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REGIONAL ASPECTS OF DEVIATIONS OF SOUTH-WEST MONSOON RAINFALL IN THE SEVEN SISTER STATES OF NORTH-EASTERN INDIA (1981-2021)

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ABSTRACT

The South-West Monsoon (SWM) rainfall season is a distinct climatic season for India. It holds immense climatic significance as well is the lifeline of the country in ways more than one. The months of June to September mark the advancement of monsoonal rainfall in the form of a marked rainy season for majority of the landscape of the country. The progression of SWM rainfall is observed in two flow systems - The Arabian Sea Branch and the Bay of Bengal Branch. In the current context, it is important to note that the North-eastern part of the country encounters the initial stage of the Bay of Bengal Branch which is also a mark of onset of monsoon in half of the country. Monsoonal rainfall has been exhibiting variations as a consequence of climate change and the study of average rainfall during SWM over a substantial period of time can help identify its behaviour. In this regard, the North-eastern part of the country offers a very important case to analyse owing to its geography and the fact that it has the record of highest rainfall in the world, besides being a region extremely rich in biodiversity. The current study is an examination of average SWM rainfall and its behaviour with regards to its trends and deviations in the Seven Sister states of the country from 1981-2021.Findings have indicated that there are mixed deviation trends of rainfall but a negative trend is becoming more pronounced in the last few years.

Keywords: *Deviations, India, North-Eastern States, Rainfall, South-West Monsoon.*

Introduction

The South-West Monsoon (SWM) rainfall is the lifeline of Indian economy and society in ways more than one (IMD, n.d.). The months of June - September mark this rainfall period (IMD, n.d.). SWM is an outcome of inter - connection between the realms of the Earth - air, water and biosphere as a whole in response to solar heating. The study of SWM rainfall can be done in two modes (Wang *et al.*, 2011). The first mode is of June, July, August and September rainfall (JJAS) minus December, January, February and March (DJFM) rainfall and is termed as the 'solstitial mode' and the second mode is defined as April-May (AM) minus October, November (ON) rainfall and is called the 'equinoctial-asymmetric mode' (Wang *et al.*, 2011). SWM is also called one of the two monsoons of India and on average is responsible for about 75% of the rainfall taking place in the country (IMD, n.d.). The second monsoon is the North-East Monsoon or winter monsoon, providing rainfall in the months of October to November (Chowdary *et al.*, 2021).

Observing the mechanism of SWM indicates that the moisture laden winds strike the Indian subcontinent at the southernmost tip of the Indian peninsula by the last week of May (Chowdary *et al.*, 2021; IMD, n.d.). The advancement of the South-West Monsoon Current (SWMC) (Vinayachandra *et al.*, 1999) takes place in two flows- the Arabian Sea Branch and the Bay of Bengal (BOB) Branch (Society, 2021). The BOB Branch is the eastward flow of SWMC which flows towards the east in south of India and turns around Sri Lanka and enters the BOB and advances further due to other forcing mechanisms (Vinayachandra *et al.*, 1999; Das *et al.*, 2018). The onset of SWM takes place with the Arabian Sea Branch striking the Kerala coast and the BOB Branch striking northeast India around the 1st of June (Rao *et al.*, 2008).

One of the specific characteristics of monsoonal rainfall is its significant variability in time and space (Wu *et al.*, 2012; Kumar *et al.*, 2013; Sinha *et al.*, 2018; IMD, n.d.). The North-eastern states of India offer a special case of studying the SWM rainfall in multiple ways as their geography provides them favourability as a region for highest rainfall in the world (Zahan *et al.*, 2021), they share international borders, have rich biodiversity yet a fragile ecosystem, and social instabilities (Das *et al.*, n.d.) along with unbridled flooding during this period every year (Sangomla, 2021). The region is distinct in nature owing to its geography and hydro-geomorphology (Oza & Kishtwal, 2014).

The examination conducted here is of SWM rainfall in the Seven Sister states of North-East India from 2011-2021 to observe the deviation of rainfall. Seven Sister states are a part of the eight states of the North-East Region of the country (NER) which includes the state of Sikkim also (Deka *et al.* 2015). For this purpose, the base time period of 1981-2021 is taken for observing these deviations in the geographically contiguous states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, and Nagaland.

Deviations in rainfall in the region indicate a spatio-temporal variability of a larger magnitude (Sangomla, 2021), as is observed in the Brahmaputra and Barak basins from 2001-2010 (Deka *et al.*, 2015). Studies on the aspect of deviations related to both, observations and modelling of SWM rainfall, indicate mixed results ranging from an increased dryness to an increased moisture content (Deka *et al.*, 2015; Goyal *et al.*, 2019; Guhathakurta, *et al.*, 2020a.; Zahan *et al.*, 2021; Chowdary *et al.*, 2021; Debbarma *et al.*, 2021).

