INDIAN INSTITUTE OF SCIENCE

भारतीय विज्ञान संस्थान

CE 223 Hydroclimatology: Final Project

Name: Vivek Kumar Yadav, PhD

SR Number: 19535

Department: ICWaR

Date of Submission: 25-04-2022

Identification of terrestrial evaporation response to rainfall in monsoon period across India

Abstract: The Indian Summer Monsoon Rainfall is driven largely by monsoon and moisture brought from the Indian Ocean. It has been shown by Pathak. A (*ref 1*) et al, a large contribution to the rainfall in ISMR comes from the recycling of the evapotranspiration. This “recycled precipitation plays and important role in precipitation over the central & northwestern India. This study is aimed identifying the response of land hydrology to rainfall. Daily rainfall series was obtained by from IMD Gridded Precipitation dataset. Daily evaporation was obtained from GLEAM, Global Land Evaporation Amsterdam Model. Specific evaporation and rainfall variables were extracted from the data grid wise. The results show correlation of ± 0.4 & higher magnitudes with statistical significance at certain grid locations. However, ascertaining the exact reason for such results requires finer analysis at temporal & spatial scales.

Introduction: The Indian summer monsoon rainfall (ISMR) during June-mid October is part of the Asian monsoon precipitation over the Indian subcontinent. It drives the Agriculturally based part of Indian economy. Though most of the rainfall during this period is from the moisture carried by westerly monsoon winds, it has been shown by Pathak A. et al precipitation recycling also plays an important role. Where they use water vapour tracing models to find the recycling ratio across different zones of India.

Coming from the summer months of March-May the land surface is extremely dry with very large gradient of moisture and low evapotranspiration. ISMR carries out precipitation associated with Low Pressure Systems, thus summer monsoon break periods often occur in this season. These break periods have high temperatures and humidity.

With the start of monsoon, the moisture available for evaporation increases and the soil begins to infiltrate and saturate. This allows for greater evaporation, from Dalton’s Law

$$E = B(\Delta e)$$

$$E = Rate\ of\ evaporation$$

$$B = Constant\ depended\ on\ heat\ capacity\ of\ water$$

$$\Delta e = e_s - e_a\ , gradeint\ of\ vapour\ pressure$$

$$e_s = Saturated\ vapour\ pressure$$

$$e_a = Ambient\ vapour\ pressure$$

In the break period the available moisture for evaporation is directly controlled by the cumulative precipitation taking place before the break period. And the number of days of rainfall will together control the moisture gradient in the break period. The dry spell evaporation will thus be controlled by these two variables. With the formation of next low-pressure system, the dry spell will end with rain spell again starting the same cycle.

However, the with the advancement of monsoon this relation will weaken as the soil is replenished and saturated.

To find the statistical quantification of this relationship I extract specific variables from precipitation and evaporation to find the correlation. With the assumption that each grid corresponding to its characteristics will supply moisture back to atmosphere which should result in rainfall elsewhere. However, this does not allow for tracing of the vapour which has a residence time of 8 days. Based on spatial representation of the correlation a classification into the type of responses generated is attempted.

Data: Two type of data products were used for this study.

1. IMD Gridded daily Rainfall data at $0.25°X0.25°$ spatial resolution was obtained for the 5-year period from 2015 till 2019.
2. Global Land Evaporation Amsterdam Model's GLEAM v3.5b daily Evaporation at $0.25°X0.25°$ spatial resolution was obtained from 2015 till 2019.
   This dataset uses largely satellite remote sensing along with reanalysis data.

The analysis was carried out grid wise for the Indian landmass. Both the data products have processed through multiple algorithms, to avoid further manipulation grids with missing rainfall and/or evaporation values on any day were omitted.

The latitudes and longitudes of both data products were brought to same points by re-gridding the GLEAM product using Xarray package on python with bilinear interpolation.

Methodology: The analysis of relation is carried out between two periods of ISMR, monsoon active, low-pressure system driven and monsoon break periods.

The three variables of interest selected are a) Cumulative rainfall, b) Duration of rainfall period, in the in the wet spell preceding the break period and c) Cumulative evaporation in the dry spell, break period.

Rainfall threshold of 2.5 mm was selected to identify a particular day as a rainy day following previous studies (*ref 2*). A wet spell is categorized as a period of one or more day of continuous rainfall. Similarly dry spell is identified as a period of one or more day of continuous lack of rainfall. This is shown below, Figure 1.

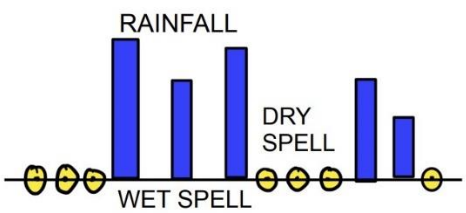


Figure 1: Only dry spell following a wet spell was considered

Since the assumption is that the wet spell variables control the dry spell variable, series starting with wet spells were selected by ignoring the dry spells in the data.

