# How useful are CORDEX products for the assessment of future agricultural drought propensity across the Indian subcontinent?

Prabal Das[1], Kironmala Chanda[1], Rajib Maity[2]

[1] *Department of Civil Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Dhanbad-826004, India*

[2]*Department of Civil Engineering, Indian Institute of Technology Kharagpur, India*

**Abstract Id. : 15885**

**Sessions : HS2.4.7 on Hydrological change: Regional hydrological behavior under transient climate and land use conditions**

**Fri, 08 May, 08:30–12:30 CEST**

# Outline

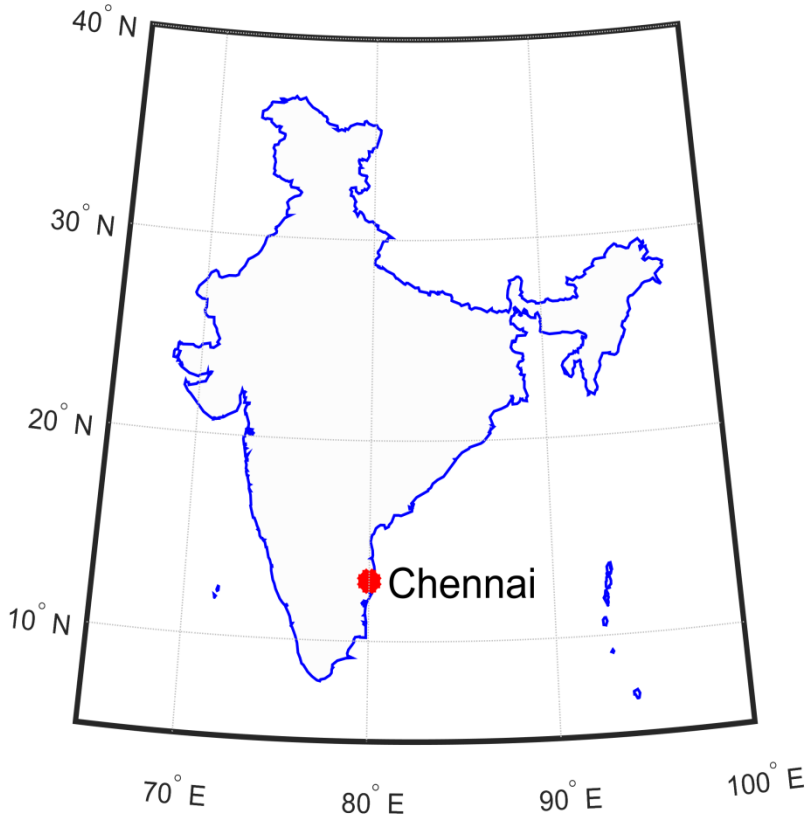
- Introduction
- Study area
- Data used
- Methodology
- Results and Discussions
- Findings and the Way Forward
- References

# Introduction

- A prolonged deficit in precipitation, soil moisture or water supply is considered as drought.
- Drought is usually quantified using indices that are derived from either precipitation, evapotranspiration, soil moisture or streamflow.
- It is necessary to quantify the slowly varying changes in soil moisture drought characteristics (Maity et.al, 2013)
- In the present study, Drought Management Index (DMI), which uses the concept of Reliability, Resilience and Vulnerability (RRV) (Hashimoto et al. 1982) is used to assess the future agricultural drought propensity using projected RCM data from CORDEX.

# Study Area

- As a pilot study, the analysis has been carried out near Chennai, India (13.25° N and 80.25° E)
- Chennai features a tropical wet and dry climate.
- The average annual rainfall is about 1400 mm.




Location Map

# Data used

## Reference data

- ERA5 soil moisture data, obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF)
- Spatial resolution = 0.25° lat. x 0.25° lon.
- Temporal resolution = Monthly
- https://cds.climate.copernicus.eu/

## Projected data

- Gridded soil moisture products from the Coordinated Regional Climate Downscaling Experiment (CORDEX)
- spatial resolution = 0.5° lat x 0.5° lon
- Temporal resolution = Monthly
- Representative Concentration Pathways (RCP8.5) - worst case scenario is considered
- http://cccr.tropmet.res.in/home/ftp_data.jsp

# Methodology

**Regridding**

- The CORDEX and the ERA5 dataset used in this study have different spatial resolution.
- ERA5 dataset are regridded to 0.5° x 0.5° so that both the dataset have common resolution

**Bias Correction**

- The bias correction used in this study is Conditional Quantile based Bias Correction (CQBC) (Chanda and Maity, 2017)

**RRV Calulation**

- Using a suitable threshold, which could be Permanent Wilting Point (PWP), the RRV characteristics are extracted from the soil moisture series.

**DMI Calculation**

- From the RRV characteristics, drought propensity is computed in the study area in terms of Drought Management Index (DMI).

