Determination of ETCCDI climate change indices in Kabini basin, India

Rudra Ramakrishnan [1], Sanat Nalini Sahoo [2] and Nathi Ajay Chandra [3]

[1] M.Tech. Scholar, Department of Civil Engineering, NIT Rourkela, Odisha – 769008, India; [2] Assistant Professor, Department of Civil Engineering, NIT Rourkela, Odisha – 769008, India; [3] PhD. Research Scholar, Department of Civil Engineering, NIT Rourkela, Odisha – 769008, India. Email: ramakrishnan.rudra@gmail.com, sanatnalinisahoo@gmail.com

Abstract

In recent decades, various natural calamities and climatic events, with ever-increasing frequency and intensity, have been observed. Researchers across the globe believe that any further variation in the severity of extreme climate measures, would result in profound effects on society and nature, thus making it imperative for us to analyse these events and their causes. However, there is very limited knowledge about the trends of these events caused by variations in precipitation and temperatures. The Expert Team on Climate Change Detection and Indices (ETCCDI) has developed a set of 27 extreme climate indices for precipitation and temperatures, by analysing which a deeper trend analysis is possible, so as to better assess the possibilities of the future. This study estimates the ETCCDI indices and trend analysis in Kabini basin. The climate for the period 2015 - 2100 is projected, based on the Coupled Model Intercomparison Project 6 (CMIP6) using the Global Climate Model (GCM), namely ACCESS-CM2 model, under two SSP scenarios (SSP2-4.5 and SSP5-8.5). This study has used RClimDex (v 1.9) software to calculate various ETCCDI Indices. The precipitation extremes indicate that the ever-increasing peak intensity will continue to increase with a narrowing time base, while the temperature indices show that there will be a growing warm spell duration coupled with a climbing maximum daily temperature. Based on these findings, policies and action initiatives may be formulated to mitigate potential risks, and also to minimise the possibility of negative climate change events.

Figure: 5 **References: 19** **Tables: 2**

KEY WORDS: *Climate change, ETCCDI, Extreme climate, Indices, RClimDex*

Introduction

In recent decades, there has been a rapid growth in the number of extreme climate events, commonly referred to as climate change. Climate change is predominantly associated with varying atmospheric water holding capacities, which increases the likelihood of extreme climate events and abnormal weather across the globe. This could cause high temperature fluctuations, heat or cold waves, droughts, or precipitation with extreme intensities causing floods, hails or cyclones (Hong Y 2018). The effects of temperature rise varyingly impacts the precipitation, and also holds a possibility of altered paths of water vapor transport in the hydrological cycle, leading to altered seasonal precipitation patterns (Cooley AK and Chang H 2021).

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 6th AR, 2020) shows that there is a 50% chance of reaching or exceeding 1.5 degrees C (2.7 degrees F) of warming within just the next two decades. If the IPCC scenario of carbon intensive pathway with very high greenhouse gas (GHG) emissions (SSP 5-8.5) is followed, although reported to be highly unlikely (Hausfather Z and Peters GP 2020), the global warming temperature might rise by 3.3 - 5.7 degrees C by the end of the century, owing to the tripling of the amount of present-day CO_2 emissions, which is in fact several times higher than the pre-industrial levels. The SSP 2-4.5 is termed as a likely scenario, given current governmental initiatives, with intermediate GHG emissions (Hausfather Z and Peters GP 2020) and the CO_2 emission level continuing as at present and reducing post 2050 accompanied by a global warming temperature of 2.1 – 3.5 degrees C. The disastrous impacts of climate change although widely known, will be unprecedented in intensity and will affect every region of the globe. With concerted effort, action can be taken in the 2020s to limit the further warming by the end of the century (IPCC 2021).