Data Analysis Duration: Since the relation between the wet spell and dry spell variables weakens with the monsoon period from saturation, higher availability of moisture and decreased moisture gradient, only the two-month, June-1 to July 31, period was selected for the analysis. This was also confirmed by the low correlations obtained from considering the full duration of monsoon from July-1(new monsoon onset) to October-15(new monsoon withdrawal).

Data Analysis: Kendall Tau Test was used to calculate the correlation between the variables. Since Kendall Tau is a non-parametric test, it uses a rank correlation of variables & hence is unaffected by the magnitudes of the variables. This is an important criterion since the length of the dry spell is controlled by many other meteorological factors, the cumulative evaporation can be very high at certain grid points where dry spells are longer.

It is calculated by ranking the variables in ascending order of ranks with the corresponding variable changing with it. Next pairs of variables are created to find the difference between their ranks. A concordant pair is created when

$$X(j) > X(i) \; \forall \; i, j,$$

else it is called a discordant pair (q). The sum of all such pairs gives

$$p = \sum_j^{N-1} \sum_i^N \alpha(X(j) - X(i))$$

Where the argument $\alpha(\cdot) = 1$ if argument is true or 0 if false.

Expected value of p is given as

$$E(p) = N(N-1)/4$$

Kendall's τ is given as

$$\tau = 2(p-q)/N(N-1)$$

This follows the standard normal distribution, and its significance can be tested as

$$|(\tau - E(\tau))/var(\tau)| > Z_{\alpha/2}$$

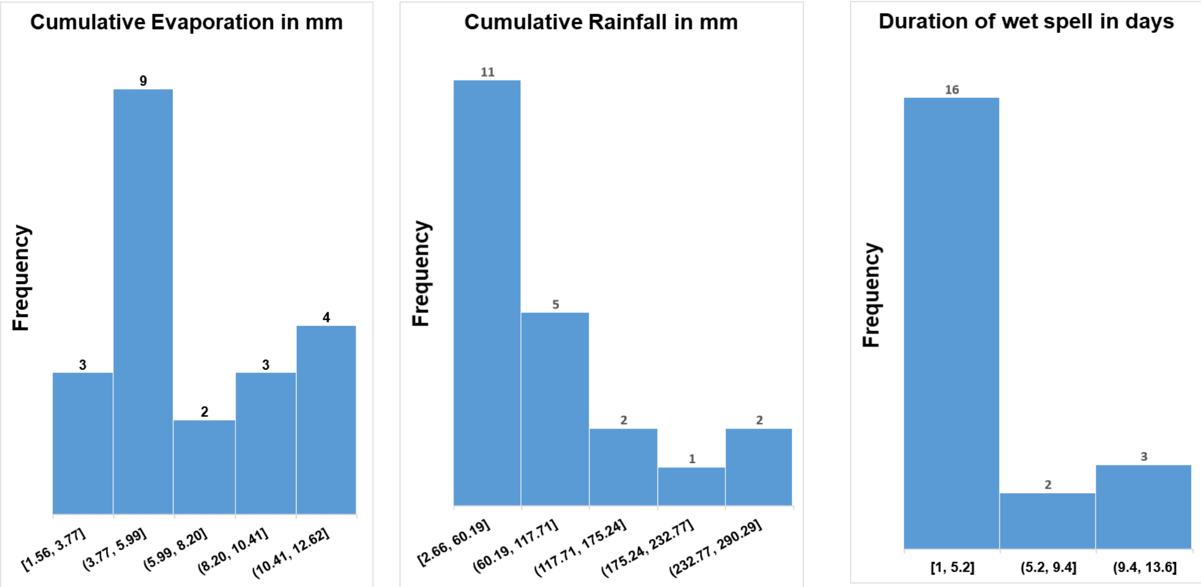
Where $Z_{\alpha/2}$ is the standard normal variate, with non-exceedance probability of $\left(1-\frac{\alpha}{2}\right)100\%$ at significance level of α. 80% confidence was chosen for the analysis.

This test statistic is not affected by the length of the series, again this is a useful fact since the number of dry (or wet) spell can be very low at any particular grid point depending on the climatology of the grid.

Also, this test does not assume the data to belong to any distribution.

