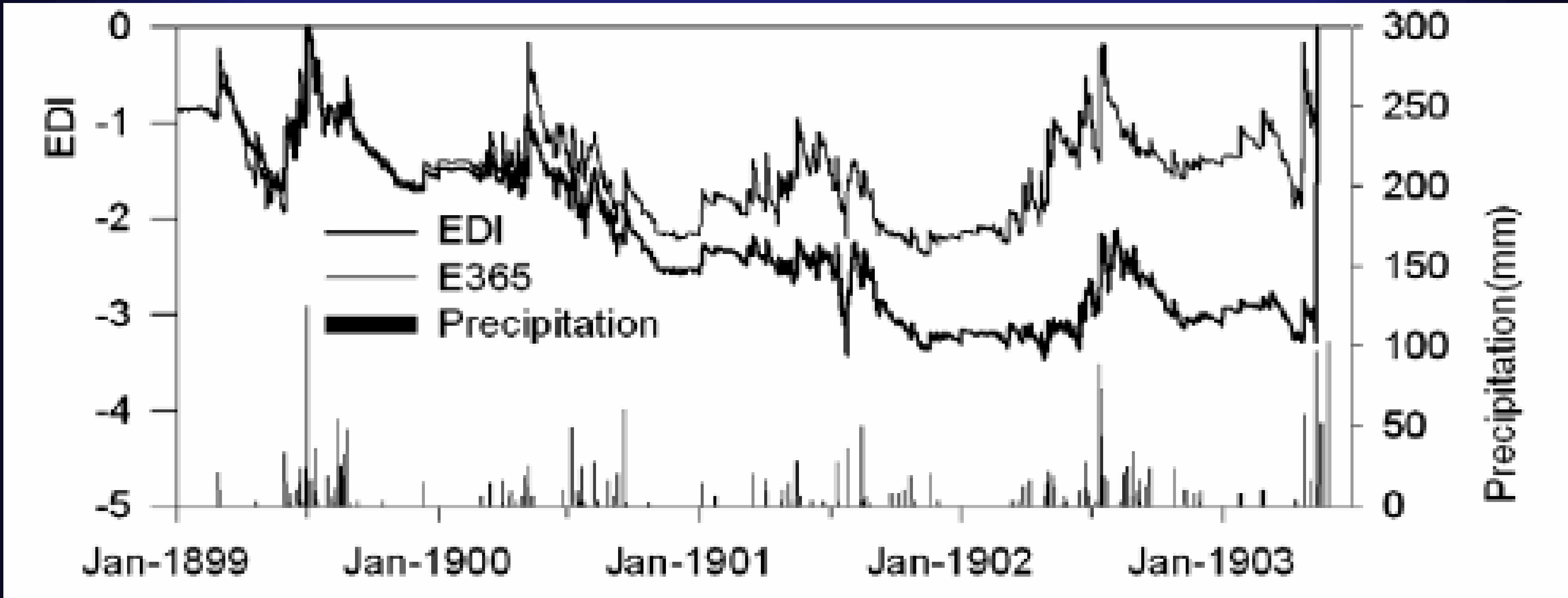
Spatio-temporal shift of Hydrological Drought

Drought dynamics in Aravali regions of Rajasthan, India



Correlation between SWI and VHI during non-monsoon periods

Application of Effective Drought Index (EDI) for drought assessment in Seoul, Korea



EDI and E365 for long term drought

E365: EDI calculated based on precipitation without considering any continued dry period

