Uncertainty in Future Projections of Water Deficit Droughts Based on Evapotranspiration Methods in the Indian Subcontinent

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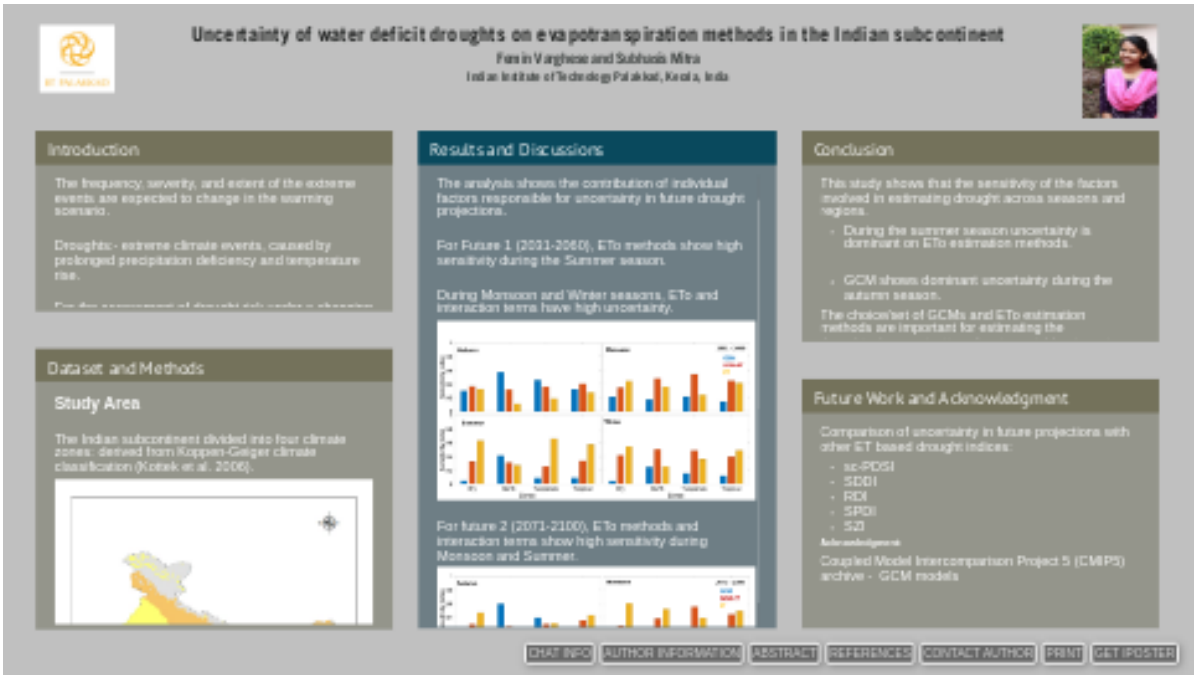
Abstract

The choice of reference evapotranspiration (ETo) estimation methods and general circulation model (GCM) are crucial for projecting water deficit under a changing climate. Standardized Precipitation Evapotranspiration Index (SPEI) derived from water deficit also varies with the choice of GCM and ETo estimation methods. In this study a variance-based global sensitivity analysis was used to estimate relative sensitivity of projected changes in future water deficit (P-ETo) and SPEI to the choice of GCM and ETo estimation methods over parts of the Indian subcontinent. For evaluating the change in water deficit and droughts, 7 GCMs and 11 ETo methods were analyzed for two distinct periods i.e. 2030-2060 and 2070-2100 compared to the baseline (1951-1980). The 11 ETo methods were grouped into 4 major categories namely based on temperature, radiation, mass transfer and combination methods. Moreover, based on the ETo categories, a non-parametric Mann-Whitney was performed to quantify robust changes under a warming climate. Results show that changes in future water deficit and droughts varies with regions and seasons. Overall, changes in water deficit droughts are more inclined to the choice of ETo method, while the GCM-ETo interaction effects are more prominent in some regions. Results also showed that within an individual ETo category, individual ETo methods do not necessarily agree on the magnitude/direction of change in projecting water deficit and SPEI for future conditions. This has important implications towards selection of appropriate ETo estimation for drought analysis in data scarce regions under a changing climate. Results of this study indicate, the role of proper ensemble formation of GCMs and ETo estimation methods based on seasons and regions, to develop a robust range of future conditions for water resources planning.

