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Research Paper

Trend analysis and change-point detection of monsoon rainfall in Uttarakhand and its impact on vegetation productivity

PRIYANKA SWAMI

Department of Agronomy, Agriculture University Jodhpur, Rajasthan, India
Corresponding author email: priyankamah30@gmail.com

ABSTRACT

This study analyzes the long-term spatio-temporal changes and trend analysis in rainfall using the data from 1901 to 2020 and its impact on vegetation from 2000 to 2020 across districts of Uttarakhand. The Pettitt test was employed to detect the abrupt change point in time frame, while the Mann-Kendall (MK) test was performed to analyze the rainfall trend. Results show that the most of the districts exhibited significant negative trend of rainfall in monsoon, except two districts. Out of 13 districts, 4 districts recorded noteworthy rainfall declining trend for the monsoon season at 0.05% significance level, while the insignificant negative trend of rainfall was detected for 7 districts of Uttarakhand. Furthermore, the significant negative trend (-2.23) was recorded for overall monsoon rainfall of Uttarakhand. Based on the findings of change detection, the most probable year of change detection was occurred primarily after 1960 for most of the districts of Uttarakhand. A significant decline rainfall was detected after 1960 while after 1970 interannual variability of rainfall was recorded to be increased. The analysis of month wise cumulative gross primary productivity (GPP) for 13 districts with rainfall trends shows that there is significant impact of rainfall trend on GPP during month of June and it gradually reduces for subsequent monsoon months. It was observed that the GPP of region is increasing at rate of 9.1 $gCm^{-2}d^{-1}$ in the region since 2000. Based on sensitivity analysis, the GPP of cropped area of region is more sensitive towards rainfall than forest area of Uttarakhand.

Keywords: Mann-Kendall (MK) test, Pettitt test, rainfall trend, gross primary productivity, forest and crop lands.

Rainfall is a key part of hydrological cycle and constant change in its pattern directly affect the water availability. Consequently, these changes demonstrated the widespread impact on the water resource, environment, terrestrial ecosystem, ocean, bio-diversity, agricultural and food security. In India, the economy is significantly influenced by rainfall, and understanding the patterns of precipitation is crucial for the nation's economic development, effective disaster management, and strategic planning of water resources (Yadav *et al.,* 2014). Hence, it is noteworthy to evaluate whether there is any trend in rainfall and any pattern in variability. Vegetation as a part of terrestrial ecosystem plays an important role in carbon cycle, energy transfer, climate regulation and water balance. The response to climate change had been accounted as one of the key features on ecological research. Gross primary productivity (GPP) has been considered as an important indicator to monitor the impact of climate change (Wang, *et al*., 2016). The primary factors effecting GPP are climatic conditions, geochemical characteristics, human activity and attributes of ecosystem itself. The dominating factor among the mentioned is proven to be climatic conditions (Nemani *et al*., 2003). Sridhara and Gopakkali (2021) analysed rainfall trends of 18 Taluks of south Karnataka using non-parametric test while Waghaye *et al.,* (2018) analyzed trend and change point detection of rainfall in Andhra Pradesh and Telangana. This research focus on impact of rainfall on cumulative GPP during monsoon. The study further focuses on subjectivity of variation towards percentage of cropland and forest in area as an account for sensitivity of component towards monsoon trend.

MATERIAL AND METHODS

Study area and data source

The geographical extent of Uttarakhand state extends from

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28°44’ and 31°28’ N Latitude and 77°35’ and 81°01’ East longitude, respectively. The rainfall data for 120 years (1901–2020) was obtained from gridded data at 0.25degree spatial resolution provided by Indian Meteorological Department (IMD). The GPP data was obtained from Penman-Monteith-Leuning Evapotranspiration V2 (PML_V2) product. This product, is available at 8-day temporal and 500m spatial resolutions. It incorporates carbon constraints on ET, providing consistent results with the same forcing data. The calculation of gross primary production (GPP) is performed using a coupled diagnostic biophysical model known as PML-V2. This model is constructed using the Google Earth Engine platform and relies on various inputs, including MODIS data and GLDAS meteorological forcing data. Specifically, the MODIS data used as inputs for the model consist of parameters such as leaf area index (LAI), albedo, and emissivity. These data provide essential information about vegetation characteristics and energy exchange processes within the Earth’s system. Additionally, the model requires meteorological forcing data from the Global Land Data Assimilation System (GLDAS) (Zhang *et al.,* 2019). These data include variables such as temperature, precipitation, radiation, and other meteorological parameters needed to simulate and understand the biophysical processes related to GPP. By combining the MODIS data and GLDAS meteorological forcing data, the PML-V2 model calculates GPP, which represents the total amount of carbon dioxide that plants convert into organic matter through photosynthesis during a specific time period. For the purpose of study spatial mean values for the period of June, July, August and September was calculated from year 2000-2020 using google earth engine for the study area.