With the increased knowledge of climate change due to continuous research in this domain, a state-of-the-art Coupled Model Intercomparison Project, Phase 6 (CMIP6) (Eyring et al. 2016) has been developed, which includes models developed by various institutions across the globe, with higher spatial resolution and additional physical complexity in comparison to the models of the previous phases of the project. ACCESS-CM2 developed by Commonwealth Scientific and Industrial Research Organisation, Australian Research Council Centre of Excellence for Climate System Science (CSIRO-ARCCSS) is one such model developed. This model predicts the precipitation with greater accuracy, owing to the greater degree of accuracy of the global hydrological balance models (Daohua B 2020). The model has been used to model the climate data of the future up to the year 2100.

In order to shape potentially effective remedial measures, it is important to study the trends of the past as well as the projections for the future and draw critical insights.

Analysis of the high temporal resolution data will be tedious owing to the varied research and reporting methods across the globe. To improve the cooperation and communication of data and events, common metrics for measuring change in precipitation and temperature are needed (AK Cooley 2021).

Scientific communities across the globe have developed many indices to help overcome this hurdle. The World Meteorological Organization (WHO) Commission for Climatology (CCl) and Climate Variability and Predictability (CLIVAR) helped set up the Expert Team on Climate Change Detection and Indices (ETCCDI) project and also the Expert Team on Sector-specific Climate Indices (ET-SCI). There has been an international collaborative effort to develop, calculate and analyse a wide range of indices for uniform assessment of climate data across the globe (Karl TR 1999). The working group developed a set of 27 core indices based on precipitation and temperature data of a high temporal resolution of 1 day (Peterson TC 2005).

The indices are broadly classified as absolute threshold indices, percentile indices, duration indices and intensity indices among others (Rehana S *et.al.* 2022). They present absolute values like duration of events (for example the consecutive dry days (CDD) and consecutive wet days (CWD)), percentile threshold exceedance (for example the Warm days (TX90p)), probability of occurrence of given quantities and the intensity or persistence of extreme events (Zhang et al. 2011). Due to the complexity involved in the calculation of percentile-based indices which includes bootstrapping procedure to eliminate inhomogeneity, a computer-based calculation mechanism was required.

RClimDex is a R based software package developed by the National Climate Data Centre (NCDC) of National Oceanic and Atmospheric Association, USA (NOAA), and has been used by CCl/CLIVAR for studies on climate indices since the early 2000s. It has the ability to compute all the recommended 27 core indices along with a few indices based on user defined threshold (Zhang X and Yang F 2018).

Questions related to extremes of climate change affecting humans and natural systems, can be effectively and objectively answered with the help of the analysis of the indices derived from daily weather data (Zhang et al. 2011).

Study Area, Data and Methods

Study Area

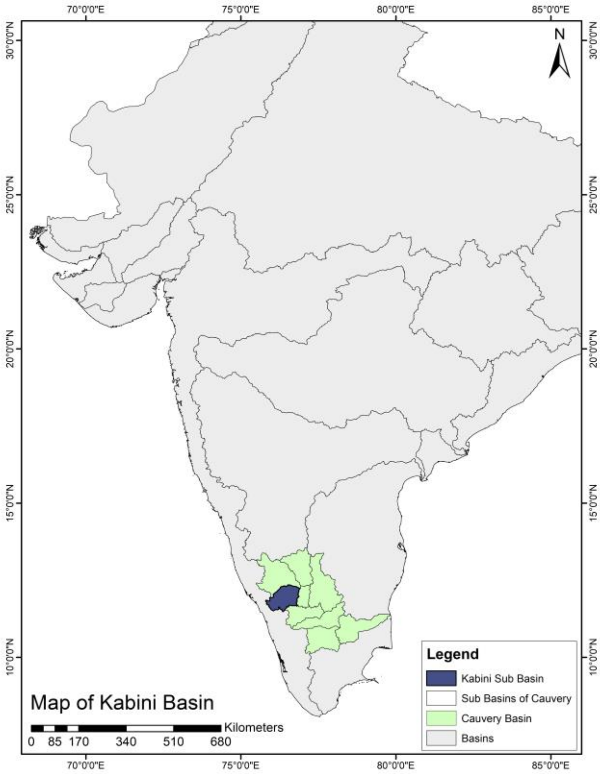

Fig. 1: Map showing the location of the Kabini River basin along with watershed basins of India