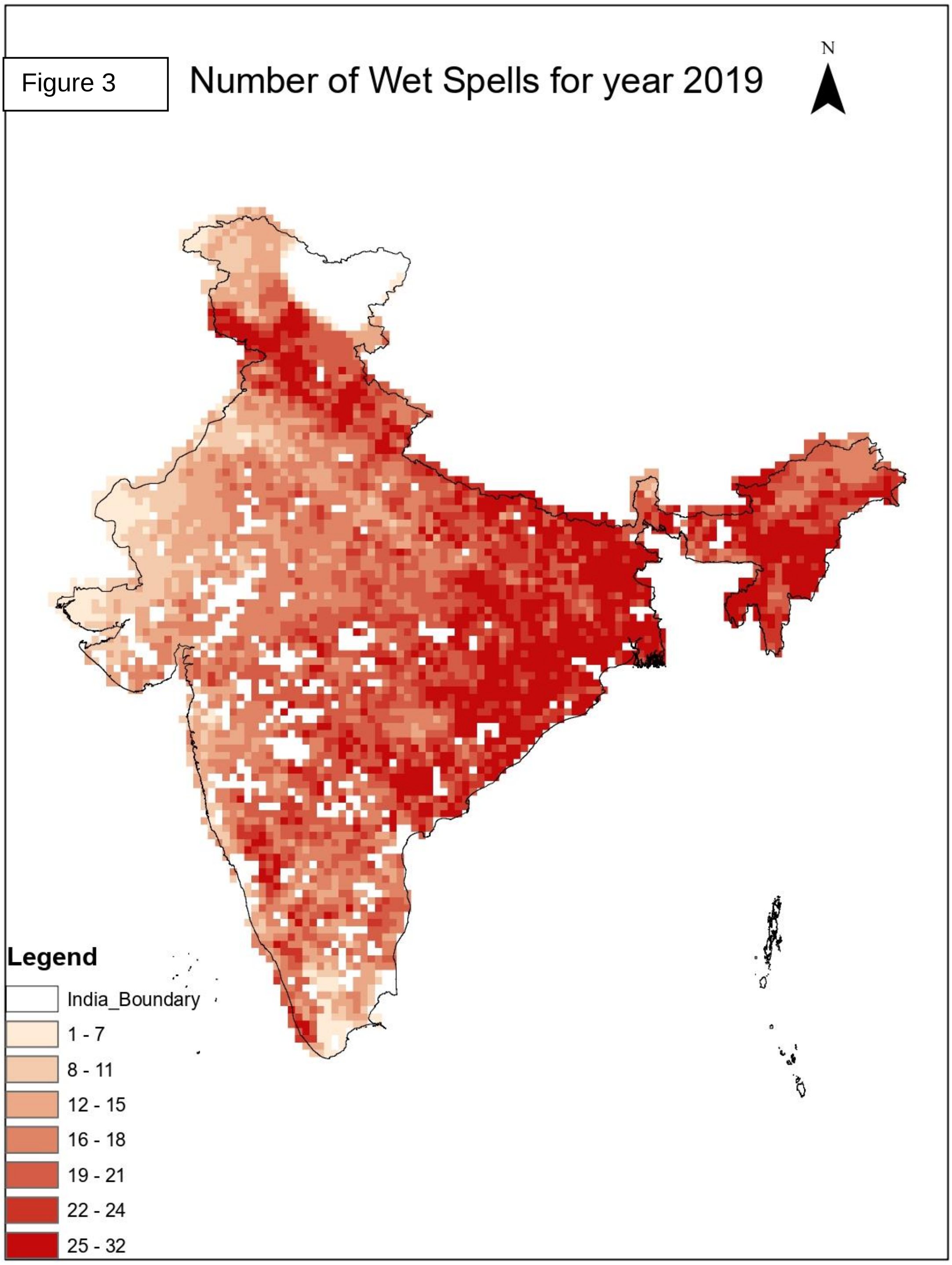
Multimodality of wet and dry spell variables was observed, this was expected since the rainfall when considered in intervals is result of LPS activities whose intensities are dependent on meteorological conditions. Thus, multiple peaks were observed in the series generated. This did not allow the data to be fitted to a normal distribution.

Figure 2: Example of variables for grid 81.25E,19.50N, year 2019



Cumulative Evaporation in DS	**Cumulaitve rainfall in WS**	**Duration of Wet Spell**
5.42	6.75	1
4.84	13.74	3
12.41	26.94	3
1.56	117.17	4
12.62	179.02	12
4.13	48.98	4
7.29	16.78	2
12.07	33.71	1
3.85	242.72	6
4.09	47.57	4
2.03	125.90	4
5.96	64.34	3
7.49	67.81	2
4.29	92.18	7
11.40	290.29	10
5.89	36.37	2
5.92	119.36	11
9.78	2.66	1
3.45	31.16	2
10.24	6.01	1
9.61	78.04	3

Table 1: Typical variable series for 1 grid



The number of wet spells widely varies across India. And the rainfall and evaporation activity inside them also varies largely.

