Check for updates

Journal of Climate Change, Vol. 5, No. 1 (2019), pp. 33-40.
DOI 10.3233/JCC190004

Extreme Climate Event Footprint at Delhi, India: A Comparison of Last One Decade Meteorological Conditions

Shyam Ranjan[1], AL. Ramanathan[1*] and Virendra Bahadur Singh[2]

[1]School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India
[2]Department of Geology, University of Delhi, New Delhi, India
✉ alrjnu@gmail.com

Received November 11, 2018; revised and accepted December 25, 2018

Abstract: Rapid urbanization and rise of greenhouse gaseous emission due to anthropogenic influences have increased the pressure on global climate to maintain its equilibrium. Anthropogenic influences have further increased the extreme events, i.e., heat wave, flash flood and cold wave event. Our results indicate that years 2012, 2015 and 2016 encountered with heat wave event while the year 2013 recorded the highest precipitation which is coinciding with the well known flash flood event in northern India (Uttarakhand) where intense precipitation with cloud burst occurred. Correlation and wavelet coherence analysis was performed among temperature (T), relative humidity (RH), wind speed (WS), precipitation (ppt), potential evapotranspiration (PET) and actual evapotranspiration (AET). PET shows strong association with T during the heatwave event while AET exhibits the strong association during the flash flood event. T and RH show the time lag at averaged monthly scale where T attains its peak during the summer time while RH attains its peak during the monsoon time. The highest coefficient of variation (COV) shown by ppt is due to its dependency on Indian Summer Monsoon (ISM) during the monsoon time. We have further analysed the monthly amplitudinal variation of all parameters in order to observe the seasonality. Furthermore, wavelet coherence analysis was also performed to see the dependency among all parameters at high temporal scale.

Key words: Extreme event; Heatwave; Flash flood.

Introduction

Rapid urbanization and increased pressure of population lead to an increase in demand and supply chain resulting in rapid industrialization. Such kind of development comes at the expanse of greenhouse gaseous emission which is threatening the global climate through the anomalous extreme events, i.e., heat wave event, flash flood event due to sudden intense and extreme precipitation, cold wave event, etc. India is encountering frequent heat wave event (Mishra et al., 2015) which is severely affecting the human population. According to India Meteorological Department (IMD, http://imd.gov.in/section/nhac/termglossary.pdf), heatwave need not be considered till the maximum temperature of a station reaches at least 40° C for plains and at least 30° C for hilly region. The intensity of heat wave further can be increased due to the anthropogenic emissions (Easterling, 2000; Meehl, 2004; Schär et al., 2004). Studies suggest a further increase of the heat wave frequencies in the future climate scenario (Jones et al., 2007; Lau and Nath, 2014; Schär, 2016). Another consequence of global climate change is intense and extreme precipitation which resulted into the flash flood

*Corresponding Author

events which further intensified in the urban areas due to increase in the cementing of land surface to meet the population demand.

Cloudburst is a sudden aggressive rainstorm due to the rapid convective lifting of moist air mass under the conditions of steep orography and thermodynamic instability, resulting into the intense rainfall in a shorter time duration reaching the rainfall intensity more than 100 mm/hr. This intense rainfall together with cloud burst brings the massive destruction especially in the hilly areas where it increases its destructive force by the inclusion of landslides and boulder movement along with shooting velocity of moving water. Such kind of extreme events is important to study especially in the urban areas i.e. Delhi, where millions of population reside. Delhi shows semi-arid climatic conditions with a clear contrast in the winter, summer and monsoon seasons. The major contribution of precipitation is from the Indian summer monsoon (ISM) depression, which is an important synoptic scale tropical disturbances during June to September (Sikka, 1977) over India. In this paper, we have focused our study on to see the last decade's meteorological conditions and identifying the extreme events through the meteorological parameter as well as through the calculated potential evapotranspiration and actual evapotranspiration.