# Theory of DMI

- Computation of DMI consists of three steps:

a) Computing the RRV from soil moisture series.
   - Reliability (R): probability that a system is in satisfactory state
   - Resilience (R): describes how quickly a system will recover from failure state once failure has occurred
   - Vulnerability (V): measure of the severity of damage caused by a failure event.

b) Obtaining the joint probability distribution between these measures using the copula tool

c) Computation of the probabilistic index DMI over the study area (Chanda et al. 2014)

# Computation of DMI

- The basis for computing the DMI is the RRV which are determined from monthly soil moisture series considering a 5-year temporal scale from 1979 – 2099 (i.e., 1979-83, 1980-84, ….etc.)
- Reliability is given by:

$$\alpha = P(X_t \, \epsilon \, S)$$

where S is the satisfactory state

- For a time series:

$$\alpha = \lim_{n \to \infty} \left( \frac{1}{n} \sum_{t=1}^{n} Z_t \right)$$

Where $Z_t$=1 if $X_t \, \epsilon \, S$ and $Z_t$=0, if $X_t \, \epsilon \, F$

# Computation of DMI (Contd.)

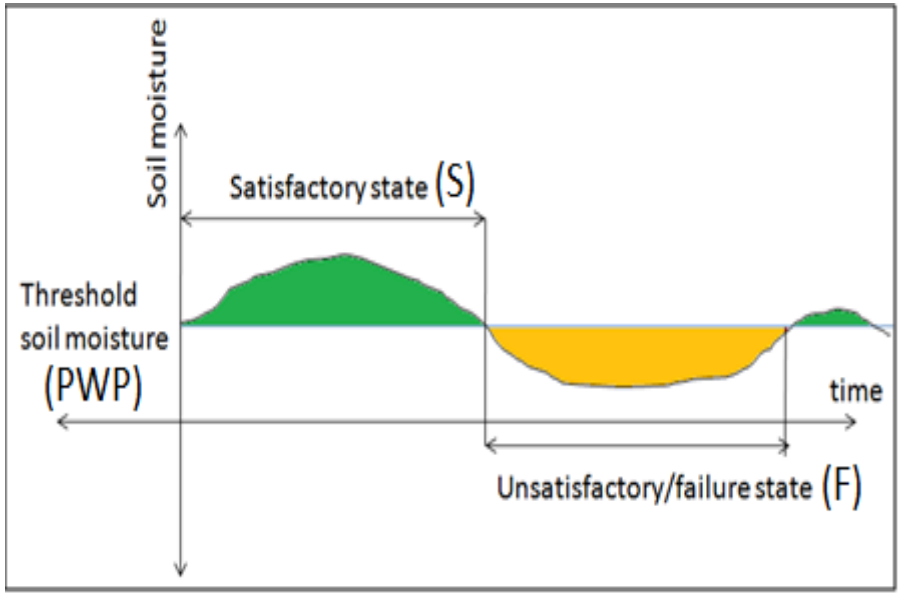
- Mathematical expression of Resilience is given by:

$$R = \frac{\lim_{n\to\infty} \frac{1}{n} (\sum_{t=1}^{n} W_t)}{1 - (\lim_{n\to\infty} \frac{1}{n} \sum_{t=1}^{n} Z_t)}$$

- Where $W_t$ indicates the event of transformation of soil moisture from satisfactory to failure state (or vice versa)
- Vulnerability is expressed as:

$$V = \frac{1}{n} \sum_{j=1}^{n} v_j$$

Where $v_j$ is the deficit volume at the j[th] time step and n is the total number of time steps.



# Computation of DMI (Contd.)

- After calculating the RRV, the joint probabilistic distribution of resilience and vulnerability is obtained using copula.
- This operation is carried out using the "gamlss" package in RStudio 4.6.2, wherein the data is fitted to all possible families of copula and the one that captured the dependencies best is selected.
- In this study, rotated Joe-Frank (BB8) (Joe 1997) Copula is found to be most suitable, compared to other copulas.
- Next, DMI, is developed such that it should increase with *increase in vulnerability* and *decrease in resilience* and vice versa. It is indicated by an exceedence in resilience and non-exceedence in vulnerability. Thus,

$$DMI = P\left[R > r, V \leq v\right]$$

where $P[\ldots]$ stands for probability of the event $[\ldots]$, $R$ stands for resilience and $V$ stands for vulnerability, and $r$ and $v$ are the reduced resilience and reduced vulnerability respectively.