Results and Discussion:

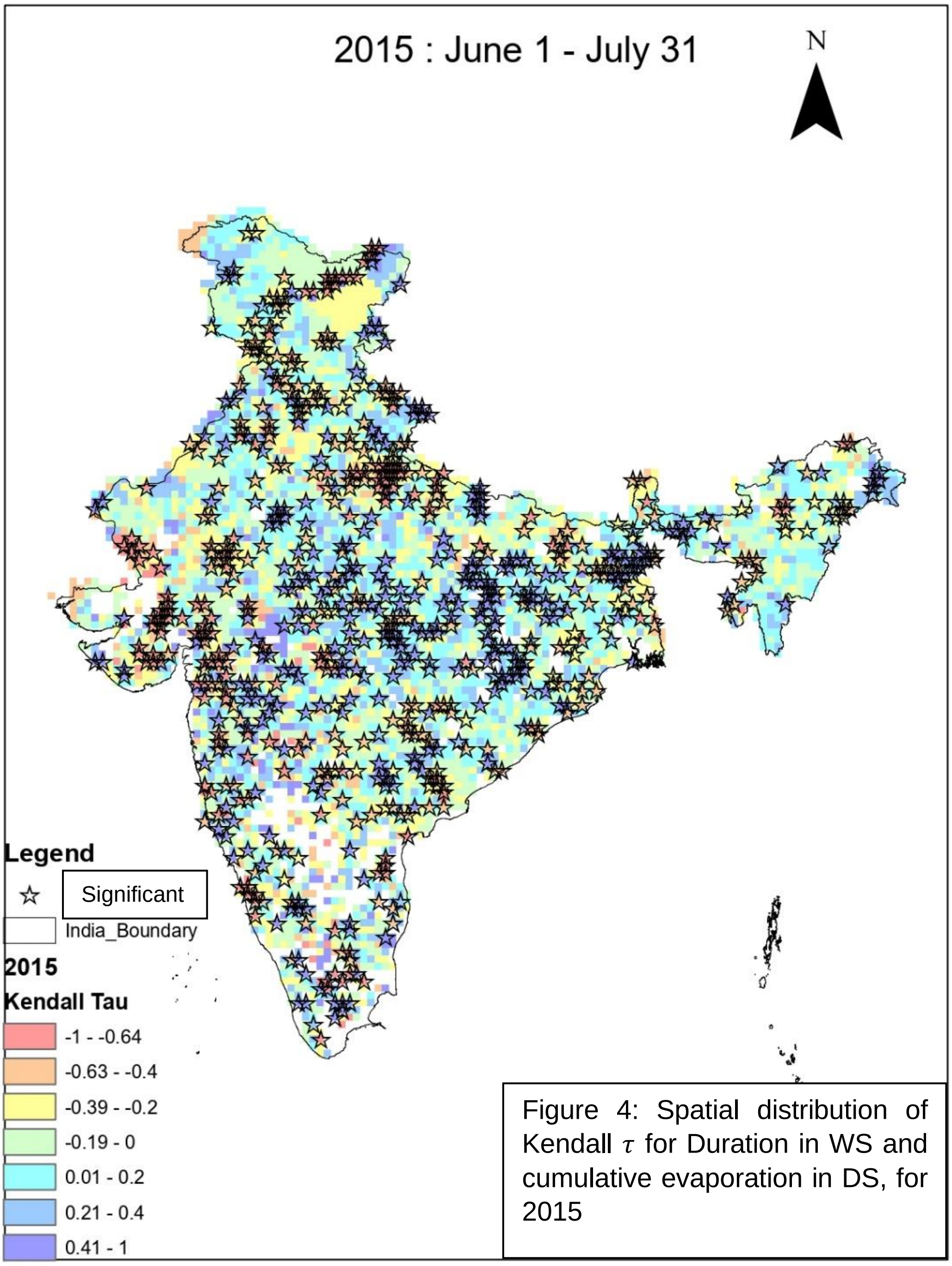


Figure 4: Spatial distribution of Kendall τ for Duration in WS and cumulative evaporation in DS, for 2015

Plot of correlation were plotted only for the “duration of rainfall variable’ and “cumulative evaporation” since it gave higher magnitudes of correlation but similar number of grid points.

The year 2015 was a monsoon deficient year (IMD Annual Report 2015). In this regard we see positive, significant correlation in central parts of India. Relatively weaker correlations in the Northeastern parts. Strong negative correlation in central and western part of Gujrat. Incidentally the correlations are weaker in the peninsular region. And overall negative correlation in Ladakh region. Western Ghats also show negative correlation.

