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Climate Extremes Related with Rainfall Trends in Agniyar River Basin

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Abstract

The rainfall extremes variability due to climate change can be detected by the trend analysis. The trend analysis is implemented for the precipitation data period starting from year 1980 to 2021 (42 years) for the Agniyar river basin. The Mann-Kendall (M-K) test is employed to identify trends in precipitation, while The trend's magnitude is calculated using the Sen's slope method. The rainfall trend in Yearly Maximum Daily Rainfall (YMDR), South West Monsoon (SWM), Summer season, North East Monsoon (NEM), winter season and annual rainfall are computed. The results of twelve rain gauge stations in the Agniyar river basin revealed increasing, decreasing, and non-significant trends, with a notable increase in precipitation observed at some locations with acceptable significance. Most of the stations showing declining trend in precipitation based on Sen's magnitude and negative slope. The outcome of this study needs of hour to the hydrologists, water resources engineers, water resources managers, environmentalist, sustainable development policy makers, inter-disciplinary climate change researchers and consultants involved in solving problems related to change in climate impact. The results of precipitation extremes are necessary for creating adaptation strategies in response to climate change.

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Introduction

The Intergovernmental Panel on Climate Change (IPCC) published the 6th assessment report (AR6) which is helpful in understanding current global climate. As per the IPCC AR6 report the global warming in the near-term will touch or go beyond 1.5°C even to the lesser scenarios for greenhouse gas emissions.[1] The newest synthesis document from the United Nations Framework Convention on Climate Change (UNFCCC) published in 2022, which includes recent Nationally Determined Contributions (NDCs), indicates that the commitments made under the Paris Agreement by 196 parties are expected to decrease greenhouse gas (GHG) emissions by 0.3% by 2030 year.[2] Globally as per the Sustainable Development Goal (SDG) report published in 2023,

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the highly vulnerable regions during the period 2010 to 2020 nearly 3.3-3.6 billion people experienced high mortality rates from drought, storms and floods in comparison with very low vulnerable regions.[3] Water scarcity is arising all over the world due to rainfall extremes and exposed to accumulative pressures.[4-6] Land use and land cover (LULC) is the major contributor for the water quality however, sometime, it amplifies due the effect of climate change.[7] The river basin flow patterns were altered by the effects of climate change on rainfall and evapotranspiration.[8] Climate change is one of the factors contributing to the severity of floods.[9] The duration and intensity of rainfall plays a crucial role in flood damages and flood losses.[10]

Rainfall extremes and rainfall variability increases the risks of food availability and water security especially in Asian countries.[1] The surface temperature of annual average time scale over India are normally 25°C or more in the current climate (1951-2010) and are predicted to escalate by 3 - 5°C in the projected period (2051-2110). The future rainfall predicted in the southwest region having arid and semi-arid climate types shows a rise of 0.5mm/day rainfall amount. The rainfall intensity of wet days and strong rainfall events increase by 7mm/day and higher than 25mm/day respectively.[11] The Cauvery river basin is the major river basin in Tamil Nadu having tropical and sub-tropical climate. The annual rainfall of approximately 70% is received in North East Monsoon season (NEM) and shows a rising trend.[12] A non-parametric Man-Kendall and Sen's tests carried out on observed and projected precipitation of Thanjavur delta region situated in the state of Tamil Nadu. The observed precipitation of IMD grid over the period 1970-2014 showed a growing trend.[13] The declining trend is seen in the case of projected precipitation over the 2015-2050 period.[13] The M-K and Sen's methods are useful in indicating the temporal and spatial patterns in the annual and seasonal rainfall series towards Tamil Nadu state. There is a rise in NEM precipitation in the Western Ghat region and also 4.97% increase in yearly precipitation between the 1901-2015 period.[14] The slope from the Sen's test results showed that a decreasing trend of rainfall with the rate of -1.27 cm per year noticed in coastal Andhra Pradesh region.[15] The present research study aims to recognize the rainfall variability through their spatial and temporal trend patterns so as to find hydrological solutions to recover habitable condition of the river basin. For the effective management for water and propose suitable climate change adaptation strategies, the understanding of rainfall trends is essential.[16]

