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Trend and Periodicity Analysis in Rainfall Pattern of Nira Basin, Central India

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Abstract

Seasonal and annual rainfall data of the stations: Akluj, Baramati, Bhor and Malsiras stations located in Nira Basin, Central India, were analyzed for studying trend and periodicity using 104 years' rainfall data. The analysis was carried out by using Mann-Kendall (MK), Modified Mann-Kendall (MMK) and Theil and Sen's slope estimator tests describing rising trend at all the stations. However, it is statistically significant at Akluj and Bhor stations at 10% significance level. Bhor station showed the maximum increase in percentage change *i.e.* 0.28% in annual rainfall. Monsoon and post-monsoon seasonal rainfall shows a rising trend while the summer and winter seasonal rainfall shows a falling trend. Wavelet analysis showed prominent annual rainfall periods ranging from 2 to 8 years at all the stations after 1960s resulting in describing more changes in the rainfall patterns after 1960s.

Keywords

Trend Analysis; MK; MMK; Autocorrelation; Wavelet Analysis; Nira Basin

1. Introduction

Non-stationary characteristics include many different periodic events in the earth science system which occurred in different time scale periods. A change in components, precipitation [1]-[6], temperature [7] [8], evaporation [9] [10], streamflow [11] [12]) and water quality [13] [14] in climatic and hydrologic time series all over around the world can be indicated through presence of increasing and decreasing trend. Apparently, in relation to changing rainfall pattern, there is no clear increasing or decreasing trend in the average amount of rainfall over India [15]-[17]. Significant trends have been found in monsoon rainfall on a regional scale [18]-[24].

In climatic and hydrologic time series, one of the most widely used nonparametric methods, *i.e*. Mann-Kendall

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[25] [26], has been used for trend studies [1] [27]-[29]. Autocorrelation in hydrological or climatic records commonly has made a detailed analysis on the effect of autocorrelation on trend and *vice versa* [30] [31]. Attempts to modify the Mann Kendall test to make it suitable for an analysis of auto-correlated series include the Modified Mann-Kendall (MMK) [32] [33]. The wavelet transform is a strong mathematical tool that provides a time-frequency representation of a signal in the time domain [34] [35] and hence is used for analyzing non-stationary processes such as hydro-meteorological variables [36]. Especially in meteorology and climatology, such analysis seems to be advantageous [37]. Wavelet transformations have been successfully applied to climate characteristics analysis, such as streamflow characterization [38], relationship between the north Atlantic oscillation and sea level changes [39], inter-annual temperature events and shifts in the global temperature [40], inter-decadal and inter-annual variations of annual and extreme precipitations [41] to study El Nino-Southern oscillation [42].

Climate has large spatial and temporal variations in India due to its vast size and geographical complexity [23]. Rainfall is one of the major indicators in the climate change impact studies which influences water resources system and agriculture sector of the region. Therefore, this study examined the historical variations in seasonal and annual rainfall pattern in the Nira basin of Maharashtra to observed effect of climate change on regional scale through trend and wavelet analysis.

2. Study Area and Data

The Nira catchment is a sub basin of the Bhima watershed located in the state of Maharashtra in India with an area of 6900 km^2 (**Figure 1**) having a total length of river about 180 km. It originates in Sahyadri hills in Bhor Tahsil and flows through Satara, Pune and Solapur districts. Karha is tributary of Nira Basin. The basin lies between 445 m to 1410 m with annual rainfall about 500 mm - 1000 mm. The banks of the Nira River are steep and rocky and its bed is generally gravelly. The agro based (especially sugar, distilleries, dairy, paper etc.); automobile and textile industries are comprised in the basin. Bajara, Wheat, Pulses, Sugar Cane, Maize etc. are