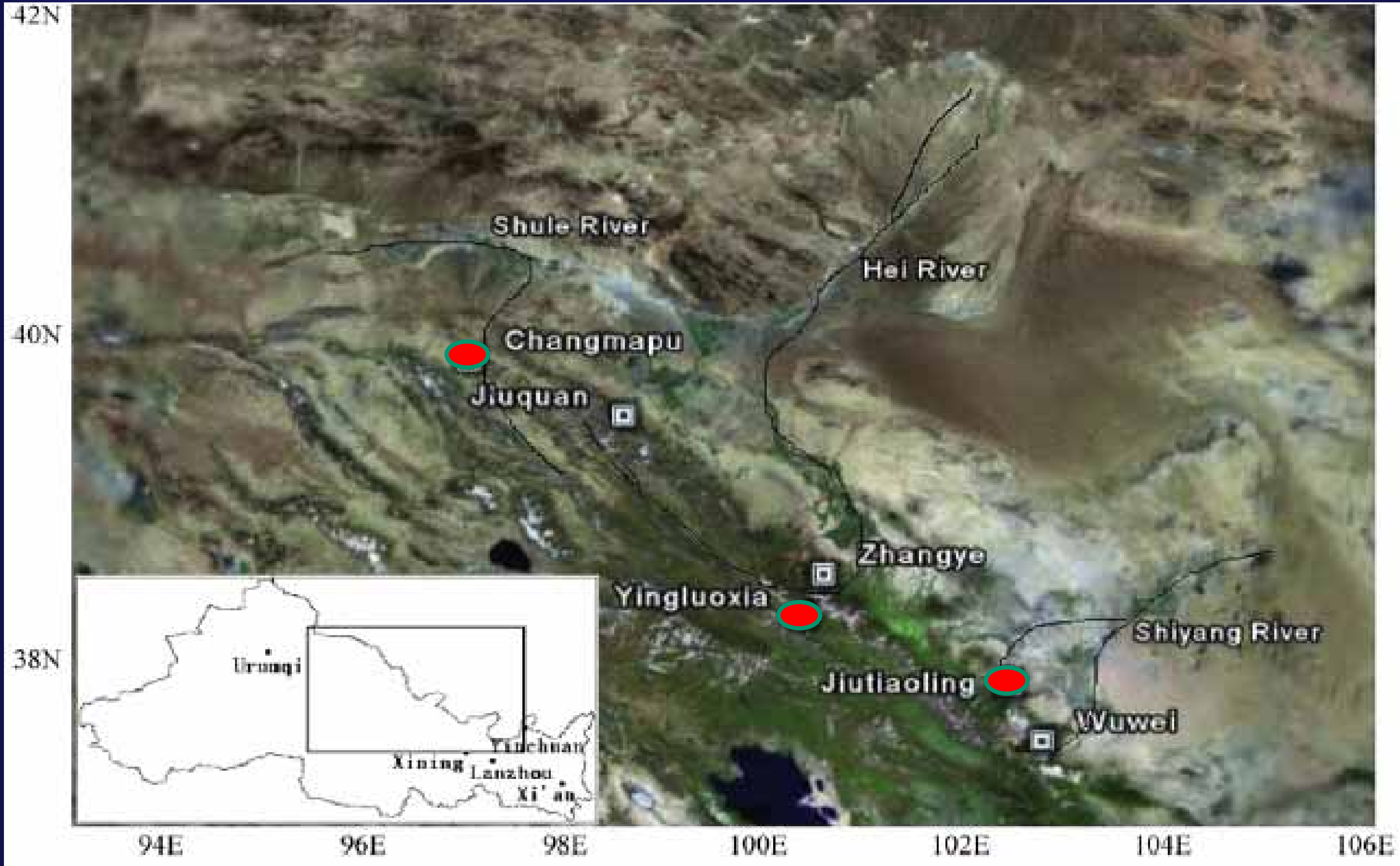
Kim et al. (2009)

Application of effective Drought Index (EDI) for drought assessment in Seoul, Korea

Type	Explanation	Characteristics	Use
EDI	• Intensive measure that considers the daily water accumulation with the weighting function of time passage • Although the calculation period for total precipitation is set at 365 days, when a dry period begins, the total days of the dry period is added to the 365 days	• Measures the drought severity on a daily basis • Measures the drought severity without time-scale limitations	• Monitoring ongoing drought severity • Defining the onset and secession of drought.
CEDI	• In case of heavy rain, it considers the factor of large outflow over a short period of time	• Corrects the lowered description of the drought severity arisen by the intermittent heavy rainfall.	• As EDI but at regions that experience occasional periods of heavy rainfall
AEDI	• Summation of negative EDI values during the consecutive dry period	• Approximation of accumulated drought severity during the case • Provides effective scale in comparing different drought cases	• Comparative analysis of severity between drought events • Estimation of the accumulated damage
$YAEDI_{365}$	• Sum the negative EDI values for yearly unit and then divide it by 365	• Quantitative expression of the dryness of each year	• Comparative analysis on the annual drought severity
$YAEDI_{ND}$	• As in $YAEDI_{365}$ but divide it by the number of days that EDI was negative during that year.	• Shows how intensive the drought was during the year	• Utilized as supplementary material in measuring annual drought severity
AWRI	• Estimates current available water resources accumulated for 365 days	• Reflects the actual amount of available water resources • An absolute scale that is independent of seasonality	• Utilized as supplementary material in determining drought status

