CHAPTER 7

APPLICATION OF NOVEL TREND APPROACH: VARIABLE SIZED CLUSTER ANALYSIS (VSCA)

7.1 General

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear. The MK test can be used in place of a parametric linear regression analysis, which can be used to test if the slope of the estimated linear regression line is different from zero. the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test; that is, the MK test is a non-parametric (distribution-free) test. Thus, a Novel tool, VSCA, has been developed using repeated application of MK test over the time period and has been implemented over Uttar Pradesh and Jharkhand states.

7.2 Application of VSCA over Uttar Pradesh

Figures (7.1, 7.4, 7.7 … 7.52) show a 3-D triangular zone constituted by an erratic surface and a green color flat triangular surface. Since the minimum size of the data cluster adopted for determining the trend is 10, the first point for the erratic surface is placed at (Tb=1, Te=10) with its corresponding Z-statistic. The last point of the computed erratic surface will be at (Tb=1, Te=118). The elevation of the erratic surface at any given point represents Z-statistic for that point. The magnitude of Z-statistic was found to vary in the range of -6 to 4 for all districts; therefore, the graph's color spectrum was chosen accordingly. The light green and blue color shades show decreasing (Z positive) trend, whereas yellow to red color combinations represent an increasing trend. It is important to note that the triangular flat green surface is not utilized because the data cluster for implementing the MK test begins from a given starting year until at 118th data at the ending year. For example, if the data cluster starts from 41st data, the value of the first Z-statistic for this case will be plotted at (T_b=41, T_e=50). The non-availability of Z-value below T_b =41 causes a flat green surface to appear in Figures (7.1, 7.4, 7.7 … 7.51). Moreover, a similar situation prevails for each starting time. The total number of data in a series is 118, and the first data cluster that has been adopted to yield Z-score at T_b=1 comprises 10 data (1st to 10th of a given series), and subsequent data clusters comprise 11, 12, 13…118 data points respectively as one move along ordinate axis. As starting year (T_b) is increased, say 2, the first data of the cluster will be the 2nd data and the last data as of 11th. Subsequent clusters are constituted by 2nd to 12th, 2-13th, 2-14th, and so on.

7.2.1 Precipitation Characteristics of Agra

3D and 2D patterns of precipitation characteristics for Agra are shown in Figures 7.1-7.2, and modified PMW statistics are plotted in Figure 7.3. The multi-modal characteristics of the pattern of the trend are visible in Figure 7.1, and it clearly shows two zones of the trough (corresponding to Patches 1&3 in 2D Figure 7.2) and one zone of a crest (Patch 2 in Figure 7.2). Zone 1 signifies a reducing precipitation trend during decades around the 40s compared to the initial decades of the 19th century. A distinct disruption in the continuity of the shades of the color along the line drawn parallel to the x-axis at ending year 118 is evident in Figure 7.2 that corresponds to the starting year 41st year around. This point refers to the change in precipitation trend while considering the overall time duration of the data series. Figure 7.3 also demonstrates a similar pattern of the trend of precipitation as that observed in Figure 7.2. The variable-sized cluster analysis here also enabled one to identify the change point and demonstrate the pattern of the trend that occurred over various spans of time for a century-long duration. Thus, VSCA owns the potential to detect one or even more change points if they occurred over the long duration of the study period. The same is evident from Figures 7.1-7.2.

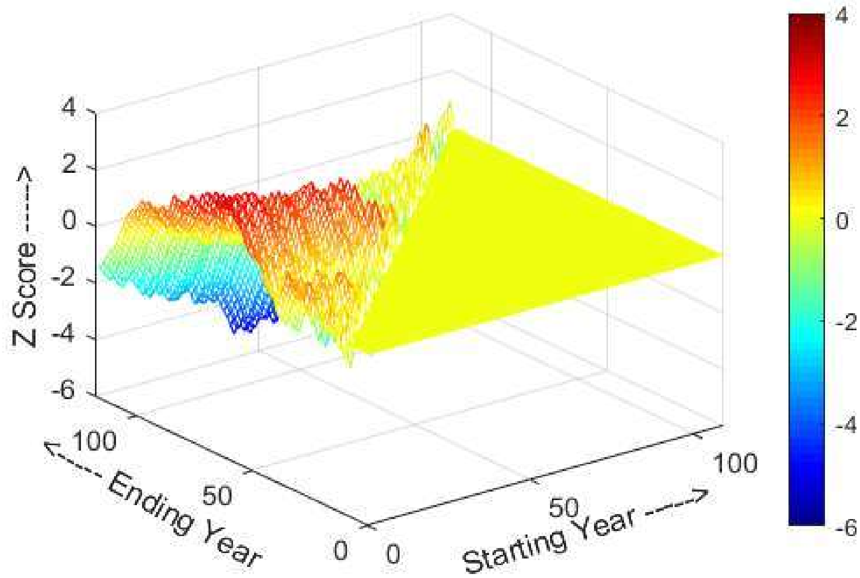

Figure 7.1 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Agra.

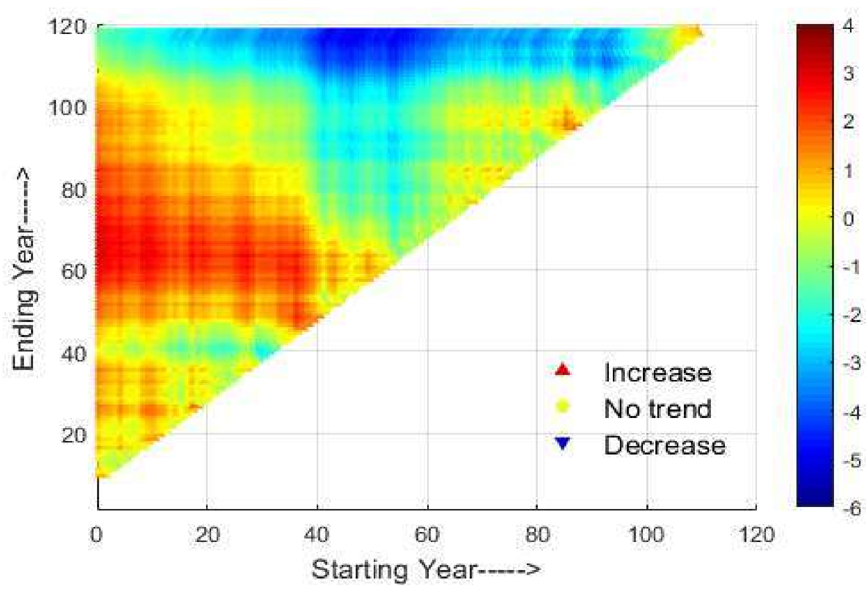

Figure 7.2 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Agra

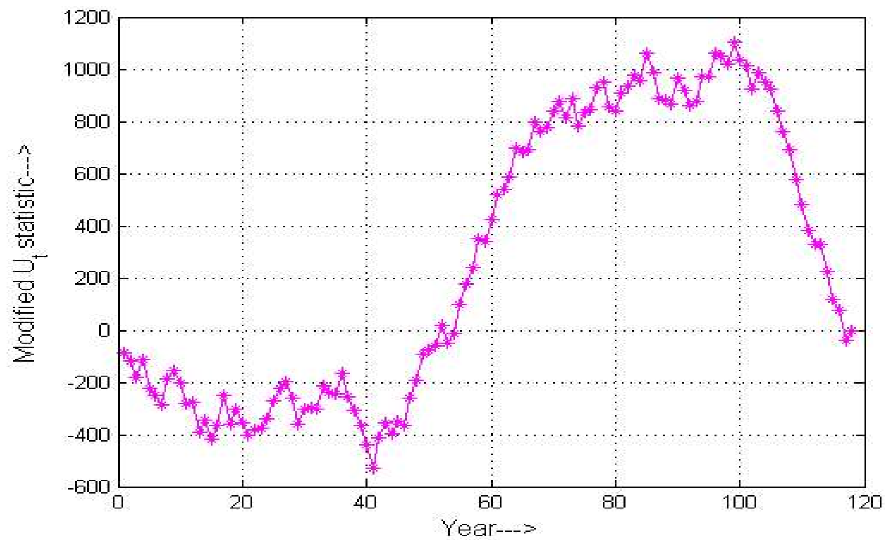

Figure 7.3 Variation of modified U_t over the years for ascertaining change points for Agra

7.2.2 Precipitation Characteristics of Aligarh

Figures 7.4-7.5 represent 3D, and 2D patterns of precipitation characteristics and modified PMW statistics are plotted in Figure 7.6 for Aligarh. The points on the line drawn parallel to the x-axis at ending year 118 display several changes in the shades of the color. Disruption in the continuity of the shades of the color is marked as the change point. The occurrences of these points at around 29th, 41^{st,} and 96th years respectively demonstrate the change in the pattern of the trend of precipitation. The multi-modal characteristics of the pattern of the trend are clearly visible in Figure 7.4, and it shows two zones of the trough (corresponding to patches 1&3 in 2D Figure 7.5) and one zone of a crest (Patch 2). The modified PMW statistics plotted in Figure 7.6 confirm a similar pattern as well of the trend. In fact, the PMW test uses a single maximum value of U_t to give only one change point for the overall time span. However, the variable-sized cluster analysis enables one to identify the various change points that might have occurred in the available historical record of precipitation data. Thus, VSCA owns the potential to detect multiple change points if they occurred over the long duration of the study period. The same is evident from Figures 7.4-7.5.

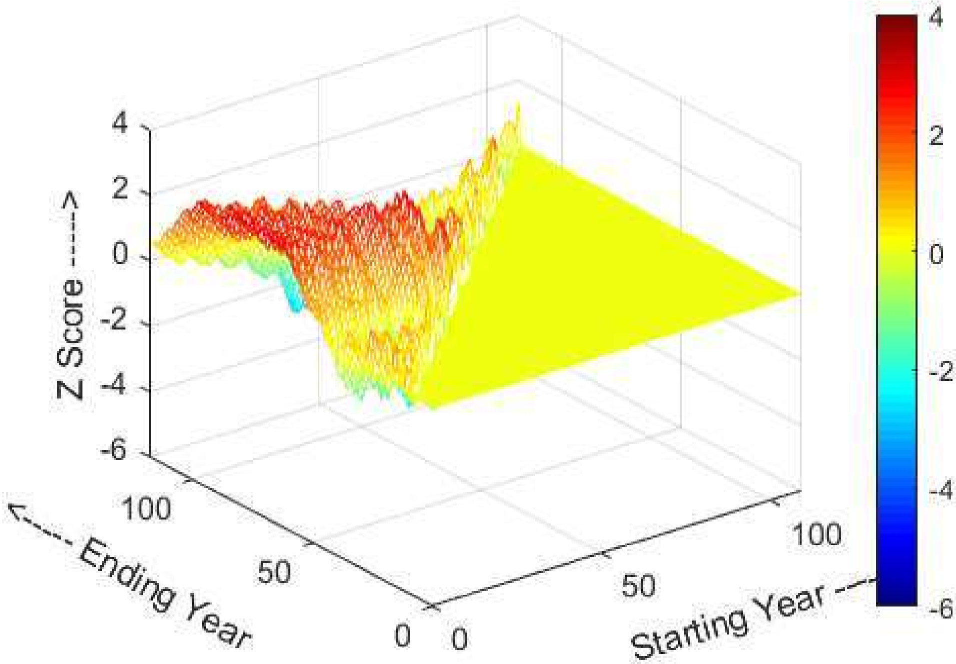

Figure 7.4 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Aligarh.

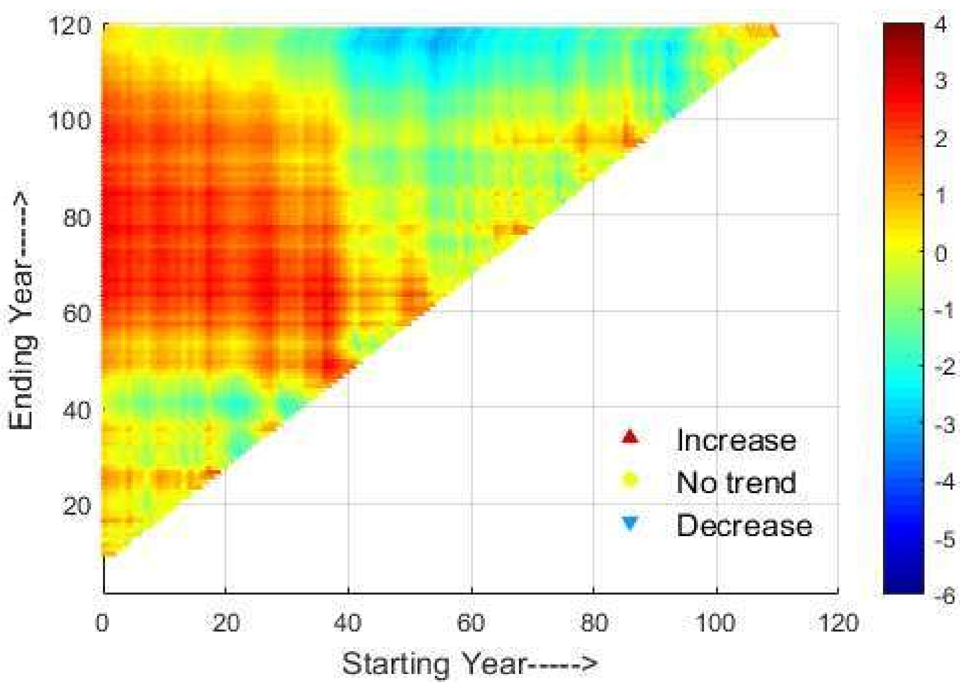

Figure 7.5 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Aligarh

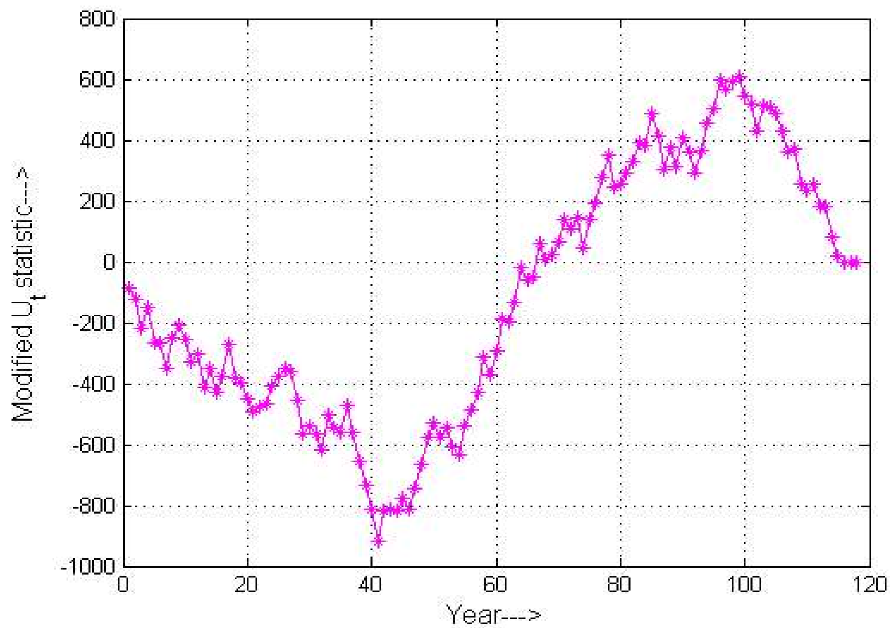

Figure 7.6 Variation of modified U_t over the years for ascertaining change points for Aligarh

7.2.3 Precipitation Characteristics of Allahabad (Prayagraj)

3D and 2D visualizations of the pattern of the trend for Allahabad (Prayagraj) are shown in Figures 7.7-7.8 and modified PMW statistics in Figure 7.9. Two zones that correspond to crest and trough, respectively, are visible in Figure 7.7. These Zones 1-2 correspond to the two Patches 1-2 respectively in Figure 7.8. The Patch-2 shows a reducing precipitation trend during the years ahead of the 90s compared to the earlier decades of the 19th century. It is important to note that Patch-2 is of mostly blue shade toward the end of the year. This Patch-2 is created by the data clusters of larger size (118, 117, 116…) with a similar trend depicted by all clusters of data after the 1990s. That enables one to have more confidence in the result (reducing trend) than the trend analysis carried out by a data cluster of a single size, i.e., involving the total length of the data series. Two distinct disruptions in the continuity of the shade of the color along the Patch-2 have been marked at 63rd and 81st year as the year of major change in the trend of precipitation. The distinction of the Patches 1-2 shown in Figure

7.8 corresponds to the two Zones (1-2) of crest and trough in Figure 7.7, representing a less distinctive precipitation regime with no or slight increase, and distinctly reducing regime. The modified PMW statistics determined based on overall time series are plotted in Figure 7.9, and it demonstrates the similar change identified by Figures 7.7-7.8. Thus, VSCA detected more change points over the long duration of the study period.

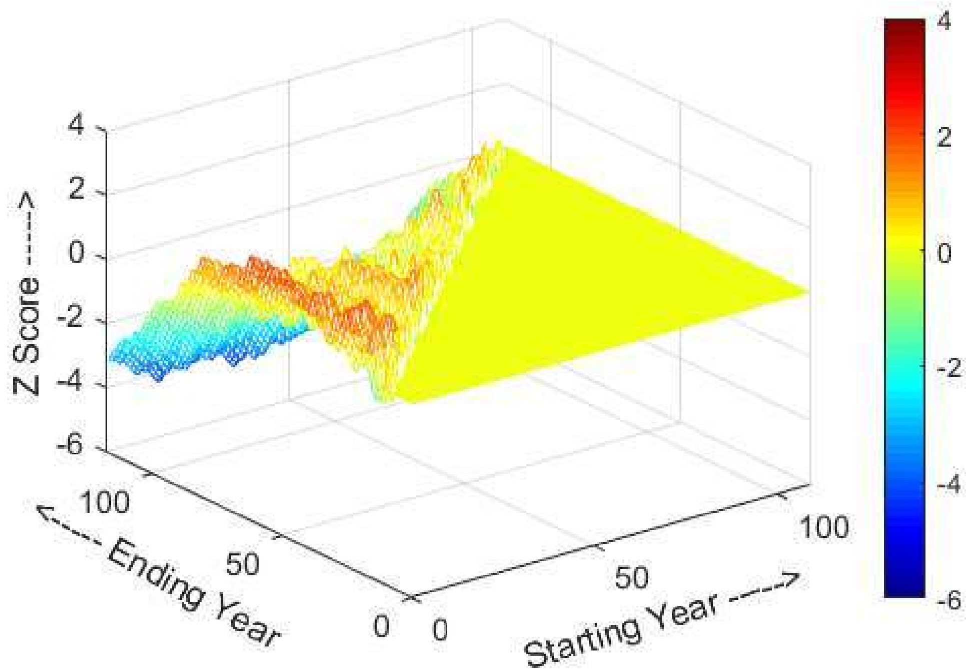

Figure 7.7 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Allahabad.

