

Chapter 6

3D-PATTERN CHARACTERIZATION OF MULTIPLE CLIMATIC EXTREME INDICES

6.1 General

The Assessment of multiple climate extremes through trend analysis in 2D and 3D representations Floods and Droughts are significantly impacted by rainfall, a crucial component of the hydrological cycle. This study evaluates long-term rainfall trends using Variable-Size Cluster Analysis (VSCA) to examine trends and change points. Eight localities in the Damodar River Basin of India (Bardhaman, Dhanbad, Giridih, Hazaribag, Koderma, Ramgarh, Purulia, and West-Medinipur) provided rainfall data from 1922 to 2021. The Mann-Kendall (MK) test with Sen's slope estimator reveals monotonic trends and magnitudes; VSCA analyzes rainfall patterns and change points. Changing climate statistics were summarized using a modified Pettitt-Mann-Whitney (PMW) test version. The robustness of VSCA was proven by integrating MK and PMW tests with a minimum of 100 years of data. Rainfall patterns that changed over time were represented graphically using three-dimensional (3D) representations for 100 years of data with a minimum cluster size of 10. For Bardhaman, Dhanbad, Giridih, and Hazaribag, VSCA analysis showed a declining trend in rainfall beginning about 1990, with Notable variations in 1970–1980. On the other hand, Koderma and Purulia had rising patterns starting in 1970 and lasting roughly from 1960 to 1980. Most of the time, West-Medinipur showed both declining and no-trend conditions. For Bardhaman, Dhanbad, Giridih, Hazaribag, Ramgarh, and West-Medinipur, the M-K test and Sen's slope technique revealed a significant negative trend in rainfall, with magnitudes of -1.28 mm/year, -1.03 mm/year, -1.67 mm/year, -0.61 mm/year, -2.54 mm/year, and -1.92 mm/year, respectively. Purulia and Koderma displayed rising trends with magnitudes of 0.84. This research enhances our understanding and provides valuable insights for managing water resources.

6.2 Application of VSCA over Damodar River Basin

The application of Variable-Sized Cluster Analysis (VSCA) over the Damodar River Basin allows for the identification of significant hydrological trends and change points in river discharge and precipitation patterns. By analyzing long-term datasets such as

seasonal discharge and precipitation levels, VSCA can detect shifts in the basin's hydrology due to factors like climate change, dam constructions, and urbanization. The technique helps isolate periods of significant increase or decrease in water flow, highlighting both temporal and spatial zones of variability. This enables a deeper understanding of the basin's dynamic response to environmental and anthropogenic influences, crucial for future water resource management and flood control in the region.

6.2.1 Characteristics of Multiple Climatic Indices in Asansol

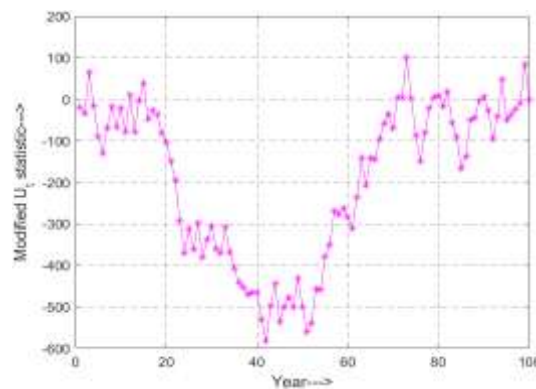
Asansol station, situated in the West Bengal portion of the Damodar River Basin (DRB), has been a focal point for numerous research projects aimed at analyzing long-term trends in extreme climate indices. This station was specifically selected for a comprehensive trend analysis from 1923 to 2022. Figures 6.1(b-c) to 6.15(b-c) provide both two-dimensional and three-dimensional visualizations of the extreme climate variables observed at Asansol. The early segments of these figures reveal a pattern of peaks and valleys, where peaks indicate the magnitude and intensity of the trend, and troughs represent fluctuations over time. These patterns highlight significant changes in extreme climate indices throughout the period. The visual representations, marked by varying color zones, display troughs in the lower portion of the triangular shapes and crests in the upper portion, capturing the dynamic nature of climate trends. The right-hand bar in Figures 6.1(c) to 6.15(c) illustrates the increasing (red) and decreasing (blue) rainfall trends, with green representing periods of no significant trend.