Specifications of EDI and its derivative indexes

Runoff derived drought index for the arid area of Hexi corridor, Northwest China



Location map of Shule, Hei and Shiyang river and their hydrological monitoring stations

Wang et al. (2009)

Runoff derived drought index for the arid area of Hexi corridor, Northwest China

Runoff anomaly percent, Δ	Corresponding category	Runoff status	Percent of different categories at three rivers (%)			Mean percent of different categories of three rivers (%)
			Shule	Hei	Shiyang	
$\Delta < -30\%$	−2	Low	13.0	15.2	15.2	14.5
$-30\% \leq \Delta \leq -10\%$	−1	Lower	21.7	19.6	26.1	22.5
$-10\% \leq \Delta < 10\%$	0	Normal	41.3	36.9	34.7	37.7
$10\% \leq \Delta < 30\%$	1	Higher	15.2	17.4	15.2	15.9
$\Delta > 30\%$	2	High	8.7	10.9	8.7	9.4

Runoff anomaly categories of Shule, Hei and Shiyang rivers (1959-2004)

Runoff derived drought index for the arid area of Hexi corridor, Northwest China

Category	D/F	Events			MFD
		Shule	Hei	Shiyang	
1	Flood	4	2	3	6.5%
2	Light flood	10	13	12	25.4%
3	Normal	19	19	17	39.9%
4	Light drought	11	10	12	23.9%
5	Drought	2	2	2	4.3%

* D/F = drought or flood, and MFD = mean frequency distribution.

Drought/flood events in Shule, Hei and Shiyang rivers (1959-2004)

Runoff derived drought index for the arid area of Hexi corridor, Northwest China

Category	Z value	Related drought severity and irrigation
1	$Z \geqq -0.5244$	For "normal", and no operation needed
2	$-1.0846 < Z < -0.5244$	For "slightly light drought", and delaying the time of first irrigation, use of reservoir water
3	$-1.6448 \leq Z \leq -1.0846$	For "heavier drought", and delaying the time of first irrigation, use of reservoir water and appropriate extraction of underground water
4	$Z < -1.6448$	For "drought", and necessity of utilizing underground water

Z of this Table is denoted as Z_{ir} to indicate the levels of normal, light drought, heavier dryness and real drought for categories 1–4, respectively.