Study Area and Methodology

The study area (Figure 1) covered an area of 1483 km^2 and located 76.84E, 28.41N by 77.35E, 28.88N coordinates. Delhi comprises nine districts and together with adjoining districts forms an integral part of the National Capital Region (NCR). As per the Census 2011, Delhi has a population of 1.68 crores, which has an increase of 0.29 crore from 2001 census. As per census 2011, the total Delhi population is 16,787,941 of which sex ratio of male and female are 8,987,326 and 7,800,615 respectively. The location of Delhi is unique as it is situated in between the Himalayas (in the north), Aravallis (in the south) and the river Yamuna in the eastern part. The city elevation ranges in between the 200 to 300 m. Delhi experiences hot and dry summers where summertime temperature easily reaches above 40° C. Delhi also receives fairly in the months of December and January while maximum precipitation is through the Indian summer monsoon. Precipitation in the winter time is mainly due to the western disturbances which become further stronger toward the northwestern Himalayan regions.

Figure 1: Google Earth image showing the location of Delhi (encircled with red line).

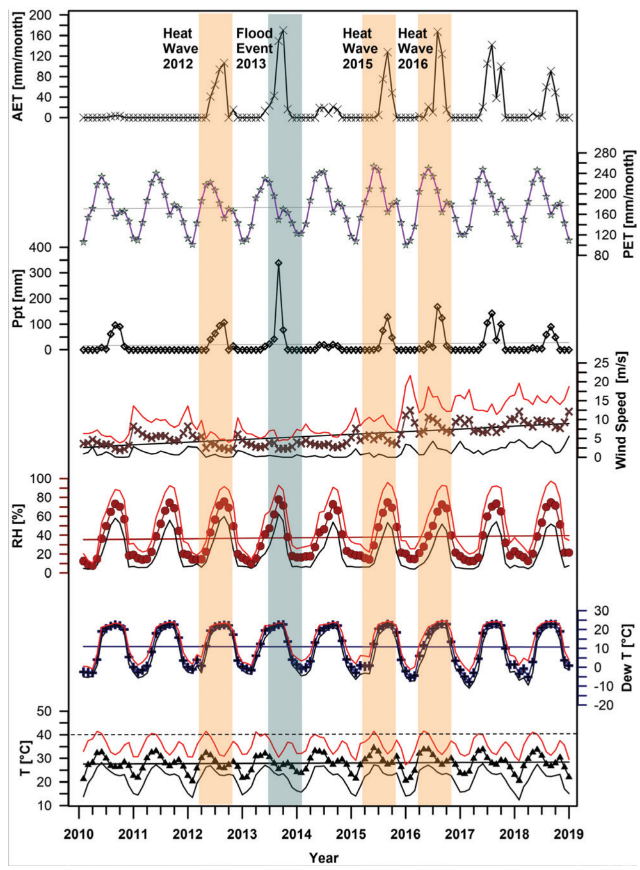

Figure 2: The monthly variation of all parameters where extreme heat wave events in 2012, 2015 and 2016 are highlighted in orange and flash flood events are highlighted with shade colour. Minimum and maximum of T, DT, RH, wind speed are shown in black and red colour respectively. Precipitation value is the cumulative sum.

One decade (2010-2018) meteorological parameters namely, average, maximum, minimum of temperature (T), relative humidity (RH), wind speed (WS), dew point temperature (DT), and atmospheric pressure (P) are obtained from the Weather Underground web (https://www.wunderground.com/history/) while potential evapotranspiration (PET) and actual evapotranspiration (AET) are calculated by using the Thornthwaite Method (Thornthwaite, 1948).

According to this method,

PET (Potential Evapotranspiration) = 16.2 $df\,[10T^{a/I}]^{a}$,

where df = no of sunlight hours in a month/360 and it depends on latitude, T = mean monthly temperature, a (location dependent coefficient) = $6.75 \times 10E\text{-}9\, I^3 - 7.71 \times 10E\text{-}6\, I^2 + 1.179 \times 10E\text{-}2\, I + 0.492$ and I = heat Index.