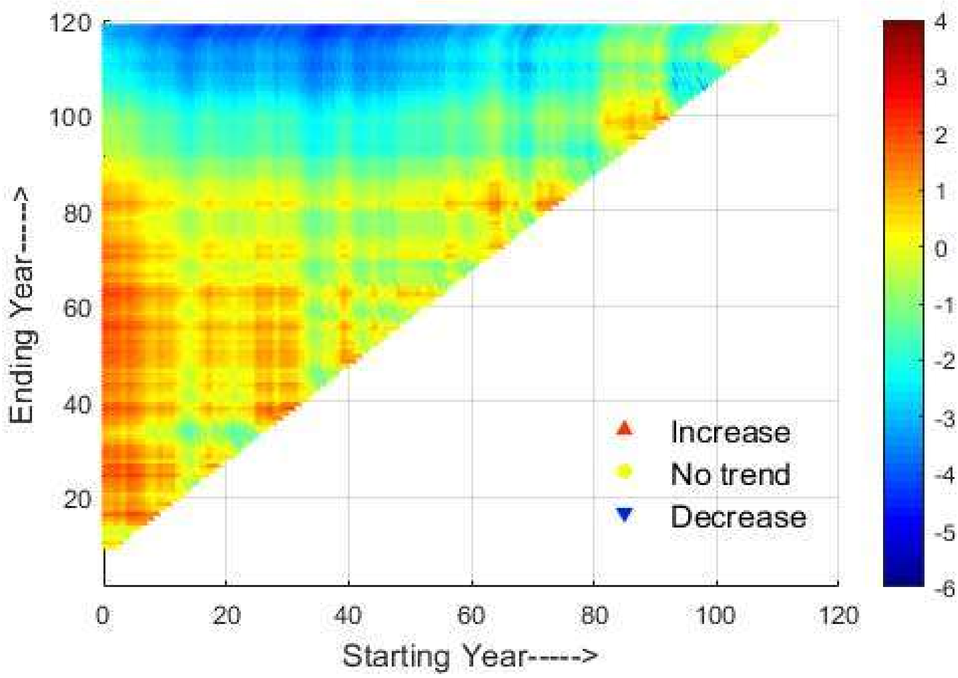

Figure 7.8 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Allahabad

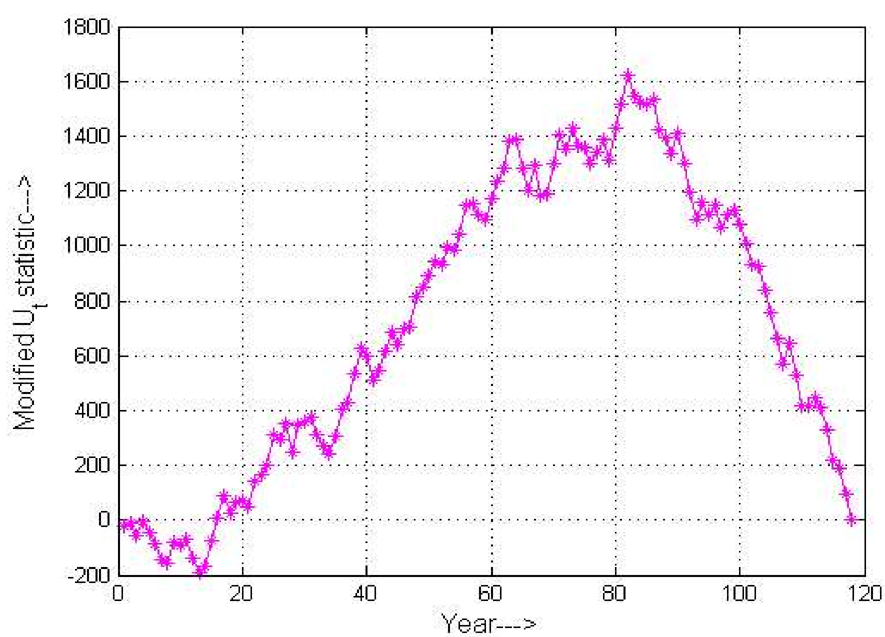

Figure 7.9 Variation of modified U_t over the years for ascertaining change points for Allahabad

7.2.4 Precipitation Characteristics of Azamgarh

Figures 7.10-7.11 show 3D and 2D patterns of precipitation characteristics, whereas, Figure 7.12 displays modified PMW statistics for Azamgarh. Two patches 1-2 are clearly evident in Figure 7.11, which separate the corresponding two zones of crest and depression visible in Figure 7.10. The multi-modal characteristics of the pattern of the trend in Figure 7.10 and the 2D pattern in Figure 7.11 were utilized to identify the change points for the Azamgarh district. Variation in the shades of the color along the line drawn parallel to the x-axis at ending year 118 is visible in 2D Figure 7.11. Alteration in the continuity of the shades of the color is identified as the point where a significant change in the trend has occurred. The occurrences of change in the trend can be marked at around 17^{th}, 63^{th}, $73^{st,}$ and 82^{nd} year (on the x-axis). These multiple change points are more distinct in Figure 7.10, where they cause the formation of crests and/or troughs. In order to identify the multiple change points, modified U_t statistics have been plotted in Figure 7.12. The PMW statistics plotted in Figure 7.12 demonstrated the same change points as obtained by the 2D/ 3D figures for the trend pattern. As against the PMW test that yields a single change point (82^{nd} year), VSCA offered multiple change points.

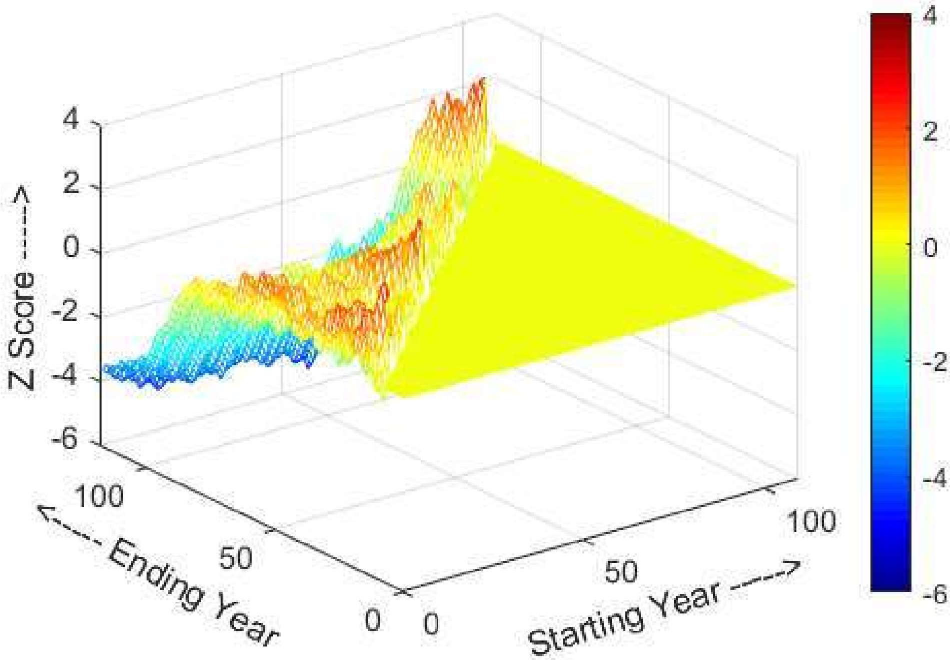

Figure 7.10 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Azamgarh.

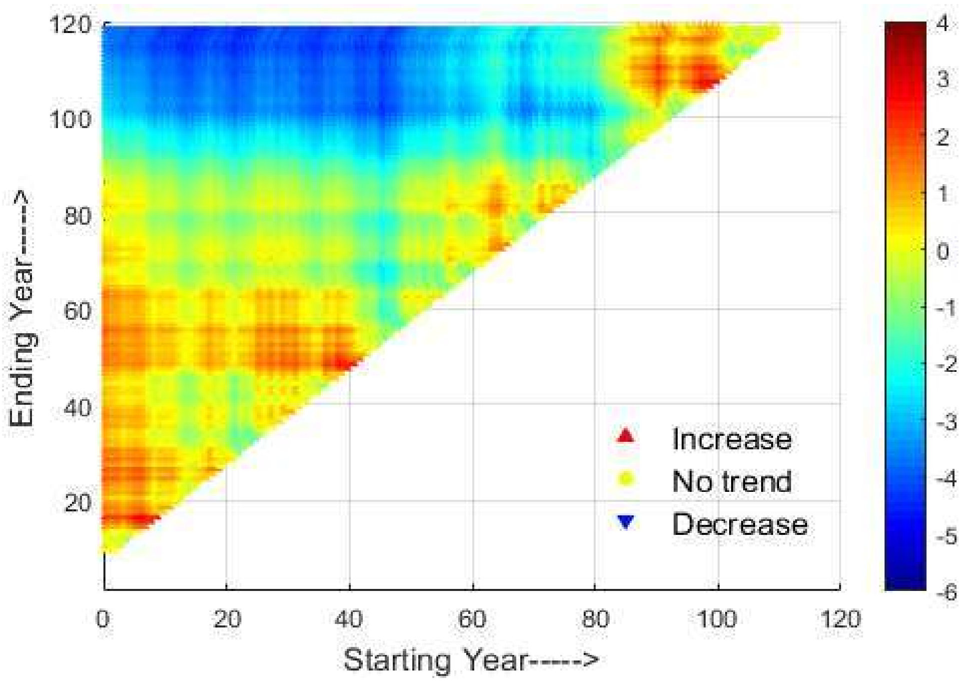

Figure 7.11 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Azamgarh

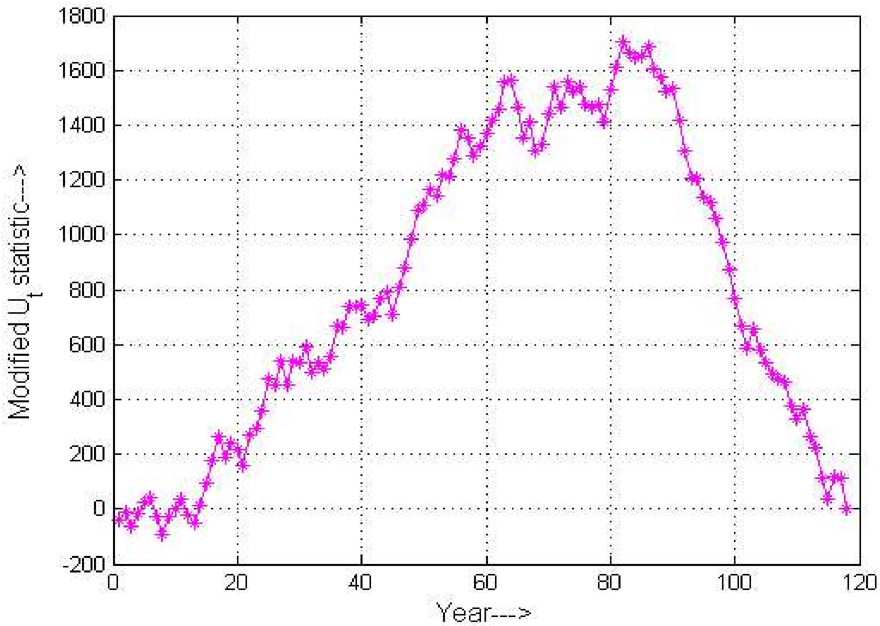

Figure 7.12 Variation of modified U_t over the years for ascertaining change points for Azamgarh

7.2.5 Precipitation Characteristics of Bareilly

Figures 7.13-7.14 represent 3D and 2D patterns of precipitation characteristics, and modified PMW statistics are plotted in Figure 7.15 for Bareilly. The points on the line drawn parallel to the x-axis at ending year 118 display several changes in the shades of the color. Disruption in the continuity of the shades of the color is marked as the change point. The occurrence of these points at around 14^{th}, 27^{th}, 41^{st}, $51^{th,}$ and 82^{nd} year, respectively, demonstrates the change in the pattern of precipitation trend. The multi-modal characteristics of the pattern of the trend are clearly visible in Figure 7.13, and it shows two zones of the trough (corresponding to patches 1&3 in 2D Figure 7.14) and one zone of the crest (Patch 2). The modified PMW statistics plotted in Figure 7.15 confirm a similar pattern as well of the trend. In fact, the PMW test uses a single maximum value of U_t to give only one change point for the overall time span. However, the variable-sized cluster analysis enables one to identify the various change points that might have occurred in the available historical record of precipitation data. Thus, VSCA owns the potential to detect multiple change points if they occurred over the long duration of the study period. The same is evident from Figures 7.13-7.14.

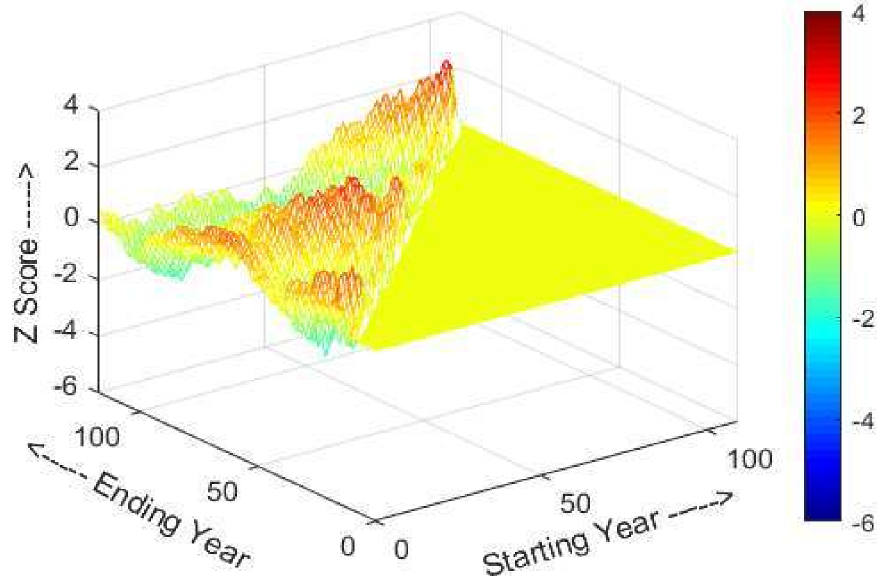

Figure 7.13 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Bareilly

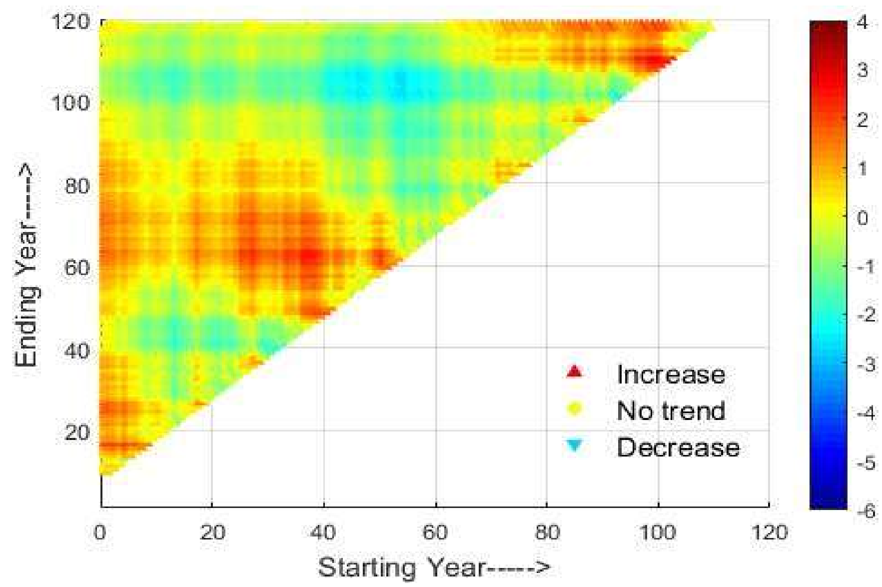

Figure 7.14 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Bareilly

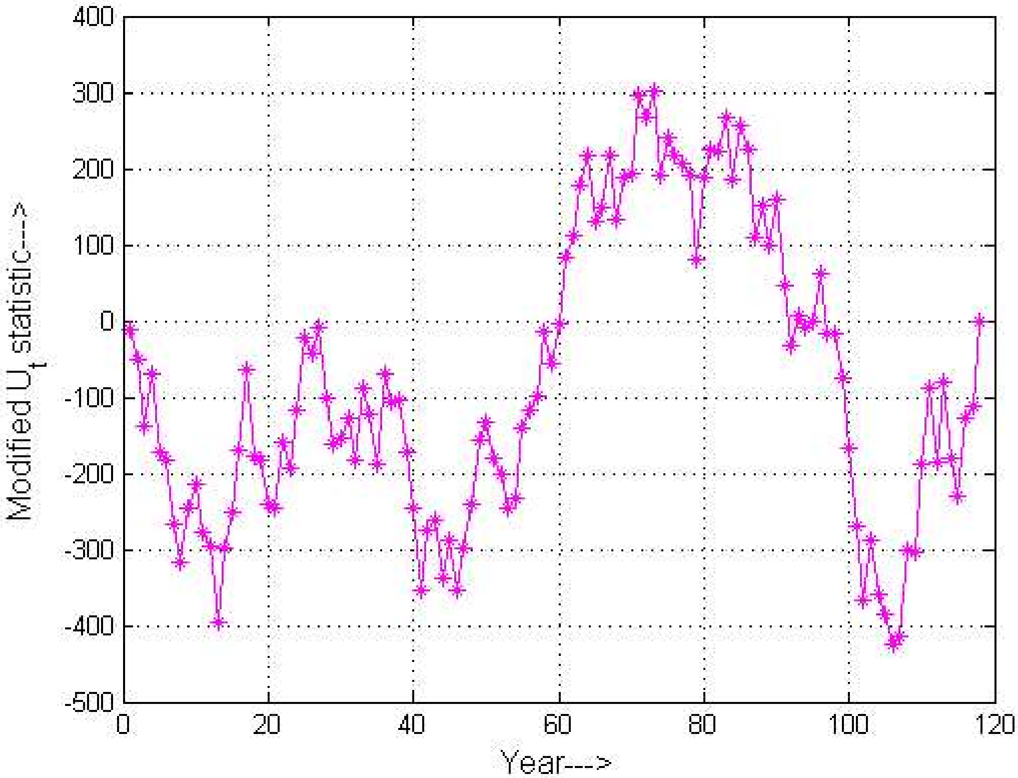

Figure 7.15 Variation of modified U_t over the years for ascertaining change points for Bareilly

7.2.6 Precipitation Characteristics of Basti

Figures 7.16-7.17 represent 3D and 2D patterns of precipitation characteristics, and modified PMW statistics are plotted in Figure 7.18 for Basti. The points on the line drawn parallel to the x-axis at ending year 118 display several changes in the shades of the color. Disruption in the continuity of the shades of the color is marked as the change point. The occurrences of these points at around 16th, 62^{th,} and 82nd year respectively demonstrate the change in the pattern of precipitation trend. The multi-modal characteristics of the pattern of the trend are clearly visible in Figure 7.16, and it shows two zones of the trough (corresponding to patches 1&3 in 2D Figure 7.17) and one zone of a crest (Patch 2). The modified PMW statistics plotted in Figure 7.18 confirm a similar pattern as well of the trend. In fact, the PMW test uses the single maximum value of U_t to give only one change point for the overall time span.

However, the variable-sized cluster analysis enables one to identify the various change points that might have occurred in the available historical record of precipitation data. Thus, VSCA owns the potential to detect multiple change points if they occurred over the long duration of the study period. The same is evident from Figures 7.16-7.17.

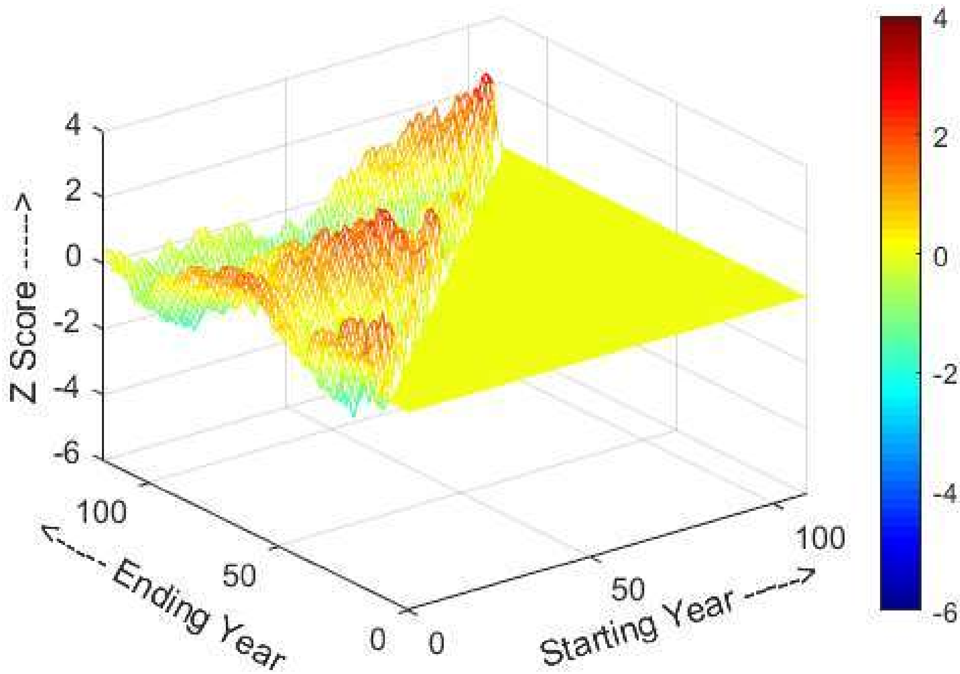

Figure 7.16 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Basti

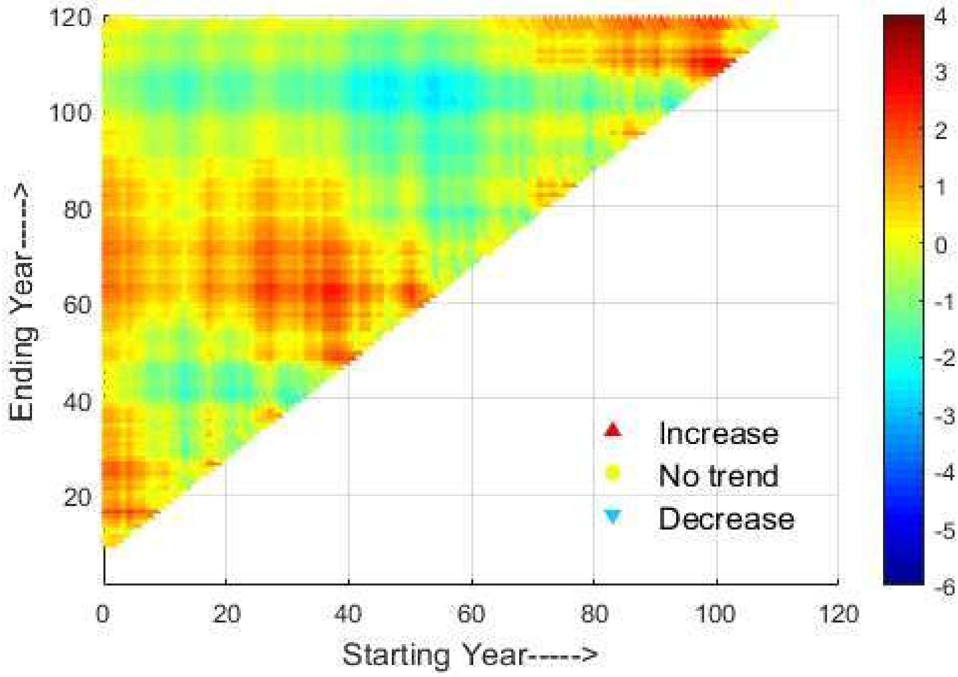

Figure 7.17 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Basti

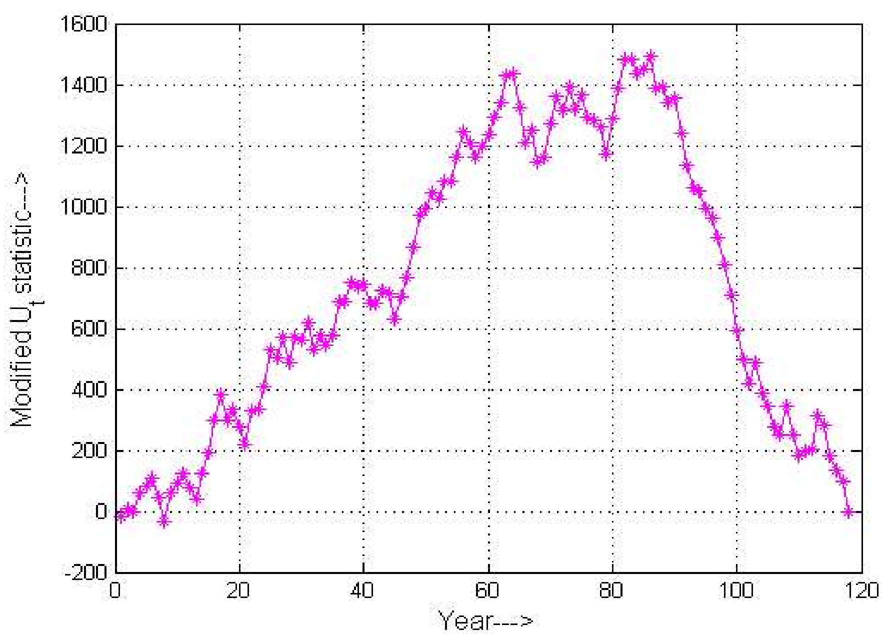

Figure 7.18 Variation of modified U_t over the years for ascertaining change points for Basti

7.2.7 Precipitation Characteristics of Chitrakoot

Figures 7.19-7.20 show 3D and 2D patterns of precipitation characteristics, whereas, Figure 7.21 displays modified PMW statistics for Chitrakoot. Two patches 1-2 are clearly evident in Figure 7.20, which separate the corresponding two zones of crest and depression visible in Figure 7.19. The multi-modal characteristics of the pattern of the trend in Figure 7.19 and the 2D pattern in Figure 7.20 were utilized to identify the change points for the district of Chitrakoot. Variation in the shades of the color along the line drawn parallel to the x-axis at ending year 118 is visible in 2D Figure 7.20. Alteration in the continuity of the shades of the color is identified as the point where a significant change in the trend has occurred. The occurrences of change in the trend can be marked at around 16th, 63th, 82^{nd,} and 98th year (on x-axis). These multiple change points are more distinct in Figure 7.19, where they cause the formation of crests and/or troughs. In order to identify the multiple change points, modified U_t statistics have been plotted in Figure 7.21. The PMW statistics plotted in Figure 7.21 demonstrated the same change points as obtained by the 2D/ 3D figures for the pattern of the trend. As against the PMW test that yields a single change point (82nd year), VSCA offered multiple change points.