Mann-Kendal test

The present work has utilized Mann-Kendal (MK) test (Mann, 1945), a rank based non-parametric statistical test, to detect the trend in 120 years rainfall data series. The MK test is mainly used for detecting trend in hydro-climatic data series due to lower sensitivity to any sudden change. The Sen’s slope is,

$$S = \sum^{n} \sum^{n} sgn(k_j - k_i)$$

Where,

$$sgn(k_j - k_i) = \begin{cases} 1, if\ (k_j - k_i) > \\ 0, if\ (k_j - k_i) = \\ -1, if\ (k_j - k_i) < \end{cases}$$

If the null hypothesis is true then S is normally distributed with mean value 0.

$$var(s) = \left[\frac{n(n-1)(2n+5)}{18}\right]$$

The significance of trend of time series is quantified using value of Z_{MK} as,

$$Z_{MK} = \frac{|S|}{var(s)^{0.5}}$$

The increasing and decreasing trend can be identified using positive and negative value of Z. The 0 value of Z represents normally distributed data.

Method for change point detection – Pettitt test

The Pettitt test is a rank based statistical non-parametric test independent of distribution of data used to detect change point in time series. Given the duration of timeseries data is t and the shift takes place at m years, the resulting test statistics is given below, test is characterized using two time series and .

$$U_{t,m} = \sum^{m} \sum^{t} sgn(k_j - k_i)$$

Where sgn is defined as ,

$$sgn(k_i - k_j) = \begin{cases} 1, if\ (k_i - k_j) > \\ 0, if\ (k_i - k_j) = \\ -1, if\ (k_i - k_j) < \end{cases}$$

The value of test statistics is calculate for all variables from 1 to n. The major distinctive changes are observed where magnitude of the is highest.

$$Z_t = Max_{1 \le t < m} |U_{t,m}|$$

The probability of shift in a year is calculated when is maximum,

$$P = 1 - exp\left[\frac{-6Z_t^2}{K^2 + K^3}\right]$$

If p-value is less than significance level α, the null hypothesis is considered to be rejected.

RESULTS AND DISCUSSION

District wise rainfall trends

The present section describes the trend observed at district and state level (Table 1) using intensity of Z values and trend at 0.05 significance level as parameters calculated using MK test on monsoon rainfall and rainfall received during individual months of monsoon period. The results shows that there is a significant increasing trend observed in Chamoli and Rudraprayag districts for month of July and August and the overall trend of rainfall in the mentioned districts is increasing at 95% significance level. A decreasing trend in rainfall was observed for Uttarakhand with Z value -2.23 at 95% significance. The districts Dehradun, Nainital, Pauri Garhwal and Tehri Garhwal showing significant decreasing trend coherent with the state with most highly negative z value of MK test recorded for Dehradun -7.07 at 95% significance. The results obtained were different when calculated at a narrower time frame during 1971-2011 as reported by Yadav *et al.*, (2014) an increasing trend in rainfall of Haridwar, Dehradun and Uttarkashi, indicating the existence of a major change point during 1901-2020.

Table 1: Results of the MK test (Z) and trend for monthly rainfall for the period of 1901–2020. *(# - no trend, ↑ - increasing, ↓ - decreasing, at 0.05 significance level)*

District	Monsoon	June	July	August	September
Almora	-1.73 #	-1.37 #	-1.34 #	-1.65 #	-0.48 #
Bageshwar	-1.8 #	-1.68 #	-1.24 #	-1.19 #	-0.59 #
Chamoli	4.03 ↑	-0.05 #	3.16 ↑	3.88 ↑	1.25 #
Champawat	-0.71 #	-1.43 #	-0.28 #	-0.35 #	-0.59 #
Dehradun	-7.07 ↓	-0.99 #	-5.8 ↓	-7.31 ↓	-2.67 ↓
Haridwar	-1.85 #	0.04 #	-1.68 #	-1.13 #	-0.66 #
Nainital	-4.59 ↓	-1.78 #	-3.22 ↓	-4.15 ↓	-1.25 #
Pauri Garhwal	-5.43 ↓	-1.8 #	-4.37 ↓	-4.11 ↓	-1.94 #
Pithoragarh	-0.51 #	-0.77 #	-0.39 #	-0.79 #	-0.24 #
Rudraprayag	3.87 ↑	0.48 #	3.55 ↑	3.62 ↑	1.92 #
Tehri Garwal	-4.81 ↓	-0.33 #	-3.79 ↓	-4.85 ↓	-1.74 #
Udham Singh Nagar	-0.25 #	0.71 #	-0.07 #	-1.26 #	-0.02 #
Uttarkashi	-1.54 #	-0.32 #	-0.76 #	-1.33 #	-0.71 #
Uttarakhand	-2.23 ↓	-0.77 #	-1.77 #	-2.09 ↓	-0.62 #