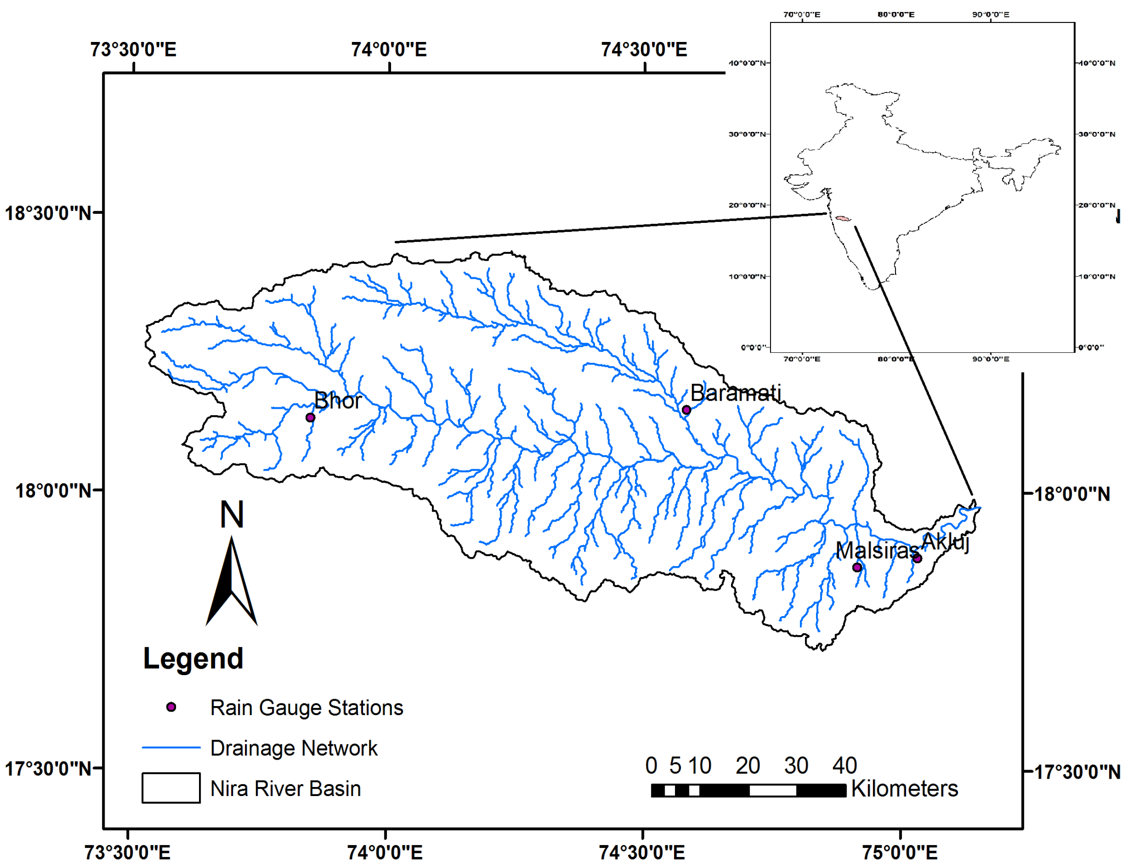

Figure 1. Nira river basin map.

crops being cultivated in the basin. Nowadays, horticultural activities are increasing particularly fruits of orange, sweet limes, grapes, banana etc.

Daily rainfall data from four raingauge stations were obtained from the India Meteorology Department, Pune (**Table 1**). According to the Indian Meteorological Department, four prominent seasons namely: 1) winter (December to February), 2) summer (March to May), 3) monsoon (June to September) and 4) post-monsoon (October and November) are present in India. For each month and season, the percent rainfall contribution of annual rainfall is shown in **Table 2**.

3. Methodology

3.1. Trend Analysis

Applying the rules of rainfall for missing data filling methods, all the data gaps were filled up by the normal ratio method for Bhor station and by a correlation coefficient weighted method for the other three stations using data from three nearby stations. The effect of autocorrelation on hydrologic data is one of the major concerns. The autocorrelation coefficient of rainfall series for lag 1 was estimated and its significance was checked by the student's t-test at 10% significance level. Rainfall trend detection was carried out for seasonal and annual series

Table 1. Rain gauge stations in Nira basin, Maharashtra.

Station	District	Latitude (deg)	Longitude (deg)	Altitude (m)
Akluj	Solapur	18.15	74.58	487
Baramati	Pune	18.13	74.85	548
Bhor	Pune	17.88	75.03	610
Malsiras	Solapur	17.87	74.92	526

Table 2. Annual percentage contribution of rainfall in each month and season at all stations.