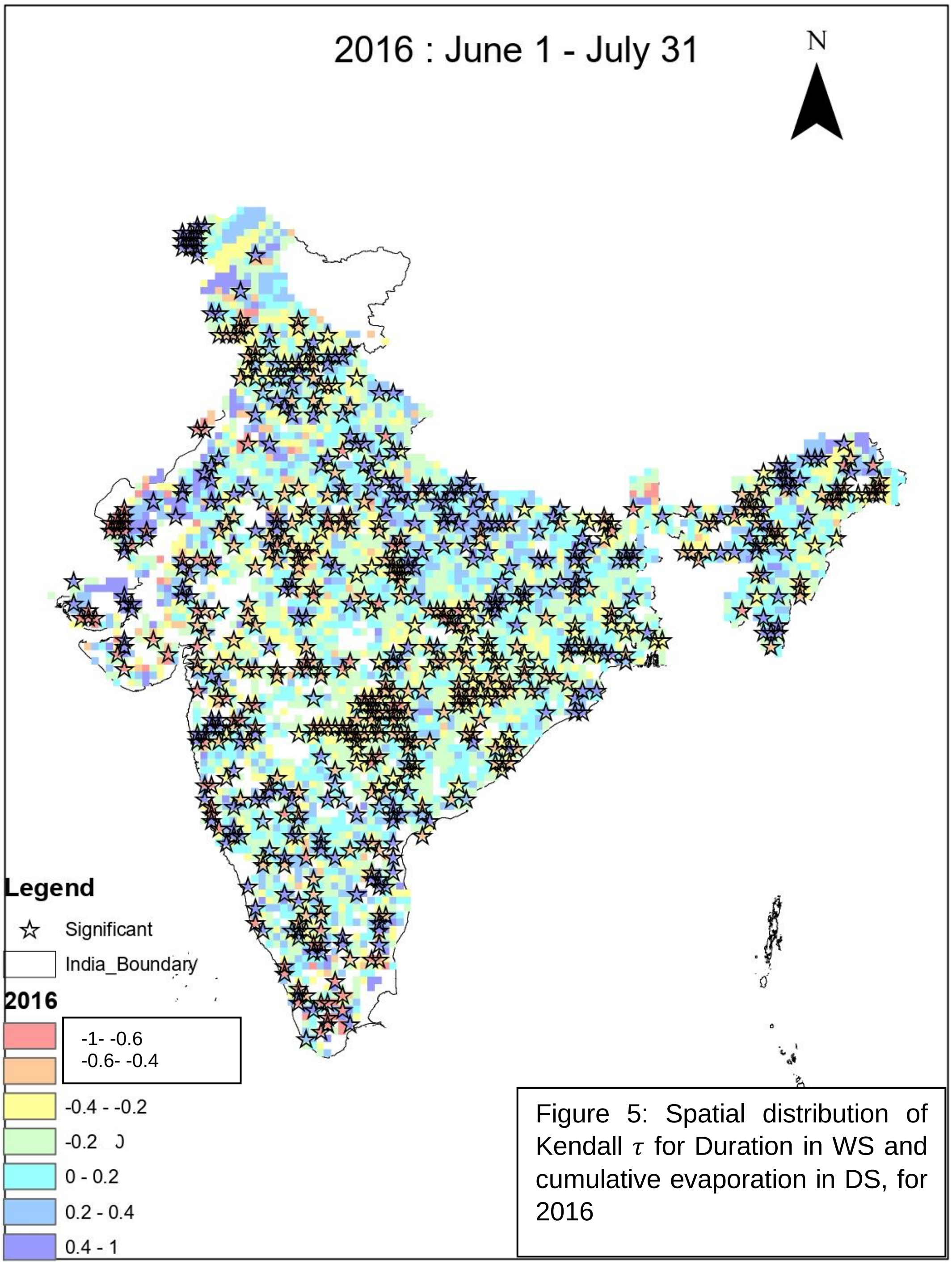


Figure 5: Spatial distribution of Kendall τ for Duration in WS and cumulative evaporation in DS, for 2016

Year 2016 was a normal monsoon year (IMD Annual Report 2016). We observe correlations over the central Indian region has decreased. While it has increased in the Northeastern, Northern and Northwestern parts. While peninsular region now shows higher correlated areas. Western Ghats show improved correlation.