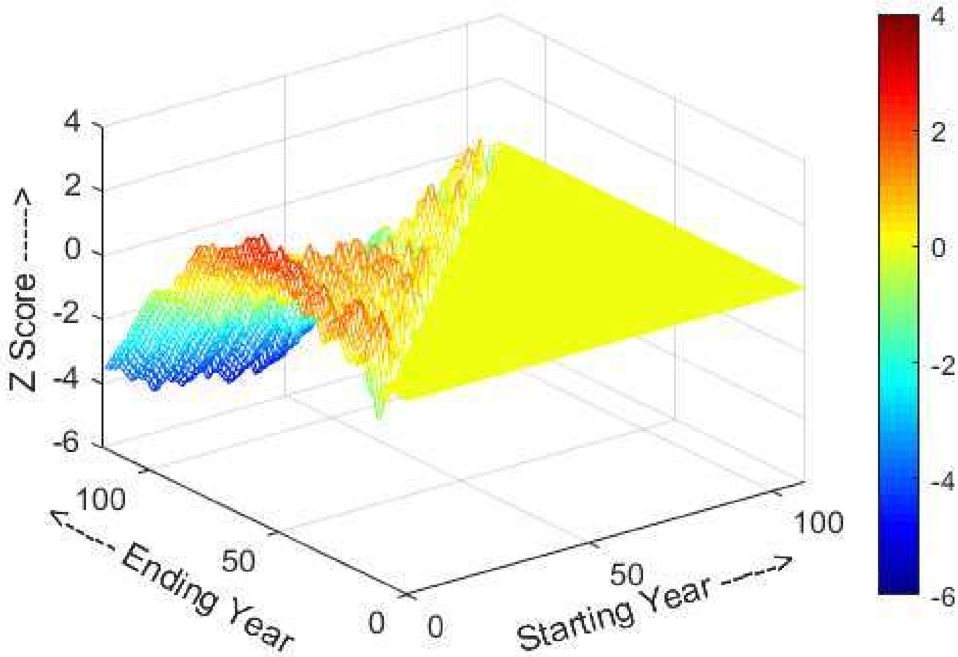

Figure 7.19 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Chitrakoot

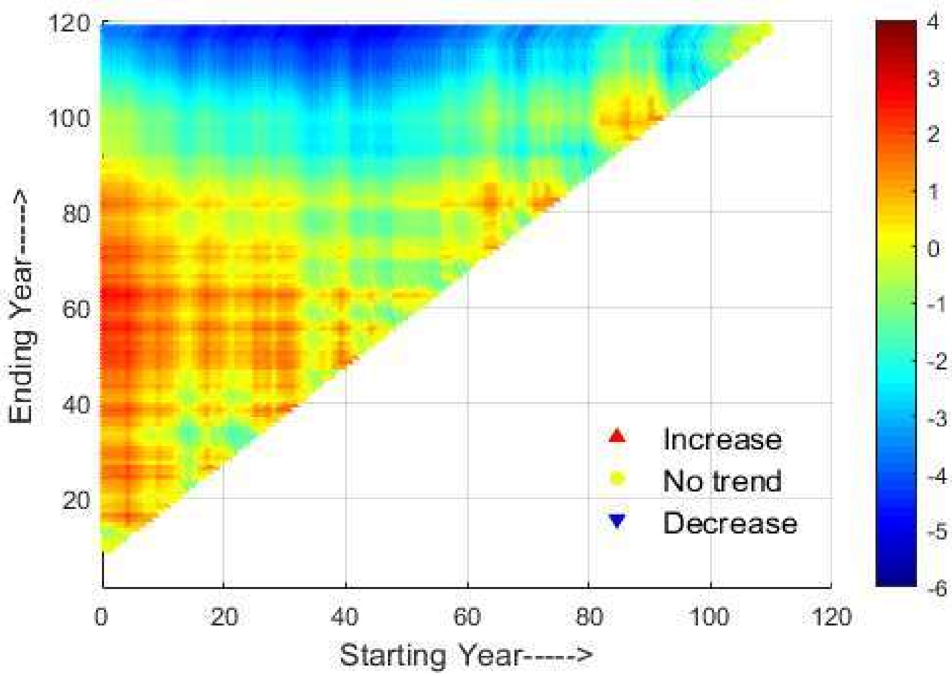

Figure 7.20 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Chitrakoot

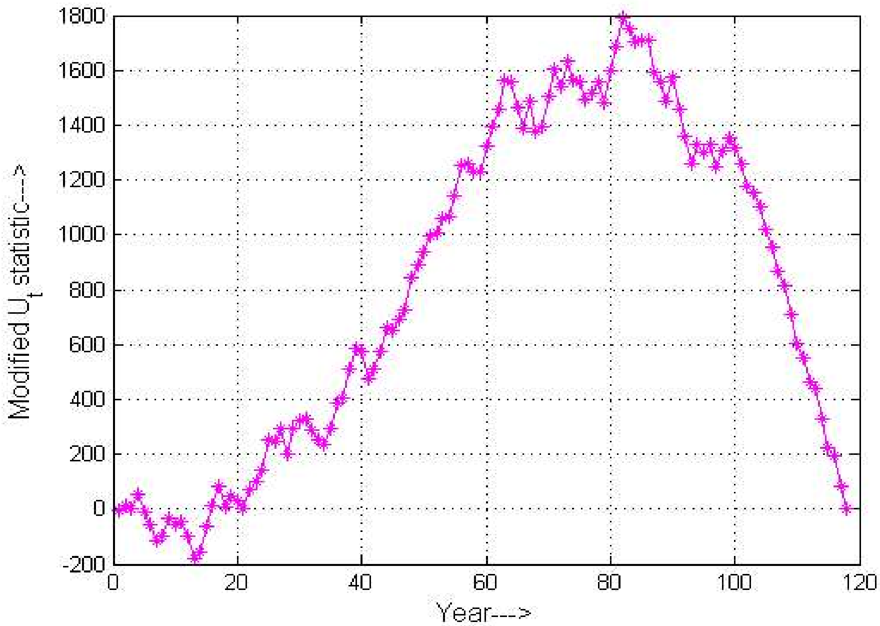

Figure 7.21 Variation of modified U_t over the years for ascertaining change points for Chitrakoot

7.2.8 Precipitation Characteristics of Faizabad

Figures 7.22-7.23 show 3D and 2D patterns of precipitation characteristics, whereas, Figure 7.24 displays modified PMW statistics for Faizabad. Two patches 1-2 are clearly evident in Figure 7.23, which separate the corresponding two zones of crest and depression visible in Figure 7.22. The multi-modal characteristics of the pattern of the trend in Figure 7.22 and the 2D pattern in Figure 7.23 were utilized to identify the change points for the district of Faizabad. Variation in the shades of the color along the line drawn parallel to the x-axis at ending year 118 is visible in 2D Figure 7.23. Alteration in the continuity of the shades of the color is identified as the point where a significant change in the trend has occurred. The occurrences of change in the trend can be marked at around 16th, 62th, 82^{nd,} and 85th year (on x-axis). These multiple change points are more distinct in Figure 7.22, where they cause the formation of crests and/or troughs. In order to identify the multiple change points, modified U_t statistics have been plotted in Figure 7.24. The PMW statistics plotted in Figure 7.24

demonstrated the same change points as obtained by the 2D/ 3D figures for the trend pattern. As against the PMW test that yields a single change point (82nd year), VSCA offered multiple change points.

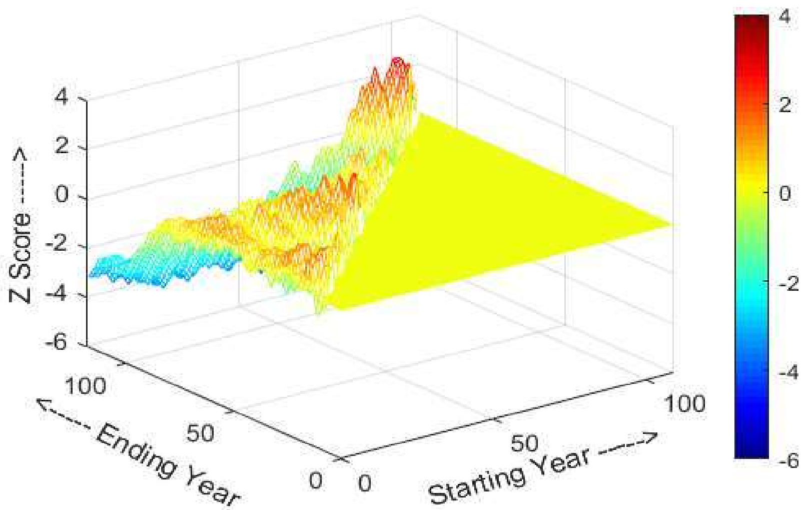

Figure 7.22 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Faizabad

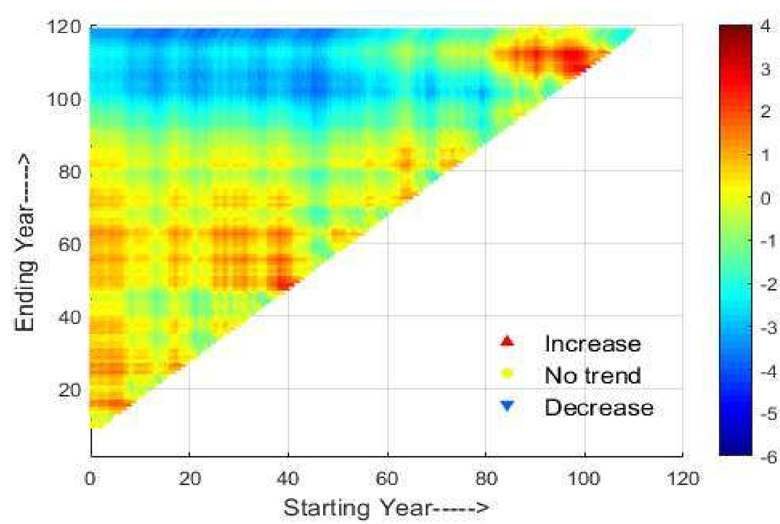

Figure 7.23 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Faizabad

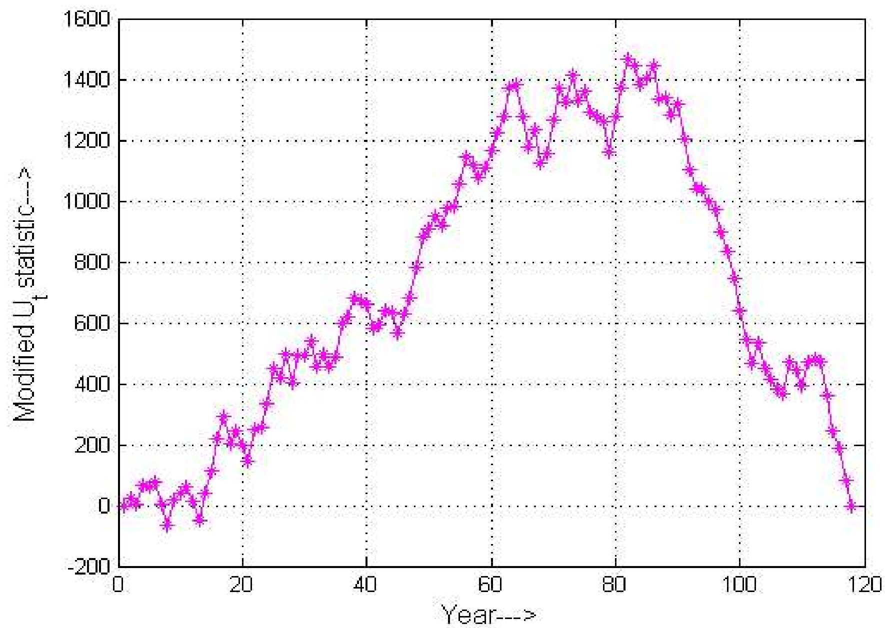

Figure 7.24 Variation of modified U_t over the years for ascertaining change points for Faizabad

7.2.9 Precipitation Characteristics of Gonda

Figures 7.25-7.26 show 3D and 2D patterns of precipitation characteristics, whereas, Figure 7.27 displays modified PMW statistics for Gonda. Two patches 1-2 are clearly evident in Figure 7.26, which separate the corresponding two zones of crest and depression visible in Figure 7.25. The multi-modal characteristics of the pattern of the trend in Figure 7.25, along with the 2D pattern in Figure 7.26, were utilized to identify the change points for the district of Gonda. Alteration in the continuity of the shades of the color is identified as the point where a significant change in the trend has occurred. The occurrences of change in the trend can be marked at around 16^{th}, 62^{th}, $82^{nd,}$ and 85^{th} (on x-axis). These multiple change points are more distinct in Figure 7.25, where they cause the formation of crests and/or troughs. In order to identify the multiple change points, modified U_t statistics have been plotted in Figure 7.27. The PMW statistics plotted in Figure 7.27 demonstrated the same change points as obtained by the 2D/ 3D figures for the pattern of the trend. As against the PMW test that yields a single change point (82nd year), VSCA offered multiple change points.

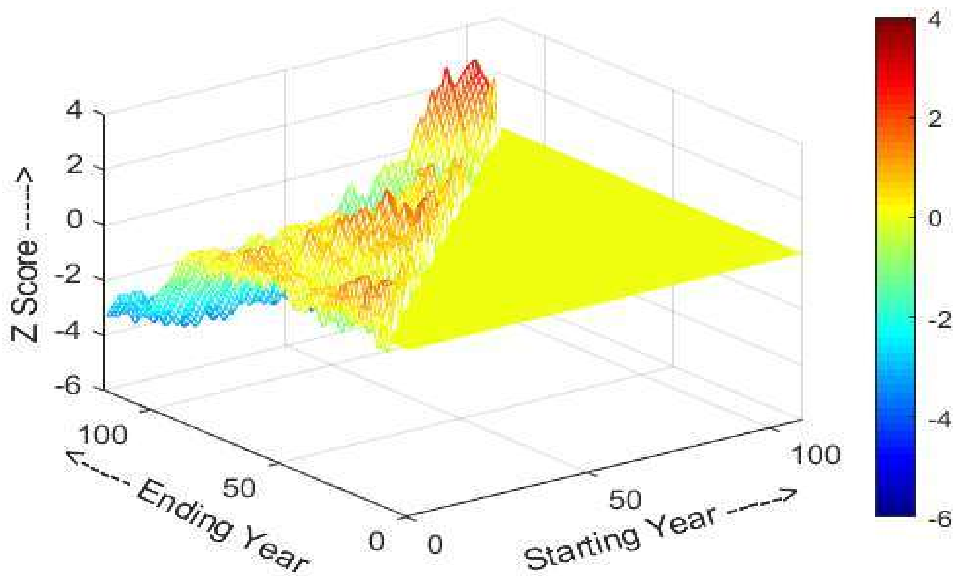

Figure 7.25 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Gonda

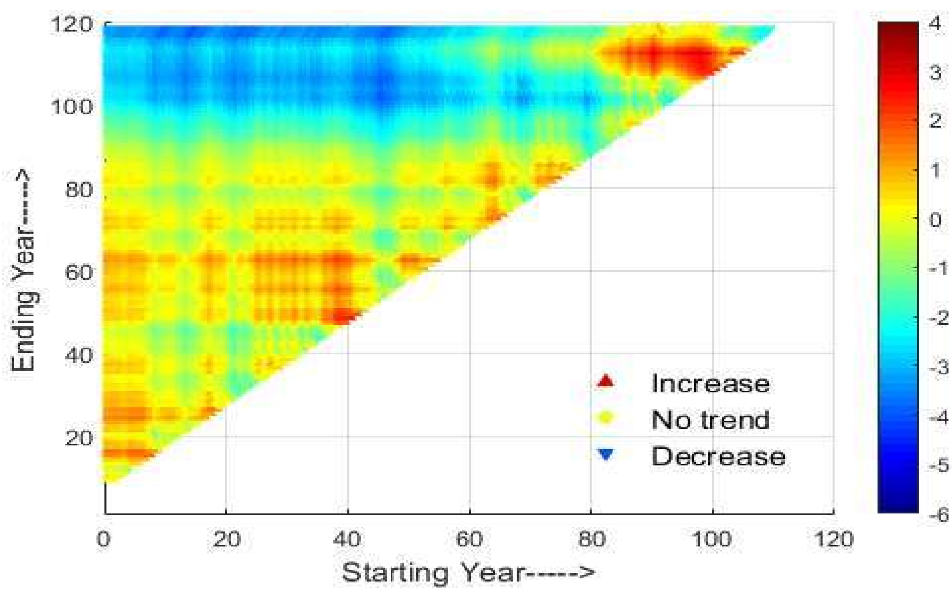

Figure 7.26 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Gonda

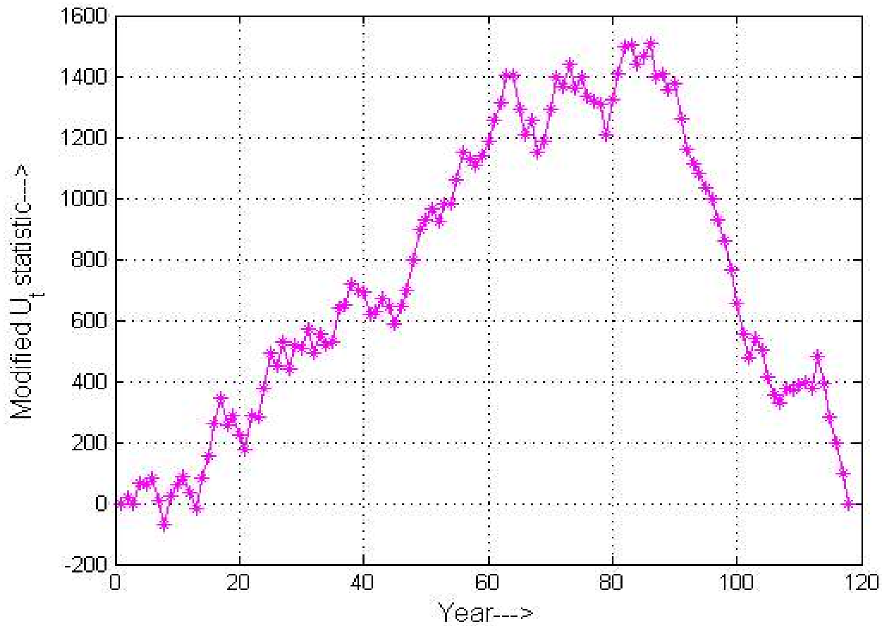

Figure 7.27 Variation of modified U_t over the years for ascertaining change points for Gonda

7.2.10 Precipitation Characteristics of Gorakhpur

3D and 2D visualizations of the pattern of the trend for Gorakhpur are shown in Figures 7.28-7.29 and modified PMW statistics in Figure 7.30. Two zones that correspond to crest and trough, respectively, are visible in Figure 7.28. These Zones 1-2 correspond to the two Patches 1-2 respectively in Figure 7.29. Patch-2 shows a reducing precipitation trend during the 90s compared to the earlier decades of the 19th century. It is important to note that Patch-2 is of mostly blue shade. This Patch-2 is created by the data clusters of larger size (118, 117, 116…) with a similar trend depicted by all clusters of data after the 1990s. That enables one to have more confidence in the result (reducing trend) than the trend analysis carried out by a data cluster of a single size, i.e., involving the total length of the data series. Two distinct disruptions in the continuity of the shade of the color along the Patch-2 have been marked at 63rd and 84th year as the year of major change in the trend of precipitation. The distinction of the Patches 1-2 shown in Figure 7.29 corresponds to the two Zones (1-2) of crest and trough in Figure 7.28, representing a less distinctive precipitation regime with no or slight increase, and distinctly reducing regime. The modified PMW statistics determined based on overall time series are plotted in Figure 7.30, and it demonstrates the similar change identified by Figures 7.28-7.29. Thus, VSCA detected more change points over the long duration of the study period.