The climate extremes study at basin level is in the urgent need because it is having higher impact on regional level sectors like agriculture, environment, water resources, health, social, economic, energy, coastal, atmospheric condition etc. climate extremes studies were carried out and analysed at the side of many research scholars at global level.[17,18] The regional level study pertaining to climate studies are very scarce in Indian basins, hence it is an urgent need to analyse rainfall extremes which caused human, land and agricultural loss in the earlier two decades.

Study Area

The Agniyar basin is the flood prone river basin which is situated in the middle and eastern side of Tamil Nadu in the southern part of India is presented in Fig.1. The geographical position of the Agniyar river basin lies between the Latitude 09°55'N and 10°45'N and Longitude 78°15'E and 79°30'E. The spatial area enclosed by the basin is 4663 sq.km. North -Western portion of the basin is occupied by the Cauvery basin, Southern portion of the basin is covered by Pambar and Kottakaraiyar basin, Eartern side is Palk straight and Bay of Bengal is present. The districts covering the Agniyar river basin are Pudukkottai, Thanjavur, Tiruchirapalli, Sivagangai and Dindigul. The basin comprises three sub-basins: Agniyar, Ambuliyar, and South Vellar. Physiographically, the Agniyar basin is distributed into three terrains (i) Western hard rock terrain, (ii) Eastern sedimentary terrain and coastal region, (iii) Central pediplain terrain. About 29.8% of basin land area is agricultural land, 3.9% of land is forest area, 1% is built-up area, 0.18% comprises of water bodies. The main part of 63.5% terrain is waste ground, which encompasses the land impacted by alkalinity, barren space, salt pan, Juliflora grown area, land covered with scrub, shrubs, and exposed rock formations.

The basin is completely a rain-fed area suffering more by the unavailability of irrigation water and domestic water supply. The major types of soil

present in this basin namely, Alfisols, Vertisols and Entisols. Agniyar basin is located in the tropical monsoon zone. Based on the hydro meteorological condition of the river basin the year is separated into rainy season (June to December) and non- rainy season (January to May) periods. The monsoon period is categorized into SWM southwest monsoon season occurs from June to September, while the NEM season takes place from October to December. The 60% of yearly water requirement is fulfilled by NEM and it is having an important role in water resources augmentation and agricultural activities.[19] The non-monsoon time is further separated into winter spans January to February, and the summer seasons lasts from March to May. The average yearly precipitation of the Agniyar basin is 931 mm.