Kabini river is one of the major tributaries of the river Cauvery (Fig. 1) which flows through the southern parts of India. The Kabini river originates in Wayanad district of Kerala at an elevation of 2140 m above MSL and flows across the other locations. It passes through parts of southern states of Kerala, Karnataka and Tamil Nadu. The Kabini river basin occupying an area of about 7040 sq. km, lies between the north latitudes 11°45’ – 12°30’ and east longitudes 75°45’ – 77°00’ and has a general slope towards the south. The average annual rainfall of the basin is approximately 1470 mm. The basin houses the Kabini river, a 7^{th} order stream which is roughly 240 km in length, supplying water to over 10 million people in the areas surrounding the basin. The Kabini reservoir is the source of irrigation for around 40,000 hectares of agricultural land and provides around 80 MW of power (Nagaraju D and Papanna C 2009; Cauvery Basin Report 2014).

The river has a yearly water depletion rate of around 27% (1972 – 2013), while the drought risk stays low and the risk of floods is extremely high. Wayanad district has faced a serious drought in 2016 and 2017 as the Kabini went dry even after the monsoons. This dire situation is the main motivation behind this study. While knowing past events and analysing it may prove helpful, analysing the future climate prediction data will aid in taking corrective measures to avoid such scenarios in the future.

Extreme Climate Indices

Among the set of 27 core indices, 9 indices (Table 1) covering precipitation and temperature have been determined and analysed. These indices are chosen so as to be able to address a range of basic as well as extreme characteristics of precipitation and temperature events such as magnitude, duration, frequency and intensity (Dash S and Maity R 2019).

Table 1: List of ETCCDI climate indices calculated

ID	Indicator name	Units
CDD	Consecutive dry days	Days
R99p	Extreme wet days	mm
TX90p	Warm days	Days
WSDI	Warm spell duration indicator	Days

Table 2: Definitions of calculated ETCCDI climate indices

ID	Definitions
CDD	Maximum number of consecutive days with RR* < 1 mm
R99p	Total annual precipitation of days with rainfall more than the 99th percentile of RR*
TX90p	Percentage of days when TX** > 90th percentile
WSDI	Annual count of days with at least 6 consecutive days when TX** > 90th percentile

RR* - Daily precipitation, TX** - Maximum of daily temperature

Data

CMIP 6 datasets of the ACCESS CM2 GCM model for the period 2015 – 2100 was accessed from the World Climate Research Programme (WRCP) website (https://www.wcrp-climate.org). The GCM dataset was of coarse resolution of 1.25° latitude × 1.875° longitude (arc degrees) (Ahmed K *et. al.* 2020), which required regirdding to a very high spatial resolution of 0.25° longitude × 0.25° latitude (arc degrees) with the use of Climate Data Operator (CDO) software followed by Empirical Quantile Mapping (EQM) method of downscaling and bias correction (Tiwari AD 2022) using the SD-GCM software package. The output was in obtained in NetCDF format which required conversion into a readable csv format before being processed.

The climate data for the study area was extracted and brought to the required input format (year, month, day, precipitation, maximum temperature and minimum temperature), as required by the RClimDex software package (Zhang X and Yang F 2018).

Methods

ACCESS-CM2 datasets were regridded and bias corrected data was converted to csv format in the prescribed data format. The input data was loaded onto the RClimDex software package which was run on the R software.

The data must be quality controlled first before the calculation of indices, to check and replace all the missing and unreasonable data values with the default -99.9 value, and also to identify outliers beyond the default 3 σ of mean data for a particular day in a year. This is followed by the indices calculation which requires base period for index calculation (preferably it must be greater than 10 years so as to make sure the climatology of the study area does not change drastically), along with user-defined thresholds for precipitation and temperature, based on which the user defined extreme climate indices will be calculated (Zhang X and Yang F 2018).