Table 2: Results of the Pettitt test (change point analysis) of monsoon rainfall for the period of 1901–2020.

District	h	p	Probable change point (year)	Mean pre (mm)	Mean post (mm)
Almora	True	0.01405	1970	1043.34	919.44
Bageshwar	True	0.027	1962	1407.37	1276.52
Chamoli	True	0	1974	771.3	955.92
Champawat	False	0.28835	1970	1253.97	1139.33
Dehradun	True	0	1967	1657.78	1090.88
Haridwar	True	0.0216	1970	1160.49	1006.63
Nainital	True	0	1972	1476.82	1107.94
Pauri Garhwal	True	0	1968	1257.15	905.4
Pithoragarh	False	0.08715	1926	1784.94	1507.82
Rudraprayag	True	0.00005	1961	751.39	1042.19
Tehri Garwal	True	0	1955	1244.86	949.51
Udham Singh Nagar	False	0.4149	1965	1278.58	1175.07
Uttarkashi	FALSE	0.08285	1974	967.8	876.98
Uttarakhand	TRUE	0.00715	1965	1217.7	1083.44

It was also observed that the trend in rainfall during monsoon is primarily governed by rainfall during the month of July and August and the trend observed during the mentioned month decide the nature of trend of monsoon season in Uttarakhand.

Change point analysis

The difference in rainfall trends reported by previous studies on shorter timescale are different from the results obtained from the study indicating the variation in rainfall trends at different time scale (Yadav *et al.*, 2014) indicating the need of change point analysis. Furthermore, the selection of change point for monsoon rainfall in each district based on the performances (p value) of these tests (Table 2). Therefore, these abrupt change points suggest that the rainfall had no monotonous trend. The selected change points for districts of Uttarakhand and state were detected during the period of 1961-1974. For Uttarakhand state the probable abrupt change point was in year 1965. It can be further observed that pre-change point the mean rainfall was observed to be 1217.7 while post change-point mean rainfall was 1083.44 mm during the monsoon season for Uttarakhand highlighting the decrease in rainfall received during the monsoon period since 1901. District level analysis shows that the total mean rainfall received had increased for Chamoli (184.62 mm) and Rudraprayag (290.8 mm), while for all the remaining districts the mean rainfall post change point has decreased.

Analysis of gross primary productivity

Due to limited availability of gross primary productivity data the analysis was confined between 2000 and 2020. The mean values of cumulative GPP for the duration of monsoon (Table 3) shows that Champawat district have highest cumulative mean

Table 3: Mean cumulative value of GPP for 13 districts of Uttarakhand (2000-2020) for period of Monsoon.

Districts	Mean GPP (gC m-2)	Forest (%)	Crop (%)	Area (%)
Almora	99.21	50.8	13.9	7.75
Bageshwar	85.19	52.99	10.16	3.46
Chamoli	55	59.42	3.65	14.19
Champawat	103.15	56.74	6.05	3.89
Dehradun	91.61	55.6	9.28	6.05
Haridwar	88.15	34.49	46.5	4.07
Nainital	94.98	73.08	9.5	6.8
Pauri Garhwal	91.48	57.56	6.03	11.15
Pithoragarh	58.28	72.33	4.67	12.44
Rudraprayag	87.49	76.82	7.92	3.91
Tehri Garwal	94.07	66.23	9.69	8.09
Udham Singh Nagar	90.85	33.53	47.92	4.66
Uttarkashi	59.66	88.8	3.55	13.54

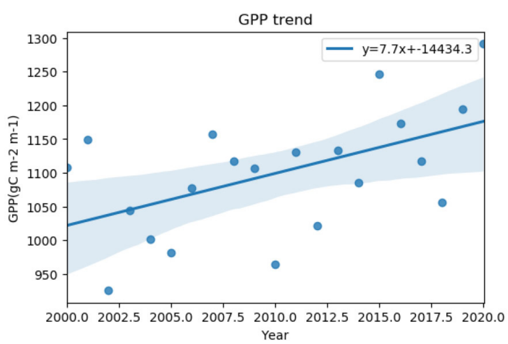

Fig. 1: Temporal linear trend of GPP during 2000 to 2020 for state of Uttarakhand.