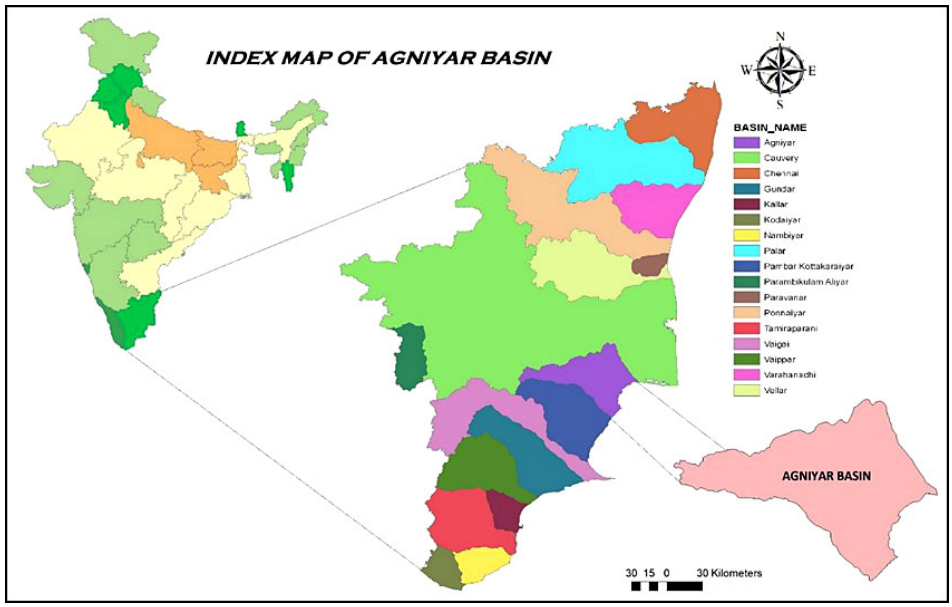

Fig. 1: Index map of Agniyar basin

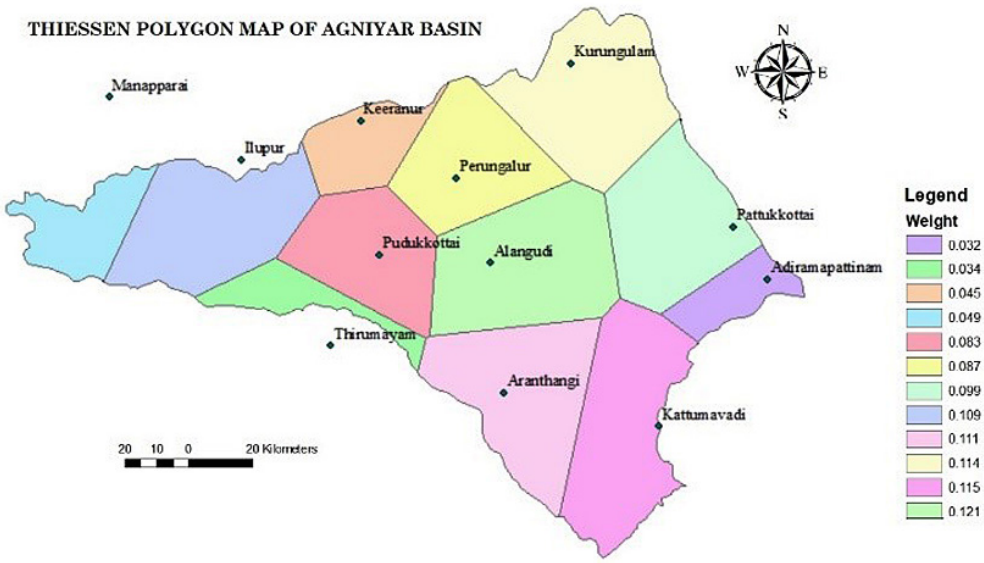

Fig. 2: Thiessen Polygon map of 12 rain gauge stations

Methodology

Trend Detection using M-K and Sen's Test

The recorded rainfall data of 12 rain gauge was obtained from the State Ground and Surface Water Resources Data Centre, Chennai for the historical period of 1980 to 2021 (42 years). The most influencing rain gauge stations present within and near the Agniyar basin is presented in the Figure 2. The longer duration of available observed data incorporated for the better results.

The M-K test is an extensively adopted non-parametric statistical test[20,21] and the Theil-Sen trend detection test.[22,23] Which are employed for the trend analysis of precipitation. The non-parametric median based Theil Sen method provides the slope magnitude which gives the trend of the data series under study. The M-K statistic S and the standardized check statistic Z are expressed as follows,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_v - X_u) \quad ..(1)$$

$$sign(X_v - X_u) = \begin{cases} 1 \; if \; X_v - X_u > 0 \\ 0 \; if \; X_v - X_{u\,j} = 0 \\ -1 \; if \; X_v - X_u < 0 \end{cases} \quad ..(2)$$