Results

Considering GCM simulated annual daily temperature and precipitation data for an 85-year period (2015 – 2100) subdivided into 3 sub-periods – short-term (2015 – 2030), mid-term (2031 – 2050) and long-term (2051 – 2100), the ETCCDI indices as mentioned in Table 1 are calculated. The indices for the station points were calculated using the RClimDex software, basin averages for the selected set of indices were determined, and are presented below in the form of graphs along with trendlines.

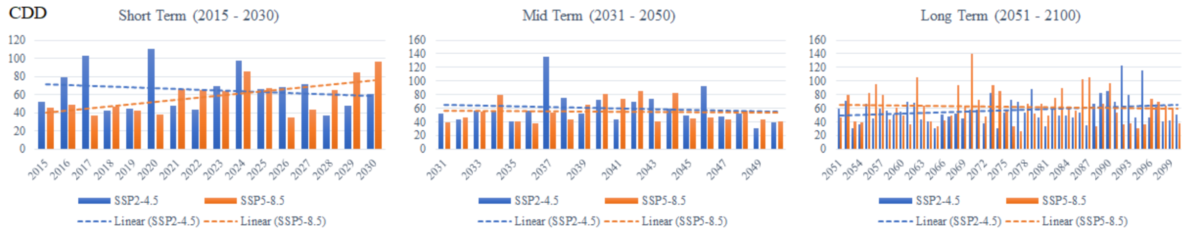

Fig. 2: Time series of extreme precipitation index indicating the consecutive dry days (CDD) for the 3 sub-periods

Fig. 2 shows the temporal variation in the number of consecutive dry days, and an extreme precipitation index which is indicative of the number of consecutive days with daily rainfall amount less than 1 mm. The averaged CDD value of the first scenario (SSP2-4.5) tends to reduce from around 65 days in the short-term period to about 60 days with a maximum duration of 135 days in the year 2037 in the mid-term period, before tending upwards in the later half of the century, although this period presents a lower average value of around 57 consecutive dry days. On the other hand, the scenario representing carbon intensive climate shows a different trend. The temporal variation increases in the short-term period from an initial average of around 40 days till the year 2030 with an averaged value of around 78 days. In the following two periods this reduces and stabilises at around 58 days till the end of the century.

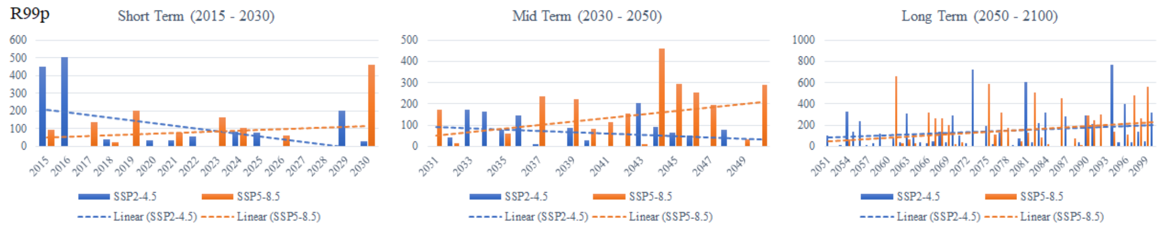

Fig. 3: Time series of extreme precipitation index indicating the extreme wet days (R99p) for the 3 sub-periods

The extreme wet days index (R99p) calculates the total amount of precipitation in a particular calendar year, taking into account the daily rainfall amount which is greater than the 99th – percentile threshold of all the daily precipitation amounts. It is evident from the graphs (Fig. 3) of SSP2-4.5, that the number of extreme wet days is declining in the first half of the century, from around 94 mm on average in 2015 – 2031 to about 61 mm in 2031 – 2050, before reversing the direction and climbing up to average of 143 mm owing to the highest value of 763 mm, indicating higher volumes of precipitation over the second half of the century. The SSP5-8.5 shows a different picture with ever increasing amounts of total rainfall crossing the 99th – percentile mark throughout the century. The short-term averages at around 83 mm while the mid-term average is 130 mm. the long-term average grows linearly to about 181 mm in the last 50 years of the century. Such extreme precipitation events lead to climatic effects like floods, leading to significant soil erosion and crop damage.