Based on the PET, AET (actual evapotranspiration) is calculated.

Results and Discussion

Meteorological Conditions of Last One Decade

The highest and lowest monthly mean temperature (Figure 2) of 40.5° C and 14.4° C was observed in the months of April (pre-monsoon) and January (winter season), respectively while relative humidity (hereafter, RH which is expressed % as, the ratio of water vapour amount in the air relative to the water vapour amount needed for saturation at a given temperature) shows the highest and lowest value of 62.8% and 5.7% in August and January, respectively. Delhi receives maximum rainfall in the month of August and experiences cold and dry weather condition in the month of January. The dew point temperature (hereafter, DT), wind speed and atmospheric pressure exhibits the monthly mean of 10.9° C (ranges from 14.0° C to 8.0° C), 5.75 m/s (ranged from 1.37 mph to 5.75 mph) and 29.8 (Hg) (ranged from (29.7 Hg to 29.8 Hg), respectively, while the mean of PET (ranged from 227 to 109 mm/month) and AET are 18.96 mm/month, respectively.

The maximum AET value observed in August (73.4 mm/month) which is in line with the maximum rainfall in August month dominated by ISM. The last decade annual variations in the meteorological parameters show that the year 2016 received the highest average T of 28.7°C while the year 2012 received the lowest of 27.1° C, respectively. In the case of RH, the year 2018 and 2010 exhibit the highest and lowest averaged RH of 39.41% and 36.18%, respectively. The maximum cumulative precipitation of 497 mm was recorded in the year 2013 which is in line with the 2013 massive flash flood event in Uttarakhand, North India. The highest value of PET and AET is in the years 2016 and 2013 respectively. The coefficient of variation (COV) is highest for AET while atmospheric pressure shows the lowest COV. The highest COV shown by AET could be due to the high variability in the precipitation amount in different seasons.

Seasonal Variations and Trend Analysis

Delhi can be characterized by four different seasons, namely winter (Jan and Feb.), Premonsoon (March to May), Monsoon (June to September) and Post-monsoon (Oct. to Dec.) based on the meteorological conditions. Summer season exhibits the highest average T and PET while winter exhibits the lowest value (Figure 3). The calculated PET through Thornthwaite Model is mainly T dependent and thus shows similar behaviour. The highest precipitation received during monsoon time where RH also shows an increasing value due to the increasing amount of atmospheric moisture. The averaged wind speed in the monsoon season is lower compared to the rest of the seasons while atm. pressure remains the same throughout all seasons. The AET shows the highest value in the monsoon while lowest in the winter time. Among all parameters, DT and precipitation show the highest COV while atm. pressure (P) remains the lowest one. The T and RH exhibit (Figure 4) a time lag phase where T attains its peak during the summertime while RH attains its peak during the monsoon time. Wind speed is relatively higher in the winter time while precipitation shows its peak during the monsoon.

PET and AET also exhibit the time lag as PET attains its maximum during the summertime while AET attains its peak during the monsoon time which could be understood with the fact that the PET shows the maximum amount of water vapour that atmosphere can remove from the plant and soil surface assuming no control on water supply while AET explains the amount of water actually evaporated from the soil and plant surface. The annual trend analysis (from 2010 to 2018) of T, DT, RH, WS, precipitation, PE and AES shows an increasing trend of 0.87° C, –1.32° C, 1.02%, 0.63 mph, 0.04 mm/yr, 0.32 mm/yr and 0.29 mm/yr, respectively followed by the regression coefficient of 0.33, 0.23, 0.10, 0.63, 0.04, 0.32 and 0.29 respectively.