Uncertainty of water deficit droughts on evapotranspiration methods in the Indian subcontinent



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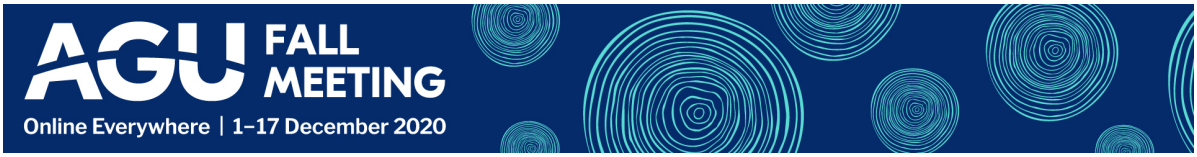


INTRODUCTION

The frequency, severity, and extent of the extreme events are expected to change in the warming scenario.

Droughts:- extreme climate events, caused by prolonged precipitation deficiency and temperature rise.

For the assessment of drought risk under a changing climate, drought projections are important.

Changes in future precipitation and potential evapotranspiration are likely to affect future drought characteristics.

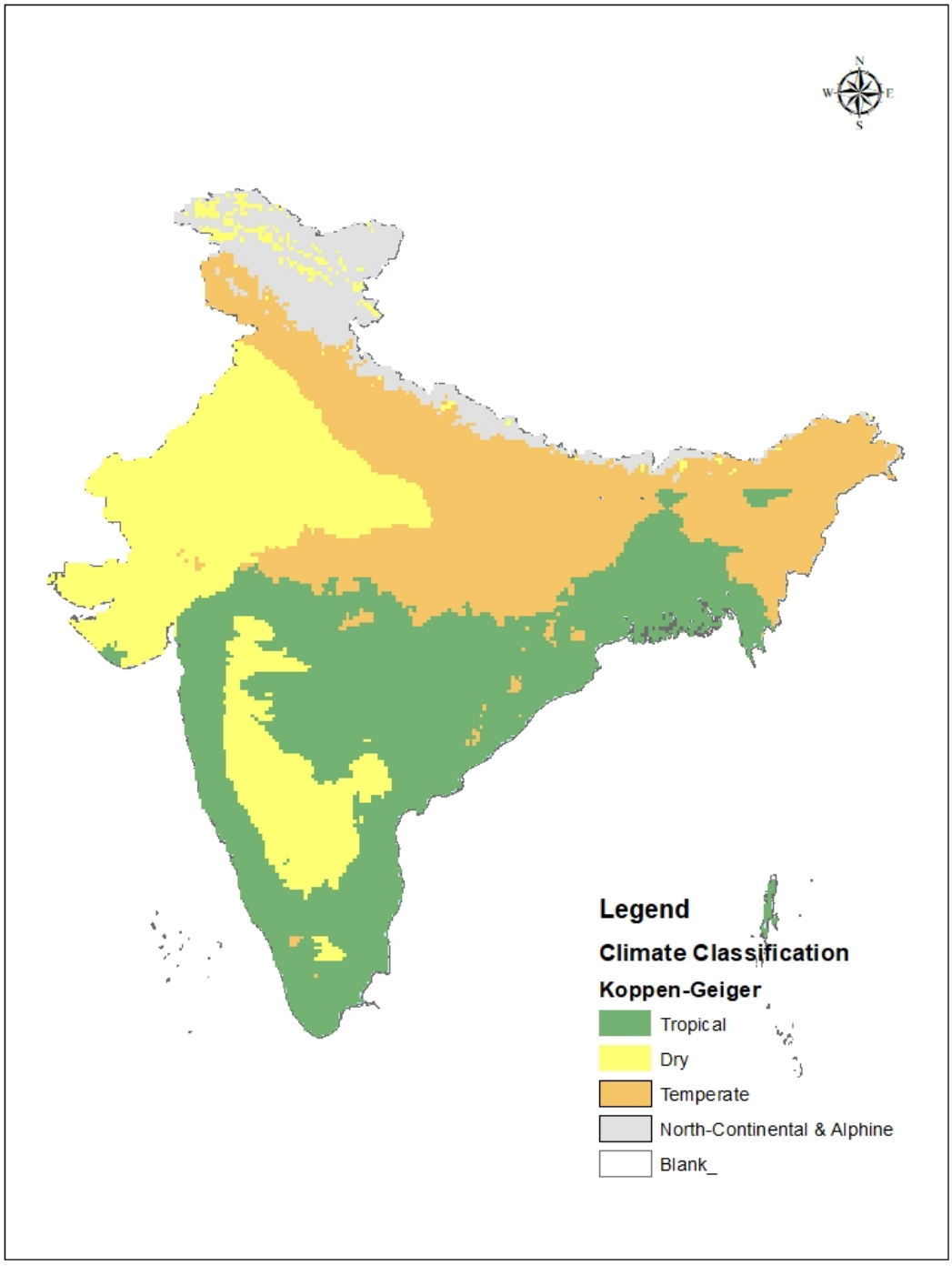
Different model projections have uncertainties in projected climate variables, thus affecting drought tendencies.