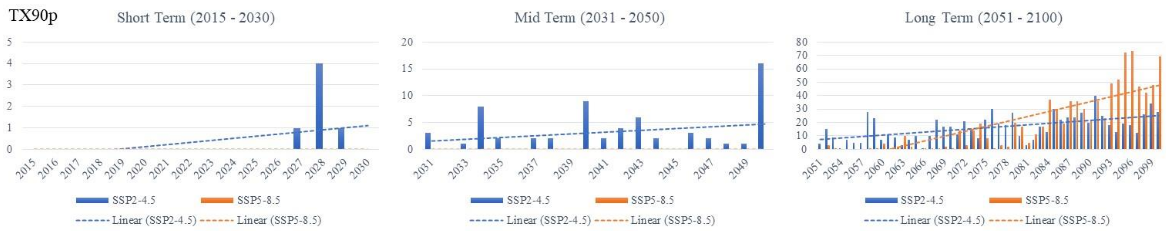

Fig. 4: Time series of extreme precipitation index indicating the warm days (TX90p) for the 3 sub-periods

The warm days index (TX90p) is the number of days in a calendar year with daily maximum temperatures breaching the 90th – percentile temperature. As seen from the graphs (Fig. 4), for the intermediate GHG emission scenario (SSP2-4.5) there is a likelihood of low number of warm days in the first half of this century, with negligible average of around 1.95 days above the 90th -percentile threshold, while there are no predicted warm days in this period if the carbon intensive pathway (SSP5-8.5) is followed. This is expected to change in the later part of the century, as seen in the graph representing the long-term period of 2051 – 2100, which shows an increase in both the pathways, with the carbon intensive one showing a more dramatic increase in the later years. Although the period average for the two scenarios is 16.24 days and 17.72 days and roughly equal to each other, the SSP2-4.5 scenario shows a maximum of only 40 days above the 90th – percentile threshold, while in the SSP5-8.5 scenario a much higher value of 73 days above the threshold can be expected.

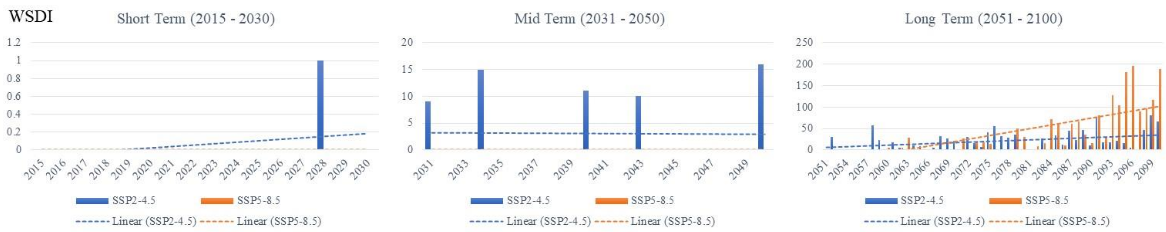

Fig. 5: Time series of extreme precipitation index indicating the warm spell duration index (WSDI) for the 3 sub-periods

The warm spell duration indicator (WSDI) indicates the annual count of days with a minimum of 6 consecutive days in a calendar year, centred on a 5-day window with daily maximum temperatures above the 90th percentile temperature. Fig. 5 clearly shows the difference in the impacts of the two SSP scenarios (SSP2-4.5 and SSP5-8.5). The SSP2-4.5 indicates the start of warmer periods from late 2020s which fairly remains stable up to the year 2050 with an average index value of 3.05. However, the long-term future (2051 – 2100) sees a sharp and more frequent spikes in the number of warmer days with the index averaging at 20.62 for the period. On the other hand, the index indicates 0 days of warm spell from 2015 to 2060. From the year 2060, there is an exponential increase in the index values with an average of 20.38 for the period of 2050 – 2100, with ever shortening gap between the consecutive years.