Correlation Analysis

The correlation analysis (Figure 5) performed among all parameters at 95% confidence interval ($p < 0.05$)

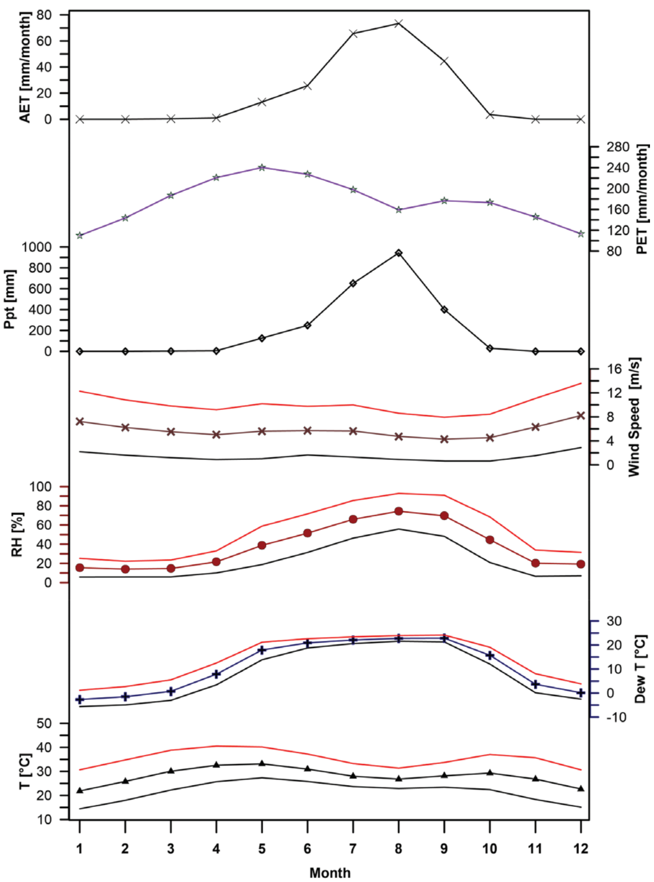

Figure 3: The averaged (mean of each season during 2010-2018) monthly variation of all parameters. Minimum and maximum of T, DT, RH, wind speed are shown in black and red colour respectively. Precipitation value is the cumulative sum.

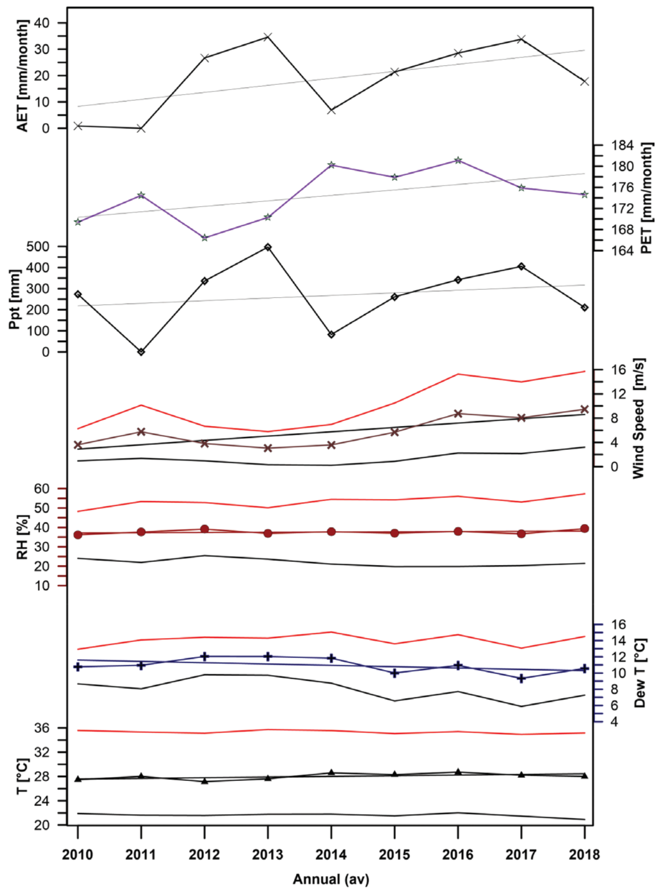

Figure 4: The annual variation with trend line (2010-2018) of all parameters. Minimum and maximum of T, DT, RH, wind speed are shown in black and red colour respectively. Precipitation value is the cumulative sum.