Month	Akluj	Baramati	Bhor	Malsiras
Jan	0.45	0.70	0.12	0.82
Feb	0.65	0.16	0.05	0.18
Mar	1.88	0.36	0.22	0.47
Apr	3.94	1.11	1.17	1.64
May	13.60	5.05	2.69	3.80
Jun	13.46	16.78	15.59	17.52
Jul	13.44	10.79	34.29	12.85
Aug	11.84	10.84	22.03	11.50
Sep	16.78	30.09	12.40	27.43
Oct	9.12	17.11	8.17	15.96
Nov	2.19	5.36	2.79	5.66
Dec	1.26	1.05	0.50	1.60
Seasons				
Winter	2.22	1.92	0.67	2.60
Summer	16.37	6.51	4.07	5.91
Monsoon	48.65	38.41	71.91	41.88
Post-Monsoon	32.76	52.55	23.36	49.11

of four rainfall stations. The Mann Kendall (MK) test was used for non-autocorrelated rainfall series while the Modified Mann Kendall (MMK) tests for autocorrelated rainfall series at 10% significance level. Trend line and its significance were also checked using t-test statistics. Magnitude of trend slope was computed by Theil and Sen's median slope estimator. It is a non-parametric robust estimate indicates an increasing and decreasing tendency by a positive or negative value.

A single global trend over all four stations was obtained by using homogeneity test [13] [43].

3.2. Wavelet Analysis

Wavelet analysis was performed on the annual rainfall series for visualization of occurrence of events in a broad time scale by using available online tool http://paos.colorado.edu/research/wavelets/. Global wavelet spectrum and Morlet wavelet transform were used for the analysis of rainfall time series in order to clarify time-scale characteristics of measured series [42]. At the border of the wavelet power spectra a zone called the cone of influence, where zero padding has reduced the variance. Since we are dealing with finite-length time series, errors will occur at the beginning and end of the wavelet power spectrum [44].

The methodology in details with formulae was given in many above citied references, so has not been given in this study.

4. Results and Discussion

4.1. Seasonal and Annual Rainfall Trend

Monsoon and post monsoon seasons show maximum percent contribution of annual rainfall at all stations. More rainfall occurs in the monsoon months (June, July, August and September). The results of the autocorrelation analysis and MK test in case of non-autocorrelated and MMK test for autocorrelated series for trend detection in annual and seasonal series are shown in **Table 3**. All tests are considered at 10% significance level. Fourteen series are autocorrelated out of 20 series. Statistically significant rising trend are observed in annual rainfall series at Akluj and Bhor stations (**Figure 2**). Bhor has high variability in annual series than Akluj. There is no significant trend in annual rainfall at Baramati and Bhor stations (**Figure 3**). The magnitude of trend and percent change are also shown in **Table 3**. The magnitude of the increasing trends in annual rainfall ranged between 0.61 mm per year (at Malsiras) to 2.76 mm per year (at Bhor station). Bhor station (0.28%) showed the maximum increase in percentage change in annual rainfall over the 104 years period. In case of season, monsoon and post monsoon seasons have rising trend whereas falling trend observed for summer and winter seasons. The magnitude of trend in monsoon rainfall varied between −0.18 mm/year (Akluj) to 2.26 mm/year (Bhor). For summer series, the decrease in magnitude varied from 0.09 mm/year (Bhor) to 1.03 mm/year (Akluj station). The decrease in percentage change varied between 0.22% (Bhor) to 1.31% (Akluj) in summer season.

Changes in seasonal series depending on the time of year are shown in (**Figures 4-7**). There is an increase in the variability in post-monsoon since 1967 and less variability in summer at Akluj station. Bhor and Malsiras show variability only in monsoon season. The t-test statistics (**Table 4**) indicated that annual, monsoon, post-monsoon and summer rainfall trends in Nira basin to be significant at 10% levels. Hydrology of the basin and agriculture will influence by variability of post-monsoon as it contributes major share of annual rainfall.

For basin wide global annual and seasonal trend statement was obtained using MK/MMK statistics at 10% significance level (**Table 5**). From table, the null hypothesis is accepted for annual and seasonal trend as χ^2_{homog} was less than critical value at 10% significance level. That means the four stations have homogeneous trend over a Nira basin.

In the context of global climate change, basin has variation in the rainfall pattern. Decreasing tendency in the summer monsoon rainfall, increasing trend has been reported in the rainfall during pre-monsoon and post-monsoon months over Indian landmass [23]. The increasing trend was found in the monsoon precipitation along the west coast, north Andhra Pradesh and north-west India and decreasing trend over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala over 114 (1871-1984) years [45].

4.2. Application of Wavelet Analysis on Annual Rainfall Series

Wavelet analysis is used to verify the trends in the series. The intensity of energy distribution of different time

Table 3. Results of Autocorrelation and MK/MMK statistics (Z), Theil and Sen's slope estimator and % change and for annual and seasonal rainfall series.