From 1923 to 1950, Asansol exhibited a declining rainfall trend, as evidenced by the blue shading in the figures. However, an increasing trend was observed between 1950 and 1990, marked by red hues, while green zones denote periods of stability. By analyzing the clustering of these trends, researchers were able to pinpoint key moments when significant shifts in the climate occurred. The statistical data in Figures 6.1(c) to 6.15(c) confirm the reliability of these visualized trends, enhancing the credibility of the analysis.

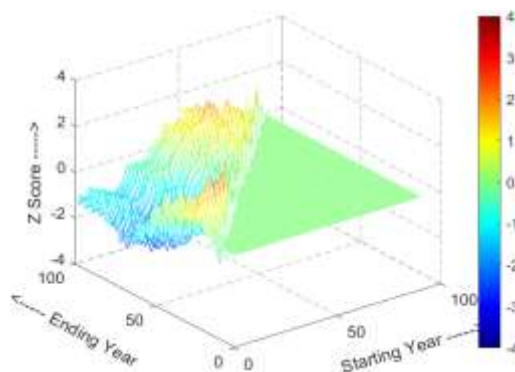
A long-term trend analysis conducted by Halder et al. (2023) across West Bengal districts also found a declining annual rainfall trend at Asansol from 1901 to 2020. This study further visualizes the increase and decrease in annual rainfall trends at Asansol, employing both 2D and 3D figures. In addition, a modified version of the PMW test was introduced in this research to detect multiple change points in the trends. Unlike

earlier studies, which focused on basic trend detection, this research provides more detailed insights by identifying and clearly displaying multiple change points through advanced graphical representations.

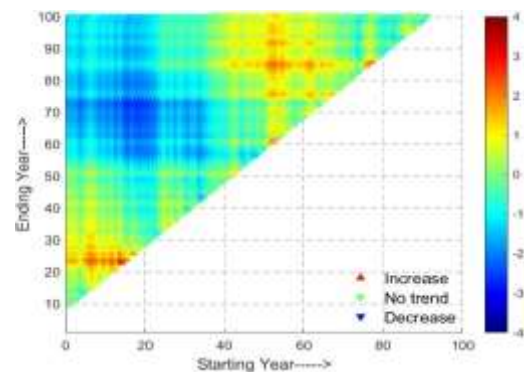
The study's findings are highly valuable for planners and policymakers, particularly in understanding the evolving nature of rainfall patterns, which is crucial for agricultural planning in the region. Since the majority of the population in this area relies on agriculture, understanding rainfall variability can significantly influence farming practices and water management strategies. By presenting rainfall trends in three dimensions and identifying critical change points, this research contributes to a deeper understanding of climate dynamics in the Asansol region.



(a)



(b)



(c)

Figure 6.1(a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the CDD trend in Asansol is at a significance level of 0.05. (c) The 2-D pattern of the CDD trend in Asansol was at a significance level of 0.05.