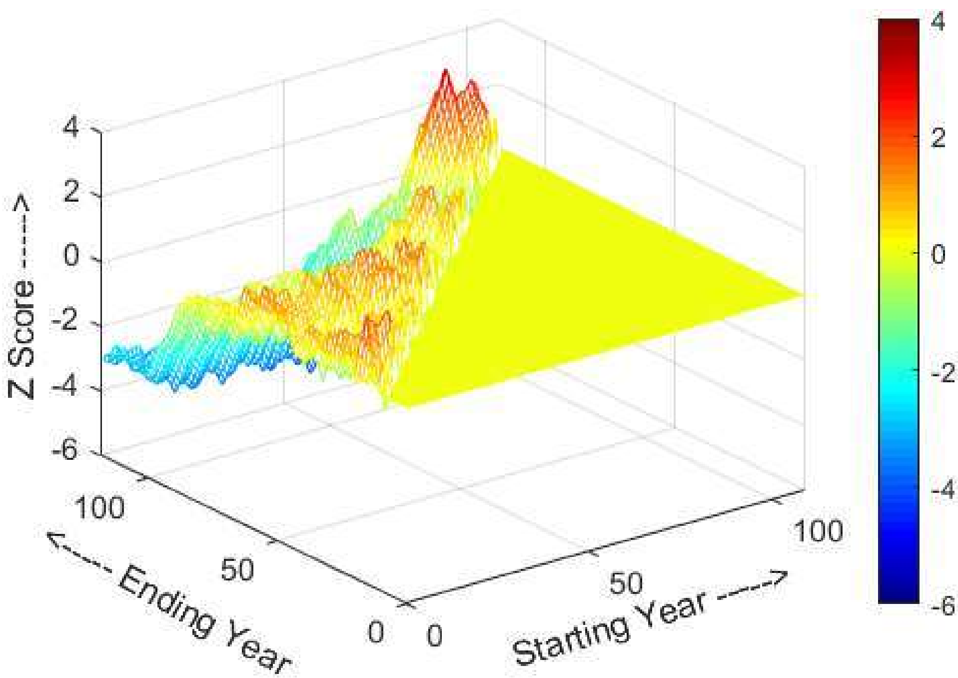

Figure 7.28 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Gorakhpur

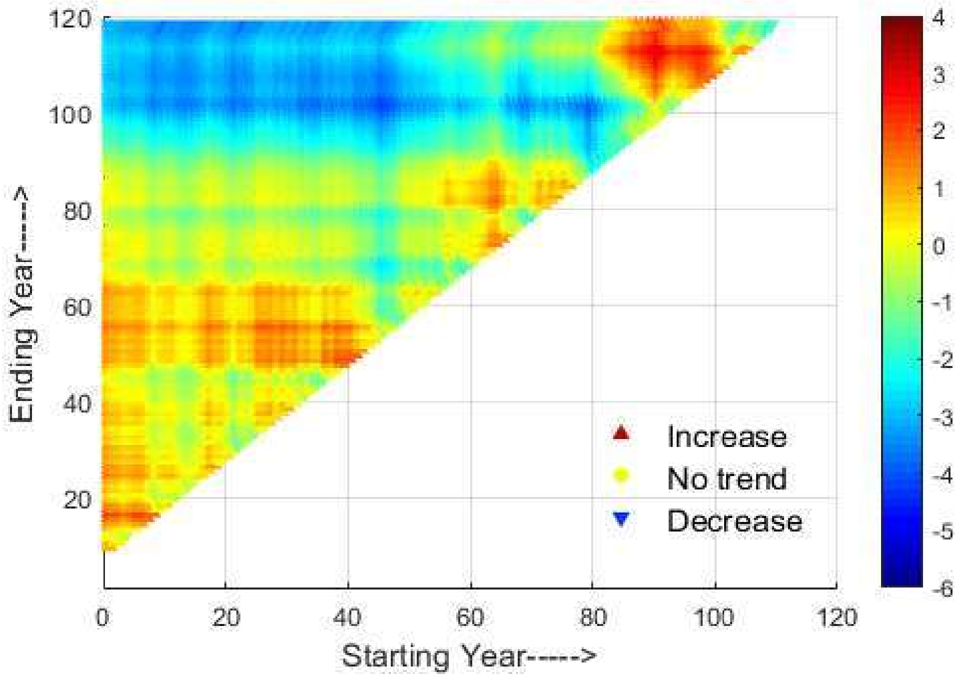

Figure 7.29 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Gorakhpur

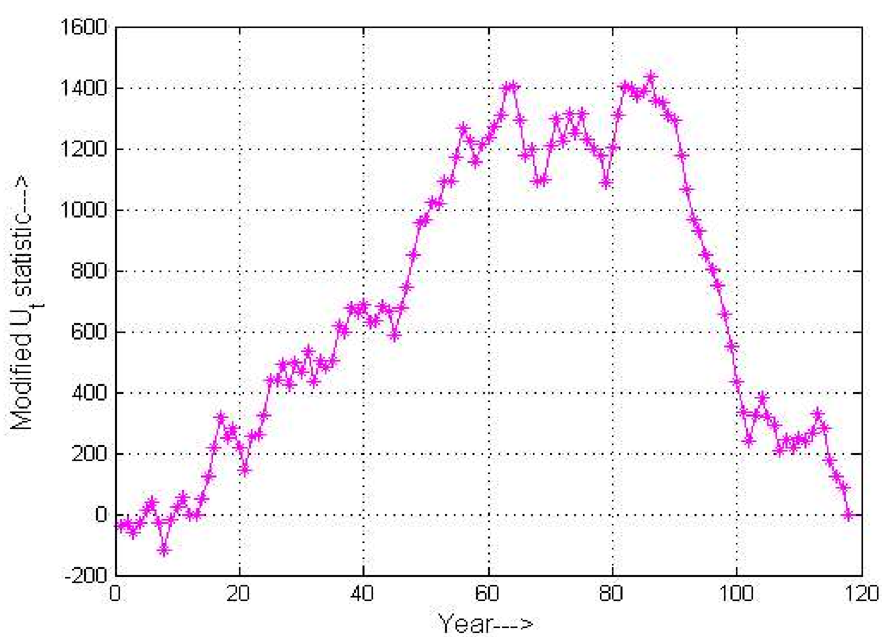

Figure 7.30 Variation of modified U_t over the years for ascertaining change points for Gorakhpur

7.2.11 Precipitation Characteristics of Jhansi

Figures 7.31-7.33 show 3D and 2D patterns of the trend along with modified PMW statistics for Jhansi. The multi-modal characteristics of the pattern of the trend in Figure 7.31 along with the 2D pattern in Figure 7.32 were utilized to identify the change points for the district of Jhansi. The Patches 1-3 observed in Figure 7.32 respectively show an increase, decrease, and mild increase dominated color shades, corresponding zones of the crest, depression, and relatively lower peak crest in Figure 7.31. Variation of the color shade along the line drawn parallel to the x-axis at ending year 118 in Figure 7.32 indicates a significant change in the trend around 21st, 64th, and 85th year as read on the x-axis. These change points give rise to crests and/or troughs and are evident from Figure 7.31. The modified PMW U_t plotted in Figure 7.33 also demonstrated the same change points obtained by 2D/ 3D Figures 7.31-732. Thus, VSCA offered multiple change points against the canonical PMW test that identifies a single change point (21st year).

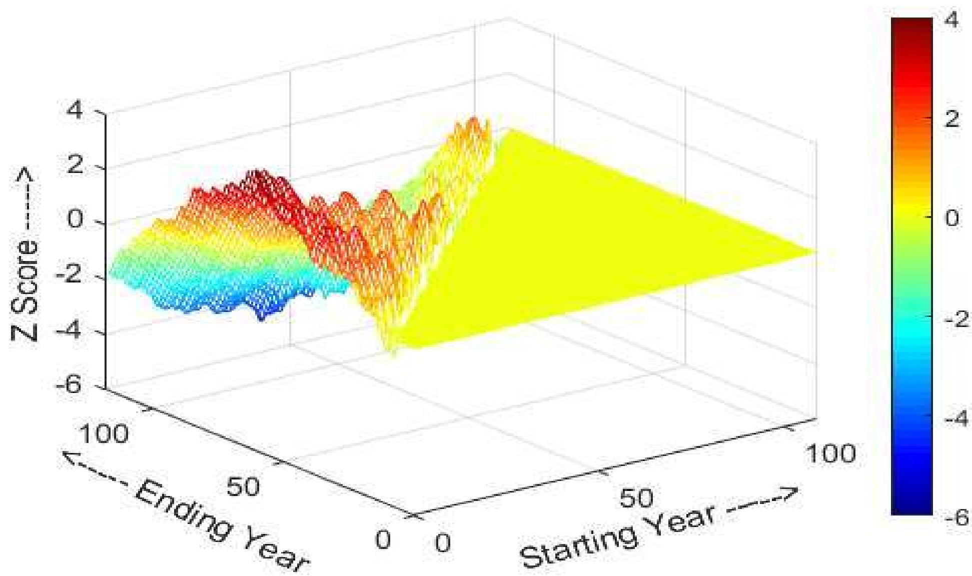

Figure 7.31 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Jhansi

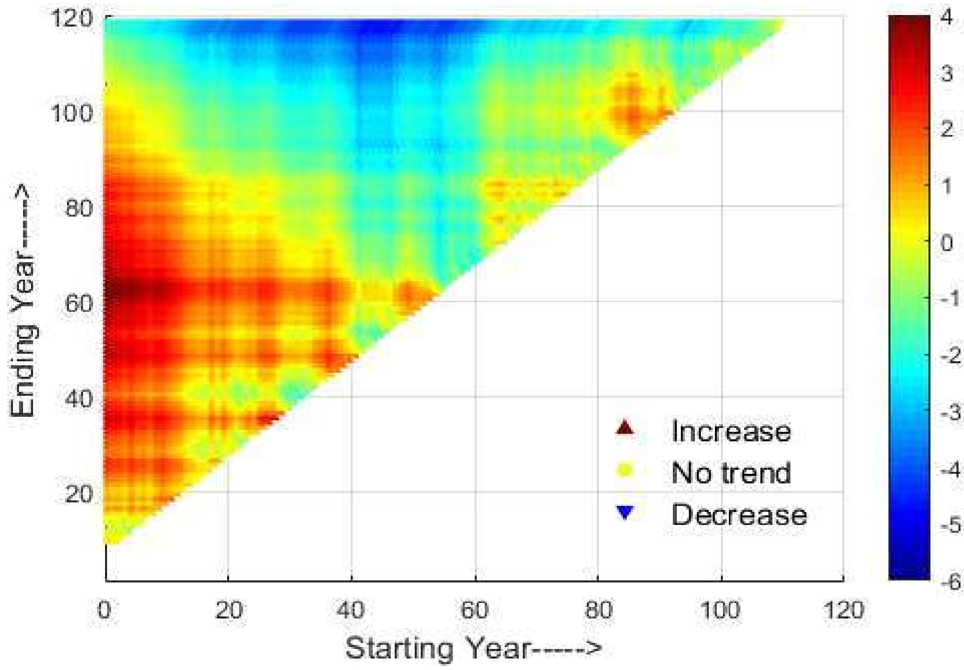

Figure 7.32 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Jhansi

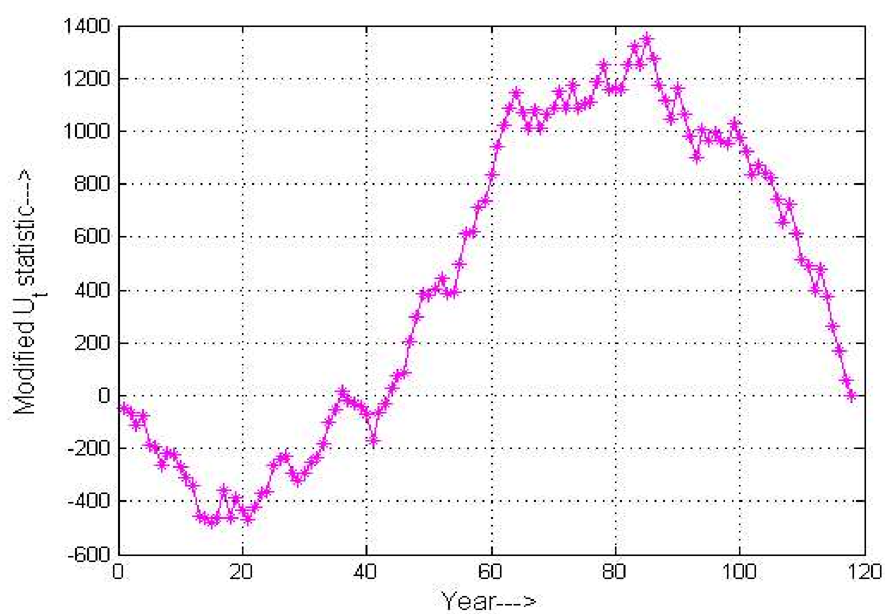

Figure 7.33 Variation of modified U_t over the years for ascertaining change points for Jhansi

7.2.12 Precipitation Characteristics of Kanpur

3D and 2D patterns of precipitation characteristics for Agra are shown in Figures 7.34-7.35, and modified PMW statistics are plotted in Figure 7.36. The multi-modal characteristics of the pattern of the trend are visible in Figure 7.34, and it clearly shows two zones of the trough (corresponding to Patches 1&3 in 2D Figure 7.35) and one zone of the crest (Patch 2 in Figure 7.35). Zone 1 signifies a reducing trend of precipitation during decades around the 40s compared to the initial decades of the 19th century. A distinct disruption in the continuity of the shades of the color along the line drawn parallel to the x-axis at ending year 118 is evident in Figure 7.35 that corresponds to the starting year 41st year around. This point refers to the change in precipitation trend while considering the overall time duration of the data series. Figure 7.36 also demonstrates a similar pattern of the trend of precipitation as that observed from Figure 7.35. The variable-sized cluster analysis here also enabled one to identify the change point and demonstrate the pattern of the trend over various spans of time for a century-long duration. Thus, VSCA owns the potential to detect one or even more change points if they occurred over the long duration of the study period. The same is evident from Figures 7.34-7.35.

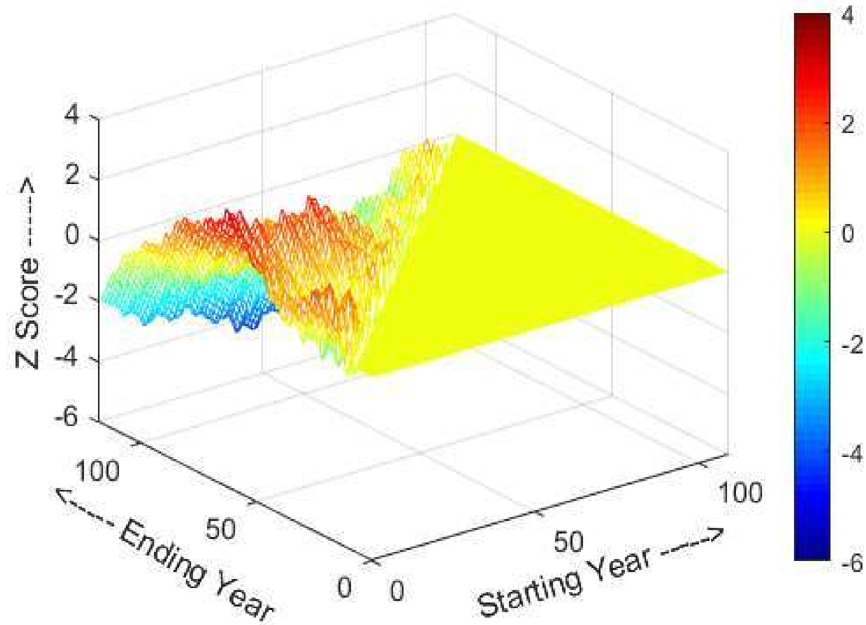

Figure 7.34 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Kanpur

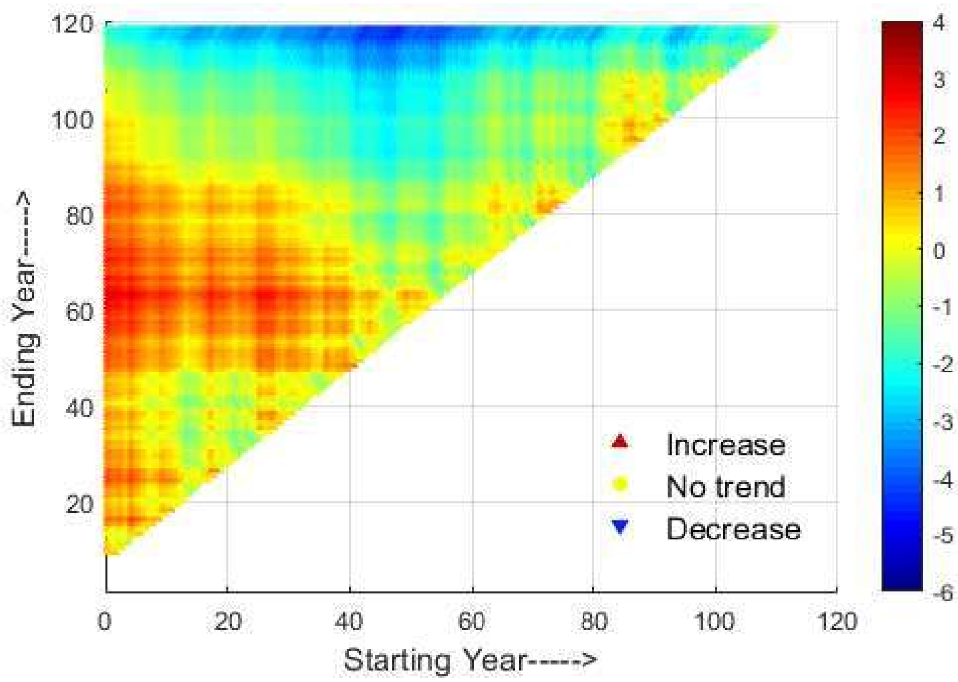

Figure 7.35 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Kanpur

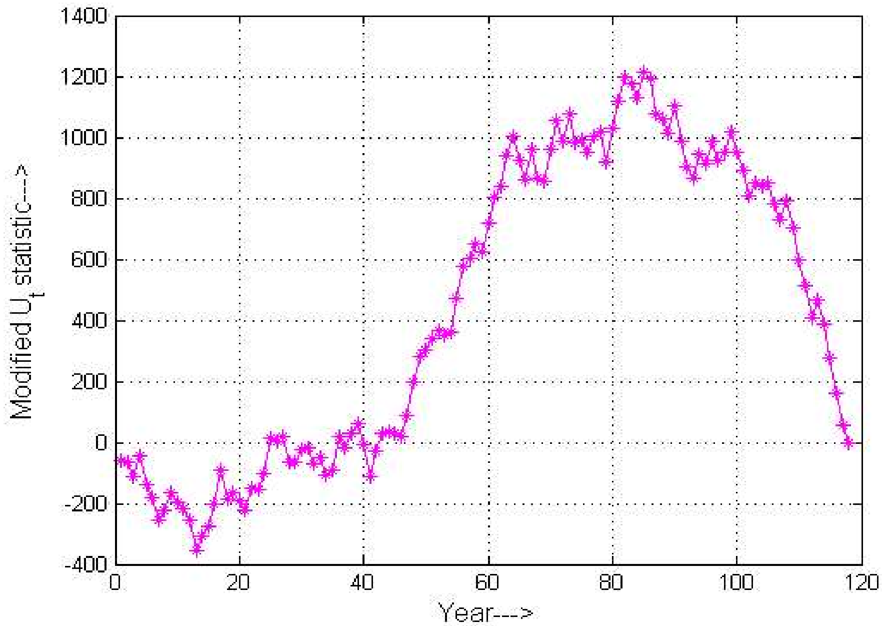

Figure 7.36 Variation of modified U_t over the years for ascertaining change points for Kanpur

7.2.13 Precipitation Characteristics of Lucknow

Two patches 1-2 are clearly evident in Figure 7.38, which separate the corresponding two zones of crest and depression visible in Figure 7.37. The multi-modal characteristics of the pattern of the trend in Figure 7.37 along with the 2D pattern in Figure 7.38 were utilized to identify the change points for the district of Lucknow. Variation in the shades of the color along the line drawn parallel to the x-axis at ending year 118 is visible in 2D Figure 7.38. Alteration in the continuity of the shades of the color is identified as the point where a significant change in the trend has occurred. The occurrences of change in the trend can be marked at around 13th, 63th, 82^{nd,} and 85th year (on x-axis). These multiple change points are more distinct in Figure 7.37, where they cause the formation of crests and/or troughs. In order to identify the multiple change points, modified U_t statistics have been plotted in Figure 7.39. The PMW statistics plotted in Figure 7.39 demonstrated the same change points as obtained by the 2D/ 3D figures for the trend pattern. As against the PMW test that yields a single change point (82nd year), VSCA offered multiple change points.