shows that the T (T_max, T_av, T_min,) has a strong association with PET while the correlation with wind speed is rather weak. No significant correlation was observed among T and rest of the parameters. The DT (Dew_max, Dew_av, Dew_min) shows significant strong anti-correlation only with the RH (RH_max, RH_av, RH_min) while the positive correlation with PET. The correlation between DT and AET is only visible in Dew_max and Dew_av, respectively. In the case of wind speed, it shows the anti-correlation with T (T_av, and T min) and RH (RH_max, RH_av, RH_min) and weak correlation with PET. No significant correlations were observed among wind speed, AET, and ppt, respectively. The correlation of ppt is only visible with DT (Dew_max, Dew_av, Dew_min) and RH (RH_max, RH_av, RH_min), respectively.

The observed correlation analysis among all parameters shows the role of multiple factors for climatic control of Delhi including: (1) influence of

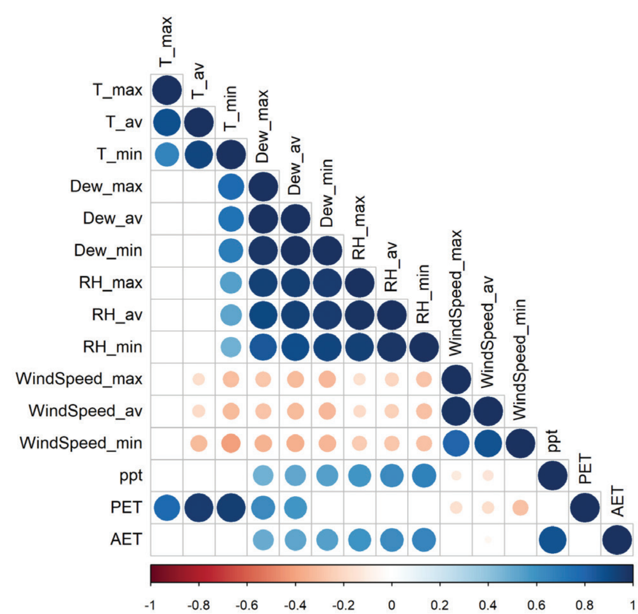

Figure 5: The correlation analysis among all parameters. Positive and negative correlations are shown in blue and red colour respectively. The insignificant correlation (*p* < 0.05) are left blank.

synoptic scale ISM disturbances in the monsoon time, (2) breaking of active monsoon period, (3) influence of western disturbances during the winter time, (4) local micro-meteorological effects and anthropogenic effect (i.e., Delhi has heavy load of vehicular emission which inject the greenhouse gases as well as particulate matters in the local atmosphere which further offset the meteorological conditions especially T and RH) and (5) influence of hot and dry wind from the western part of India.

Wavelet-Coherence Analysis

In order to understand in detail about the association among meteorological parameters and the calculated PET and AET, wavelet coherence analysis (Figure 6) was performed. Such kind of analysis provides the detailed information of coherency which further helps to understand the association among different parameters during the anomalous events, i.e., heat wave event, flood event, cold wave event, etc. The coherence between RH and AET shows the strong dependence throughout the year at the one-year frequency. Interestingly, there is also strong dependency at 0.25 to 0.50 period (which corresponds to the three to six months) in the year 2012 and during 2015 which could be due to the well-known heatwave event in 2012 and 2015 (Mishra et al., 2017). The year 2016, which was also encountered with the heat wave, also shows strong dependency at 6-month period. In the case of AET and PET, both show strong dependency at one year period whereas the coherency between wind speed and PET shows the correlation at 0.50 periods from 2012-2016, respectively. RH v PET and ppt vs. AET show strong dependency throughout the year while T vs. AET shows the dependency only at one year period from 2012-2016. Interestingly, ppt vs. AET shows the strong dependency at all period which further indicates their interdependent relationship whereas ppt vs. RH plot (Figure 6) also exhibits the correlation at 0.25 (three months) in the year 2013 which is a coincidence with the 2013 flash flood event in Uttarakhand with.