Runoff index drought severity and irrigation

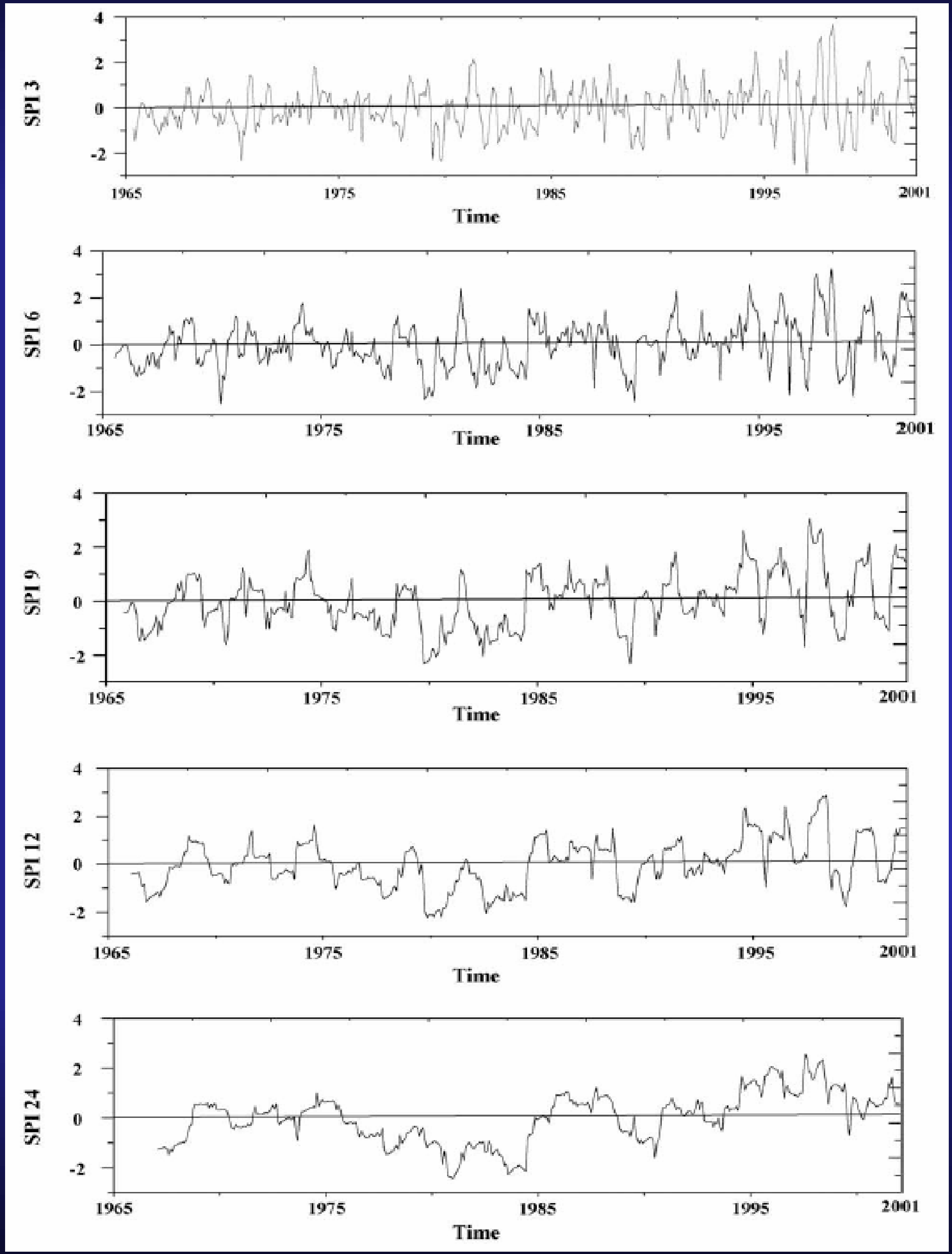
Application of SPI and using stochastic models and neural network for drought forecasting for Kansabati River Basin, West Bengal India

Station no.	Raingauge station	Area (km^2)	Elevation (m) (a.m.s.l)	Geographic coordinates	
				Latitude	Longitude
1	Simulia	1279.5	220.97	23°10′	86°22′
2	Rangagora	1151.55	222.92	23°4′	86°24′
3	Tusuma	554.45	158.6	23°08′	86°43′
4	Kharidwar	682.4	135.96	23°00′	86°38′
5	Phulberia	597.1	144.32	22°55′	86°37′

Rain gauge stations in the river basin

Mishra and Desai (2006)

Application of SPI and using stochastic models and neural network for drought forecasting for Kansabati River Basin, West Bengal India