Studies which have indicated an overall period of drying as becoming more pronounced in the region suggest that this is bound to have serious implications on the region's ecosystem (Mahanta *et al.*, 2012; Sangomla, 2021; Zahan *et al.*, 2021).

But here, pre-monsoon and post-monsoon rainfall has, however, shown an increase (Deka *et al.*, 2015). Geographically, it has also been detected that the further eastern part of the NER experiences a steeper decline in rainfall (Oza & Kishtwal, 2014). Studies have also indicated that a recent change in rainfall in North-east India is more pronounced as compared to the 1980s and 1990s in which drought is becoming pronounced (Parida & Oinam, 2015). The northeastern part of the country is described as being at a high vulnerability to 'global changes' and is also the least examined (Dash *et al.*, 2012; da Silva *et al.*, 2015). It is also forwarded that numerous studies are available on examining rainfall trends in India, its variability and its extremity for the past hundred years and more, but recent analysis are not available (Guhathakurta *et al.*, 2020b). Rainfall is the main precipitation type in this region (Guhathakurta *et al.*, 2020b) which is analysed here. All these aspects make the current study relevant.

Study Area

The present study examines the deviations in SWM rainfall in the Seven Sister states of India which are - Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura (Dash *et al.*, 2012). The study area is shown in **Figure 1**. Along with Sikkim, these eight states comprise of North-East India (NEI) (Dash *et al.*, 2012). With about 8% area of the country and about 2.1% of the country's population, the states are diverse in physiography and hydrogeology (Das *et al.*, 2016). There is diversity in population and ethnic background in these states with about 75% of the population being tribal (Das *et al.*, 2016). Besides, the states are extremely rich in biodiversity and are amongst the 'biodiversity hot spots' of the world (Das *et al.*, 2016). High hills, plateaux, plains and lush forests dominate the landscape (Sangomla, 2021). The mighty Brahmaputra river which is amongst the largest rivers of the world, flows through the region and with Barak river it forms a significant river basin in Assam (Ahmad & Lodrick, 2021). For states, Assam has uneven topography comprised of hills, plains and rivers (Assam, 2019); Arunachal Pradesh has a topography marked by plateaus and ridges with the Himalayan peaks to the east (Lodrick, 2019); Manipur is marked by a plain in the interior and uneven hills and narrow valleys in the outer parts (Manipur, 2021); Meghalaya's topographic features are marked by hills and plateaus (Raghavan & Lodrick, 2020); Mizoram has rolling hills, rivers and lakes as dominant topography (Mizoram, 2020); Nagaland's topography is dominated by hill ranges which are dissected (Nagaland, n.d.) and Tripura observes three specific zones as- hills, rolling plateau and plain (Lodrick, 2020). Besides these specific features, whole of the region is rich hydrologically as well with a number of rivers, their tributaries, streams, marshes and lakes (Bhaduri n.d.; SANDRP n.d.).