The uncertainty in the projected drought occurrence: from the choice of GCMs and/or ETo estimation methods

DATASET AND METHODS

Study Area

The Indian subcontinent divided into four climate zones: derived from Koppen-Geiger climate classification (Kottek et al. 2006).



Dataset

Seven GCMs from the Coupled Model Intercomparison Project 5 (CMIP5) archive selected for analysis:- Perform well in capturing the South Asian summer monsoon.

Table 1: Description of GCMs

Model	Institute	GCM grid(degree)
ACCESS 1	Centre for Australian Weather and Climate Research (CAWCR)	1.5
CNRM-CM5	Centre National de Recherches Meteorologiques	1.4
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory	1.9
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory	2.2
MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo)	2.2
MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo)	2.8
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo)	1.4

- Historical base period (1950-2005)
- Future period (2006-2100)
- RCP 8.5

Eleven reference evapotranspiration estimation methods

- (Blaney- Criddle, Hamon, Hargreaves, Kharrufa, Thornwaithe, Dalton, Meyer, Irmak-Rn, Irmak-Rs, Priestley-Taylor, and Penman-Monteith)
- Mainly categorized based on temperature, radiation, mass transfer, and, the combination.

Methods

Standardized Precipitation Evaporation Index (SPEI) is calculated using the water deficit (P-ETo) series which is fitted into a log-logistic distribution.

The uncertainty of changes in future water deficit droughts (SPEI), to the choice of GCMs and ETo estimation methods:- studied using the variance-based global sensitivity analysis (GSA).

- Given a model $Y=f(X1X2\ldots Xk)$ where Xi represents the factors considered. The conditional expectation $E(Y/Xi)$, is the average over Y/Xi, which shows the variance

across Xi values. Hence, the variance of conditional expectation can be considered as a measure of sensitivity. The first-order sensitivity index is obtained as:

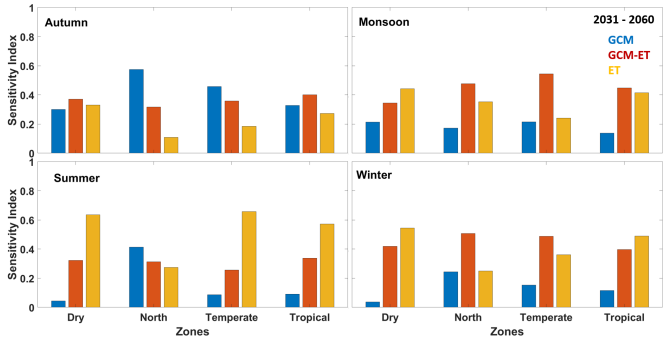
- $\frac{Si=V[E(Y/Xi)]}{V(Y)}$ where V(Y) is the total variance over all Xi. Si is a normalized index varying between 0 and 1, as the numerator varies between 0 and V(Y).