Extreme Events

Extreme events, i.e., heat wave are becoming more common in many parts of the world due to which highly populated areas, i.e., urban cities are under threat (Christidis et al., 2015; Mishra et al., 2015; Panda et al., 2017; Sun et al., 2014). Extreme precipitation and cloud burst especially at hilly area lead to the flash flood event which heavily damages the human life (Das, 2013). Based on the meteorological parameters, PET and AET, our results indicate (Figure 2 and Figure 6) the well-known heat wave events of 2012, 2015 and 2016. The Year 2013 received the highest amount of precipitation which is a coincidence with the 2013 flash flood event in Uttarakhand where extreme rainfall with cloud burst occurred. It has been documented that the severity of heat wave in 2012 was more intense, but the death number was more in 2015 (Mishra et al., 2017). An increasing number of heat wave events is indication of global climate change (Mishra et al., 2015; Mishra et al., 2017) which can potentially increase due to anthropogenic influence on urban areas by deforestation, an increasing number of air conditioner, heat exhauster, and vehicular emission. Further, in-depth investigations are required to understand the extreme events and its early prediction to control the severe damage to human life.

Conclusion

We have investigated the last decade's meteorological parameters and used the Thornthwaite model to calculate the PET and AET by using the temperature and precipitation data. Based on our observation, we delineated the heat wave event which can be further evidenced through the AET results. The highest AET observed in 2013 is a coincidence with the 2013 flash flood event in north India where intense rainfall occurred. This can be further evidenced through the wavelet coherence plot where it shows strong association among parameters during the extreme heat wave and flash flood event. Precipitation shows the highest COV which is due to the characteristics of the study location which lies in the semi-arid region where ISM contributes the maximum precipitation amount in the monsoon season. Our correlation and coherence analysis indicate that high COV in precipitation at Delhi is controlled by multi-factors including large synoptic scale ISM in monsoon time and western disturbances in the winter time. Further investigation would be needed to understand the processes governing the extreme event and its magnitude in urban areas with increasing population stress and changing the climate.

Acknowledgements

Author has given sincere thanks to DST-SERB (SR/FTP/ES-134/2014) for funding support.