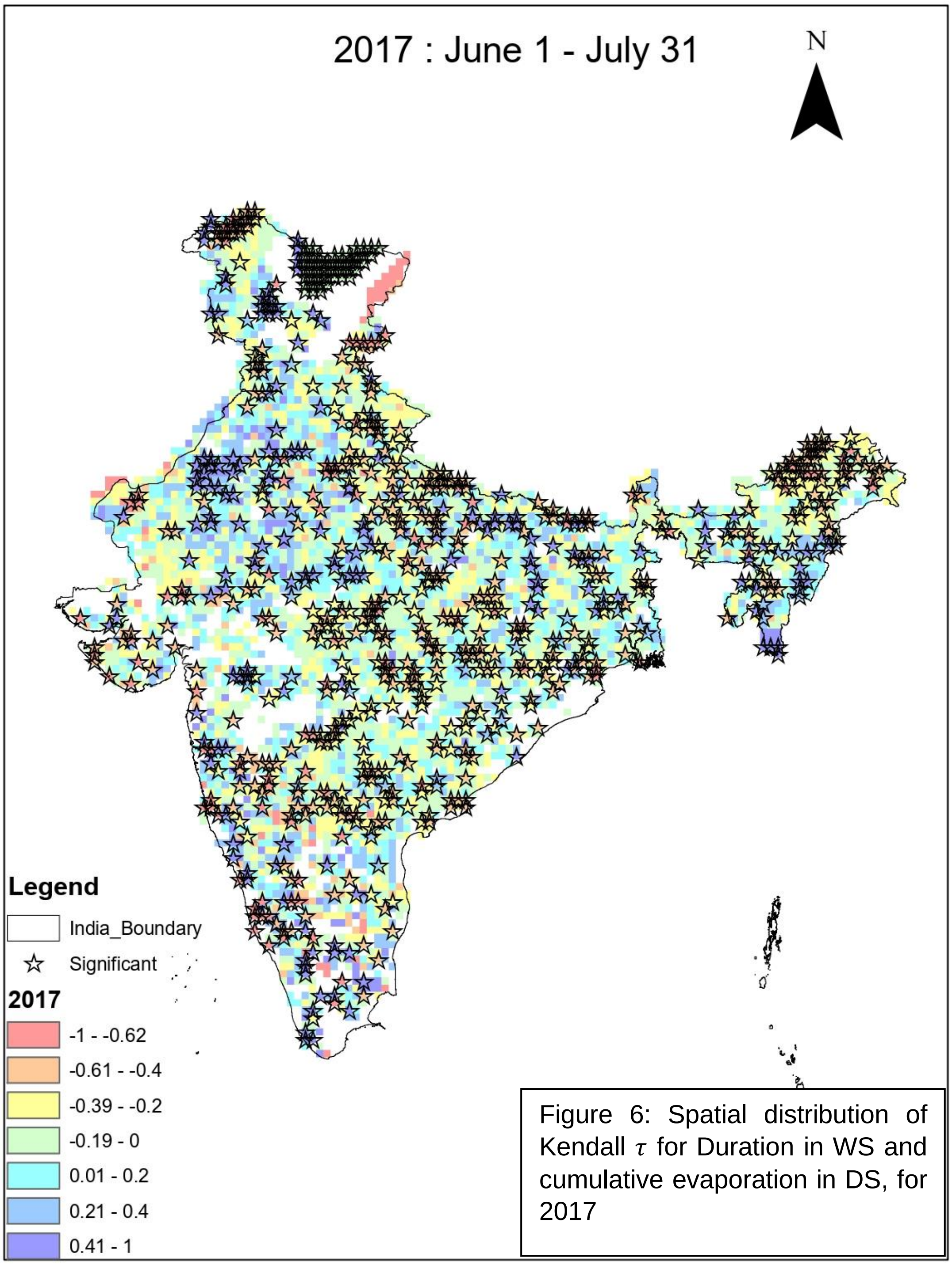


Figure 6: Spatial distribution of Kendall τ for Duration in WS and cumulative evaporation in DS, for 2017

Year 2017 was also a normal monsoon year but with deficient rainfall in the first 2 months (IMD Annual Report 2017). Thus the correlation over Northwestern India has decreased. Peninsular region also shows lesser positive, and few negatively correlated grids. Northeastern also shows lesser correlation corresponding to the rainfall deficiency. Western ghats show similar results.