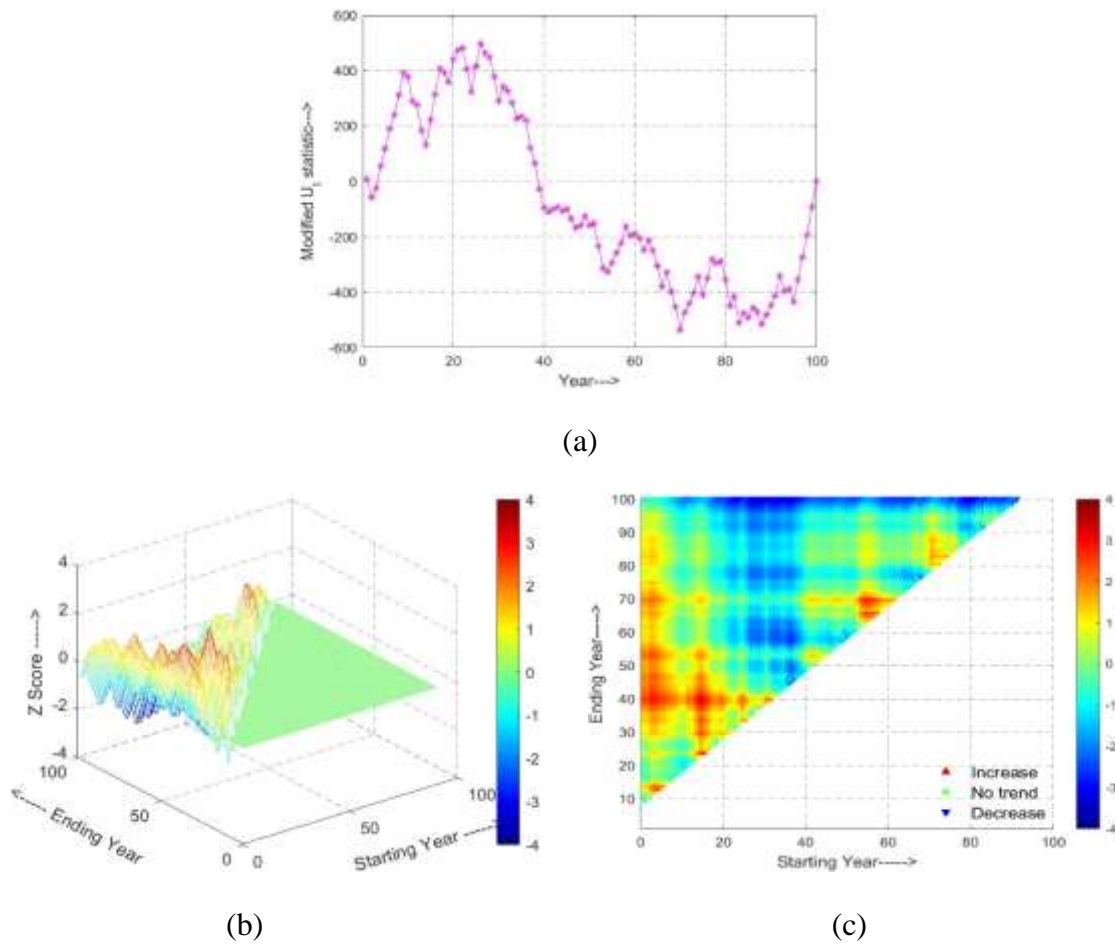
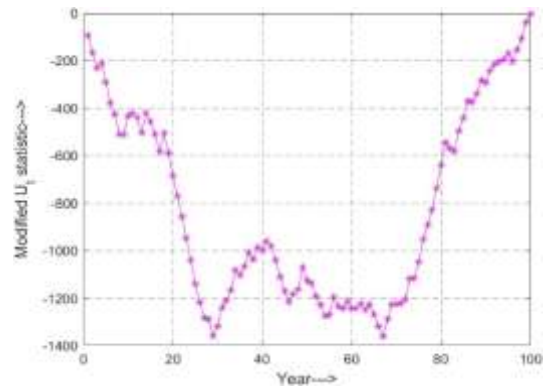
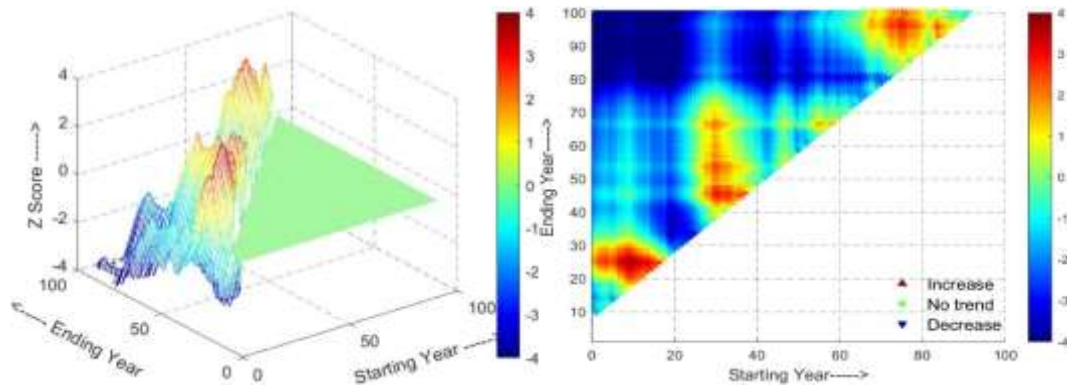