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad ...(3)$$

$$Z = \begin{cases} \frac{S-1}{\sigma^2} \; for \; S > 0 \\ 0 \; for \; S = 0 \\ \frac{S+1}{\sigma^2} \; forS < 0 \end{cases} \quad ...(4)$$

The statistical parameters are defined as follows: x_u and x_v represent the consecutive data values for years u and v, n is the total number of data points in the record, t_p indicates the number of ties for the pth value; and q represents the count of tied values.

$$\beta = median \; \frac{x_u - x_v}{u - v} \ldots\ldots \forall \ldots . j < i \quad ...(5)$$

where x_u and x_v are belongs to the series of sequential data values across the years u and v, and the trend's slope magnitude is denoted by β for the time series values. The trend with increasing values of Z is indicated increasing trend and the decreasing trend values of Z is indicated as declining trend of the associated time series. The H0 (zero hypothesis) represents that no trend is observed in the series and the Ha (alternate hypothesis) denotes that the trend is existing in the series. If there exists a trend in the series follows the standard normal distribution, the value denoted by Z is computed with the 5% significance level.[24] The trends were identified by the Mann-Kendall test for the precipitation data. Twelve precipitation gauge stations are incorporated in the current research study as shown in Fig. 2. The M-K test is employed to the sensing of trend in precipitation series for the 12 rain recording stations which situated within and near the basin.

Results and Discussion

Yearly Maximum, Annual and Seasonal Precipitation

The assessed M-K's S and Z values of each station for yearly maximum, annual, seasonal and time frames are represented in Table 1. The precipitation variable is exposed to high inter-annual variability. Hence the seasonal variations such as monsoon period is more significant than other seasons. The abbreviation of trend results were as I (rising trend), D (Decling trend) and N (No trend) and the outcomes are shown in the Table 2. In the M-K drift test, 5% level is taken into account for Z to be statistically significant. A significant and statistically acceptable drift is noticed in YMDR for the two stations Alangudi and Manaparai based on the Z values 2.667 and -2.124. The YMDR increasing trend indicates that rainfall will increase in Alangudi region and may cause floods. The decreasing trend of YMDR having Z value as -2.124, in Manaparai area specifies that the drought conditions may prevail due to monsoon failure.

A positive trend is found in Alangudi station for the SWM season. For the NEM season, a growing trend is identified with the Z values in Alangudi (2.492), Kattumavadi (2.23), Kurungulam (2.308) and Pudukkottai (2.286) station as per the statistical values shown in Table 1. The river basin is dependent upon NEM rainfall for the agricultural activities to enhance food security. For the winter and summer season, a non-significant trend is noticed for all the stations. The non-significant trends were observed due to highly erratic nature of the rainfall. The higher Z statistical values specified in Table 1,

in yearly rainfall time scale indicates a positive trend in Alangudi (2.667), Kattumavadi (1.39), Pudukkottai (2.449) and Thirumayam (0.704) stations.

The precipitation trend magnitude is calculated by using the Sen's slope. In annual statistical information, the maximum trend magnitude is arrived in Alangudi and Pudukkottai stations by 12.7 and 10.5 respectively. The maximum trend magnitude of NEM season is identified in Alangudi and Kurungulam stations by 7.55 and 8.61 respectively. The values of most of the rain gauge stations having negative digits in statistics and negative slope for YMDR, SWM, summer and winter indicates the rainfall all over the basin is decreasing. The rainfall is received during the rainy season and the basin remains dry in other seasons prevailing drought conditions.