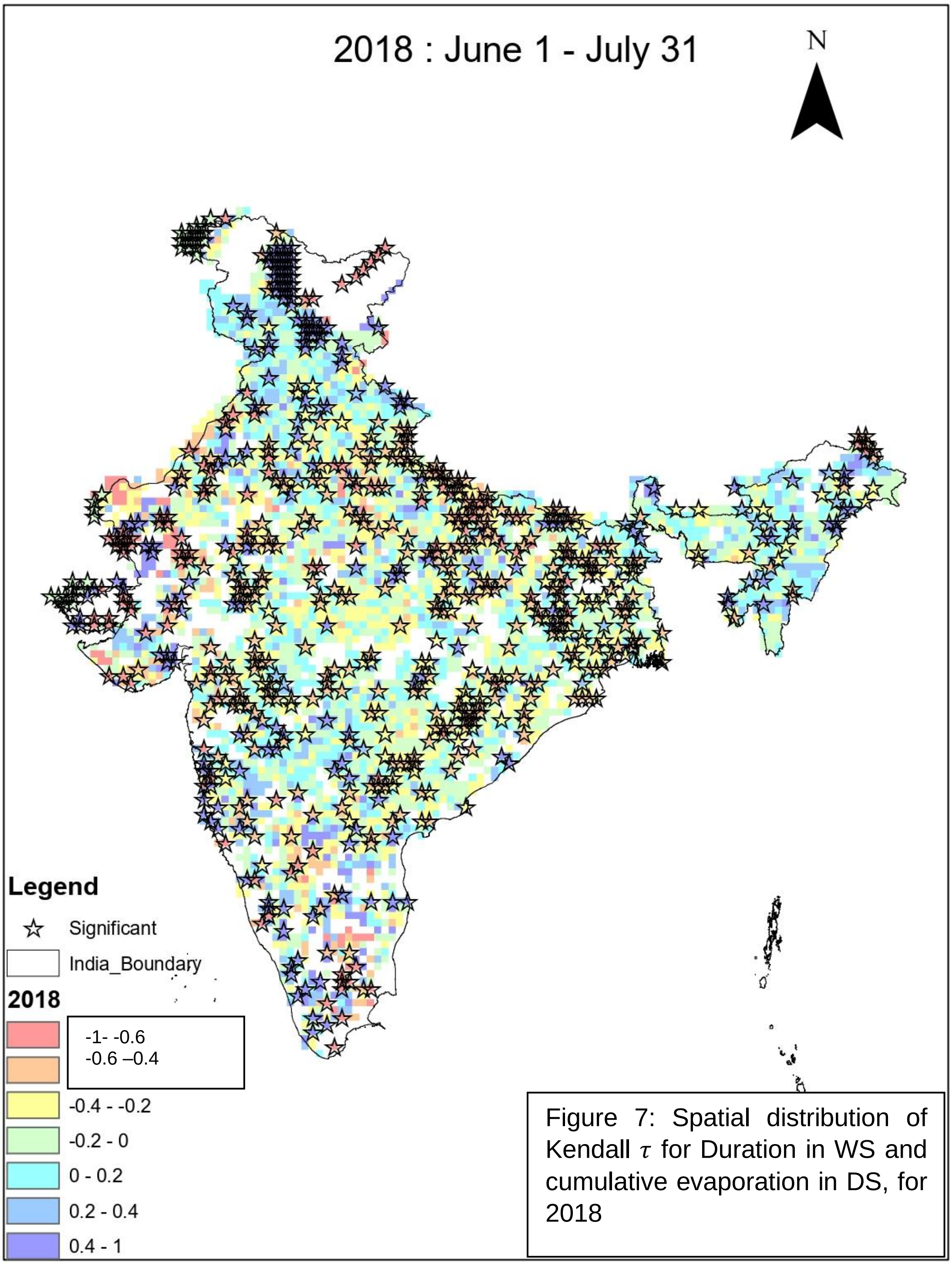


Figure 7: Spatial distribution of Kendall τ for Duration in WS and cumulative evaporation in DS, for 2018

2018 was a normal monsoon year (IMD Annual Report 2018), however we see a disruption of pattern observed across the years with higher negative or small correlation at almost all zones. It has been difficult to understand this phenomenon. Though northeastern and parts of peninsular India continue to show positive correlation.