Series	Station	Autocorrelation	MK (MMK)	Trend	Theil and Sen's Slope	% change
Annual	Akluj	Y	1.667	↑	1.11	0.23
	Baramati	Y	1.456	-	0.81	0.17
	Bhor	Y	3.075	↑	2.76	0.28
	Malsiras	N	0.934	-	0.61	0.12
Monsoon	Akluj	Y	−0.443	-	−0.18	−0.08
	Baramati	Y	0.454	-	0.12	0.06
	Bhor	Y	2.969	↑	2.26	0.32
	Malsiras	Y	2.056	↑	0.70	0.32
Post-Monsoon	Akluj	Y	4.909	↑	1.73	1.10
	Baramati	Y	1.758	↑	0.81	0.32
	Bhor	Y	1.943	↑	0.67	0.29
	Malsiras	N	0.00	-	0.0	0.00
Summer	Akluj	Y	−5.519	↓	−1.03	−1.31
	Baramati	N	−3.183	↓	−0.13	−0.41
	Bhor	Y	−1.429	-	−0.09	−0.22
	Malsiras	N	−2.079	↓	−0.15	−0.48
Winter	Akluj	Y	−0.465	-	0.0	0.00
	Baramati	N	−2.594	↓	0.0	0.00
	Bhor	Y	−1.052	-	0.0	0.00
	Malsiras	N	−2.326	↓	0.0	0.00

(Note: Y and N indicate presence of serial independence at lag 1 autocorrelation in rainfall series respectively; upward and downward arrows indicates rising and falling trend; respectively).

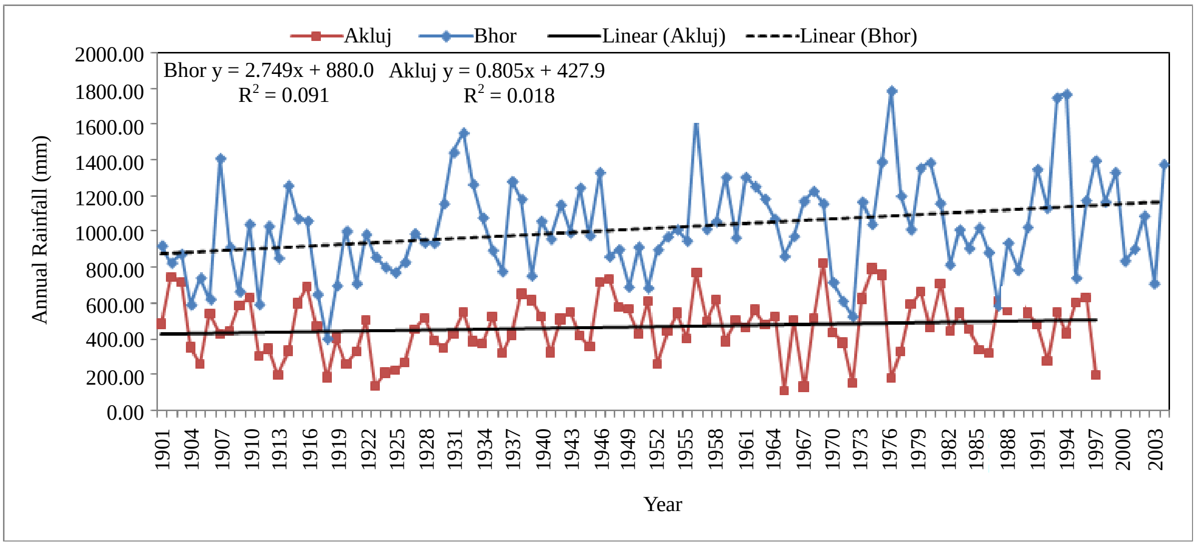

Figure 2. Annual rainfall trend at Akluj and Bhor station.