Conclusion

Four indices have been computed – two each for daily precipitation and temperatures, estimated for the future period of 85 years from 2015 – 2100 using ACCESS-CM2 GCM simulated climate data for the Kabini River basin, which after having been processed was brought to the prescribed format. Trends in the four indices were determined and analysed. In general, all the indices have shown an increasing trend over the years for both the SSP scenarios taken into consideration with the only difference being in the magnitude of variation between the two cases, except for the consecutive dry days (CDD).

CDD portrays a decreasing trendline for the highly likely scenario of SSP2-4.5 with an initial average value around 62 which decreases to around 57 days towards the end of the century. This trend is reversed in the carbon intensive pathway of SSP5-8.8 which starts at a lower average of 56 CDD which over the years climbs to a high of roughly 64 CDD. In the case of R99p, both the SSPs show a narrower gap with the averages being 57.5 and 63 mm respectively in the early years of the study period. This is seen to rise by the end of the century to around 172 mm and 188 mm for the two SSPs. From this we can gather that the rainfall quantity will surely rise over the years, however, the intensity will vary between the scenarios as the rainfall will be a lot more distributed and less intense if we follow the SSP2-4.5 pathway. However, the other pathway will witness a more quantity of rain in fewer number days, as inferred from the CDD count, indicating high intensity rainfall events, which will lead to events like flash floods, landslides and soil erosion, which will have an increased severity.

The precipitation indices may show a dangerous future if proper remedial measures are not taken, but the real implications of climate can be understood with better clarity when even the extreme temperature indices are taken into account. The warm days index (TX90p) and the warm spell duration indicator index (WSDI) used in this study help us understand about the impacts in greater detail. Following the path of intermediate carbon emissions, a very insignificant percentage of warm days can be expected till around the 2050s, after which there will be a visible increase in the percentage of warm days with an average of around 16 % of days beyond the 90th percentile. A similar, significant upward trend is observed in the WSDI index post 2050. Nevertheless, as the pathway emits relatively lower amounts of GHG gases, we witness a maximum of 81 days falling under the warm spell bracket. If the now unlikely scenario were to be followed the future would be a lot hotter and not just warm. Both the indices, TX90p as well as WSDI show the future in dire conditions in the last 2 decades of the century with the indices rising to an average which is roughly twice the value of the average for the long-term period of the study time.

In order to avoid severe consequences due to intense precipitation and warm or hot climate heading our way, appropriate actions need to be taken with great urgency. The world needs to gradually and pervasively shift towards a more sustainable path of inclusive development with environmental aspects in mind. Emphasis on economic growth needs to shift to a broader goal of human well-being, which can be achieved with an increasing commitment to achieve the goals by lowering the intensity of consumption of energy and resources.

References

[1] Ahmed K, Sachindra DA, Shamsuddin Shahid, Zafar Iqbal, Nadeem Nawaz, Najeebullah Khan, Multi-model ensemble predictions of precipitation and temperature using machine learning algorithms, *Atmospheric Research*, Volume 236, 2020, 104806, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2019.104806

[2] Cauvery Basin Report, 2014, Central Water Commission, Ministry of Water Resources.