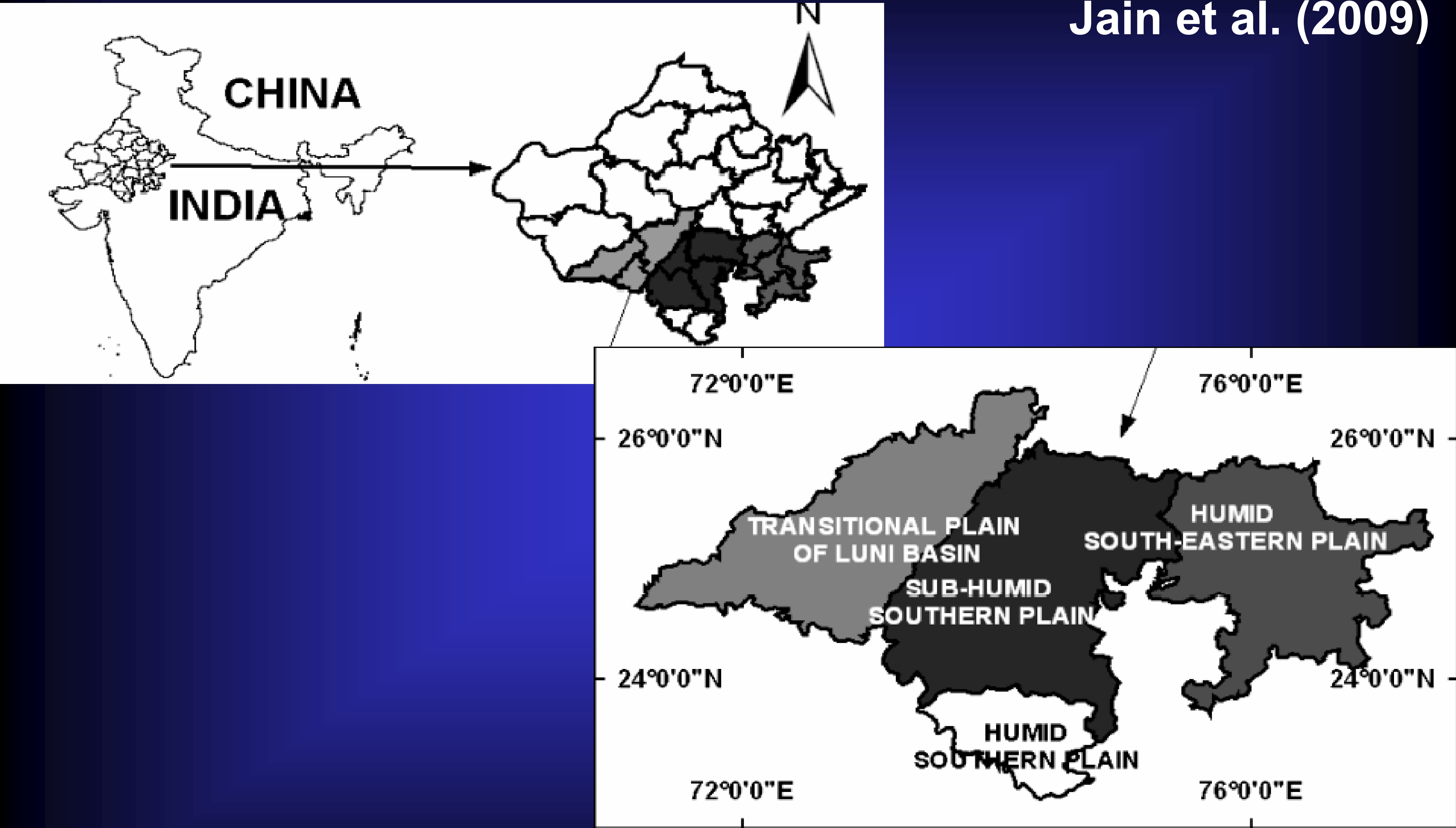
SPI series over different time scale

Application of SPI and using stochastic models and neural network for drought forecasting for Kansabati River Basin, West Bengal India

The neural network models were useful for forecasting of drought which could help local administration and water resource planners to take precautions considering severity of drought known in advance.