Table 1: M-K statistics for seasonal, Yearly maximum daily and annual rainfall

Stations	YMDR STATISTICAL DATA		SEASONAL STATISTICAL DATA								ANNUAL STATISTICAL DATA	
			SWM		NEM		WINTER		SUMMER			
	S	Z	S	Z	S	Z	S	Z	S	Z	S	Z
1 Adiramapattinam	-48	-0.509	-26	-0.271	45	0.498	71	0.761	3	0.021	0.341	0.021
2 Alangudi	247	2.667	303	3.272	231	2.492	63	0.692	57	0.607	349	3.771
3 Aranthangi	-81	-0.867	56	0.596	79	0.845	-42	-0.448	27	0.281	97	1.078
4 Iluppur	-37	-0.39	-7	-0.065	22	0.227	43	0.475	108	1.159	31	0.325
5 Kattumavadi	87	1.39	12	0.17	139	2.23	-12	-0.18	96	1.54	147	2.36
6 Keeranur	45	0.476	-87	-0.932	-26	-0.271	51	0.558	123	1.322	-120	-1.29
7 Kurungulam	59	0.628	-54	-0.574	214	2.308	8	0.079	-26	-0.271	109	1.170
8 Pattukkottai	9	0.086	-45	-0.476	122	1.311	21	0.217	-1	0	51	0.541
9 Perungalur	91	0.976	153	1.647	117	1.257	82	0.910	109	1.171	127	1.365
10 Pudukkottai	227	2.449	155	1.668	212	2.286	122	1.344	149	1.604	227	2.449
11 Thirumayam	66	0.704	138	1.484	167	1.799	126	1.376	78	0.834	199	2.145
12 Manaparai	-197	-2.124	-161	-1.733	-45	-0.476	18	0.195	-157	-1.69	-171	-1.842

Table 2: Trend assessment of seasonal, Yearly maximum daily and annual rainfall

Stations	YMDR STATISTICAL DATA		SEASONAL PERIOD STATISTICAL DATA								ANNUAL STATISTICAL DATA	
			SWM		NEM		WINTER		SUMMER			
	P	Trend	P	Trend	P	Trend	P	Trend	P	Trend	P	Trend
1 Adiramapattinam	0.610	N	0.786	N	0.633	N	0.786	N	0.983	N	0.983	N
2 Alangudi	0.008	I	0.001	I	0.013	I	0.489	N	0.544	N	0.000	I
3 Aranthangi	0.386	N	0.551	N	0.398	N	0.654	N	0.778	N	0.281	N
4 Iluppur	0.745	N	0.948	N	0.820	N	0.635	N	0.246	N	0.745	N
5 Kattumavadi	0.163	N	0.858	N	0.025	I	0.855	N	0.123	N	0.018	I
6 Keeranur	0.633	N	0.351	N	0.786	N	0.576	N	0.186	N	0.197	N
7 Kurungulam	0.530	N	0.566	N	0.021	I	0.936	N	0.786	N	0.242	N
8 Pattukkottai	0.931	N	0.633	N	0.190	N	0.827	N	1.000	N	0.588	N
9 Perungalur	0.329	N	0.099	N	0.209	N	0.363	N	0.242	N	0.172	N
10 Pudukkottai	0.190	N	0.095	N	0.022	I	0.179	N	0.109	N	0.014	I
11 Thirumayam	0.481	N	0.138	N	0.072	N	0.169	N	0.404	N	0.032	I
12 Manaparai	0.034	I	0.083	N	0.633	N	0.845	N	0.091	N	0.065	N

Conclusion

The precipitation variability is due to human influenced activities or change in climate is a crucial part for the development needs related to water resources management at a basin level. The results show that yearly maximum rainfall and NEM seasons has a significant escalating trend in central and north-western part of the basin. Most of the stations are having negative magnitude of Sen's slope indicates that the basin is undergoing drought conditions due to the variability of rainfall inter-annually in the current years. The present study concludes that the Agniyar river basin is prone to drought conditions due to global climate change. The streamflow is less during monsoon period and a prolonged dry condition prevails in the basin. The present condition is a serious hydrological threat which can create desertification condition in the Agniyar basin.

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Conflict of Interest
The authors do not have any conflict of interest.

Data Availability Statement
The manuscript incorporates rainfall datasets of 12 raingauge stations received from State Ground and Surface water resources data centre was examined throughout this research study.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required."

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