# Bias Correction of CORDEX dataset

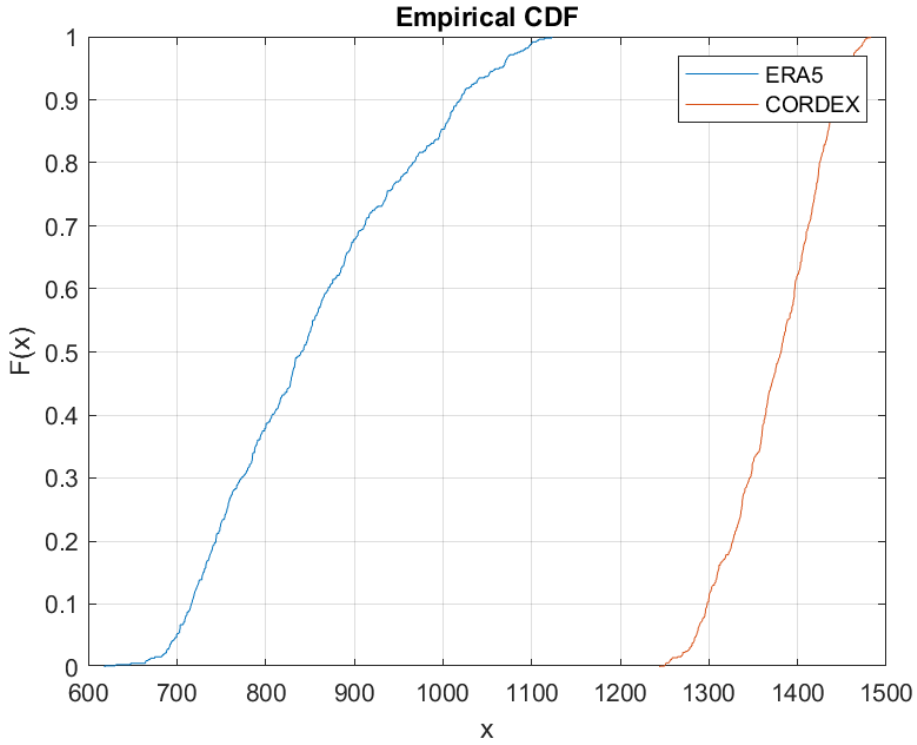
- Out of several bias correction method, we have used Conditional Quantile based Bias Correction (CQBC) method

$$\tilde{X}_m = \bar{X}_{o,q} + \left(X_m - \bar{X}_{m,q}\right) * \frac{S_{o,q}}{S_{m,q}}$$

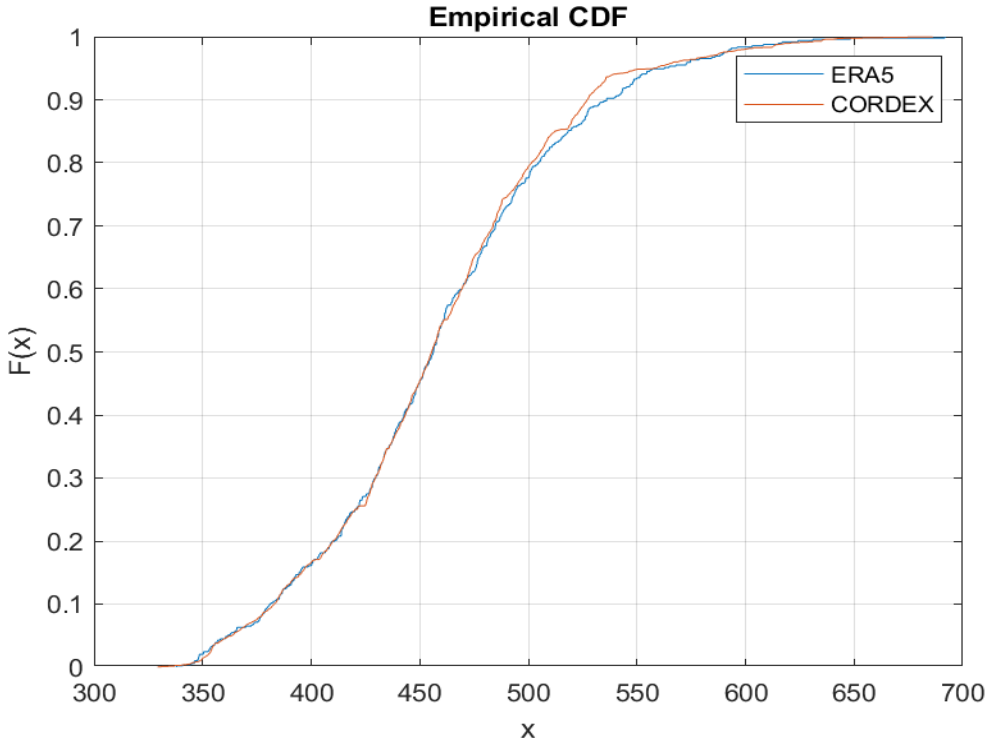
Where, $\tilde{X}_m$ is the corrected CORDEX value for raw CORDEX value $X_m$, $\bar{X}_{m,q}$ and $\bar{X}_{o,q}$ are the parameters for the concerned quantile range. $\bar{X}_{m,q}$ is the sample mean of CORDEX values for quantile interval $q$ and the ratio of standard deviation of observed $\left(S_{o,q}\right)$ and CORDEX $\left(S_{m,q}\right)$ data of quantile interval gives correction factor.