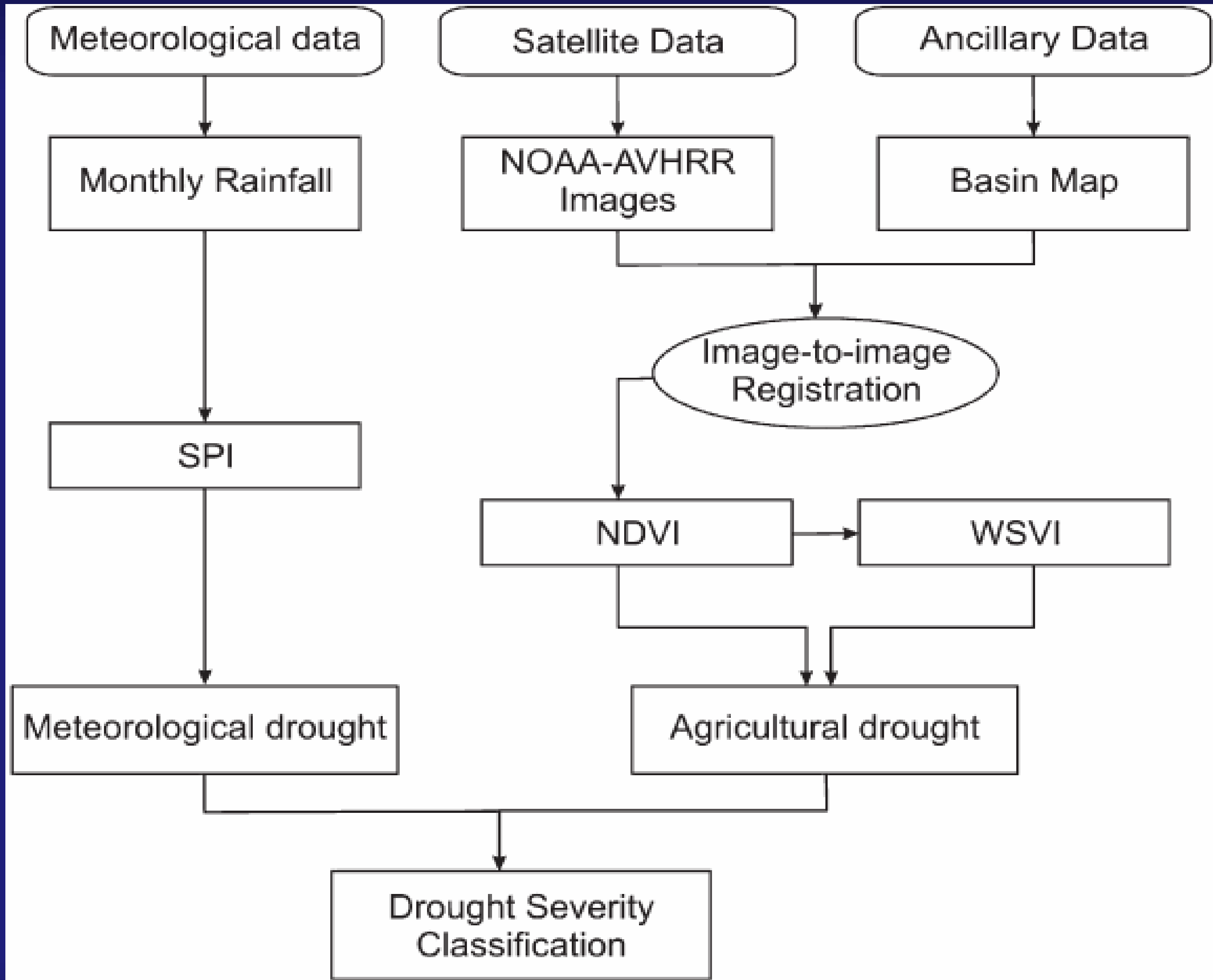
Identification of drought venerable areas using remote sensing data

Jain et al. (2009)



Remote sensing data were used for drought assessment using NDVI and Water Supplying Vegetation Index (WSVI) along with SPI for Southern Rajasthan, India