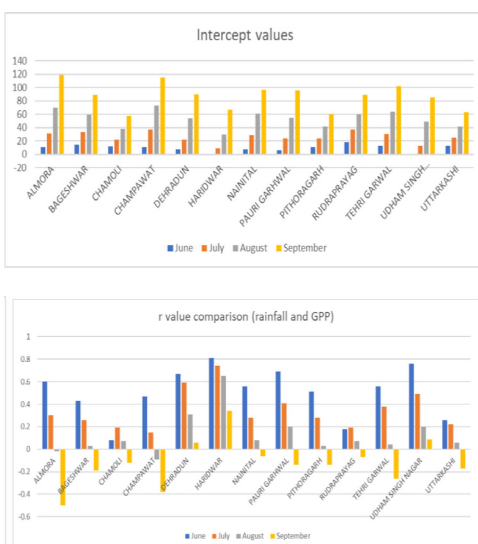

Fig. 2: Bar plot of intercept (a) and r-values (b) comparison for districts of Uttarakhand from regression between GPP and rainfall received during monsoon (2000-2020).

productivity while Chamoli displays the lowest. The area (fraction of total geographical area) crop and forest area percentages were obtained from Land use information system hosted by department of agriculture, government of India.

Trend of gross primary productivity (GPP)

It was observed the for the period of study the trend of GPP was found to be increasing with rate of 9.1 gC m^{-2} d^{-1}. A regression analysis was carried out to identify the linear trend with respect to year from 2000 to 2020 (Fig. 1). The GPP was found to be increasing with respect to year with a coefficient of correlation of 0.53.

The month wise trend analysis of GPP at district level for monsoon period shows that variation in GPP with respect to monthly rainfall was found to be positive for month of June and the value of coefficient of correlation decreases for subsequent months representing the rainfall departure during month of June significantly effects the GPP in all districts. It was also observed that for month of July, August and September the regression models become more insignificant representing the reduction in dependency on monsoon rainfall only for GPP variation during the mentioned period. The values of intercept are increasing with increase in month representing the impact of cumulative rainfall. It was also observed that the intercept values for districts Almora, Champawat and Tehri Garhwal are higher due to higher forest cover and hence showing more gross primary productivity as compared to districts with higher agriculture area percentage Udham Singh Nagar and Haridwar (Fig. 2a). The results signifies that the districts with higher percentage of agriculture are more sensitive to climate change with reference to gross primary productivity.

The gross primary productivity of districts Dehradun, Haridwar and Udham Singh Nagar are positively correlated with rainfall received during the month September while the areas