- The bias correction is applied to the data from 2006 to 2099 using parameters derived from the quantile based comparison of the CORDEX and reference dataset (ERA5) of the period 1979-2000.

# Bias Correction of CORDEX dataset (Contd.)



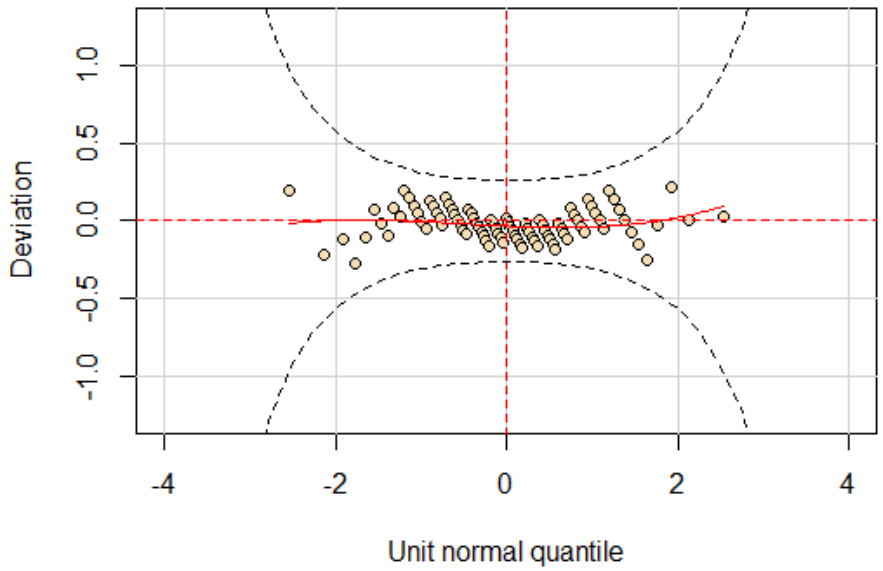

ECDF of ERA5 and CORDEX before bias correction




ECDF of ERA5 and CORDEX after bias correction

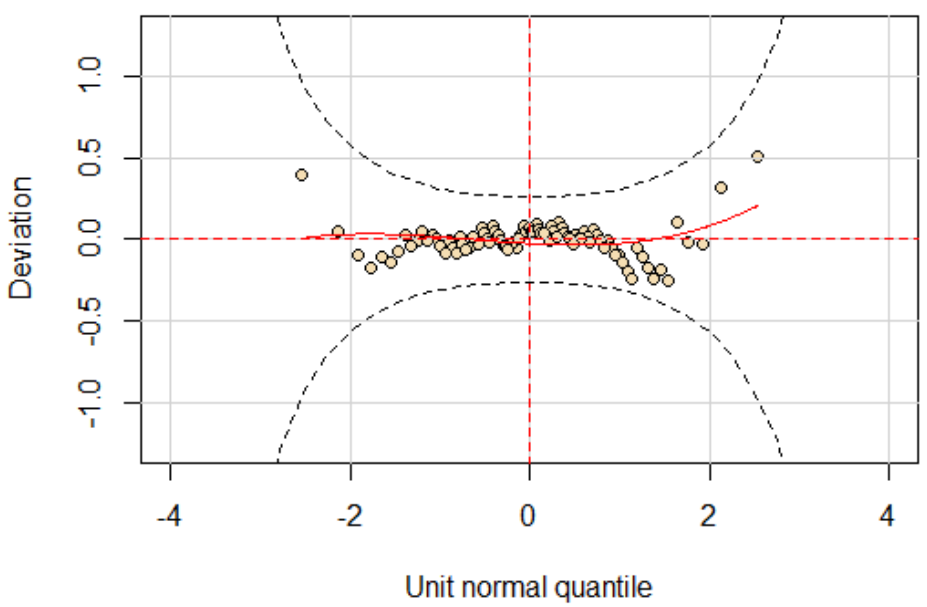
# Results and Discussions

- Reliability, resilience, and vulnerability are assessed for each 5-year-long series for the study area.
- Although different thresholds such as PWP could be used, here the long term monthly mean soil moisture values at the location over the period 1950– 2000 is used as the threshold for computing resilience and vulnerability values.
- The values of RRV computed from the set of 5-year time series are found to conform to an approximate Skew Power exponential type 3 (SEP3)
- Reliability, resilience and vulnerability all were found to have a good fit as observed from the worm plots.