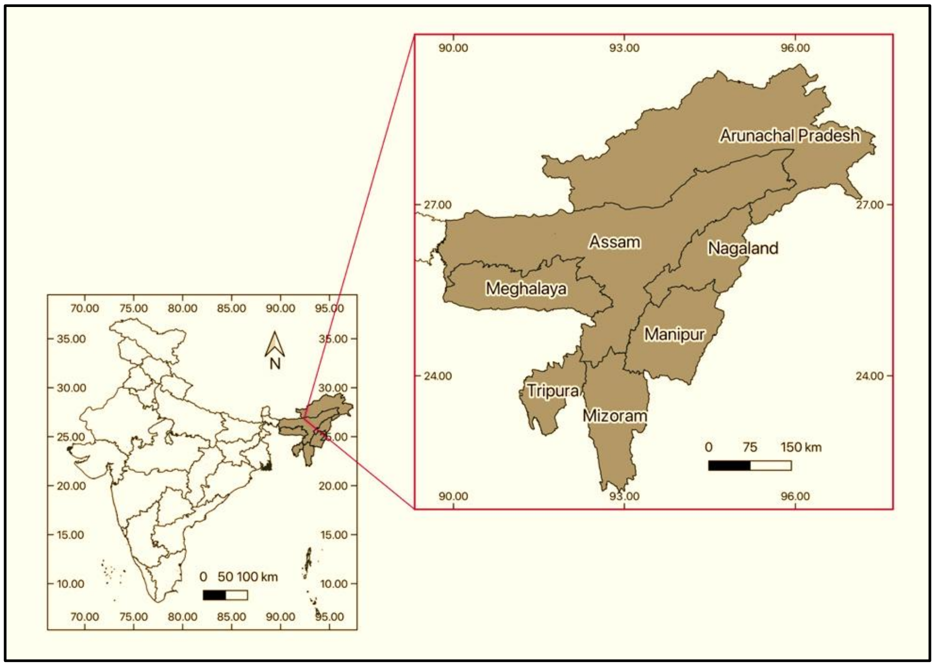

Figure 1: Location of Seven Sister States in India
Source: Author, 2021

The region due to its location and topography experiences one of the heaviest rainfalls in the country and also in the world (Sangomla, 2021; IMD, n.d.) but with a low variability (IMD, n.d.). All these factors make the region very significant to investigate for deviations in SWM rainfall.

Data base and Methodology

While numerous studies focus on the actual amount of rainfall in time and space, regional aspects are less focussed and these are the theme of the current study. Data for all analysed parameters have been derived from Climate Engine (Engine, 2021) and processing of data has been done in QGIS 3.16 software. The following database and methodology has been attempted to conduct the analysis:

a) The study initiates by observing the average conditions of rainfall for the period from 1981-2021 for the region. Data source for this information is the Terra Climate monthly precipitation satellite data (derived at a resolution of 4000m) from the Climate Engine and is mapped for analysis. Sen's slope function is also mapped to observe the trend of change in rainfall from the period 1981-2021. Since the maximum rainfall in the region takes place between June–September, the data range is selected for the period.

b) Next, SWM rainfall for the same period (June–September) respectively from 2011-2021 is observed yearly for its percentage deviation from average conditions considering the base period of 1981-2021. The time period selected for data generation is 1st June – 30th September of each year from 2011 - 2021. With this time period, the percentage deviation of rainfall from these average conditions is extracted and mapped. Data source for collecting this information is the CHIRPS daily precipitation satellite data (derived at a resolution of 4800 m), from the Climate Engine. Mapping provides geographical interpretation as to actually which region is experiencing deviation in rainfall and in what manner.

c) The analysis is further extended to respective states of the region. A summary time series analysis is attempted to observe the total rainfall pattern in each state on an annual basis from 1981-2021. This data has been derived from Climate Engine from CHIRPS annual precipitation from 1st June 1981 to 30th September 2021. Besides, running average for five years is plotted for this data to derive a broader perspective on the data.

Interpretations follow the calculations.

Results and Discussions

The average conditions of rainfall can be taken as a representative of rainfall that is expected in a year over a period of time in a region (Agency, n.d.). For the study area, the total values of precipitation are first mapped for trend analysis. The examination is depicted in **Figure 2**.

It is clearly visible from **Figure 2** that the region is facing a negative trend in rainfall in the range of -5 to -28 mm/year. The highest total value of precipitation can be seen to be in Meghalaya, which is home to the region with maximum rainfall in the world. Besides, rainfall decreases towards the exterior of the region and is minimum -

(A) **(B)**

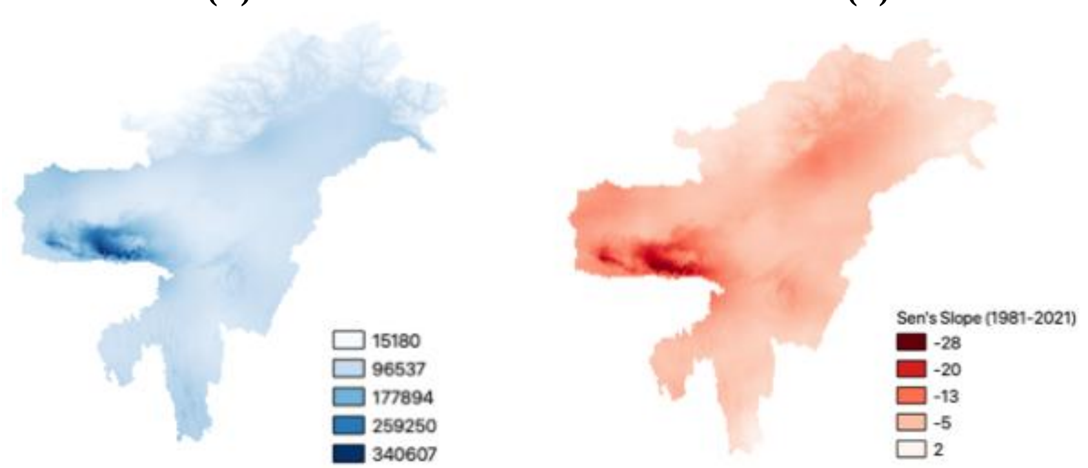

Figure 2: Seven Sister States: (A) Total Rainfall June 1981 to September 2021 & (B) Sen's Slope Estimator Mapping [(A) Rainfall data is in mm; (B) Sen's Slope - Precipitation Trend (mm/year)]