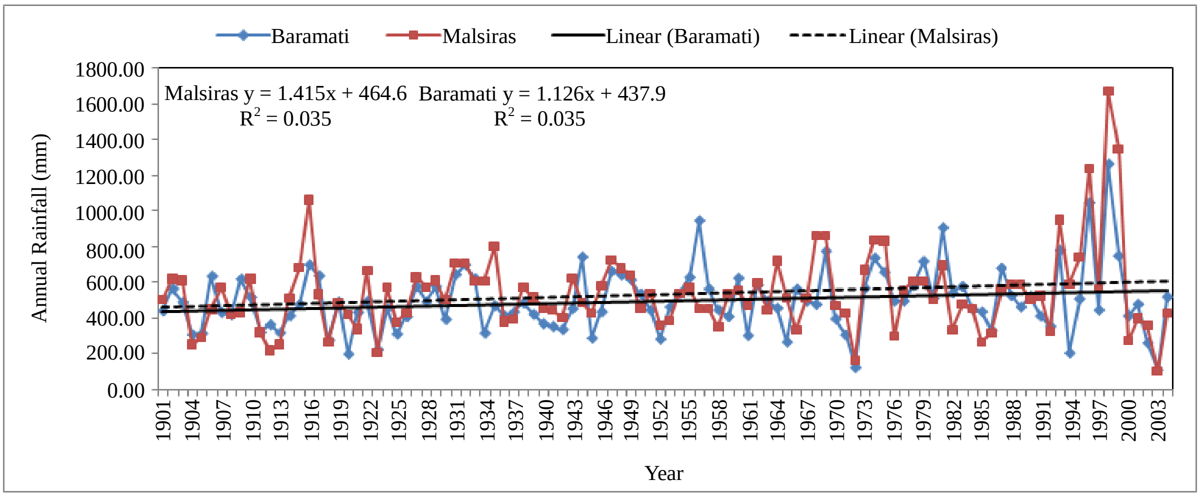

Figure 3. Annual rainfall trend at Baramati and Malsiras station.

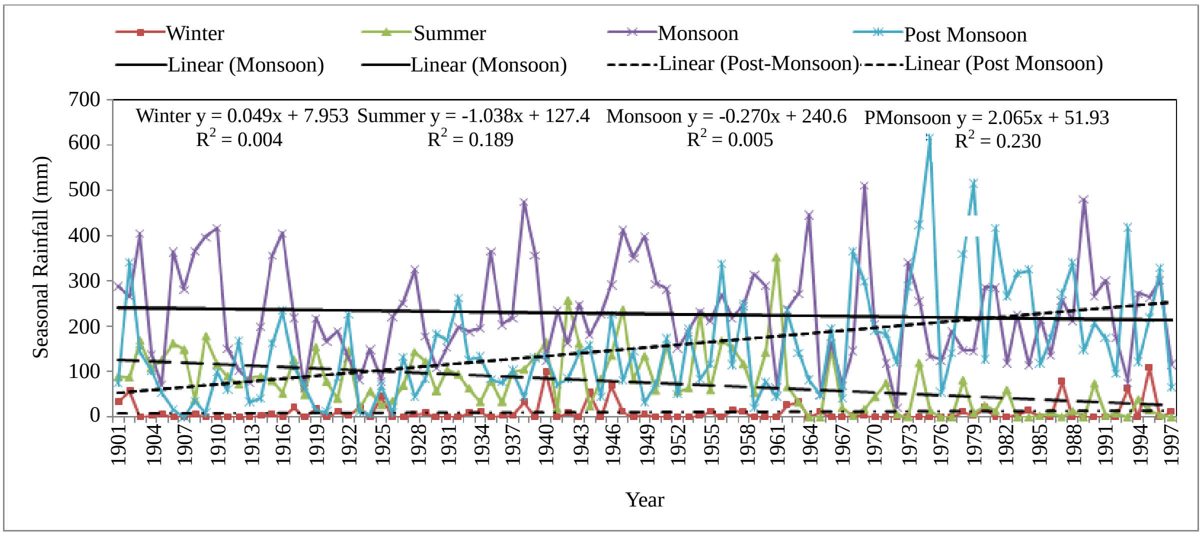

Figure 4. Seasonal rainfall trends at Akluj station.