RESULTS AND DISCUSSIONS

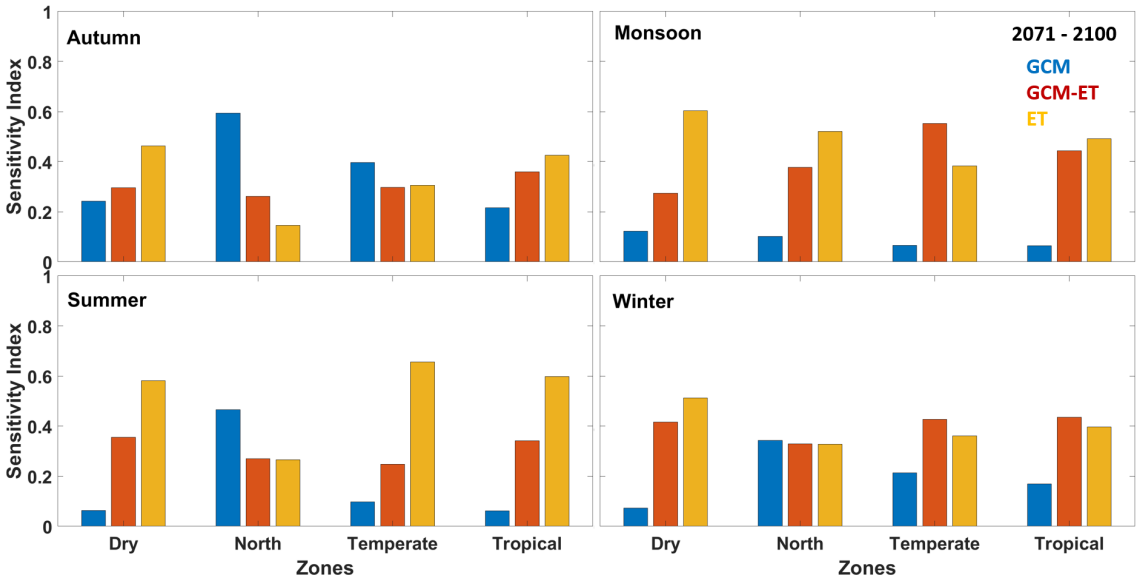
The analysis shows the contribution of individual factors responsible for uncertainty in future drought projections.

For Future 1 (2031-2060), ETo methods show high sensitivity during the Summer season.

During Monsoon and Winter seasons, ETo and interaction terms have high uncertainty.

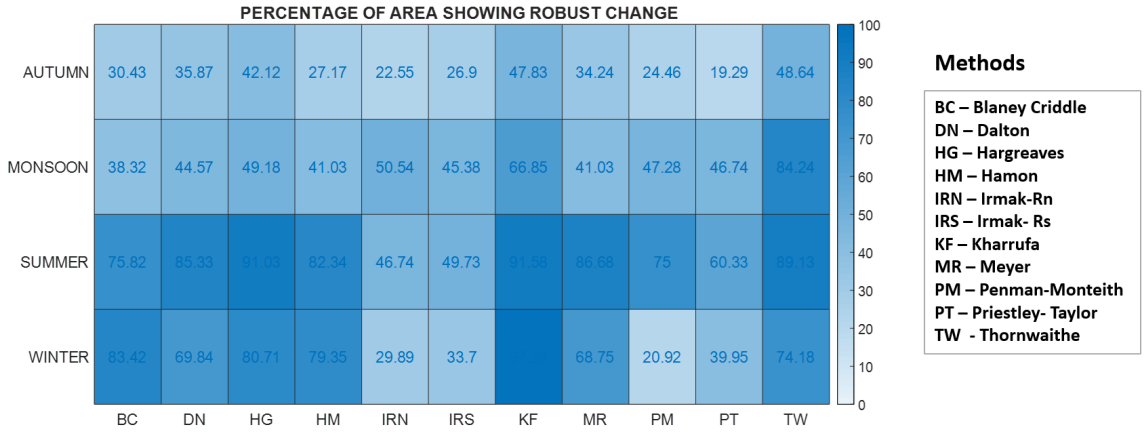


For future 2 (2071-2100), ETo methods and interaction terms show high sensitivity during Monsoon and Summer.