Source: Author, 2021 (Derived from Terra Climate Monthly Data, Climate Engine; analysed in QGIS 3.16)

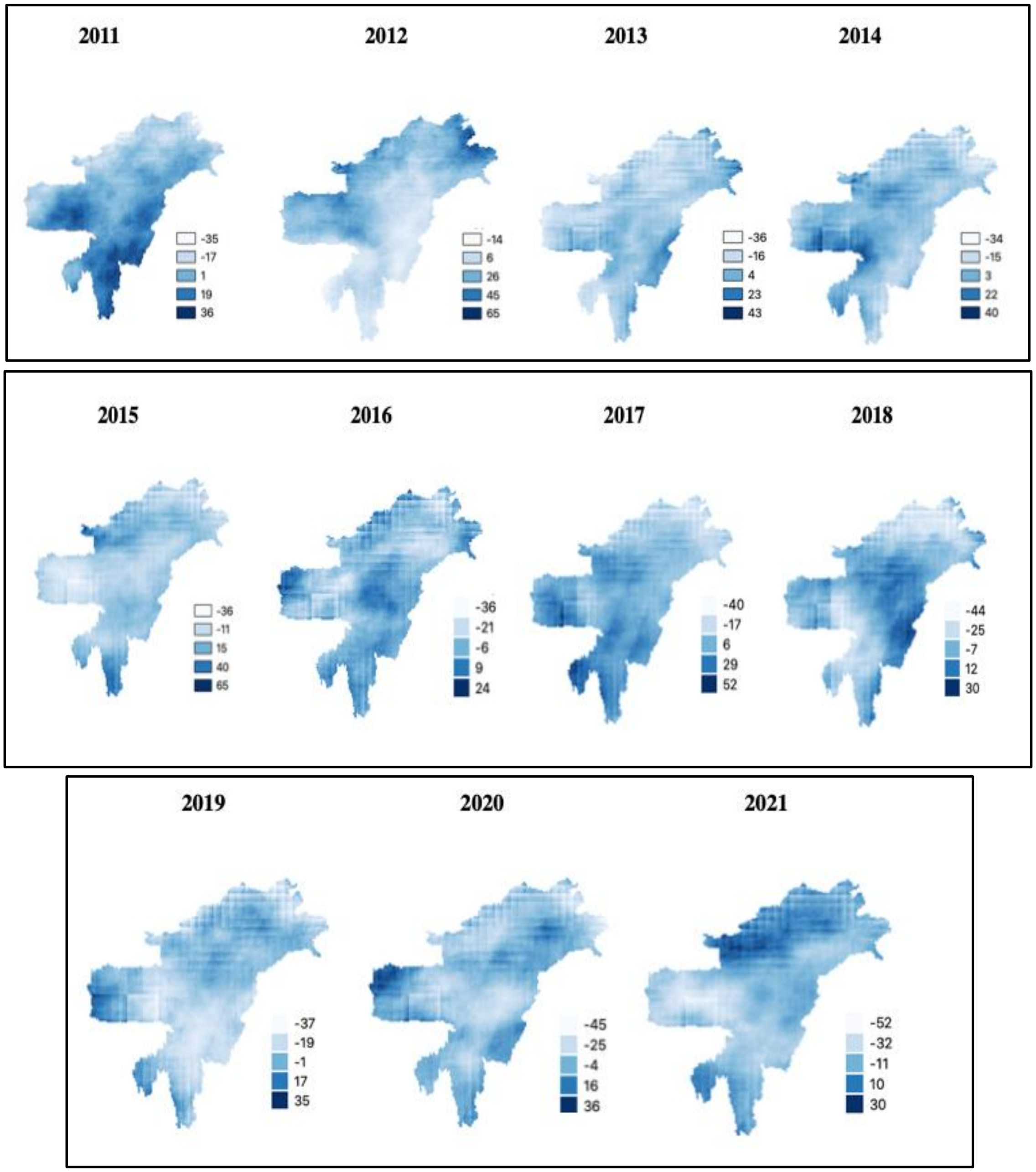

Figure 3: Seven Sister States - SWM Rainfall Deviation from Average Conditions (2011-2021) [Data is in % (Base time period of average: 1981-2021)]

Source: Author, 2021 (Derived from CHIRPS Daily Precipitation Data, Climate Engine)

towards the hill ranges in Arunachal Pradesh. The trend of rainfall as indicated by Sen's slope indicates a general decline in rainfall and what is most worrisome in this trend is that the maximum deviation is observed in the region with highest rainfall in Meghalaya state. Also, wherever positive deviations are visible geographically, they are marginal in terms of value. In this regard, the interior of the region highlights the higher range of negative deviations.