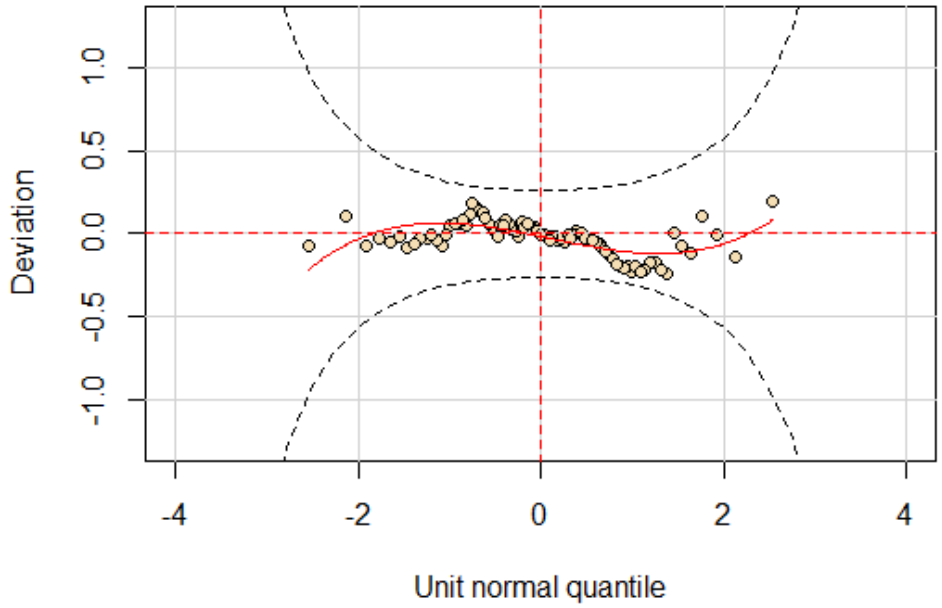



Worm plot for Reliability

# Results and Discussions (Contd.)



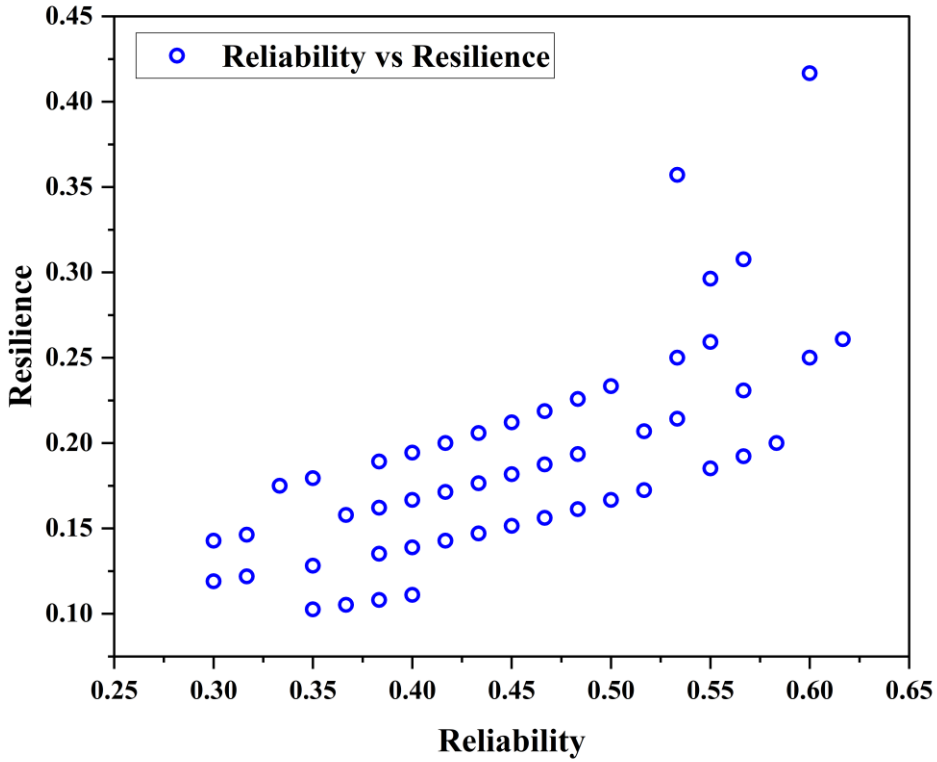

Worm plot for Reliability



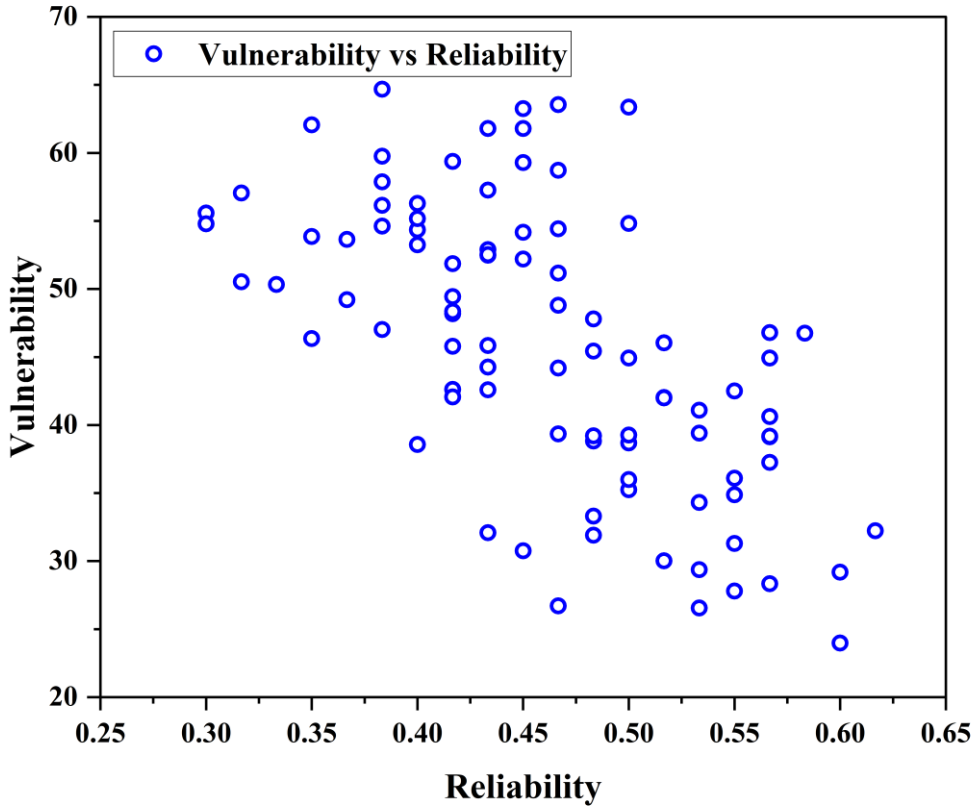

Worm Plot for Vulnerability

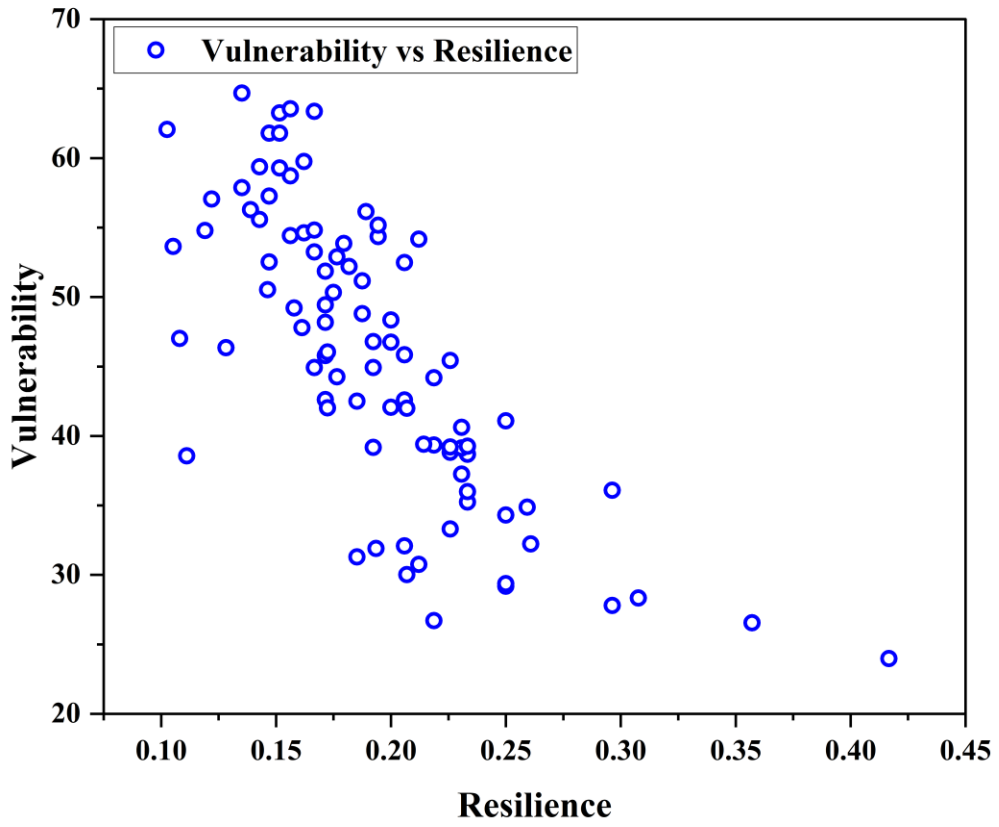
# Results and Discussions (Contd.)

- Pairwise scatter plots are prepared to understand their relationship.
- Reliability and resilience exhibit a well-defined monotonic nonlinear relationship that allows the specification of one given the other.
- Reliability and vulnerability and also resilience and vulnerability are found to be scattered with a negative association.
- The time series of Reliability, Resilience and Vulnerability is also presented across the 5-year moving window from 2005-2099.