[3] Cooley AK, Chang H, "Detecting change in precipitation indices using observed (1977–2016) and modeled future climate data in Portland, Oregon, USA". *Journal of Water and Climate Change* 1 June 2021; 12 (4): 1135–1153. doi: https://doi.org/10.2166/wcc.2020.043

[4] Daohua Bi, Dix Martin & Marsland, S. & O'Farrell, Siobhan & Sullivan, Arnold & Bodman, Roger & Law, Rachel & Harman, Ian & Jhan, Srbinovsky, & Rashid, Harun & Dobrohotoff, Peter & Chloe, Mackallah, & Hailin, Yan, & Tony, Hirst, & Savita, Abhishek & Dias, Fabio & Fiedler, R. &

Heerdegen, Aidan. (2020). Configuration and spin-up of ACCESS-CM2, the new generation Australian Community Climate and Earth System Simulator Coupled Model. *Journal of Southern Hemisphere Earth System Science*. https://doi.org/10.1071/ES19040

[5] Dash S, Maity R. Temporal evolution of precipitation-based climate change indices across India: contrast between pre- and post-1975 features. *Theor Appl Climatol* 138, 1667–1678 (2019). https://doi.org/10.1007/s00704-019-02923-8

[6] Eyring V, Bony S, Meehl GA, Senior CA, Stevens B, Stouffer RJ, and Taylor KE. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, *Geosci. Model Dev.*, 9, 1937–1958, 2016, https://doi.org/10.5194/gmd-9-1937-2016

[7] Hausfather Zeke and Peters Glen P. 2020. "Emissions – the 'business as usual' story is misleading". *Nature*. **577** (618–620). doi:10.1038/d41586-020-00177-3

[8] Hong Yin, Ying Sun, "Characteristics of extreme temperature and precipitation in China in 2017 based on ETCCDI indices", *Advances in Climate Change Research*, Volume 9, Issue 4, 2018, Pages 218-226, ISSN 1674-9278, https://doi.org/10.1016/j.accre.2019.01.001

[9] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896

[10] IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. In Press.

[11] Karl TR, N Nicholls, and A Ghazi, 1999: CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes: Workshop summary. *Climatic Change*, 42, 3-7.

[12] Nagaraju D and Papanna C, 2009, "Hydrogeochemical Studies of Kabini River Basin, Karnataka, India", *Nature Environment and Pollution Technology*, Vol. 8, No. 1, pp. 111-118, http://www.neptjournal.com/upload-images/NL-6-18-(18)B-1267-111-11.pdf

[13] Peterson TC, 2005: Climate Change Indices. WMO Bulletin, 54 (2), 83-86.

[14] Peterson TC, Folland C, Gruza G, Hogg W, Mokssit, Plummer N, Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998-2001. WMO, Rep. WCDMP-47, WMO-TD 1071, Geneve, Switzerland, 143pp.

[15] Rehana S, Yeleswarapu P, Basha G, et al. "Precipitation and temperature extremes and association with large-scale climate indices: An observational evidence over India". *J Earth Syst Sci* 131, 170 (2022). https://doi.org/10.1007/s12040-022-01911-3

[16] Tiwari AD, Parthasarathi M, and Vimal M. "Influence of Bias Correction of Meteorological and Streamflow Forecast on Hydrological Prediction in India", *Journal of Hydrometeorology* 23, 7 (2022): 1171-1192, https://doi.org/10.1175/JHM-D-20-0235.1

[17] Vondou DA, Guenang, GM, Djiotang TLA, Kamsu-Tamo PH, "Trends and Interannual Variability of Extreme Rainfall Indices over Cameroon. *Sustainability*, 2021, 13, 6803. https://doi.org/10.3390/su13126803

[18] Zhang X and Yang F, 2018, RClimDex (v 1.9) User Manual

[19] Zhang X, Alexander L, Hegerl GC, Jones P, Tank AK, Peterson TC, Trewin B and Zwiers FW. 2011, "Indices for monitoring changes in extremes based on daily temperature and precipitation data. *Wiley Interdisciplinary Reviews: Climate Change* 2 (6), 851–870. doi: 10.1002/wcc.147