The above analysis is extended further by observing the deviation of daily rainfall from 2011 and 2021 in the region for the period from June to September for each year as is shown in **Figure 3**. This calculation is done by making the time period from 1981-2021 as the 'year range for historical average/distribution' through the Climate Engine (Engine, 2021). With this as the base period for examination, the percentage of rainfall deviation from average conditions as derived during this period are mapped.

Interpretation of the diagram indicates that although there is no specific regional trend of deviation of SWM rainfall from 2011-21, but on the whole a significant trend of decline is visible across the region. This is very pronounced in the region but at different locations. A very pertinent finding with regards to daily precipitation is that there is no specific area in the region which is facing a particular trend of decline or increase but deviation from normal conditions in terms of a negative trend is increasing its scale. In 2021, it was observed at a maximum of 52% which is the highest as per record for the chosen time period of the study. However, positive deviations are also visible but the precipitation trend is fluctuating year by year. The highest value for positive deviation is recorded at 65% in 2012 and 2015. The diagrams also depict the running mean values for a period of five years for each state of the region.

The spatial nature of data is examined in the state wise study of annual rainfall pattern. The following observations were recorded for the period from 1981-2021 as seen in **Figure 4**:

a. State of Arunachal Pradesh - A trend of fluctuating highs and lows of rainfall are followed by a constant decline in annual rainfall in the hilly state around 2006-07. The lower average currently faced is by far the maximum for the selected time period and the plunge is showing a constant trend. Last few years have seen a constant negative rainfall patterning.

b. State of Assam - Both positive and negative deviations are almost equally observed for the State. In this regard, maximum negative deviations are visible post 2015.

c. State of Manipur - Negative deviations from the average are largely observed with the last three years experiencing more of this trend for the state and the highs and lows in rainfall are very cyclical in nature for the state.

d. State of Meghalaya - The state exhibits a rise and fall trends which are also cyclic in nature more of a negative deviation of rainfall with this trend more pronounced after 2015.

e. State of Mizoram - The state has shown a constant increase from the average post mid 1990s but a slight decline is currently observed.

f. State of Nagaland - Here, a lot of severe cycles of fluctuations in rainfall with extreme highs and lows and the lows are visible as early as 2000s, a trend which is not visible for any other