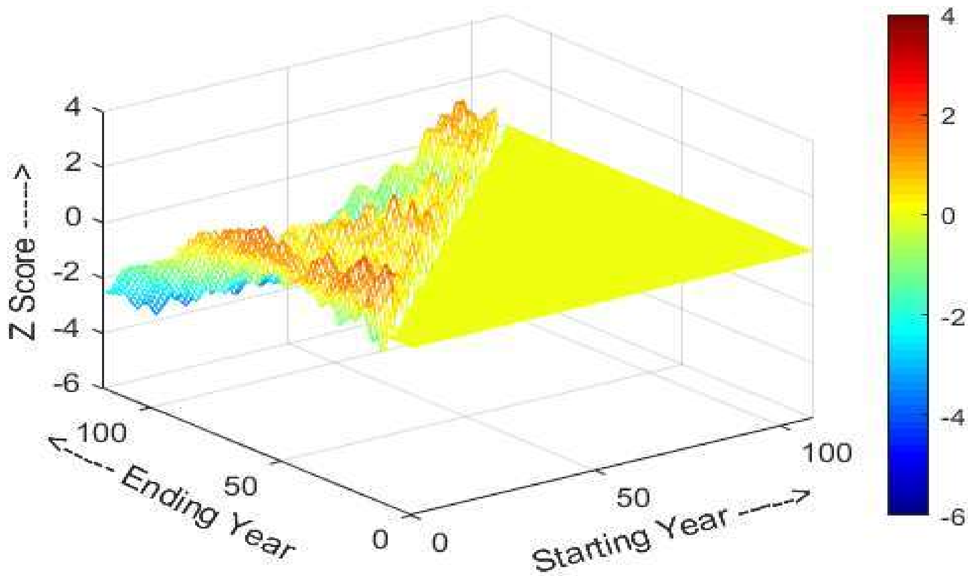

Figure 7.37 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Lucknow

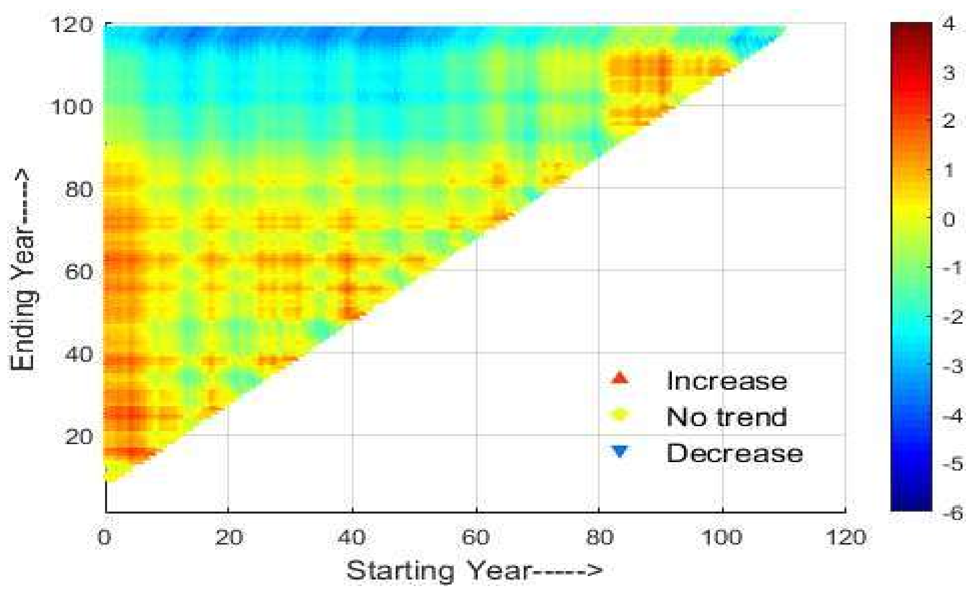

Figure 7.38 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Lucknow

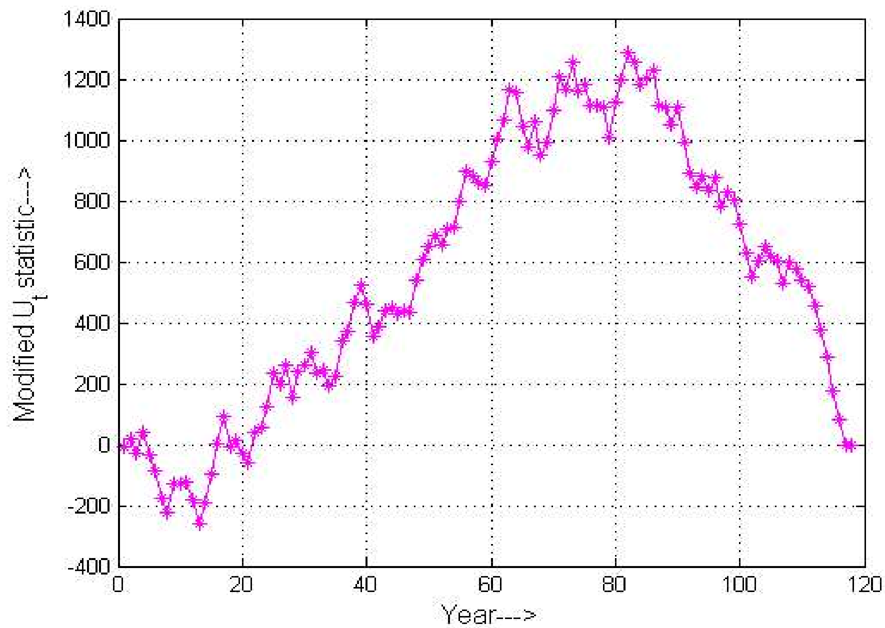

Figure 7.39 Variation of modified U_t over the years for ascertaining change points for Lucknow

7.2.14 Precipitation Characteristics of Meerut

Figures 7.40-7.41 represent 3D, 2D patterns of precipitation characteristics, and modified PMW statistics are plotted in Figure 7.41 for Meerut. The points on the line drawn parallel to the x-axis at ending year 118 display several changes in the shades of the color. Disruption in the continuity of the shades of the color is marked as the change point. The occurrences of these points at around 18th, 55^{st,} and 98th years respectively demonstrate the change in the pattern of precipitation trend. The multi-modal characteristics of the pattern of the trend are clearly visible in Figure 7.40, and it shows two zones of the trough (corresponding to patches 1&3 in 2D Figure 7.41) and one zone of the crest (Patch 2). The modified PMW statistics plotted in Figure 7.42 confirm a similar pattern as well of the trend. In fact, the PMW test uses a single maximum value of U_t to give only one change point for the overall time span. However, the variable-sized cluster analysis enables one to identify the various change points that might have occurred in the available historical record of precipitation data. Thus, VSCA owns the potential to detect multiple change points if they occurred over the long duration of the study period. The same is evident from Figures 7.40-7.41.

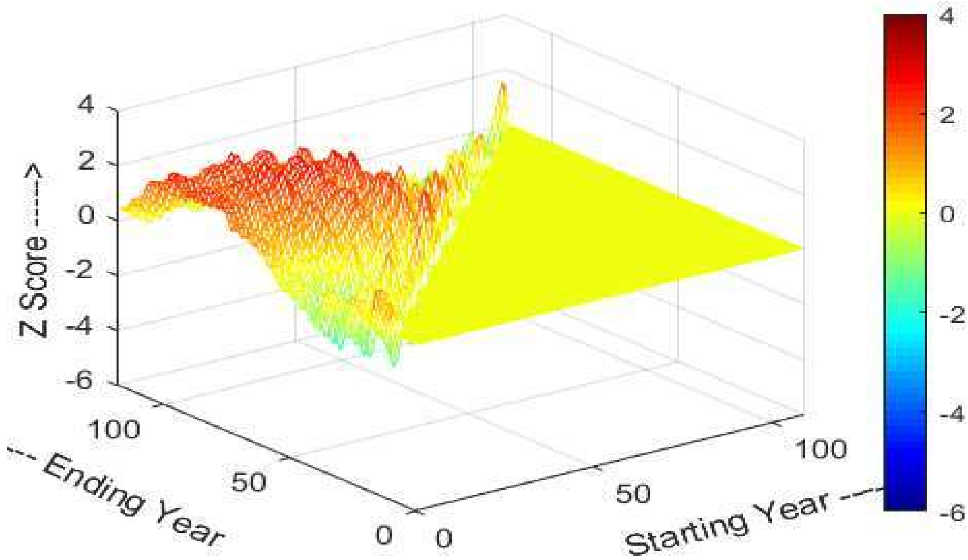

Figure 7.40 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Meerut

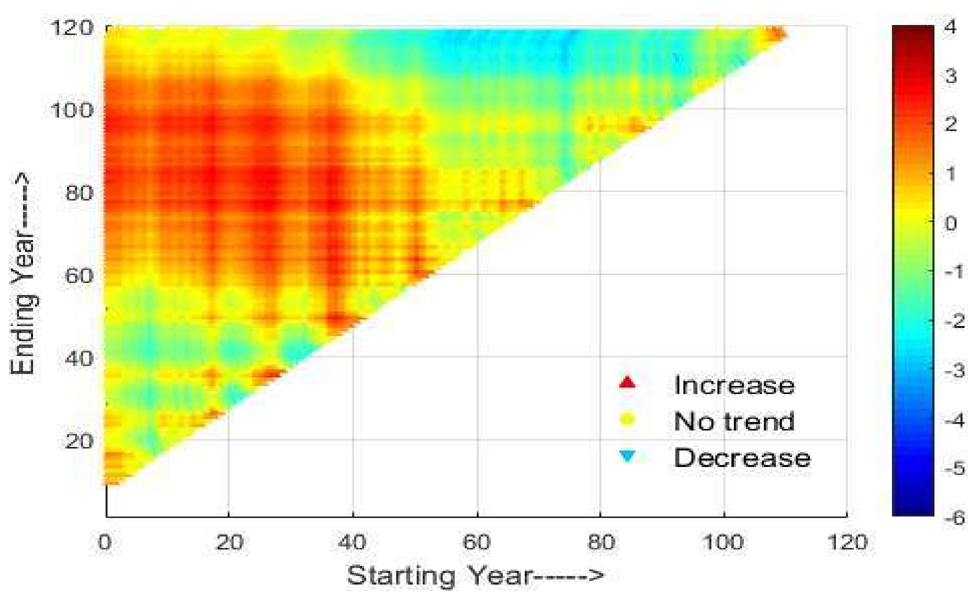

Figure 7.41 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Meerut

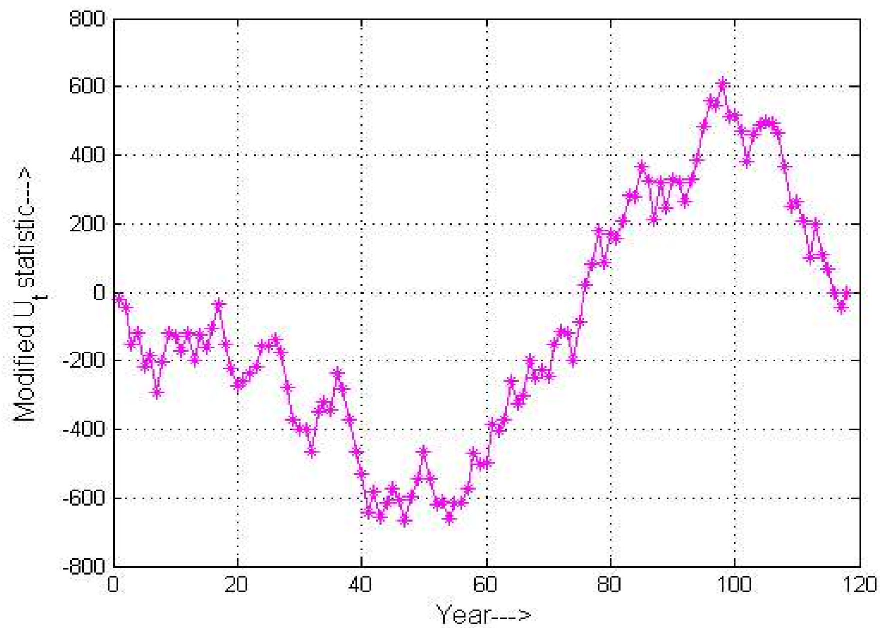

Figure 7.42 Variation of modified U_t over the years for ascertaining change points for Meerut

7.2.15 Precipitation Characteristics of Mirzapur

3D and 2D visualizations of the pattern of the trend for Mirzapur are shown in Figures 7.43-7.44 and modified PMW statistics in Figure 7.45. Two zones that correspond to crest and trough, respectively, are visible in Figure 7.43. These Zones 1-2 correspond to the two Patches 1-2 respectively in Figure 7.44. Patch-2 shows a reducing precipitation trend during the years ahead of the 90s compared to the earlier decades of the 19^{th} century. It is important to note that Patch-2 is of mostly blue shade toward the end of the year. This Patch-2 is created by the data clusters of larger size (118, 117, 116…) with a similar trend depicted by all clusters of data after the 1990s. That enables one to have more confidence in the result (reducing trend) than the trend analysis carried out by a data cluster of a single size, i.e., involving the total length of data series. Two distinct disruptions in the continuity of the shade of the color along the Patch-2 have been marked at $16^{th,}$ $35^{th,}$ and 82^{nd} year as the year of major change in the trend of precipitation. The distinction of the Patches 1-2 shown in

Figure 7.44 corresponds to the two Zones (1-2) of crest and trough in Figure 7.43, representing a less distinctive precipitation regime with no or slight increase, and distinctly reducing regime. The modified PMW statistics determined based on overall time series are plotted in Figure 7.45, demonstrating the similar change identified by Figures 7.43-7.44. Thus, VSCA detected more change points over the long duration of the study period.

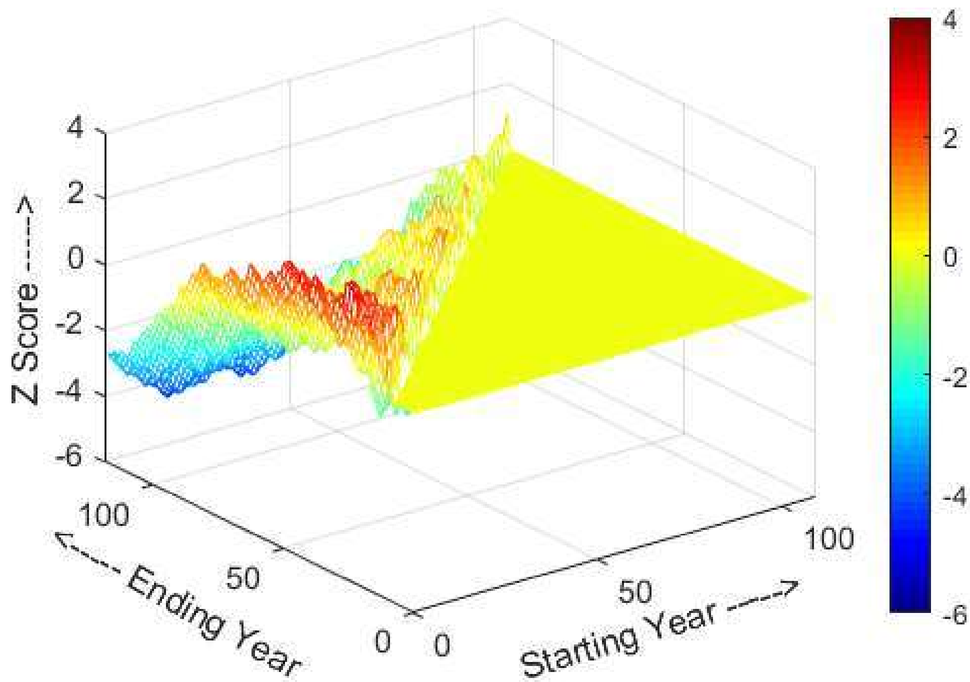

Figure 7.43 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Mirzapur

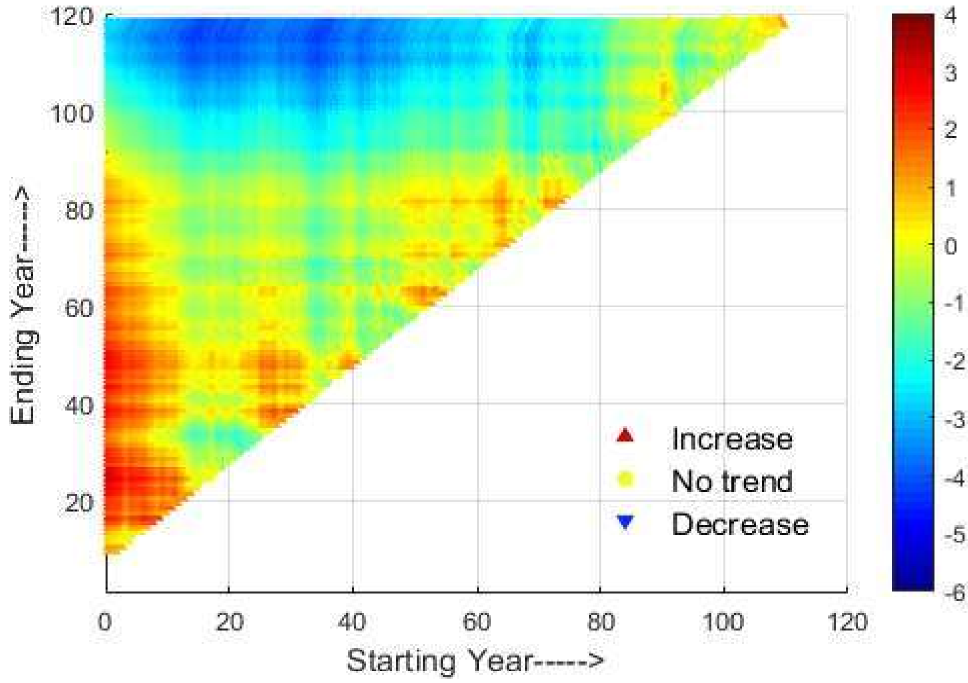

Figure 7.44 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Mirzapur

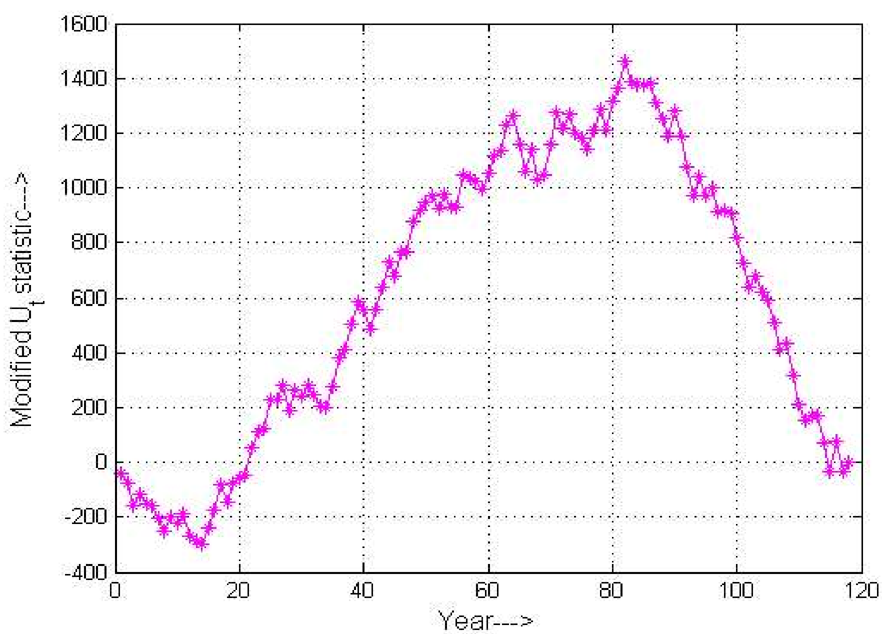

Figure 7.45 Variation of modified U_t over the years for ascertaining change points for Mirzapur

7.2.16 Precipitation Characteristics of Moradabad

Figure 7.46 clearly shows multiple crests of varying heights and troughs of varying depths. The crests represent an increasing trend, with the measure of height representing the intensity/strength of the trend direction. The multiplicity of crests/ troughs reflects the fluctuation in the trend. Thus, the trend of precipitation in Moradabad was found to alter during various periods of time. Figure 7.46 can be characterized by roughly three different zones comprising of multiple troughs (Zone-1), multiple crests (Zone-2), and a relatively less undulated surface with low amplitude crests and troughs (Zone-3). These zones are also reflected in Figure 7.47 as patches of the corresponding number. Zone-1 and corresponding patch-1 represent a decreasing precipitation trend until 1960 compared to the precipitation in the early 19th century. Zone-2 and the corresponding patch-2 show a predominant increase in precipitation concerning the decades before the 1960s. However, Zone-3 represents a weak trend for precipitation in either direction with no salient feature.