From future 1 to future 2, factors show different sensitivity across seasons and zones.

Based on ETo methods, the Mann-Whitney test is used to identify statistically significant grid points for historic and future periods.



During Summer and Winter percentage of the area showing robust change is high for all ETo methods.

CONCLUSION

This study shows that the sensitivity of the factors involved in estimating drought across seasons and regions.

- During the summer season uncertainty is dominant on ETo estimation methods.

- GCM shows dominant uncertainty during the autumn season.

The choice/set of GCMs and ETo estimation methods are important for estimating the drought when projecting climate variables in water resource planning.

FUTURE WORK AND ACKNOWLEDGMENT

Comparison of uncertainty in future projections with other ET based drought indices:

- sc-PDSI
- SDDI
- RDI
- SPDI
- SZI

Acknowledgment:

Coupled Model Intercomparison Project 5 (CMIP5) archive - GCM models

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REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M.: Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56, 1998.

Ashfaq, M., Rastogi, D., Mei, R., Touma, D., Ruby Leung, L., 2017. Sources of errors in the simulation of south Asian summer monsoon in the CMIP5 GCMs. Clim Dyn 49, 193–223.

Chang, S., Graham, W.D., Hwang, S., Muñoz-Carpena, R., 2016. Sensitivity of future continental United States water deficit projections togeneral circulation models, the evapotranspiration estimation method, and thegreenhouse gas emission scenario. Hydrol. Earth Syst. Sci. 20, 3245–3261.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F., 2006. World Map of the Köppen-Geiger climate classification updated. metz 15, 259–263

Saltelli, A. (Ed.), 2008. Global sensitivity analysis: the primer. John Wiley, Chichester, England; Hoboken, NJ.

Sharma, S., Mujumdar, P., 2017. Increasing frequency and spatial extent of concurrent meteorological droughts and heatwaves in India. Sci Rep 7, 15582.

Shi, L., Feng, P., Wang, B., Liu, D.L., Yu, Q., 2020. Quantifying future drought change and associated uncertainty in southeastern Australia with multiple potential evapotranspiration models. Journal of Hydrology 590, 125394.

Su, B., Huang, J., Fischer, T., Wang, Y., Kundzewicz, Z.W., Zhai, J., Sun, H., Wang, A., Zeng, X., Wang, G., Tao, H., Gemmer, M., Li, X., Jiang, T., 2018. Drought losses in China might double between the 1.5 °C and 2.0 °C warming. Proc Natl Acad Sci USA 115, 10600–10605.

Vardhan, D.H., Chowdary, S.Y.S., n.d. Annual Report 2017, INDIA METEOROLOGICAL DEPARTMENT MINISTRY OF EARTH SCIENCES 144.

Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., 2010. A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. Journal of Climate 23, 1696–1718.

Wang, H., Chen, Y., Pan, Y., 2015. Characteristics of drought in the arid region of northwestern China. Clim. Res. 62, 99–113.

Wang, W., Xing, W., Shao, Q., 2015. How large are uncertainties in future projection of reference evapotranspiration through different approaches? Journal of Hydrology 524, 696–700.

Xu, C.-Y., Singh, V.P., 2001. Evaluation and generalization of temperature-based methods for calculating evaporation. Hydrol. Process. 15, 305–319.

Zhao, T., Dai, A., 2017. Uncertainties in historical changes and future projections of drought. Part II: model-simulated historical and future drought changes. Climatic Change 144, 535–548.