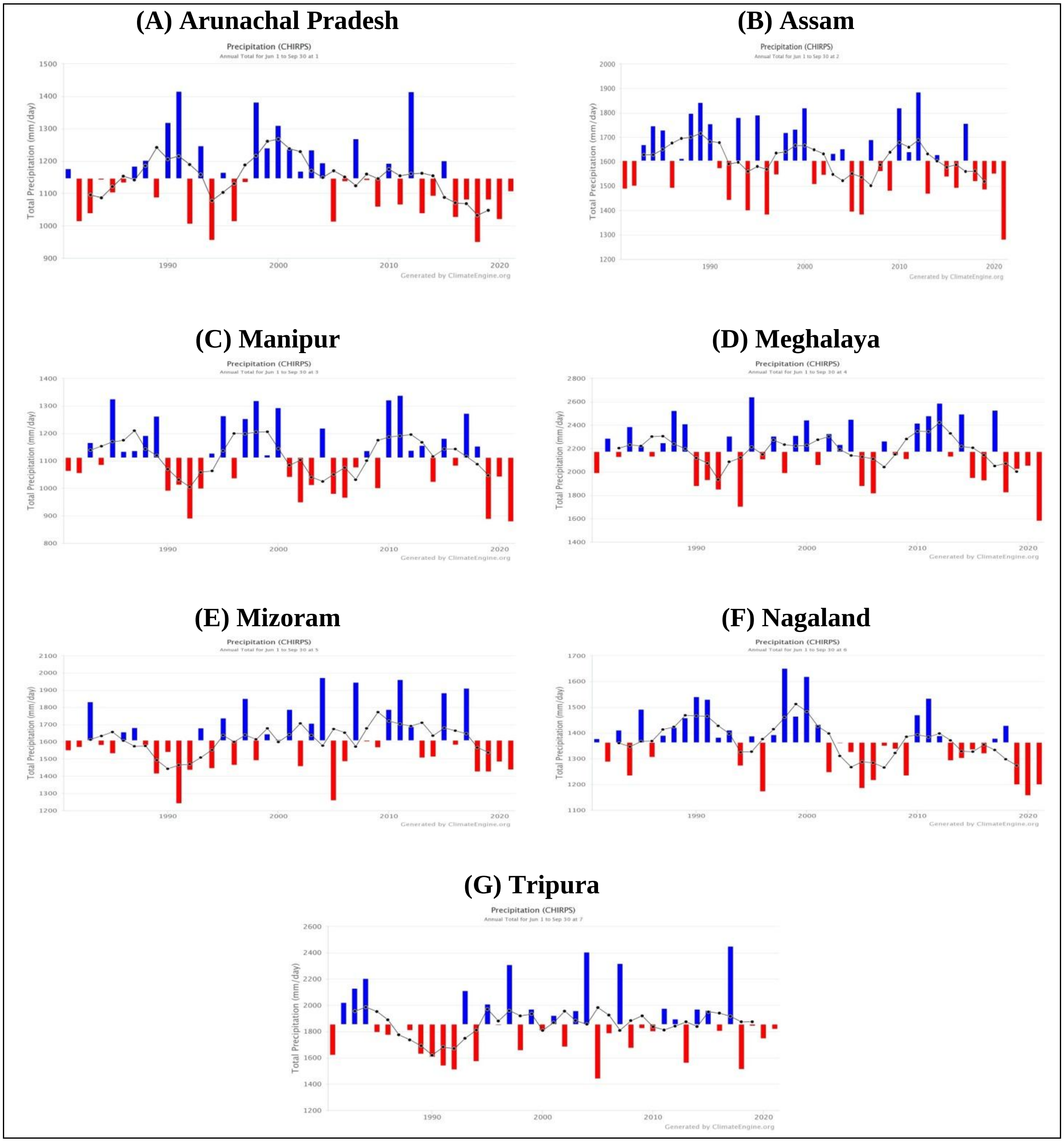

Figure 4: Seven Sister States - State Wise Analysis of Mean and Total Rainfall (1981-2021)

Source: Author, 2021 (Derived from CHIRPS Annual Precipitation, Climate Engine)

state. It exhibited peaks of positive deviations in 1990s and 1980s respectively.

g. State of Tripura - Recently, more positive deviations are visible on a constant basis here not observed for any other state.

In this context, it is noteworthy that the positive deviations in rainfall from the average are having an increased ranged in the recent years with the exception of Nagaland.

Figure 4 depicts the average of rainfall in each state of the region with deviation in rainfall of that state from its average. Total precipitation and the five yearly running mean values are also depicted. These clearly indicate that there has been a deviation trend in SWM rainfall in all Seven Sister states but with a fluctuating nature. Further, the negative trend has become more pronounced in the recent five years uniformly across the region. Prior to this, the trend was that of an increase throughout the region. Also pertinent is to observe that the negative deviation values are higher now than the negative deviation values observed earlier with minor exceptions to this trend. The year 2005 was specific in recording negative deviation values across all states of the region. From 1981-2021, no specific trend of increase or decrease can be marked for the region as a whole but fluctuating trends dominate.

A decline in rainfall since 2016 is visible across the region. Besides, geographically mentioning, the state of Arunachal Pradesh recorded the maximum negative values of deviation from normal from the region for running average of five years. This was closely followed by Nagaland. Large fluctuations from the average are observed in terms of positive values across the region from 2008-13. But the value of this deviation from the mean value is different for each state. Currently, a state of decline in rainfall is the trend across the region. The Sen's estimator of Slope calculation is mapped to check the magnitude of the trend of deviation (Aleemu & Dioha, 2020; Coen, *et al.*, 2020). It also indicates an inclination towards a trend of negative deviation in rainfall for the region as can be seen in **Figure 2**. Positive deviations are observed in a few pockets in the region for the selected time period of June to September for each year from 1981-2021. But basically, the trend shows a fluctuation of both positive and negative deviations.

Conclusions

Geographically, the region has a consistent trend of a negative and positive deviation in precipitation but no fixed trend is observed from 1981-2021. It can be conveniently concluded that the states are recently experiencing a strong negative deviation in trends in precipitation which has become more pronounced. State wise interpretation of results highlights a fluctuating trend of increase and decrease in SWM mean rainfall for the selected time period. All this is bound to have implications on the region's ecology, particularly in the light of climate change.