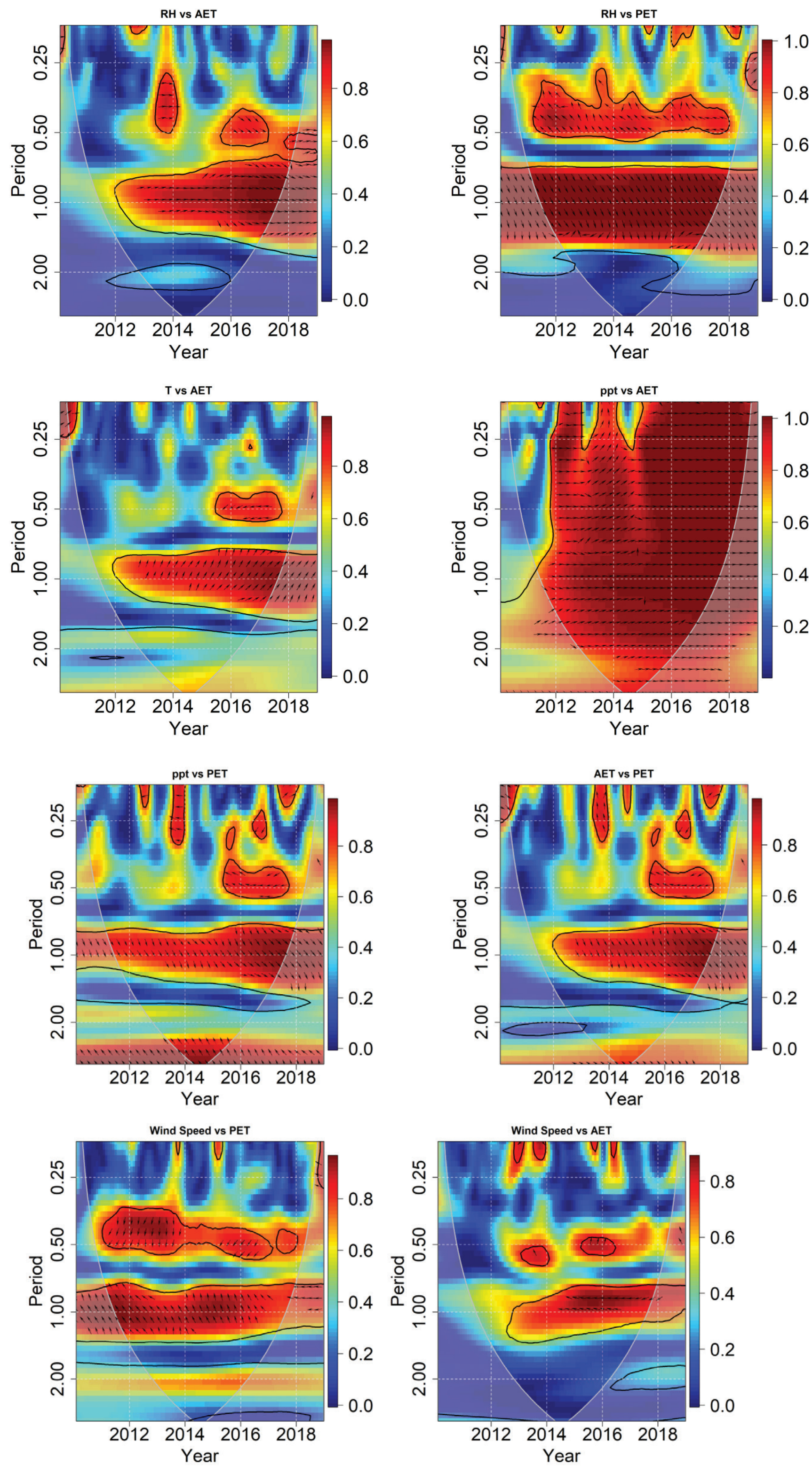

Figure 6: The wavelet coherence analysis among all parameters. Time (year) is displayed on the horizontal axis, while the vertical axis shows the frequency (the period in years). Warmer colours (red) represent regions with significant interrelation, while colder colours (blue) signify lower dependence between the series. The colour under the cone of influence represents the regression coefficient value. The blob (black encircle) represents the 95% confidence interval ($p < 0.05$).

Table 1: Statistical summary of meteorological parameters at annual scale (year 2010-2018). Precipitation value is the cumulative annual sum

	T (° C) max	*T (° C) avg*	*T (° C) min*	*Dew point (° C) max*	*Dew point (° C) avg*	*Dew point (° C) min*	*RH (%) max*	*RH (%) avg*	*RH (%) min*	*Wind speed (mph) max*	*Wind speed (mph) avg*	*Wind speed (mph) min*	*Pressure (Hg) max*	*Pressure (Hg) avg*	*Pressure (Hg) min*	*Precipitation (mm/Year)*	*PET (mm/ yr)*	*AET (mm/ yr)*
Average	35.32	28.01	21.62	14.09	10.95	8.05	53.30	37.64	21.97	10.14	5.76	1.38	29.93	29.85	29.77	267.69 (C. Sum)	174.49	18.96
Mean	35.32	28.01	21.62	14.31	10.95	8.06	53.32	37.65	21.50	10.14	5.69	0.97	29.93	29.85	29.78	273.56 (C. Sum)	174.63	21.36
Min	34.93	27.15	20.92	12.94	9.35	5.88	48.29	36.19	19.78	5.79	3.06	0.23	29.80	29.76	29.73	0.00	166.42	0.00
Max	35.73	28.72	22.02	15.06	12.05	9.79	57.33	39.41	25.49	15.70	9.46	3.23	30.00	29.90	29.80	497.08	181.12	34.62
Stdev	0.27	0.52	0.32	0.73	0.92	1.34	2.78	1.09	2.03	4.00	2.46	0.99	0.07	0.04	0.02	154.64	4.99	13.48
COV	0.76	1.86	1.48	5.20	8.45	16.66	5.21	2.90	9.23	39.46	42.71	71.73	0.23	0.14	0.07	57.77	2.86	71.11