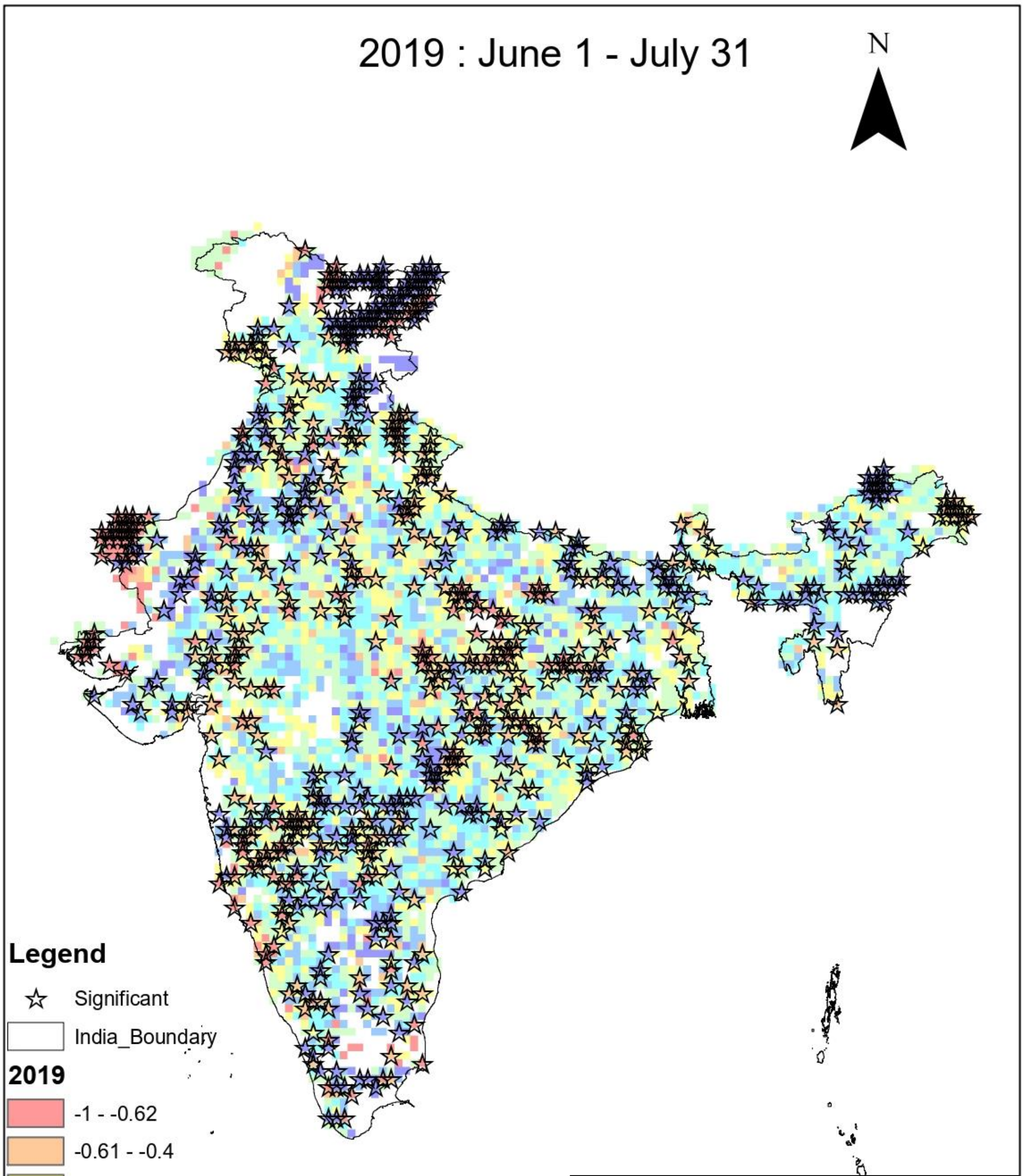


Figure 8: Spatial distribution of Kendall τ for Duration in WS and cumulative evaporation in DS, for 2019

2019 was excess rainfall year (IMD Annual Report 2019), but rainfall was normal for the first two months. Northwestern, northeastern, peninsular and regions show high correlation with significance. Central India shows negative correlations again. And parts of Gujrat and Rajasthan show significant negative correlation. While Ladakh shows a sharp division.

Conclusion: Correlation between rainfall & evaporation in wet and dry spell, respectively, for various zones of India were observed. Very specific variables were chosen for the analysis. It has been difficult to observe and relate the characteristics of land classification with the rainfall. However, it was seen that certain regions show similar response over the years. Especially northeastern, northwestern, central and peninsular India. This can indicate about some inherent land hydrology.

This statistical method was also able to identify the changed pattern for the drought year of 2015. And also show variation when rainfall was delayed, in year 2017. This approach suffered from lack of significant points, perhaps other statistical method can provide a clearer picture.

Limitations: Deliberate attempt was made to ignore any temperature or wind variables in the analysis to identify the land hydrology only. However, this led to inexplainable results such as year 2018 and many regions across all the years. Such as western ghats, eastern ghats, central eastern India and Ladakh and Karakoram ranges. Since these areas have high wind activity during June to July.

Temperature gradient across wet spell and dry spell would also play an important part but was ignored. Perhaps it can explain the negative correlations in neighborhood of certain positive correlations in peninsular India. Other geophysical phenomena like cloud cover, intensity of rainfall and land hydrology like surface runoff were also not considered.

Future: The relation can be investigated in August till mid-October months. Further month wise relation can also be looked into. Also, a similar analysis can be carried out for summer months. The reverse relationship i.e., of wet spell to dry spell can also be investigated.

Acknowledgements: Poornima Chandra Lekha Posa and Sai Kona Vikas, PhD, ICWaR, IISc Bangalore for their help in the code.

References:

1. Pathak A, Gosh S, et al 2011: Precipitation Recycling in the Indian Subcontinent during Summer Monsoon *Journal of Hydrometeorology*. https://doi.org/10.1175/JHM-D-13-0172.1
2. Das Bhowmik, R., Suchetana, B. & Lu, M. Shower effect of a rainfall onset on the heat accumulated during a preceding dry spell. *Sci Rep* 9, 7011 (2019). https://doi.org/10.1038/s41598-019-43437-7
3. Rajeevan, M., S. Gadgil, and J. Bhate, 2010: Active and break spells of Indian summer monsoon. J. *Earth. Syst. Sci*., 119, 229–247, http://dx.doi.org/10.1007/s12040-010-0019-4
4. Martens, B., Miralles, D.G., Lievens, H., van der Schalie, R., de Jeu, R.A.M., Fernández-Prieto, D., Beck, H.E., Dorigo, W.A. and Verhoest, N.E.C.: GLEAM v3: satellite-based land evaporation and root-zone soil moisture, Geoscientific Model Development, 10, 1903–1925, doi: 10.5194/gmd-10-1903-2017, 2017.
5. Miralles, D.G., Holmes, T.R.H., De Jeu, R.A.M., Gash, J.H., Meesters, A.G.C.A., Dolman, A.J.: Global land-surface evaporation estimated from

satellite-based observations, Hydrology and Earth System Sciences, 15, 453–469, doi: 10.5194/hess-15-453-2011, 2011.

6. IMD Annual Reports https://metnet.imd.gov.in/phps/publications_imdarep.php