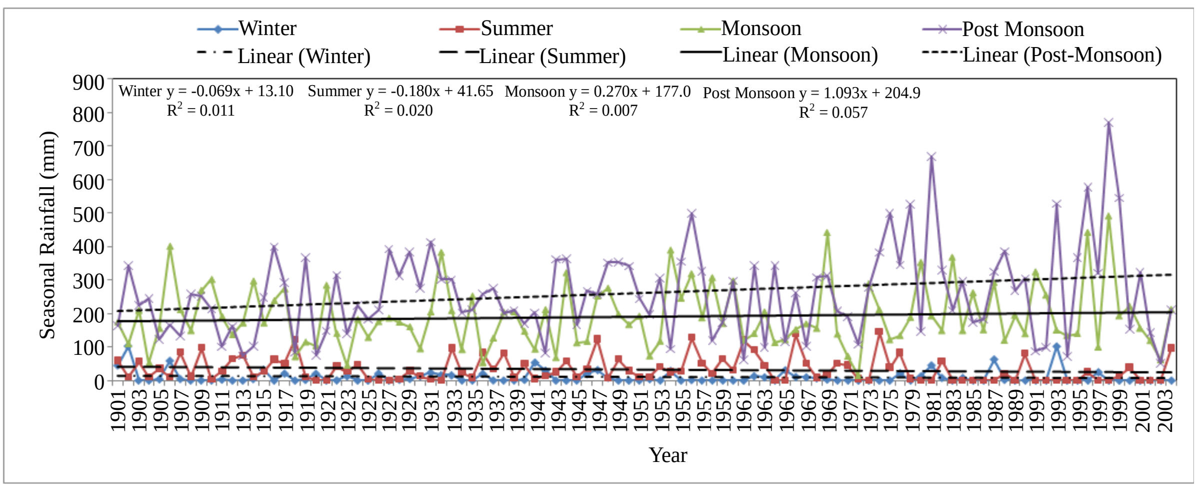

Figure 5. Seasonal rainfall trends at Baramati station.

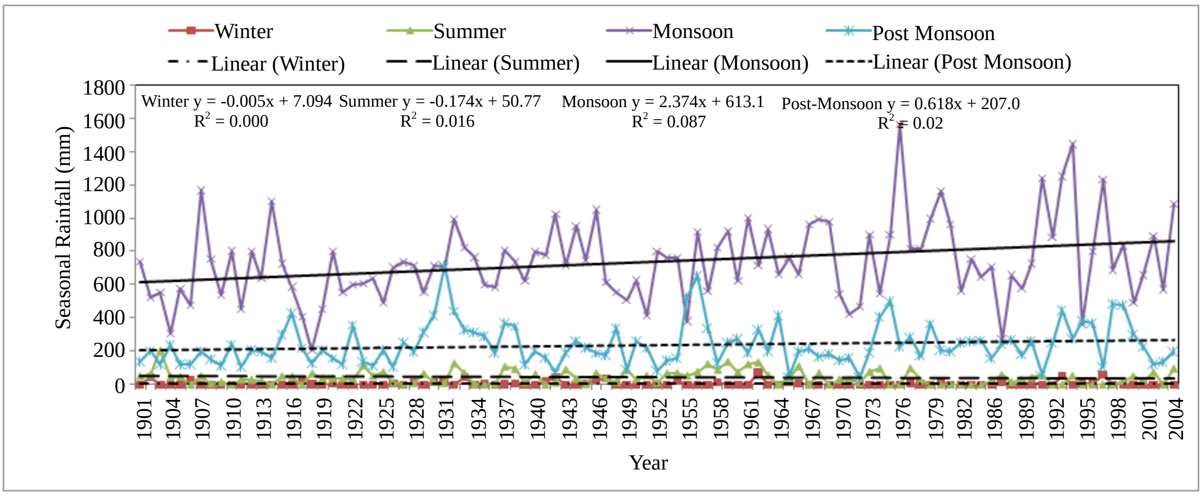

Figure 6. Seasonal rainfall trends at Bhor station.