References

Agency, E. P. (n.d.). Retrieved 2021, from https://cfpub.epa.gov.

Ahmad, N., & Lodrick, D. O. (2021, February 11). Retrieved 2021, from https://www.britannica.com:

https://www.britannica.com/place/Brahmaputra-River.

Aleemu, Z. A., & Dioha, M. O. (2020, October 10). Climate change and trend analysis of temperature: the case of Addis Ababa, Ethiopia. *Environmental Systems Research*, *9*(27), https://doi.org/10.1186/s40068-020-00190-5.

Assam, G. O. (2019). Retrieved 2021, from https://asbb.assam.gov.in: https://asbb.assam.gov.in/information-services/detail/geophysical-features.

Bhaduri, Amita. n.d. "Living Rivers, Dying Rivers: Rivers in North-East India, India Water Portal." Retrieved February 8, 2021. (https://www.indiawaterportal.org/articles/living-rivers-dying-rivers-rivers-north-east-india-lecture-iic-new-delhi-dr-chandan-mahanta).

Chowdary, J. S., Xie, S. P., & Nanjundiah, R. S. (2021). Drivers of the Indian summer monsoon climate variability. In J. S. Chowdary, A. Parekh, & C. Gnanaseelan (Ed.). *Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond* (pp. 1-28). Netherlands: Elsevier Science.

Coen, M. C., Andrews, E., Bigi, A., Martucci, G., Romanens, G., Vogt, F. P., & Vuilleumier, L. (2020). Effects of the prewhitening method, the time granularity, and the time segmentation on the Mann–Kendall trend detection and the associated Sen's slope. *Atmospheric Measurement Techniques*, *13*(12), 6945-6964.

Das, D., Mondal, P., Saha, P., & Chaudhari, S. (2018). Investigation on the Bay of Bengal branch of summer monsoon during normal and delayed onset over Gangetic West Bengal. *Meteorology and Atmospheric Physics*, 131, 957-973.

Das, Anup, P. K. Ghosh, B. U. Choudhury, D. P. Patel, G. C. Munda, S. V Ngachan, and Pulakabha Chowdhury. n.d. "ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture 32 Climate Change in Northeast India: Recent Facts and Events-Worry for Agricultural Management."

Das, Gitishree, Jayanta Kumar Patra, Sameer K. Singdevsachan, Sushanto Gouda, and Han-Seung Shin (2016). Diversity of Traditional and Fermented Foods of the Seven Sister States of India and Their Nutritional and Nutraceutical Potential: a review. *Frontiers in Life Science*, *9*(4), 92-312, DOI: 10.1080/21553769.2016.1249032.

da Silva, R. M., Santos, A. C., Moriera, M., Real, J. C., Silva, V. L., & Medeiros, I. C. (2015). Rainfall and river flow trends using Mann–Kendall and Sen's slope estimator statistical tests in the Cobres River basin. *Natural Hazards*, *77*(2), 1205-1221.

Dash, S. K., Sharma, N., Pattnayak, K. C., Gao, X. J., & Shi, Y. (2012). Temperature and precipitation changes in the north-east India and their future projections. *Global and Planetary Change*, *98-99*, 31-44.

Debbarma, N., Choudhury, P., Roy, P., & Agarwal, S. (2021). Uncertainty Analysis of Regional Rainfall Frequency Estimates in Northeast India. *Civil Engineering Journal*, 1817-1835.

Deka, R. L., Mahanta, C., Nath, K. K., & Dutta, M. K. (2015). Spatio-temporal variability of rainfall regime in the Brahmaputra valley of North-East India. *Theoretical and Applied Climatology*, *124*, 793-806.

Engine, C. (2021). Retrieved 2021, from https://app.climateengine.com/climate Engine.

Goyal, M. K., Shivam, G., & Sarma, A. K. (2019). Spatial homogeneity of extreme precipitation indices using fuzzy clustering over northeast India. *Natural Hazards*, *98*, 559-574.

Guhathakurta, P., Bandgar, A., Menon, P., Prasad, A. K., Sangwan, N., & Advani, S. C. (2020) a. Retrieved from https://imdpune.gov.in: https://imdpune.gov.in/hydrology/rainfall%20variability%20page/mizoram_final.pdf.

Guhathakurta, P., Sanap, S., Menon, P., Prasad, A. K., Sangwan, N., & Advani, S. C. (2020) b. Retrieved 2021, from https://imdpune.gov.in: https://imdpune.gov.in/hydrology/rainfall%20variability%20page/nagaland_final.pdf.

IMD (n.d.). Retrieved 2021, from http://www.imdchennai.gov.in/: http://www.imdchennai.gov.in/swweb.htm.