Another most striking information feature that one can draw out the result of this varying-sized cluster analysis is identifying the change point(s) for the trend of precipitation. A line segregating Patches 1-2 from Patch-3 is drawn by projecting a line from the point (see Figure 7.46) of the crest of the highest amplitude and a series of crests (shown along ending time 118) merges into a less undulated surface. The intersection of these lines with abscissa provides years of major changes in the trend of precipitation. Hence, the varying-sized cluster analysis involving the MK test yielded the pattern of the precipitation trend and owned a powerful capability of detecting the period of change. The differentiating line between patches 1 and 2 is drawn based on the inflection line between zones 1, and information drawn by Figures 7.46-7.47 is quite appropriate to rely upon.

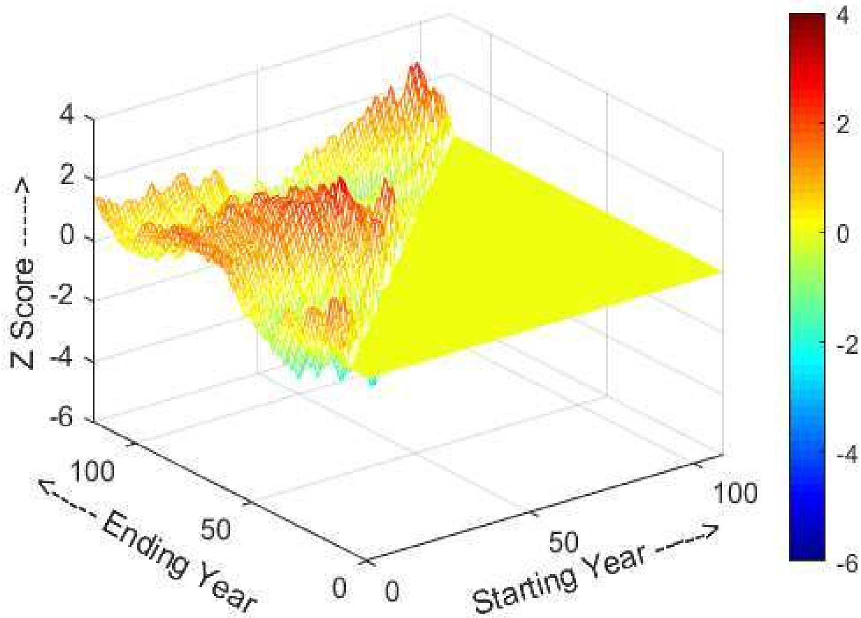

Figure 7.46 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Moradabad

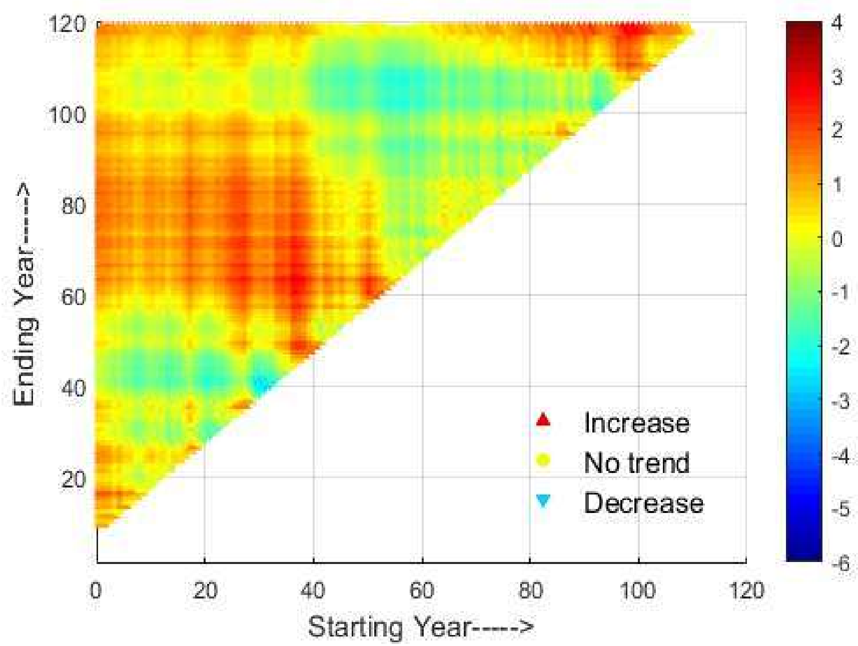

Figure 7.47 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Moradabad

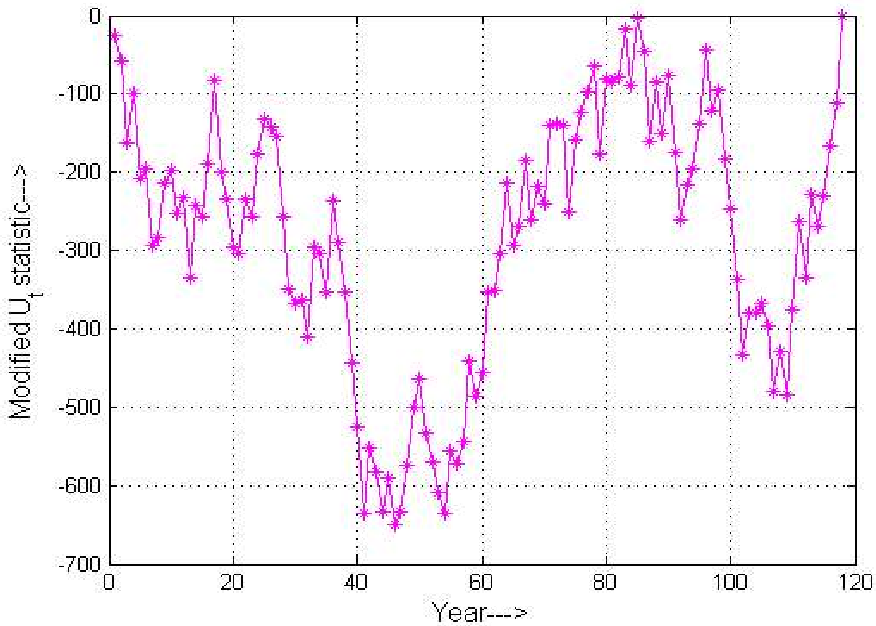

Figure 7.48 Variation of modified Ut over the years for ascertaining change points for Moradabad

7.2.17 Precipitation Characteristics of Saharanpur

Figure 7.49 clearly shows multiple crests of varying heights and troughs of varying depths. The crests represent an increasing trend, with the measure of height representing the intensity/strength of the trend direction. The multiplicity of crests/ troughs reflects the fluctuation in the trend. Thus, the pattern of the trend of precipitation in Saharanpur was found to be altering during various periods of time. Figure 7.49 can be characterized by roughly three different zones comprising of multiple troughs (Zone-1), multiple crests (Zone-2), and a relatively less undulated surface with low amplitude crests and troughs (Zone-3). These zones are also reflected in Figure 7.50 as patches of the corresponding number. Zone-1 and corresponding patch-1 represent decreasing precipitation trends until 1960 compared to the precipitation in the early 19th century. Zone-2 and the corresponding patch-2 show a predominant increase in precipitation concerning the decades before the 1960s. However, Zone-3 represents a weak trend for precipitation in either direction with no salient feature.

Another most striking information feature that one can draw out the result of this varying-sized cluster analysis is identifying the change point(s) for the trend of precipitation. A line segregating Patches 1-2 from Patch-3 is drawn by projecting a line from the point (see Figure 7.49) of the crest of the highest amplitude, and a series of crests (shown along ending time 118) merges into a less undulated surface. The differentiating line between patches 1 and 2 is drawn based on the inflection line between zones 1 and 2. The differentiation of these zones can be viewed as a change point (1960 around) when a reversal in precipitation trend occurred. The reason seems to associate with the rapid urbanization caused by industrialization in adjoining terrain, which is quite close to the capital of India, Delhi. The modified PMW statistics drawn in Figure 7.51 clearly reveal that the information is drawn in Figures 7.49-7.50 is appropriate to rely upon.

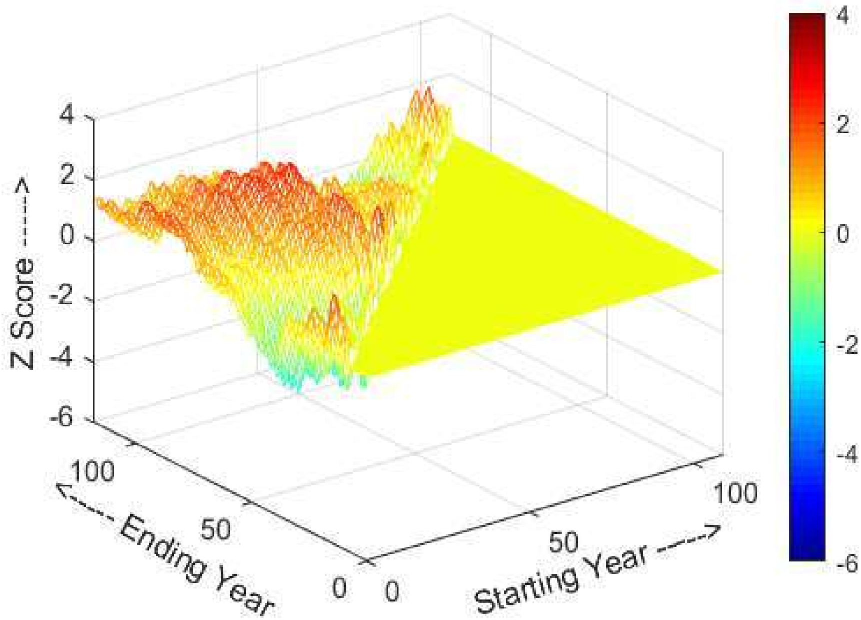

Figure 7.49 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Saharanpur

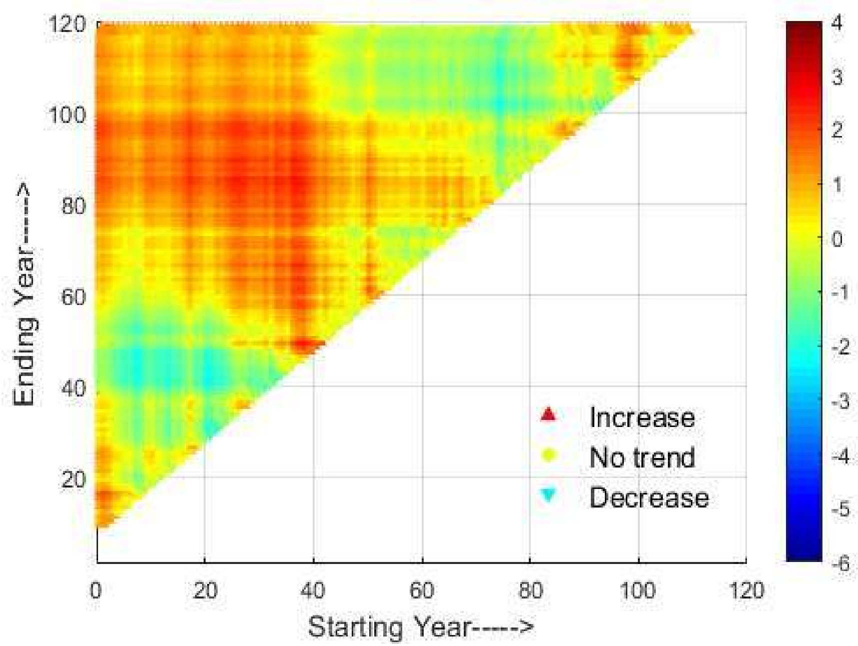

Figure 7.50 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Saharanpur

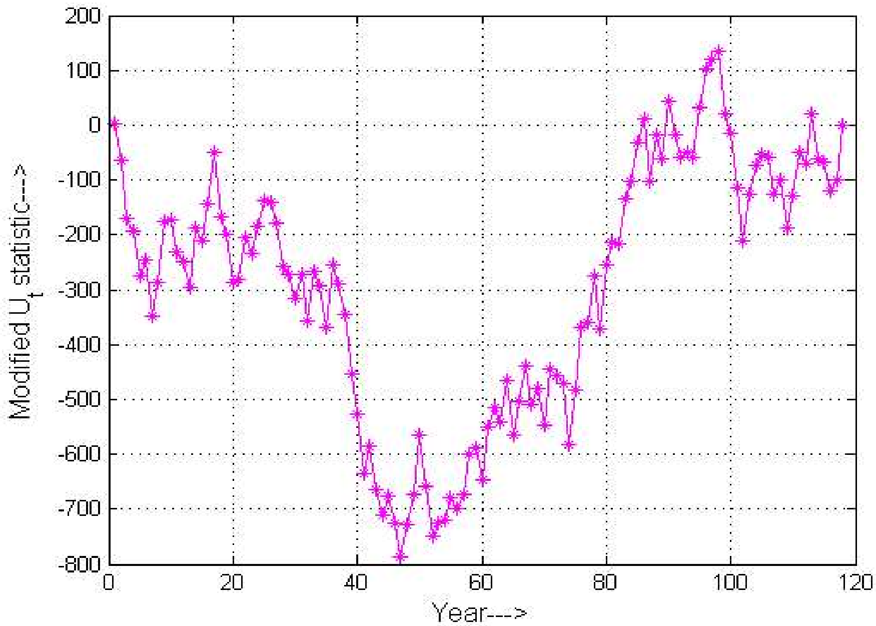

Figure 7.51 Variation of modified U_t over the years for ascertaining change points for Saharanpur

7.2.18 Precipitation Characteristics of Varanasi

3D and 2D patterns of precipitation characteristics for Varanasi are shown in Figures 7.52-7.53, whereas modified U_t statistics obtained from the PMW test are plotted in Figure 7.54. Figure 7.52 shows a zone of trough corresponding to Patch 2 of Figure 7.53. This patch reflects a decreasing precipitation trend with a change in the pattern at around the 83rd year. The lowest dip point identifies the change point in the trough shown in Figure 7.52, and it is also confirmed by locating a point along the line, parallel to the x-axis, drawn at ending year 118 at which shade of blue color strip turns greenish. The appearance of a crest near starting years (zero to ten) reflects an increasing trend of precipitation compared to the precipitation that occurred in the early years of the century. Modified U_t obtained by PMW test further confirms the same finding, as evident from Figure 7.54.

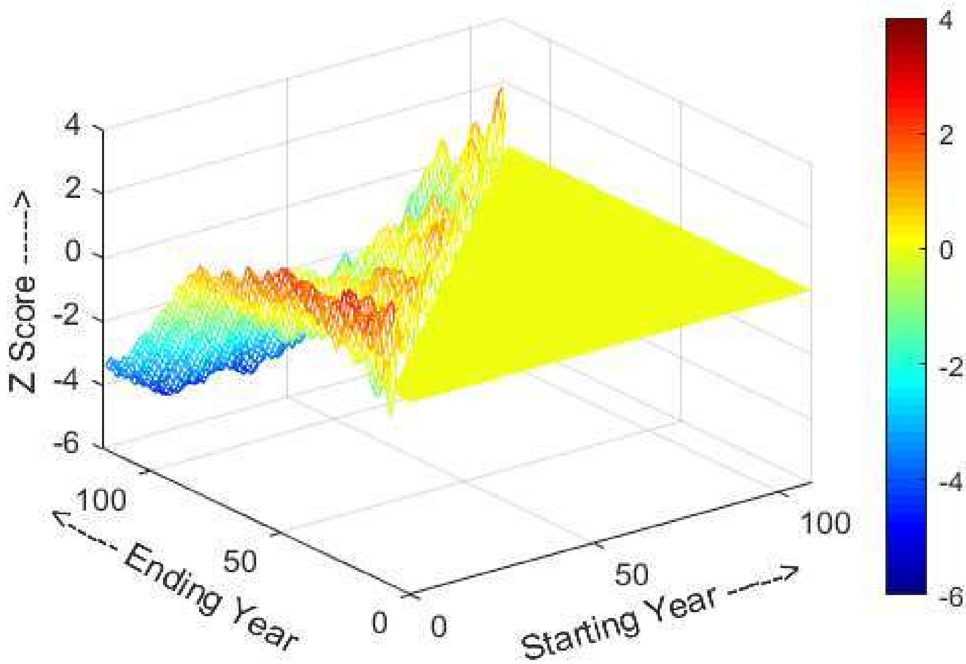

Figure 7.52 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Varanasi

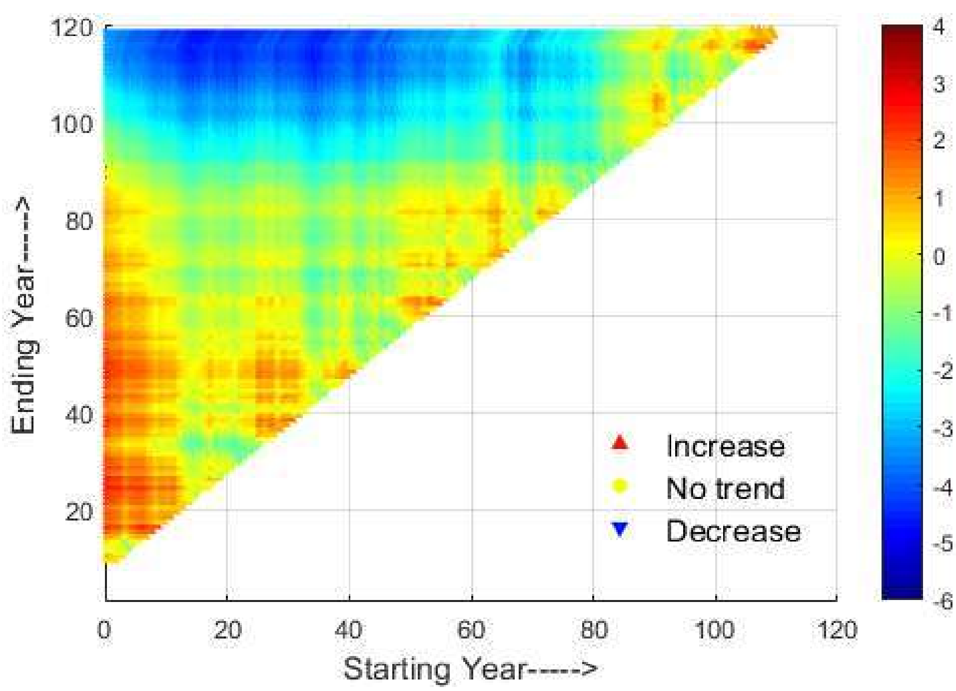

Figure 7.53 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Varanasi

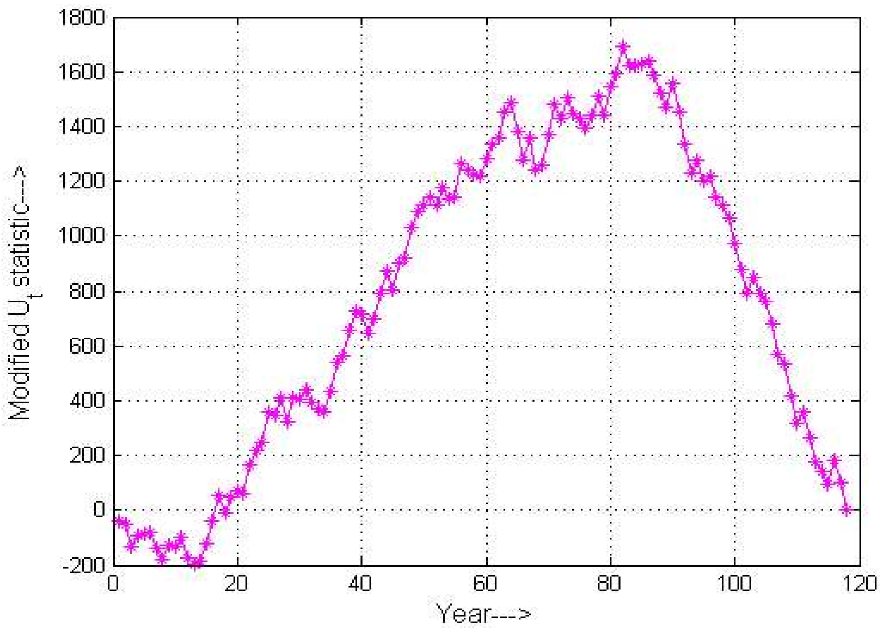

Figure 7.54 Variation of modified Ut over the years for ascertaining change points for Varanasi

7.2.19 Comparative Assessment for Spatial Variability

Trend patterns for precipitation over Lucknow, Gorakhpur, and Varanasi display similar characteristics, decreasing trends around 1990 onwards. The major change in precipitation trend over these districts also occurred during the decades of 70-80. The decreasing trend of precipitation appears to associate with the geographical locations of these districts that fall in the eastern belt of Uttar Pradesh. The proximity of Gorakhpur to the terai of Nepal has caused a significant decrease in rainfall due to increased urbanization and deforestation in Nepal. The rate of decrease of precipitation in Gorakhpur has also been relatively faster.