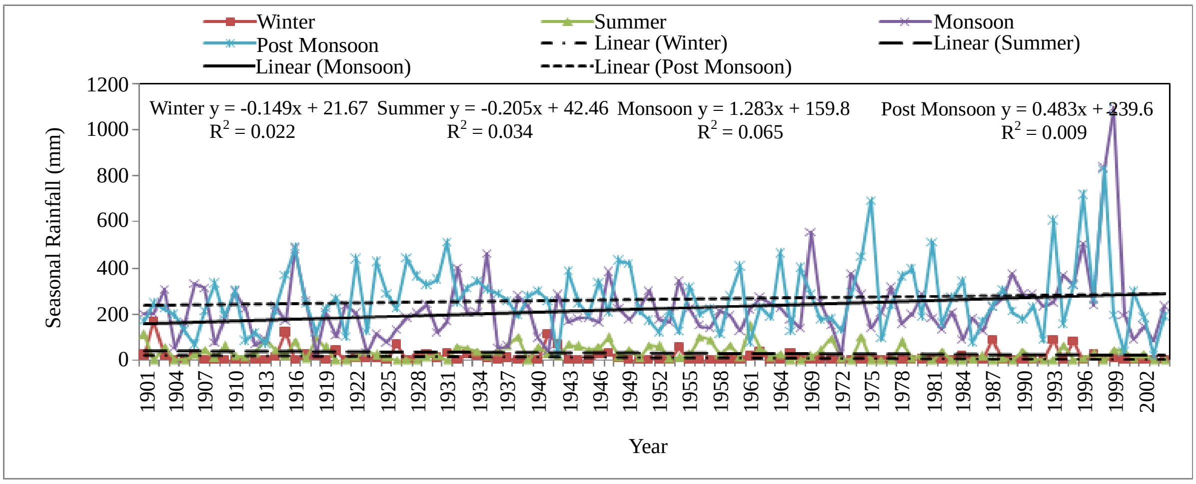

Figure 7. Seasonal rainfall trends at Malsiras station.

scale signal for annual rainfall series can be seen in Figure 8 and annual rainfall series are shown in Figures 8(a) and 8(b) show the power (absolute value squared) of the wavelet transform for the annual rainfall of all rain-gauge stations. This gives information on the relative power at a certain scale and a certain time, that means period where it oscillates with the corresponding frequency. In the case of the annual rainfall series, most of the high power (red colour) can be found concentrated within a band of 2 - 8 and 4 - 8 years at Akluj and other three stations during 1960-1980. Also higher intensity (red colour) has been observed for 2 - 8 years during recent four decades for all stations except Akluj. Due to edge effects of wavelet processing, the cone of influence which represent the periods with uninter-pretable is also shown in Figure 8(b) (hatched areas) and consequently they should be ignored in all analysis. More than 10 - 16 years periods are the apparent periodicity at the beginning and end of the time-series which is not real. The wavelet analysis clearly shows a noticeable change in the rainfall pattern after 1960'.

That means periodic component are responsible for producing increasing trend in the annual rainfall series of all stations and change in rainfall pattern after 1960. This fact might be due to climate change as larger anthropogenic trends are recorded during the period of 1960-1990 [46] [47].

5. Conclusion

This study reveals significant changes in seasonal and annual rainfall in Nira river basin of Maharashtra, Central

Table 4. t-test significance for linear equation.

Series	Station	Linear Equation	t-test statistics
Annual	Akluj	y = 0.805x + 427.9	1.345
	Baramati	y = 1.126x + 437.9	1.915*
	Bhor	y = 2.749x + 880.0	3.224*
	Malsiras	y = 1.415x + 464.6	1.916*
Monsoon	Akluj	y = −0.270x + 240.6	−0.696
	Baramati	y = 0.270x + 177.0	0.858
	Bhor	y = 2.374x + 613.1	3.104*
	Malsiras	y = 1.283x + 159.8	2.649*
Post-Monsoon	Akluj	y = 2.065x + 51.93	5.337*
	Baramati	y = 1.093x + 204.9	2.476*
	Bhor	y = 0.618x + 207.0	1.533
	Malsiras	y = 0.483x + 239.6	0.99
Summer	Akluj	y = −1.038x + 127.4	−4.716*
	Baramati	y = −0.180x + 41.65	−1.457
	Bhor	y = −0.174x + 50.77	−1.297
	Malsiras	y = −0.205x + 42.46	−1.883*
Winter	Akluj	y = 0.049x + 7.953	0.643
	Baramati	y = −0.069x + 13.10	−1.095
	Bhor	y = −0.005x + 7.094	−0108
	Malsiras	y = −0.149x + 21.67	−1.524

(*10% significance level).

Table 5. Homogeneity of stations by Chi-square statistic.