References

Christidis, N., Jones, G.S. and Stott, P.A., 2015. Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nature Climate Change*, **5(1):** 46–50. DOI: 10.1038/nclimate2468

Das, P.K., 2013. The Himalayan Tsunami—Cloudburst, flash flood & death Toll: A geographical postmortem. *IOSR Journal of Environmental Science, Toxicology And Food Technology*, **7(2):** 33–45. DOI: 10.9790/2402-0723345

Easterling, D.R., 2000. Climate extremes: Observations, modeling and impacts. *Science*, **289(5487):** 2068–2074. DOI: 10.1126/science.289.5487.2068

Jones, A., Thomson, D., Hort, M. and Devenish, B., 2007. The U.K. met office's next-generation atmospheric dispersion model, NAME III. *Air Pollution Modeling and Its Application*, **XVII:** 580–589. DOI: 10.1007/978-0-387-68854-1_62

Lau, N.-C. and Nath, M.J., 2014. Model simulation and projection of european heat waves in present-day and future climates. *Journal of Climate*, **27(10):** 3713–3730. DOI: 10.1175/jcli-d-13-00284.1

Meehl, G.A., 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, **305(5686):** 994–997. DOI: 10.1126/science.1098704

Mishra, V., Ganguly, A.R., Nijssen, B. and Lettenmaier, D.P., 2015. Changes in observed climate extremes in global urban areas. *Environmental Research Letters*, **10(2):** 24005. DOI: 10.1088/1748-9326/10/2/024005

Mishra, V., Mukherjee, S., Kumar, R. and Stone, D.A., 2017. Heatwave exposure in India in current, 1.5 °C, and 2.0 °C worlds. *Environmental Research Letters*, **12(12):** 124012. DOI: 10.1088/1748-9326/aa9388

Panda, D.K., AghaKouchak, A. and Ambast, S.K., 2017. Increasing heat waves and warm spells in India observed from a multi aspect framework. *Journal of Geophysical Research: Atmospheres*, **122(7):** 3837–3858. DOI: 10.1002/2016JD026292

Schär, C., 2016. Climate extremes: The worst heat waves to come. *Nature Climate Change*. DOI: 10.1038/nclimate2864

Schär, C., Vidale, P.L., Lüthi, D., Frei, C., Häberli, C., Liniger, M.A. and Appenzeller, C., 2004. The role of increasing temperature variability in European summer heatwaves. *Nature*, **427(6972):** 332–336. DOI: 10.1038/nature02300

Sikka, D.R., 1977. Some aspects of the life history, structure and movement of monsoon depressions. *Pure and Applied Geophysics (PAGEOPH)*, **115(5–6):** 1501–1529. DOI: 10.1007/BF00874421

Sun, Y., Zhang, X., Zwiers, F.W., Song, L., Wan, H., Hu, T., Yin, H. and Ren, G., 2014. The rapid increase in the risk of extreme summer heat in Eastern China. *Nature Climate Change*. DOI: 10.1038/nclimate2410

Thornthwaite, C.W., 1948. An Approach toward a Rational Classification of Climate. *Geographical Review*. DOI: 10.2307/210739