Saharanpur and Agra also displayed approximately similar characteristics with the increasing trend until 1940 and no-trend after that. These districts fall in the western region of Uttar Pradesh and are close to India's capital. The influence of industrialization in the national capital region after the independence of India (1947) has seized the increasing trend of precipitation to force it to acquire no-trend afterward. This characteristic is typical of these two districts. Bareilly being in the western belt of Uttar Pradesh showed a marginal reduction in precipitation but with no significant trend. Jhansi displayed a similar character of precipitation to that of the Bundelkhand region that suffers from significant drought over the last 25 years or so, and its proximity to the Bundelkhand region affiliates to the reason thereof.

7.3 Application of VSCA over Jharkhand

The application of VSCA demonstrated that the patterns of the trend for precipitation over Jharkhand state are similar to Uttar Pradesh state. In contravention to the canonical way of handling precipitation data for trend analysis that yields unique trend over the long span of time, the proposed methodology involving variable size cluster analysis represents the pictorial view of the pattern of the changing trend along with the clue for the detection of one or more change points and/or alternate trends, if it occurs, without application of Pettitt Mann Whitney method. The modified PMW statistics drawn on a graph display results congruous to the actual pattern of changing trend, and hence proved to be a better option than the traditional PMW methodology that detects only one change point/ point of the sudden jump. 3-D figures are drawn for variation of the Z-score with varying starting and ending time clearly depicted the changing trend as an undulated surface for a visual feel of the variation in the trend of precipitation that was not detectable by the ordinary MK test involving complete historical dataset. Trend analysis using station scale data showed a more realistic result than that of the grid-based data built upon spatial averaging. The same trend, if obtained by the different clusters created by sequential elimination of starting year data in the application of MK test, enabled one to have more confidence and reliability on the conclusive result.

7.3.1 Precipitation Characteristics of Dumka

Figures 7.55-7.56 shows 3- and 2-D views of the pattern of the trend of precipitation that occurred over the district of Dumka from the year 1901 to 2018. Figure 7.55 clearly shows multiple crests of varying heights and troughs of varying depths. The crests represent an increasing trend, with the measure of height representing the intensity/strength of the trend direction. The multiplicity of crests/ troughs reflects the fluctuation in the trend. Thus, the pattern of the trend of precipitation in Dumka was found to be altering during various periods of time. Figure 7.55 can be characterized by roughly three different zones comprising of multiple troughs (Zone-1), multiple crests (Zone-2), and a relatively less undulated surface with low amplitude crests and troughs (Zone-3). These zones are also reflected in Figure 7.56 as patches of the corresponding number. Zone-1 and corresponding patch-1 represent decreasing precipitation trends until 1959 compared to the precipitation in the early 19th century. Zone-2 and the corresponding patch-2 show a predominant increase in precipitation concerning the decades before the 1959. However, Zone-3 represents a weak trend for precipitation in either direction with no salient feature.

Another most striking information feature that one can draw out the result of this varying-sized cluster analysis is identifying the change point(s) for the trend of precipitation. A line segregating Patches 1-2 from Patch-3 is drawn by projecting a line from the point (see Figure 7.55) of the crest of the highest amplitude, and a series of crests (shown along ending time 118) merges into a less undulated surface. The differentiation of these zones can be viewed as a change point (1959 around) when a reversal in precipitation trend occurred. The reason seems to associate with the rapid urbanization caused by industrialization in adjoining terrain, which is quite close to the capital of India, Delhi. The modified PMW statistics drawn in Figure 7.57 clearly reveal that the information is drawn in Figures 7.55-7.56 is appropriate to rely upon.

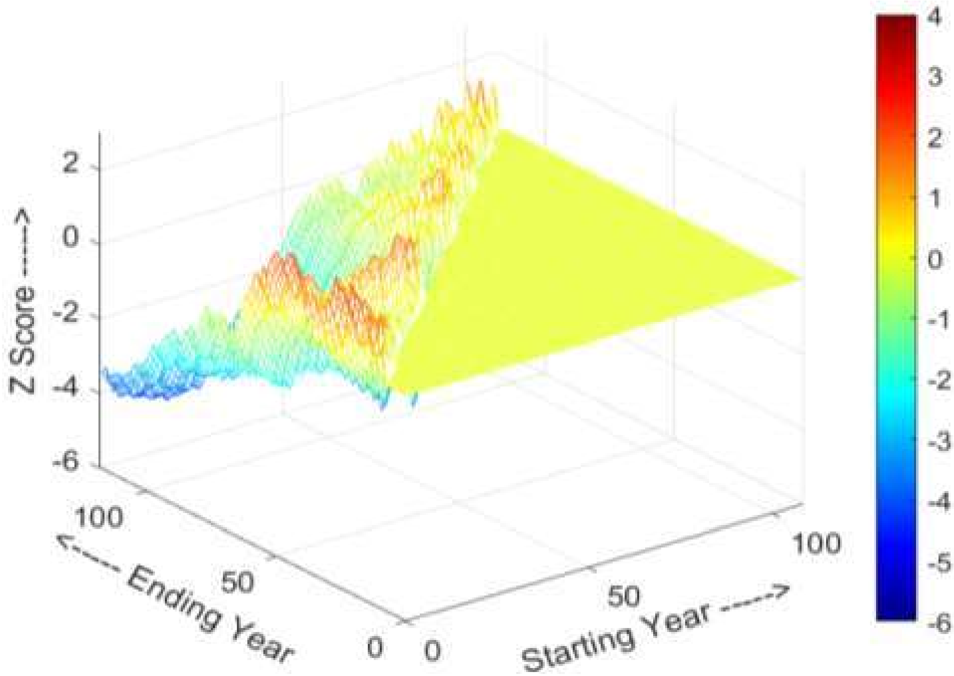

Figure 7.55 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Dumka

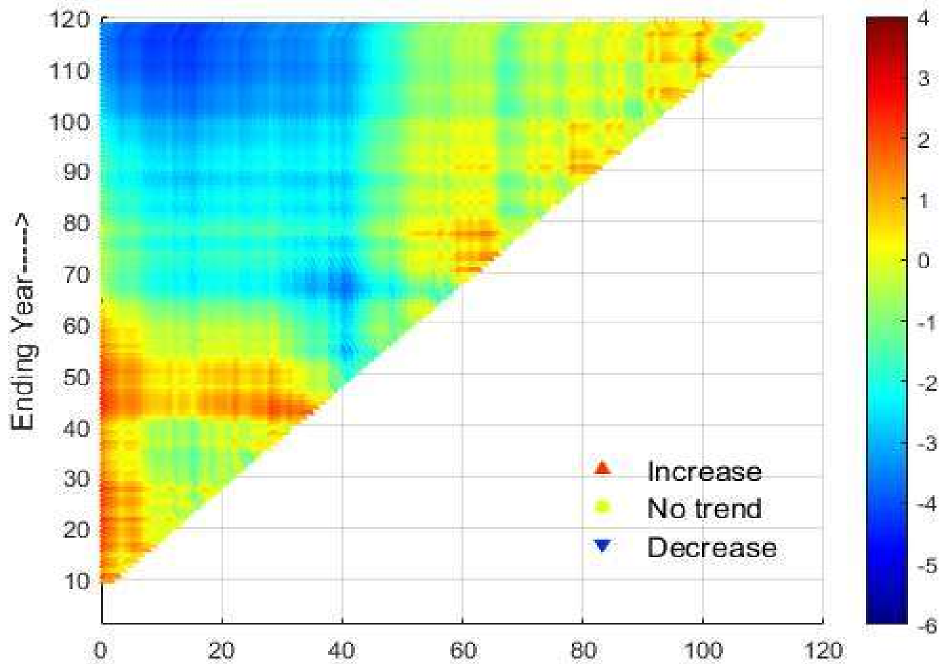

Figure 7.56 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Dumka

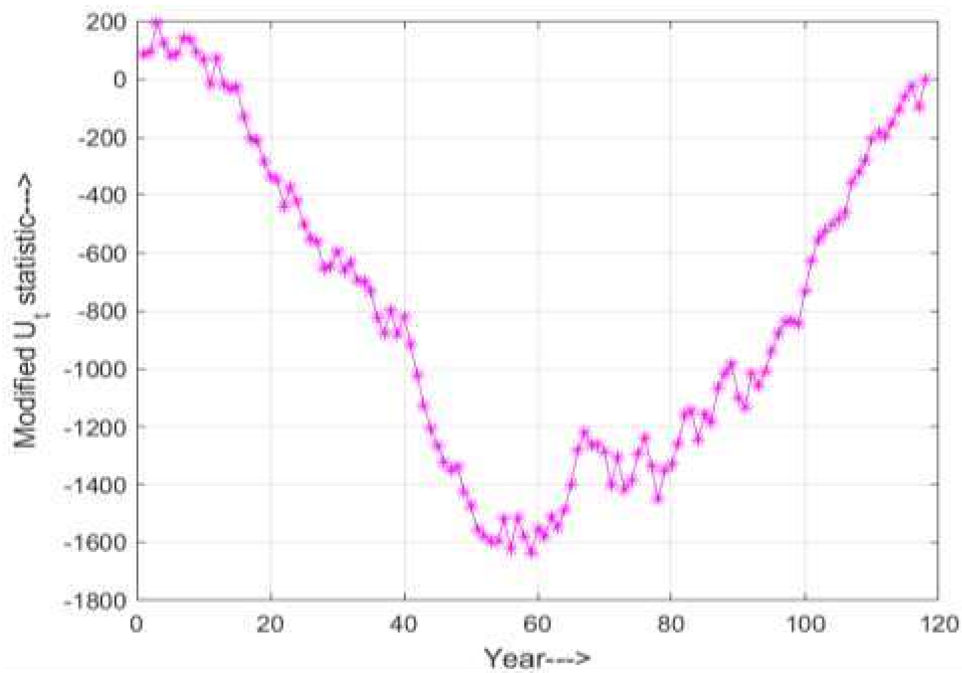

Figure 7.57 Variation of modified Ut over the years for ascertaining change points for Dumka

7.3.2 Precipitation Characteristics of Hazaribagh

3D and 2D visualizations of the pattern of the trend for Hazaribagh are shown in Figures 7.58-7.59 and modified PMW statistics in Figure 7.60. Two zones that correspond to crest and trough, respectively, are visible in Figure 7.58. These Zones 1-2 correspond to the two Patches 1-2 respectively in Figure 7.59. Patch-2 shows a reducing precipitation trend during the years ahead of the 90s compared to the earlier decades of the 19^{th} century. It is important to note that Patch-2 is of mostly blue shade toward the end of the year. This Patch-2 is created by the data clusters of larger size (118, 117, 116…) with a similar trend depicted by all clusters of data after the 1990s. That enables one to have more confidence in the result (reducing trend) than the trend analysis carried out by a data cluster of a single size, i.e., involving the total length of data series. Two distinct disruptions in the continuity of the shade of the color along the Patch-2 have been marked at $49^{th,}$ $79^{th,}$ and 91^{th} year as the year of major change in the trend of precipitation. The distinction of the Patches 1-2 shown in Figure 7.59 corresponds to the two Zones (1-2) of crest and trough in Figure 7.58, representing a less distinctive precipitation regime with no or slight increase, and distinctly reducing regime. The modified PMW statistics determined based on overall time series are plotted in Figure 7.60, demonstrating the similar change identified by Figures 7.58-7.59. Thus, VSCA detected more change points over the long duration of the study period.

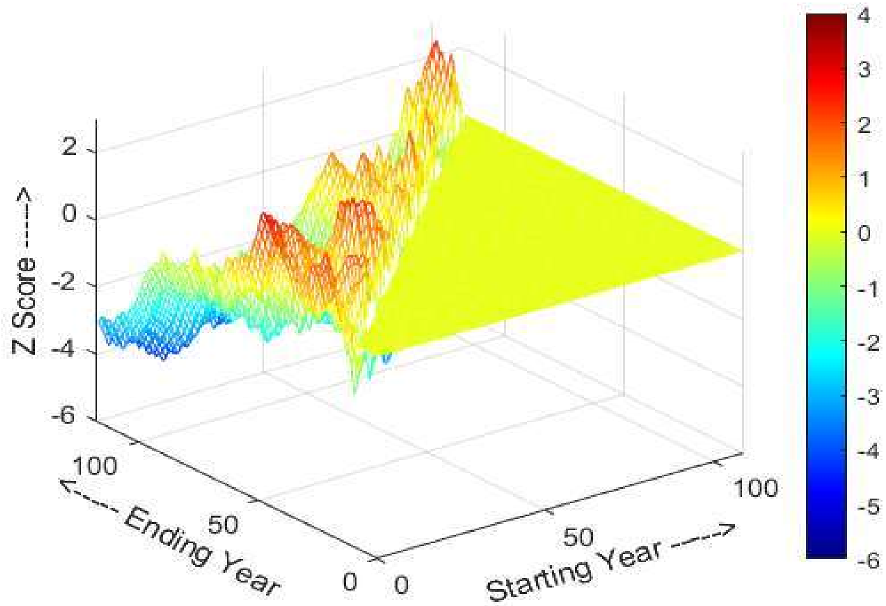

Figure 7.58 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Hazaribagh

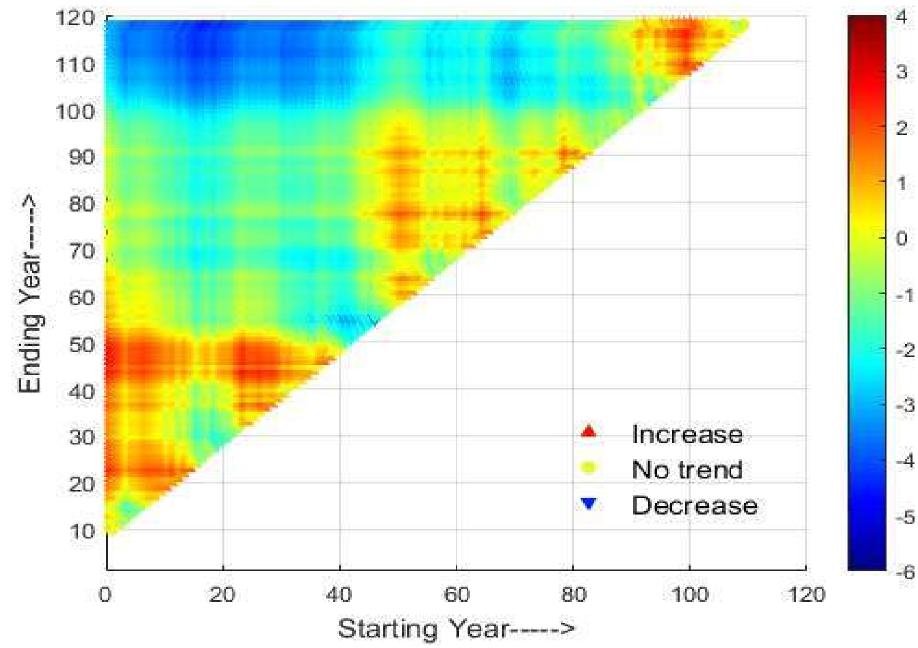

Figure 7.59 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Hazarib

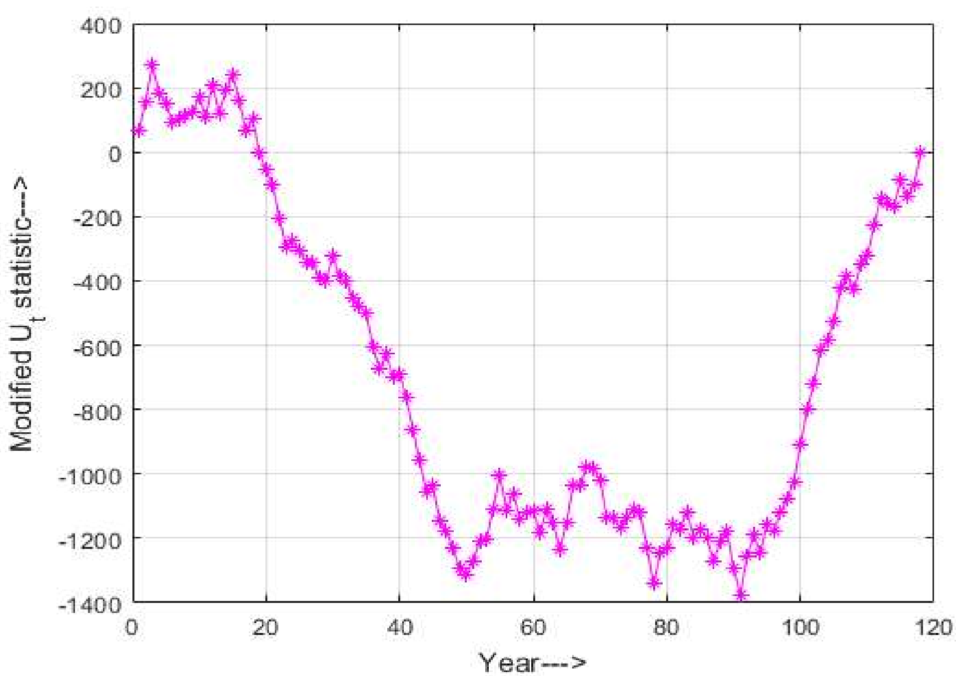

Figure 7.60 Variation of modified Ut over the years for ascertaining change points for Hazaribagh

7.3.3 Precipitation Characteristics of Palamu

3D and 2D patterns of precipitation characteristics for Palamu are shown in Figures 7.61-7.62, whereas modified U_t statistics obtained from the PMW test are plotted in Figure 7.63. Figure 7.61 shows a zone of trough corresponding to Patch 2 of Figure 7.62. This patch reflects a decreasing precipitation trend with a change in the pattern at around the 50th and 91th year. The lowest dip point identifies the change point in the trough shown in Figure 7.61, and it is also confirmed by locating a point along the line, parallel to the x-axis, drawn at ending year 118 at which shade of blue color strip turns greenish. The appearance of a crest near starting years (zero to ten) reflects an increasing trend of precipitation compared to the precipitation that occurred in the early years of the century. Modified U_t obtained by PMW test further confirms the same finding, as evident from Figure 7.63.

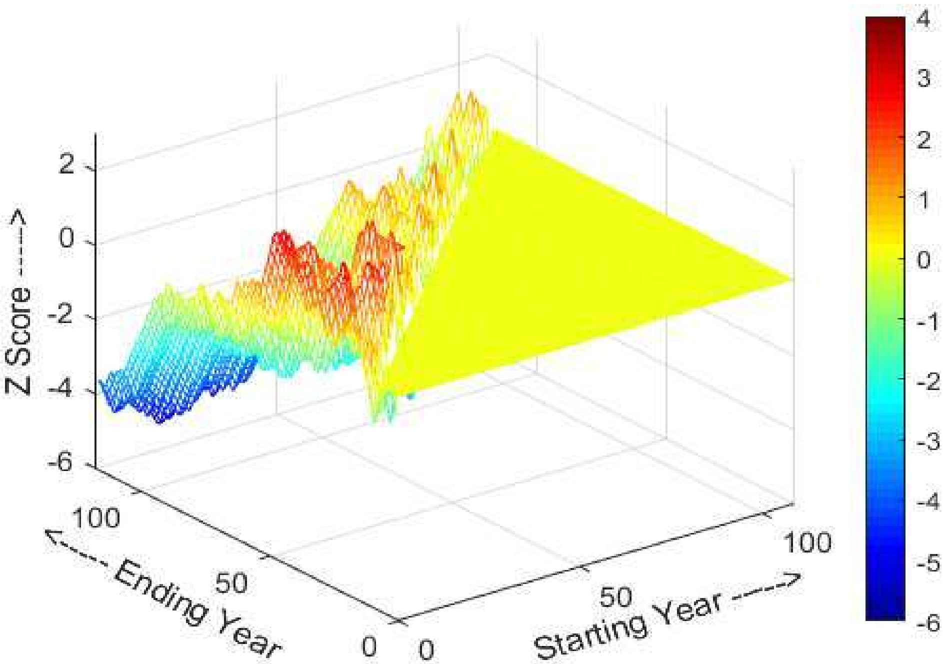

Figure 7.61 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Palamu

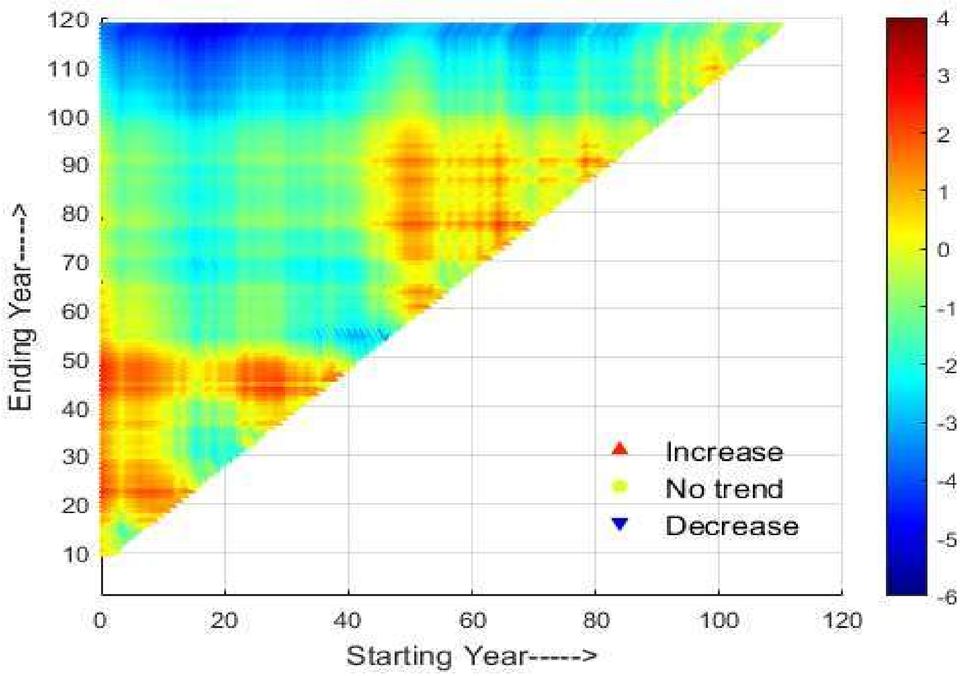

Figure 7.62 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Palamu

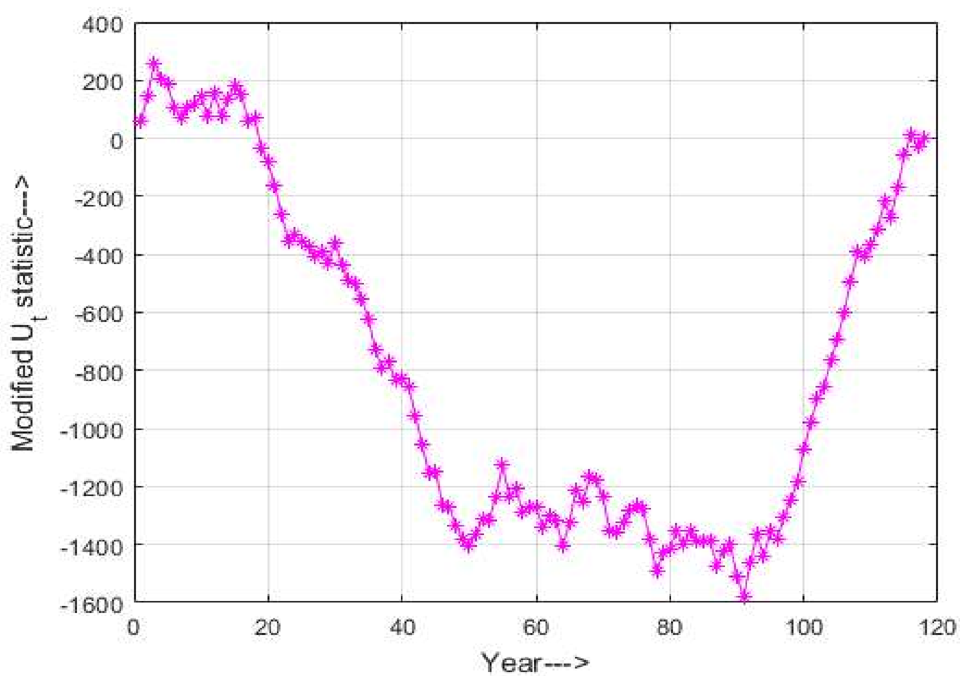

Figure 7.63 Variation of modified Ut over the years for ascertaining change points for Palamu