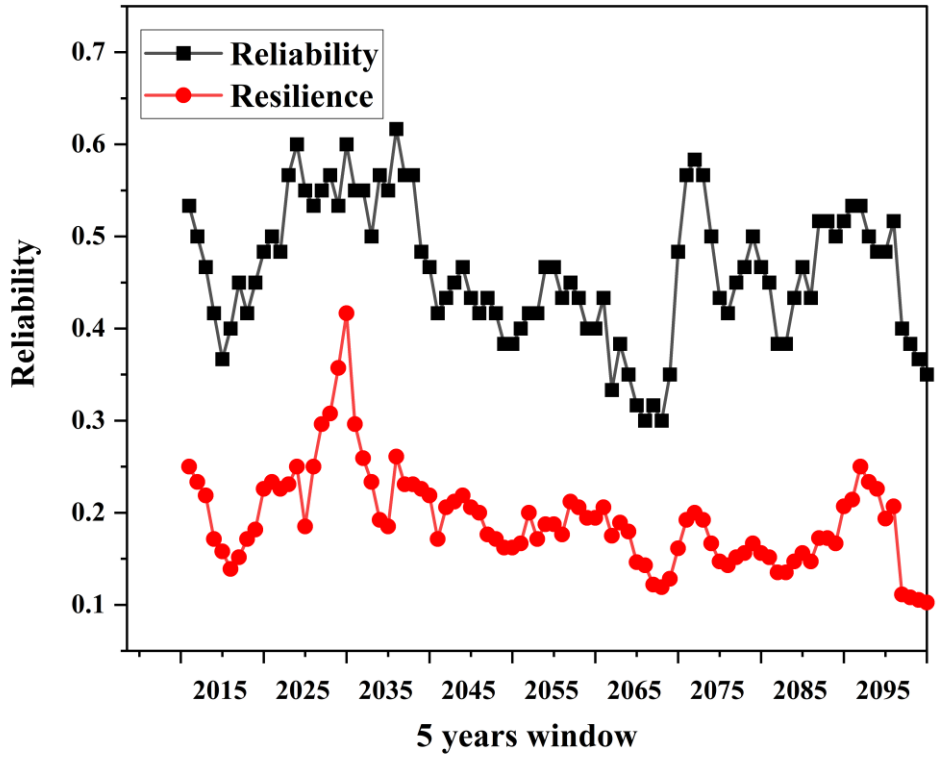
# Results and Discussions (Contd.)