Identification of drought venerable areas using remote sensing data



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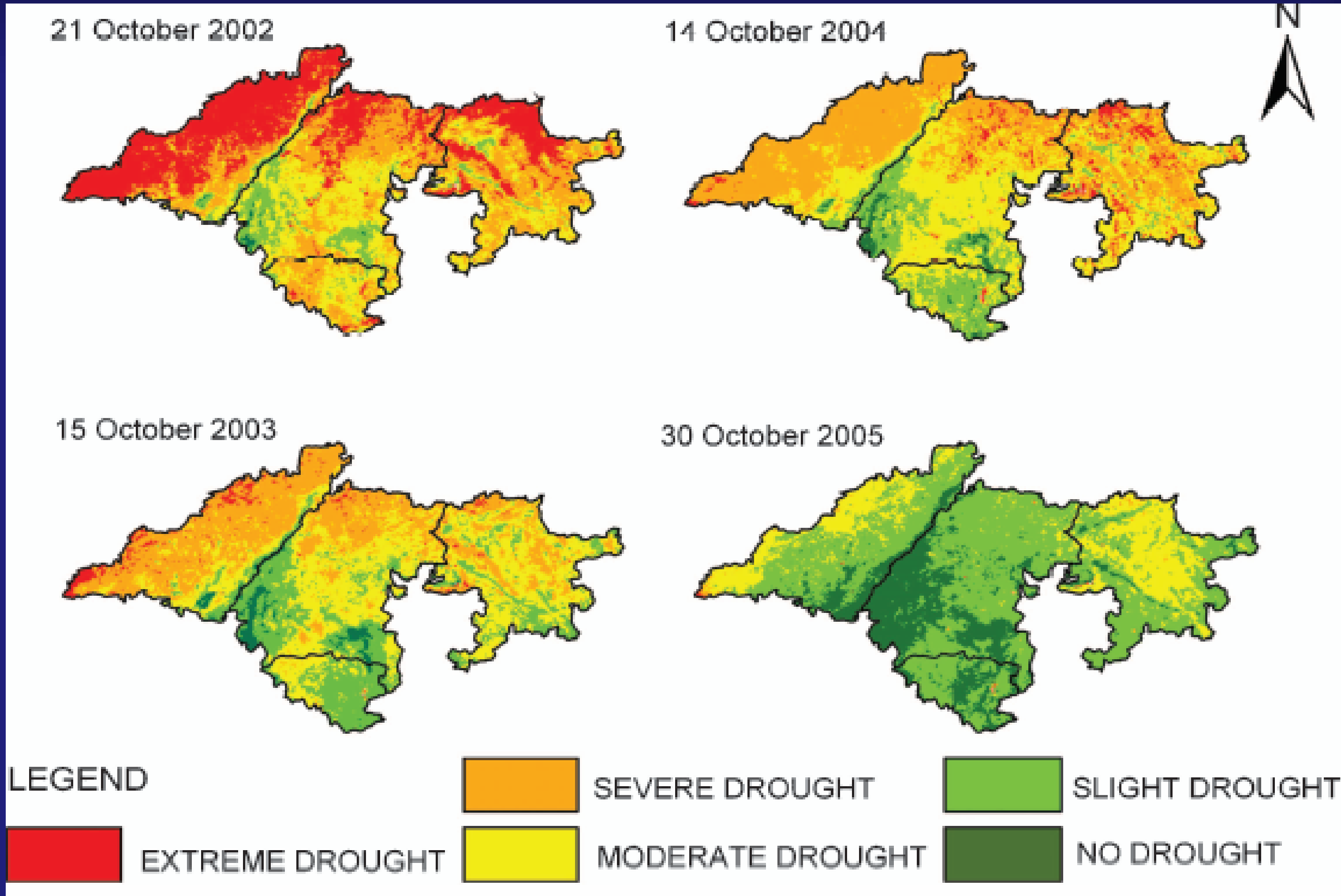


Classified post-NDVI maps of the study areas in different years

Identification of drought venerable areas using remote sensing data

Year	Extreme	Severe	Moderate	Slight	Normal
2002	33.50	33.80	25.30	7.00	0.40
2003	2.80	34.50	37.30	22.70	2.70
2004	4.70	38.40	40.30	14.70	1.90
2005	0.19	0.56	21.20	56.49	21.57

Percentage of areas under different category of drought using NDVI

Year	Extreme	Severe	Moderate	Slight	Normal
2002	36.6	35.1	22.4	5.8	0.6
2003	3.7	36.6	36.8	15.9	7.1
2004	3.2	35.6	48.0	19.7	0.6
2005	0.1	2.4	20.1	61.1	16.2