Kumar, N. K., Rajeevan, M., Pai, D. S., Srivastava, A. K., & Preethi, B. (2013). On the observed variability of monsoon droughts over India. *Weather and Climate Extremes*, *1*, 42-50.

Lodrick, D. O. (2019, May 27). Retrieved 2021, from https://www.britannica.com: https://www.britannica.com/place/Arunachal-Pradesh.

Lodrick, D. O. (2020, July 17). Retrieved 2021, from https://www.britannica.com/: https://www.britannica.com/place/Tripura-state-India.

Mahanta, R., Sharma, D., & Chodhury, A. (2012, May). Heavy rainfall occurrences in northeast India. *International Journal of Climatology*, *33*(6), 1456-1469.

Manipur, G. O. (2021, February 8). Retrieved 2021, from https://www.tpmanipur.mn.gov.in: https://www.tpmanipur.mn.gov.in/en/home_content/profile-of-the-state/#:~:text=The%20altitude%20ranges%20from%2040,between%20hills%20on%20all%20sides.

Mizoram, O. G. (2020, July 16). Retrieved 2021, from https://mizoram.gov.in: https://mizoram.gov.in/page/know-mizoram#:~:text=Mizoram%20is%20 a%20land%20of,1%2C000%20meters%20(3%2C300%20ft).

Nagaland, G. O. (2021, February 8). Retrieved 2021, from https://nsdma.nagaland.gov.in/: https://nsdma.nagaland.gov.in/geography-of-nagaland

Oza, M., & Kishtwal, C. M. (2014, October). Retrieved 2021, from https://www.researchgate.net/: https://www.researchgate.net/profile/Markand-Oza/publication/268209029_Trends_in_Rainfall_and_Temperature_Patterns_over_North_East_India/links/5463f2190cf2837efdb347f2/Trends-in-Rainfall-and-Temperature-Patterns-over-North-East-India.pdf.

Parida, B. R., & Oinam, B. (2015, January). Retrieved 2021, from https://www.researchgate.net: https://www.researchgate.net/publication/298719152_Unprecedented_drought_in_North_East_India_compared_to_Western_India

Raghavan, C., & Lodrick, D. O. (2020, July 17). https://www.britannica.com. Retrieved 2021, from https://www.britannica.com/place/Meghalaya.

Rao, D. B., Srinivas, D., & Ratna, S. B. (2008). Regional scale prediction of the onset phase of the Indian southwest monsoon with a high-resolution atmospheric model. *Atmospheric Science Letters, 9*(4), 237-244.

SANDRP. n.d. "North-East India Rivers Profile (Brahmaputra Basin) – SANDRP." Retrieved, 2021(https://sandrp.in/2017/06/13/north-east-india-rivers-profile-brahmaputra-basin/).

Sangomla. 2021. "Climate Crisis in North-East India: Monsoon Variations Should Ring Alarm Bells Now." (da Silva, Santos, Moriera, Real, Silva, & Medeiros, 2015). Retrieved 2021 (https://www.downtoearth.org.in/news/climate-change/climate-crisis-in-north-east-india-monsoon-variations-should-ring-alarm-bells-now-78707).

Sinha, N., Chattopadhyay, R., & Chakraborty, S. (2018). Bay of Bengal branch of Indian summer monsoon and its association with spatial distribution of rainfall patterns over India. *Theoretical and Applied Climatology*, *137*, 1895-1907.

Society, A. E. (2021). Retrieved 2021, from http://aees.gov.in/.

Vinayachandra, P. N., Masumoto, Y., Mikawa, T., & Yamagata, T. (1999). Intrusion of the southwest monsoon current into the Bay of Bengal. *Journal of Geophysical Research*, *104*(C5), 11077-11085.

Wang, B., Ding, Q., & Liu, J. (2011). Concept of Global Monsoon. In C. P. Chang, Y. Ding, N. C. Lau, R. H. Johnson, B. Wang, & T. Yasunari. *The Global Monsoon System: Research and Forecast* (pp. 3-14). Singapore: World Scientific.

Wu, G., Guan, Y., Liu, Y., Yan, J., & Mao, J. (2012). Air–sea interaction and formation of the Asian summer monsoon onset vortex over the Bay of

Bengal. *Climate Dynamics*, *38*, 261-279.

Zahan, Y., Mahanta, R., Rajesh, P. V., & Goswami, B. N. (2021). Impact of climate change on North-East India (NEI) summer monsoon rainfall. *Climatic Change*, *164*(2), https://doi.org/10.1007/s10584-021-02994-5.