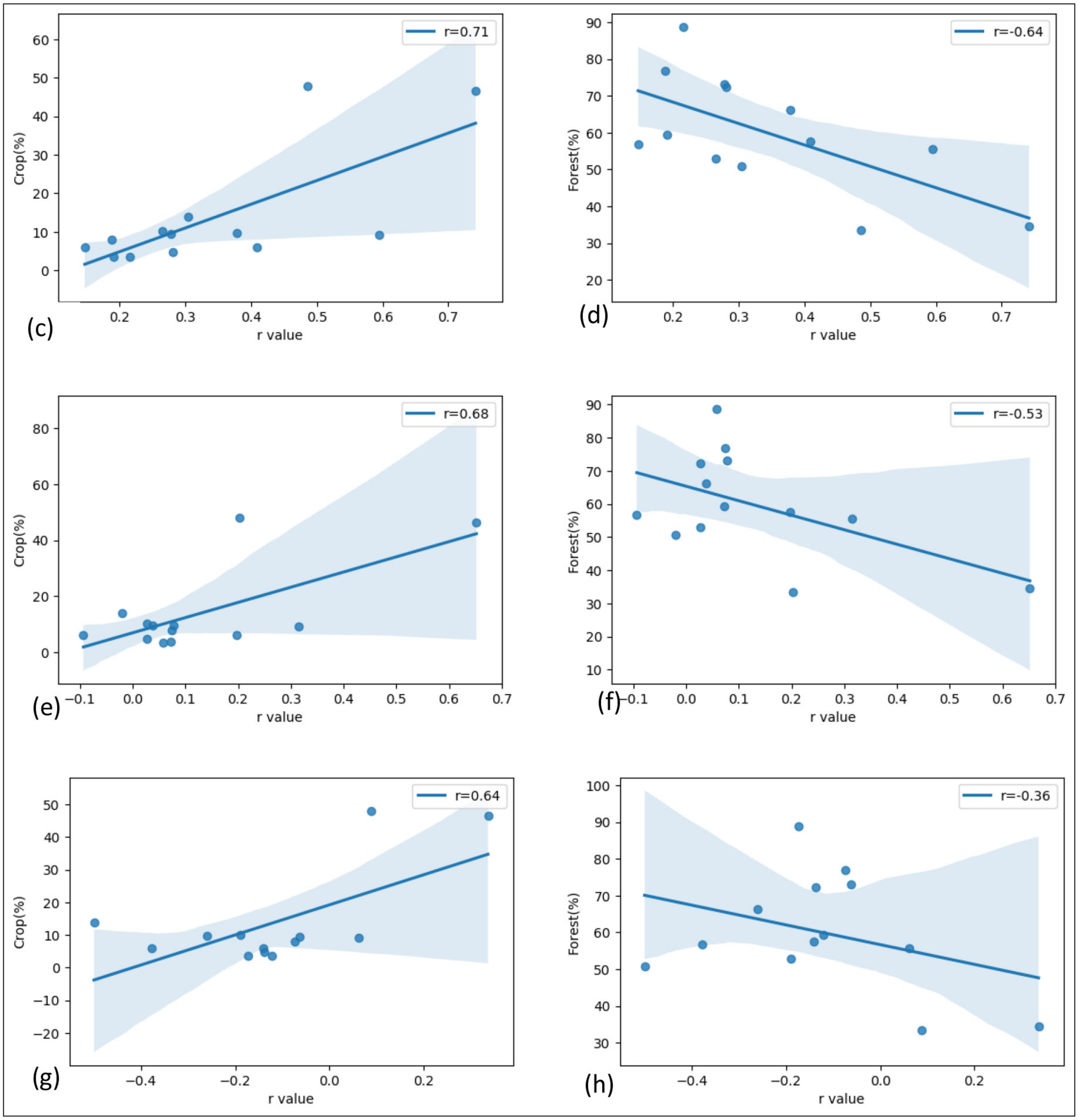

Fig. 3: Regression outputs of coefficient of correlation between GPP (monthly cumulative) and rainfall with land use class (%) at district level, (a) r values for month of June and cropped area (%), (b) r values for month of June and forest area (%), (c) r values for month of July and cropped area (%), (d) r values for month of July and forest area (%), (e) r values for month of August and cropped area (%), (f) r values for month of August and forest area (%), (g) r values for month of September and cropped area (%), (h) r values for month of September and forest area (%).

with less agriculture activities are negatively correlated (Fig. 2b). This suggests that in districts where agriculture activities are less prominent, an increase in rainfall during September is associated with a decrease in gross primary productivity.

Sensitivity of cropped and forest area GPP with respect to rainfall

The analysis was further carried out to subject the coefficient of correlation (r_value) to cropped and forest area for individual districts to identify the sensitivity of parameter toward individual land use class. The regression test results shows that the change in GPP was more sensitive to cropped area than to the forest area of the region. The r value with respect to cropped area are always >0.6 during monsoon period but is always found to be negative for forest area (Fig. 3). The results mainly predicts that the GPP of cropped area is affected by rainfall while for forest area the rainfall is not only driving force for region of Uttarakhand.

CONCLUSION

The analysis of 120 years (1901-2020) monsoon rainfall reports that the districts Dehradun, Nainital, Pauri Grahwal, Tehri Grahwal were detected negative trend, while the district Chamoli and Rudraprayag were recorded positive trend with negative trend for Uttarakhand state at 95% significance with probable change points were detected in between 1961-1974 with probable change point for Uttarakhand in year 1965. The analysis of variation of GPP with respect to years demonstrate that the value is found to be increasing with time at rate of 9.1 $gCm^{-2}d^{-1}$ in the region. It was also observed that total rainfall primarily effects the GPP during month of June while it does have a minimal impact during month of July, August and September. This is mainly because June is sowing period for kharif crops during month of June and during subsequent months the growth takes place. The finding also shows that the GPP of cropped area is more sensitive towards rainfall than that of forest area.

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