7.3.4 Precipitation Characteristics of Ranchi

Figures 7.64-7.65 represent 3D, 2D patterns of precipitation characteristics, and modified PMW statistics are plotted in Figure 7.66 for Ranchi. The points on the line drawn parallel to the x-axis at ending year 118 display several changes in the shades of the color. Disruption in the continuity of the shades of the color is marked as the change point. The occurrences of these points at around 49^{th,} and 95th years respectively demonstrate the change in the pattern of precipitation trend. The multi-modal characteristics of the pattern of the trend are clearly visible in Figure 7.64, and it shows two zones of the trough (corresponding to patches 1&3 in 2D Figure 7.65) and one zone of the crest (Patch 2). The modified PMW statistics plotted in Figure 7.66 confirm a similar pattern as well of the trend. However, the variable-sized cluster analysis enables one to identify the various change points that might have occurred in the available historical record of precipitation data. Thus, VSCA owns the potential to detect multiple change points if they occurred over the long duration of the study period. The same is evident from Figures 7.64-7.65.

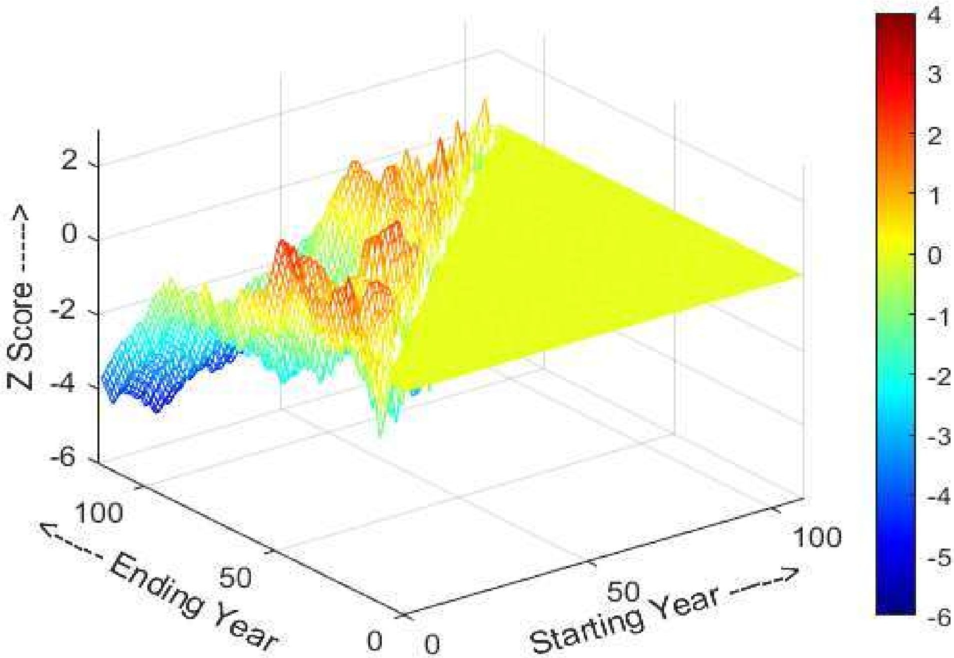

Figure 7.64 3-D characteristics of trend pattern of precipitation at significance level 0.05 for Ranchi

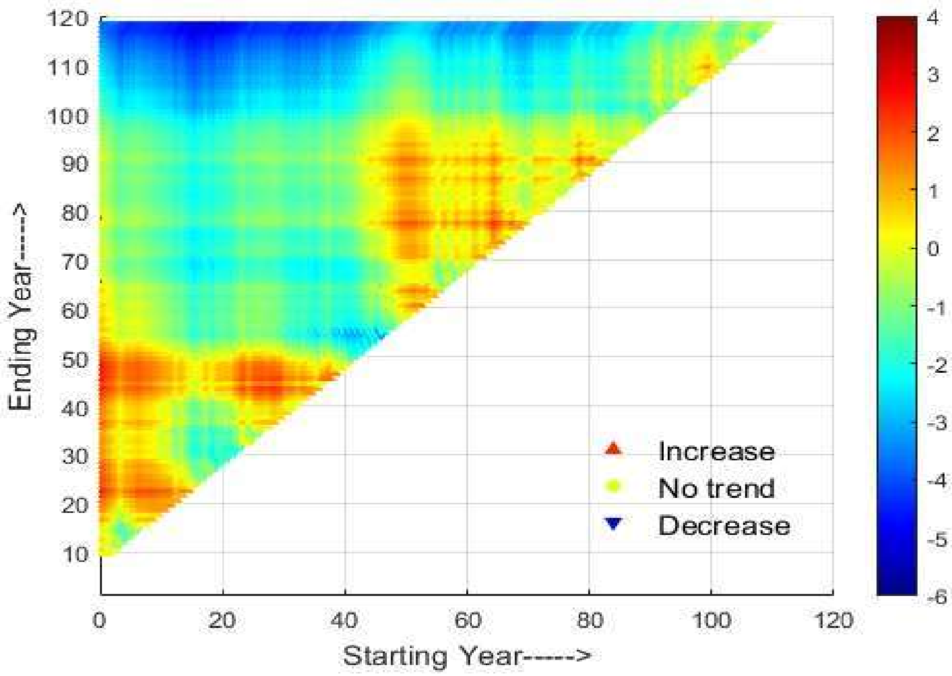

Figure 7.65 2-D characteristics of trend pattern of precipitation at significance level 0.05 for Ranchi

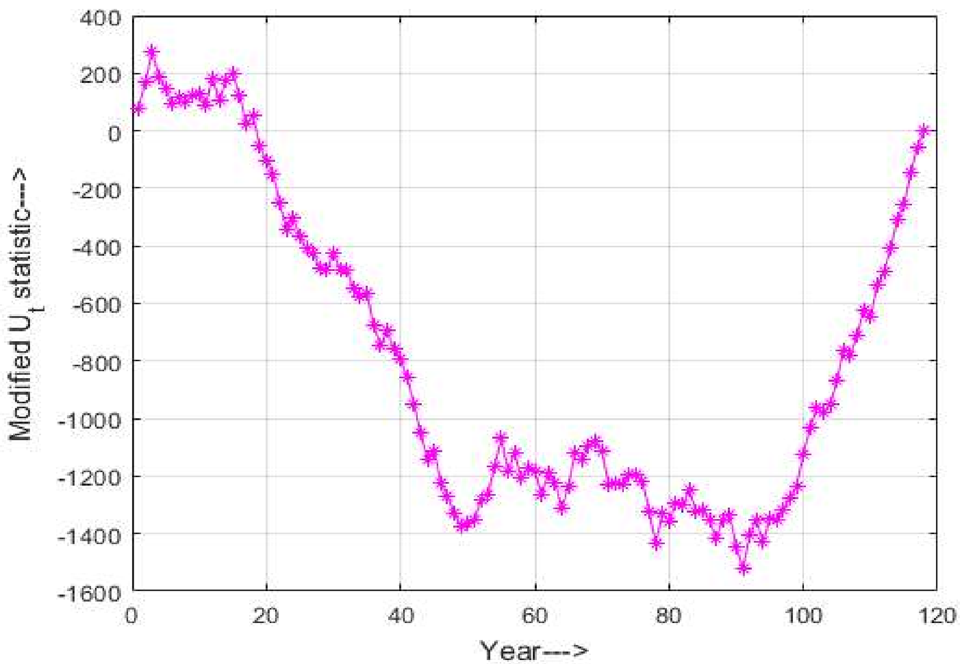

Figure 7.66 Variation of modified Ut over the years for ascertaining change points for Ranchi

7.3.5 Precipitation Characteristics of West Singhbhum

3D and 2D patterns of precipitation characteristics for West Singhbhum are shown in Figures 7.67-7.68, whereas modified U_t statistics obtained from the PMW test are plotted in Figure 7.69. Figure 7.67 shows a zone of trough corresponding to Patch 2 of Figure 7.68. This patch reflects a decreasing precipitation trend with a change in the pattern at around the 50th & 98th year. The lowest dip point identifies the change point in the trough shown in Figure 7.67, and it is also confirmed by locating a point along the line, parallel to the x-axis, drawn at ending year 118 at which shade of blue color strip turns greenish. The appearance of a crest near starting years (zero to ten) reflects an increasing trend of precipitation compared to the precipitation that occurred in the early years of the century. Modified U_t obtained by PMW test further confirms the same finding, as evident from Figure 7.69.

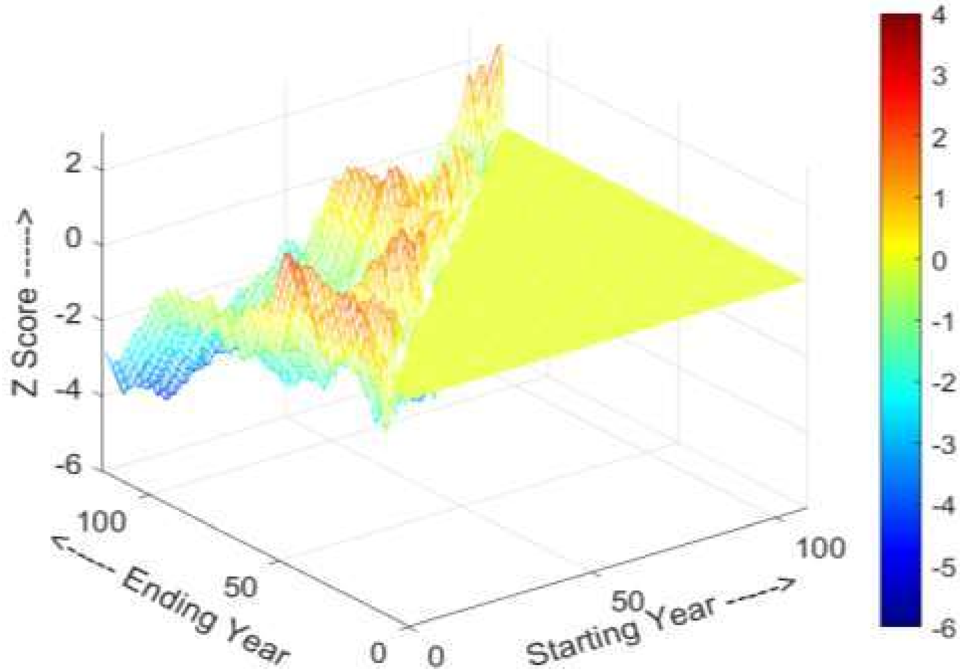

Figure 7.67 3-D characteristics of trend pattern of precipitation at significance level 0.05 for West Singhbhum

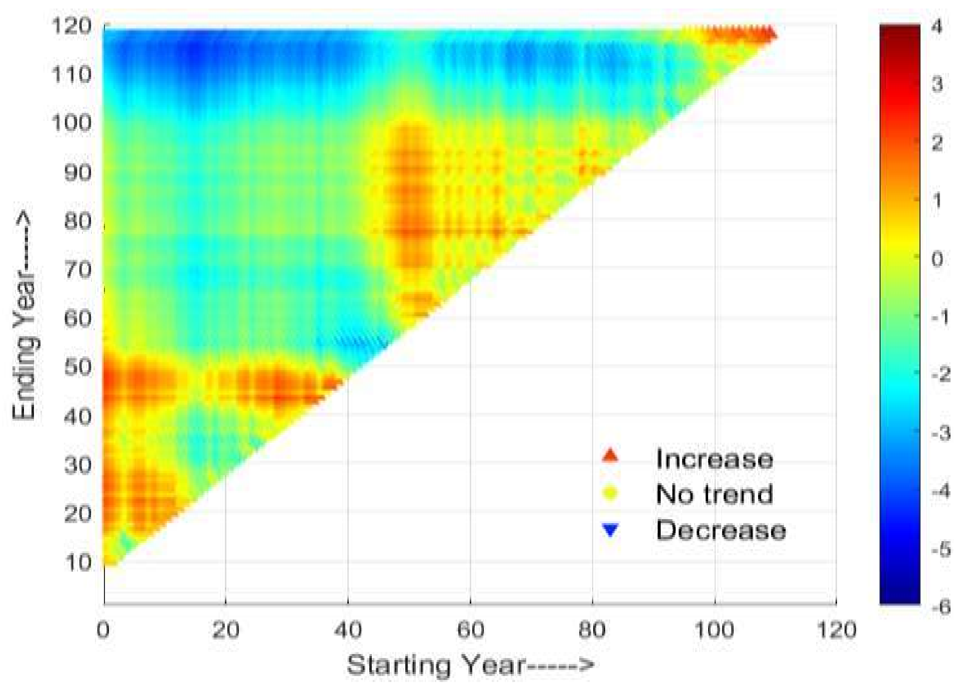

Figure 7.68 3-D characteristics of trend pattern of precipitation at significance level 0.05 for West Singhbhum

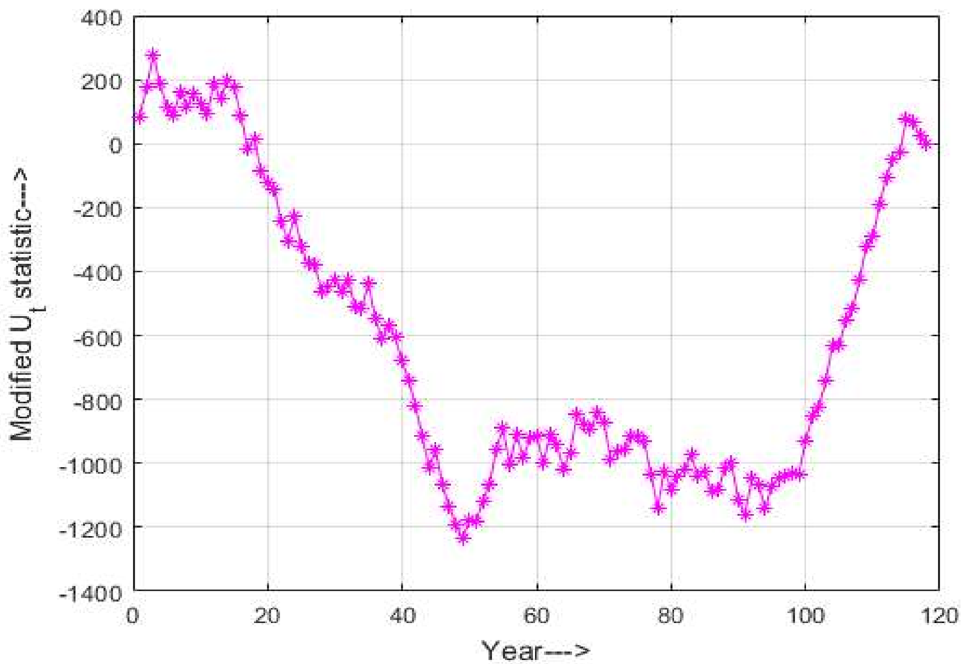

Figure 7.69 Variation of modified Ut over the years for ascertaining change points for West Singhbhum

7.3.6 Comparative Assessment for Spatial Variability

Trend patterns for precipitation over almost all the stations i.e., Hazaribagh, Palamu, Ranchi and West Singhbhum except Dumka display similar characteristics, decreasing trends around 1990 onwards. The major change in precipitation trend over these districts also occurred during the decades of 50s. The spatial distribution of long-term Mann-Kendall value (ZMK) of annual time series during the period of 118 years for all the climatic variables (Precipitation, temperature and evapotranspiration) has illustrated in Fig. 10 The color variation of the studied stations is according to the ZMK value. The ZMK value varies from -1.2 to -2.6 for the precipitation signifies the decreasing trend whereas the temperature is increasing with ZMK value from 2.4 to 4.9. Evapotranspiration is also crucial climatic variables; ZMK value varies from -0.3 to -0.74. The size of the arrow is depending on the ZMK values. Bigger the size of arrow higher the ZMK values and the size are decreasing with the ZMK values. The Mann Kendall trend test indicated that the seasonal and annual precipitation were characterized by decreasing trend in almost all localities which are depending upon geographical features with respect of forest coverage and water bodies and maintains. However, the meaningful change of precipitation observed merely in two locations, kolhan and Santhal pargana divisions and the significant change in temperature and evapotranspiration is observed in Palamu and Kolhan divisions (Fig. 10). Overall, it can be concluded that a decrease in rainfall has occurred over the entire time period. The negative values in the trend analysis map (Fig. 6) show the magnitude of decrease, whereas, the positive values show the magnitude of increase. The color spectrum shows the colour from blue (negative ZMK values) to red (positive ZMK values) with intermediate color followed by cyan, green and yellow. The spatial distribution map of rainfall and evapotranspiration, illustrates a significant decreasing trend whereas spatial distribution map of average temperature trend, demonstrates a significant increasing trend and is particularly prevalent in the Santhal pargana division of Jharkhand (Fig. 10), where an increasing trend was observed from 1-1.5 °C in the north-western region. Apart from the high increase of up to 1.5 °C in north-western part a moderate increase of temperature with 0.14-0.82 °C is observed in the northern and southwestern parts of the state, which may lead to water scarcity in the area. The findings of this study will help in spatially accessing the zones severely affected due to rising trend of maximum temperature and decreasing trend of rainfall that help government personnel to provide relief instantly. The further increasing trend may severely affect the agricultural productivity under warmer climate as, arid and semiarid regions could experience severe water stress due to a decline of soil moisture due to high temperatures.

7.4 Summary

In contravention to the canonical way of handling precipitation data for trend analysis that yields unique trend over the long span of time, the proposed methodology involving variable size cluster analysis presents the pictorial view of the pattern of the changing trend along with the clue for the detection of one or more change points and/or alternate trends, if it occurs, without application of Pettitt Mann Whitney method. The modified PMW statistics drawn on a graph display results congruous to the actual pattern of changing trend, and hence proved to be a better option than the traditional PMW methodology that detects only one change point/ point of the sudden jump. 3-D figures are drawn for variation of the Z-score with varying starting and ending time clearly depicted the pattern of the changing trend as an undulated surface for the visual feel of the variation in the trend of precipitation that was not detectable by the ordinary MK test involving complete historical dataset. Trend analysis using station scale data showed a more realistic result than that of the grid-based data built upon spatial averaging. The same trend is obtained by the different clusters created by sequential elimination of starting year data in the application of MK test enabled one has more confidence and reliability on the conclusive result.

Further, the application of VSCA demonstrated that the patterns of the trend for precipitation over Lucknow, Gorakhpur, and Varanasi are similar, and they displayed decreasing trend around 1990 onwards with a major change in the decades of 70-80. Contrarily, Saharanpur and Agra being part of western UP, displayed an increasing trend until 1940 and no-trend after that. Bareilly being in the western belt of Uttar Pradesh but closer to the Himalayan range showed a marginal reduction in precipitation with no significant trend. Jhansi being close to the Bundelkhand also showed a reduction in precipitation.