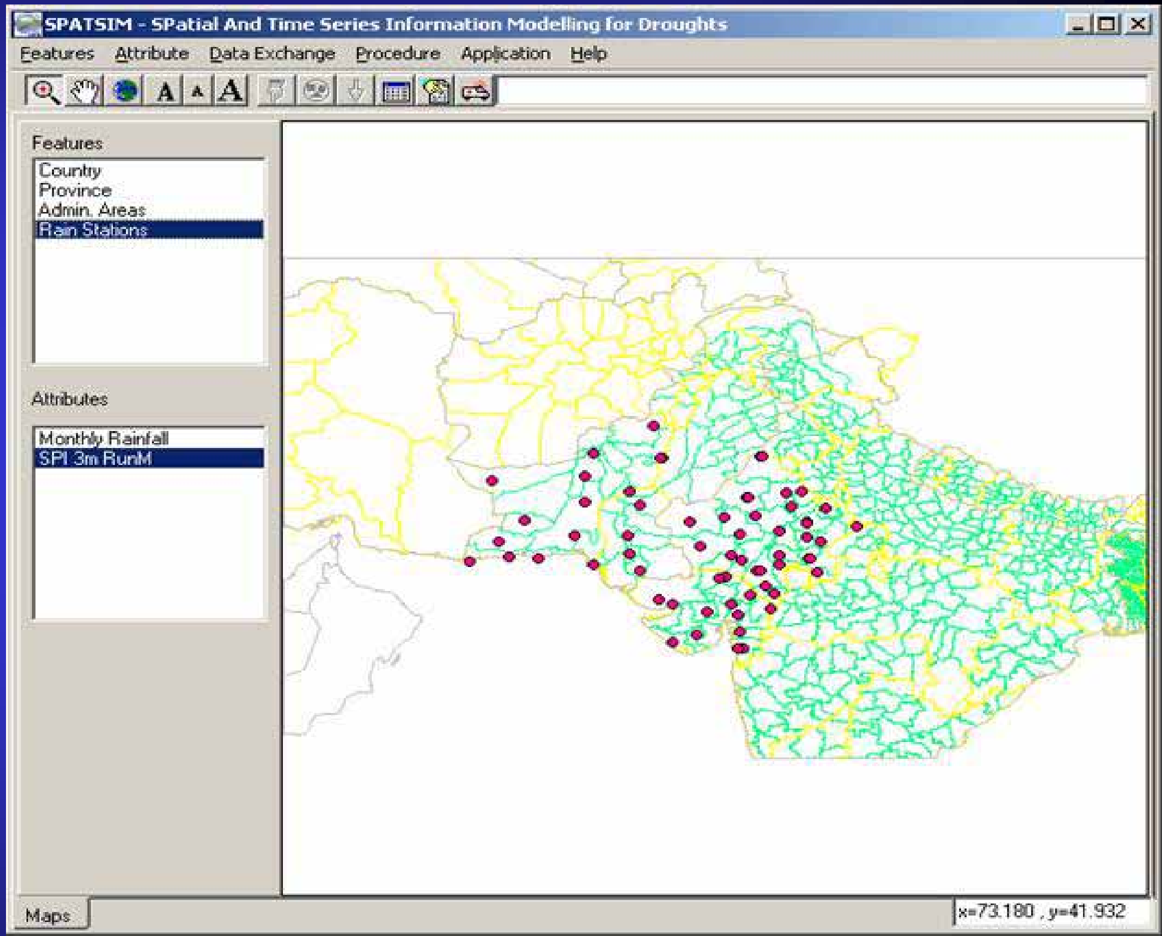
Percentage of areas under different category of drought using WSVI

Drought Software

Drought software is developed jointly by IWMI and IWR.

Part of the SPATSIM package -
SPAtial and Time Series Information Modeling.

SPATSIM is developed by the *Institute for Water Research (IWR)*, South Africa. It is permanently expanding to include more options for various water resources analyses.



Main SPATSIM screen showing a coverage of SW Asia and rainfall stations' locations

It calculates, displays, spatially plots, exports/imports areal rainfall and variety of drought indices from rainfall time series data.

Strategies to enhance adaptive capacity to climate change in vulnerable regions

Lead institution
Indian Agricultural Research Institute (IARI), New Delhi
In collaboration with
CMFRI, Mumbai, OUAT, Bhubneshwar, CRRI, Cuttack

- **Identification of current and future risks to livelihoods due to climatic variability**
- ***Development of drought indices to facilitate Early Warning System (EWS) for Drought & promoting it's use in adaptation by farmers and other stakeholders***
- **Develop community based sustainable rural livelihoods strategies to minimize adverse climatic impact in droughts as well as floods prone vulnerable districts**
- **Capacity building of the stakeholders on strategies for alternate livelihoods strategies in future climate change.**

CONCLUSIONS

- SPI is most commonly used index for hydrological drought assessment in conjunction with other indices.
- Other hydrological drought indices based on streamflow are hindered by the data availability.
- Indices baaed on groundwater levels in conjunction with other index are used for hydrological drought assessment for non monsoon periods.
- ***Lack of coordination between data monitoring agencies.***

Thank You

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