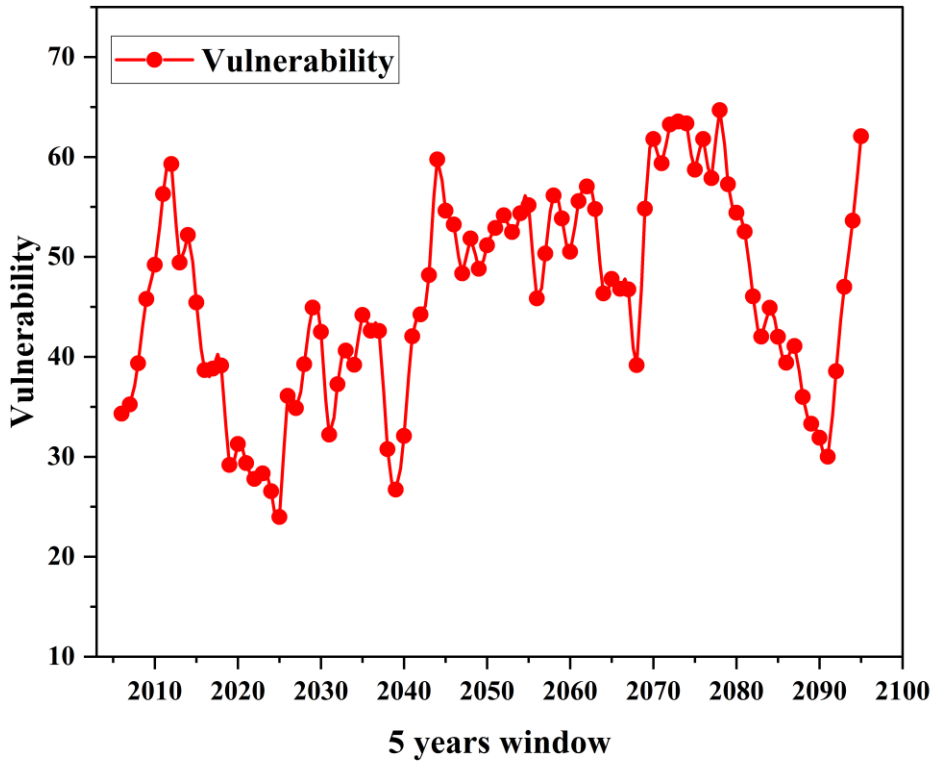



Pairwise scatter plot between Reliability, resilience and vulnerability

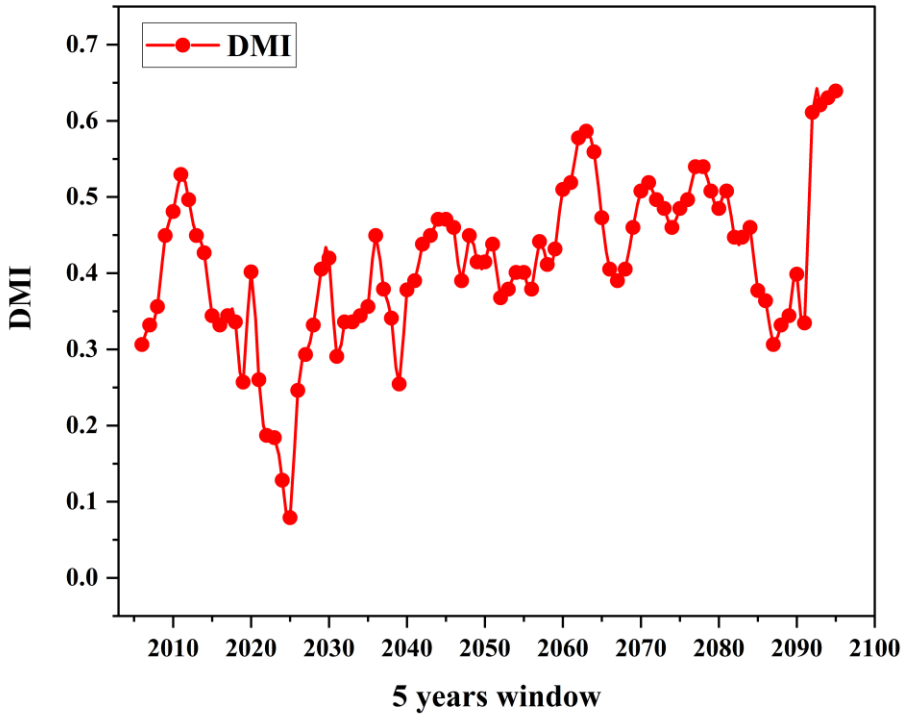
# Results and Discussions (Contd.)



# Results and Discussions (Contd.)

- In case of the time series of Reliability and Resilience, it is observed that a decreasing trend is in order as we proceed towards future
- Whereas, in case of Vulnerability, an increasing trend is followed.
- Time series of DMI also shows an increasing trend since there is an increasing trend in Vulnerability and a decreasing trend in Reliability and Resilience.
- The DMI series shows that there will be a slow increase in drought propensity over the study area, but this is the worst case scenario since we used the RCP 8.5 dataset.



# Findings and the Way Forward

- DMI is used to quantify the drought propensity using the RRV information from CORDEX projected soil moisture series.
- The study shows that for the chosen projection (worst case scenario i.e. RCP8.5 soil moisture), there will be a slow increase in Vulnerability and a decrease in Reliability and Resilience leading to a steady increase in drought propensity over the 21$^{st}$ century.
- Going forward, the sensitivity of drought propensity with the threshold will be evaluated using PWP as well as ‘Available Water’.
- Further, this concept will be applied across the Indian subcontinent across multiple emission scenarios, designated by different RCPs, and compared.

# References


- Hashimoto, T., Stedinger, J. R., & Loucks, D. P. (1982). Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. *Water resources research*, *18*(1), 14-20.
- Joe H (1997). Multivariate Models and Dependence Concepts. Chapman & Hall, London
- Maity, R., Sharma, A., Nagesh Kumar, D., & Chanda, K. (2013). Characterizing drought using the reliability-resilience-vulnerability concept. *Journal of Hydrologic Engineering*, *18*(7), 859-869.
- Chanda, K., Maity, R., Sharma, A., & Mehrotra, R. (2014). Spatiotemporal variation of long-term drought propensity through reliability-resilience-vulnerability based Drought Management Index. *Water Resources Research*, *50*(10), 7662-7676.
- Chanda, K., & Maity, R. (2017). Assessment of trend in global drought propensity in the twenty-first century using drought management index. *Water Resources Management*, *31*(4), 1209-1225.
- Urraca, R., Huld, T., Gracia-Amillo, A., Martinez-de-Pison, F. J., Kaspar, F., & Sanz-Garcia, A. (2018). Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data. *Solar Energy*, *164*, 339-354.
- Balsamo, G., Dutra, E., Albergel, C., Munier, S., Calvet, J. C., Munoz-Sabater, J., & de Rosnay, P. (2018). ERA-5 and ERA-Interim driven ISBA land surface model simulations: which one performs better?. *Hydrology and Earth System Sciences*, *22*(6), 3515-3532.
- Kisembe, J., Favre, A., Dosio, A., Lennard, C., Sabiiti, G., & Nimusiima, A. (2019). Evaluation of rainfall simulations over Uganda in CORDEX regional climate models. *Theoretical and Applied Climatology*, *137*(1-2), 1117-1134.

# Thank you!