Null Hypothesis: Stations are homogeneous with respect to trends	
Trend	χ^2_{homog}
Annual	−35.653*
Monsoon	−7.690*
Post-Monsoon	−43.18*
Summer	−99.19*
Winter	−27.98*

*null hypothesis accepted at 10% significance level

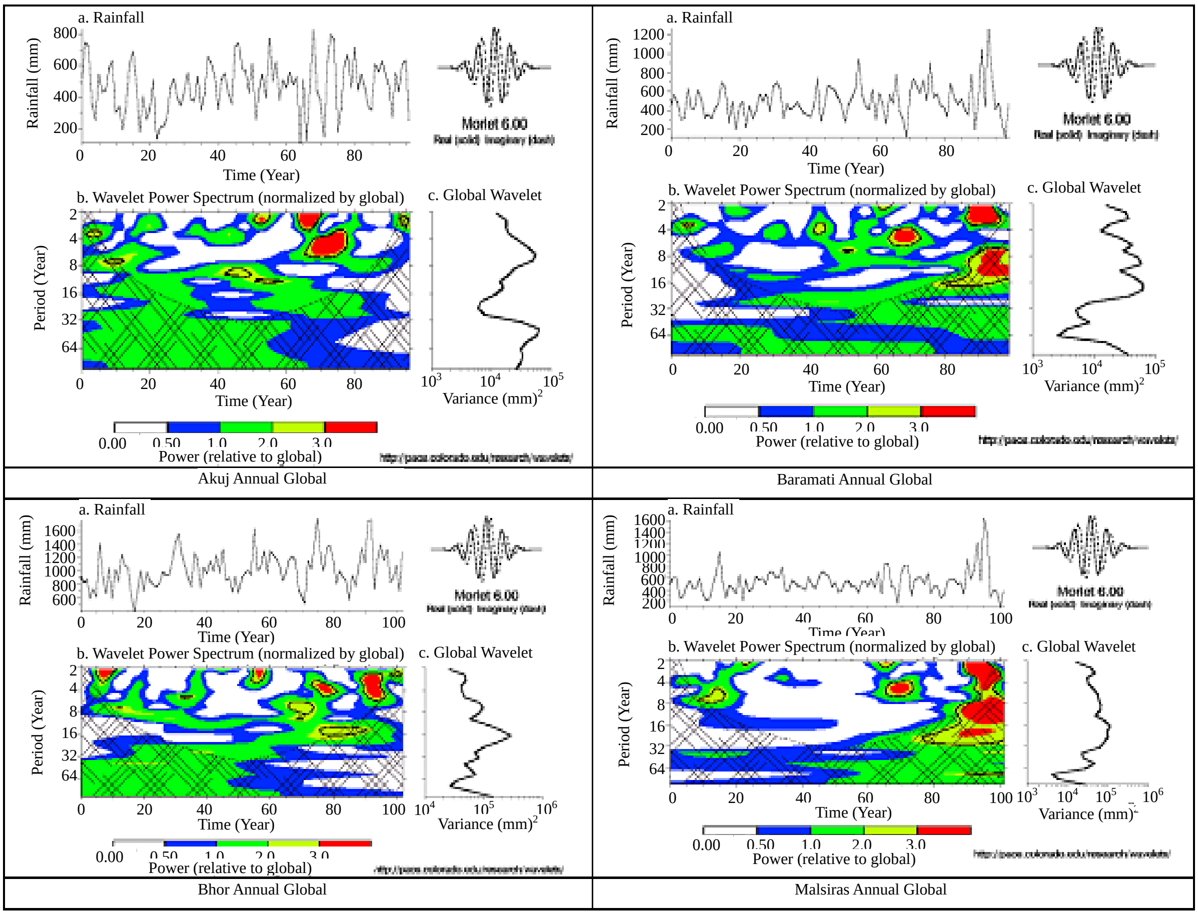

Figure 8. (a) Annual Rainfall. (b) The Wavelet Power Spectrum. The power has been scaled by the global wavelet spectrum (at right). The cross-hatched region is the cone of influence, where zero padding has reduced the variance. Black contour is the 10% significance level, using the global wavelet as the background spectrum. (c) The Global Wavelet Power Spectrum.

India during past 104 years. Significant increasing trends are detected in annual rainfall at 10% significance level for the Akluj and Bhor stations. Seasonal rainfalls in the basin have increased especially during the monsoon and post-monsoon seasons. Bhor station shows maximum change in the magnitude of trend for annual and monsoon series. The wavelet analysis shows that periodicity of 2 - 8 years is found in annual rainfall after 1960 confirming the well-known fact that more changes in the rainfall pattern have occurred after 1960. The analysis shows that larger anthropogenic trends are embedded in the climate data in the baseline period *i.e.* during 1961 to 1990. It is possible that climatic changes taking place after 1960 might have affected the rainfall pattern in the basin which needs further investigations. The analysis of rainfall data and findings shall be useful for irrigation and agricultural managers and may play an important role in managing water resources in the basin.

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