Figure 6.2 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the CWD trend in Asansol is at a significance level of 0.05. (c) The 2-D pattern of the CWD trend in Asansol was at a significance level of 0.05.



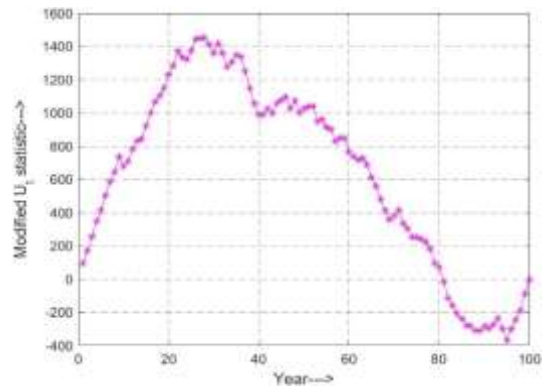
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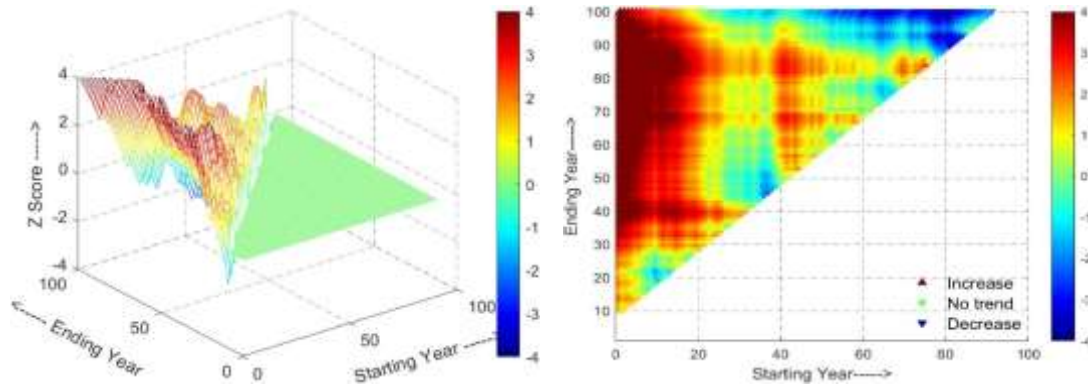
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Figure 6.3 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the DTR trend in Asansol is at a significance level of 0.05. (c) The 2-D pattern of the DTR trend in Asansol was at a significance level of 0.05



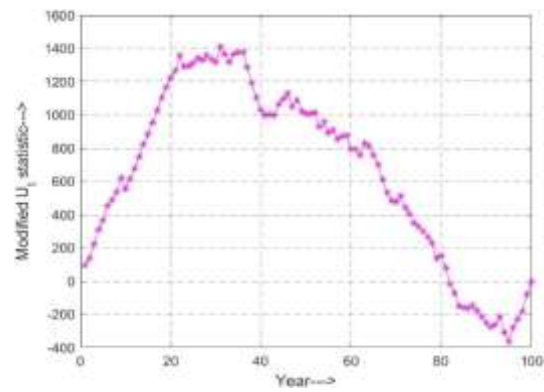
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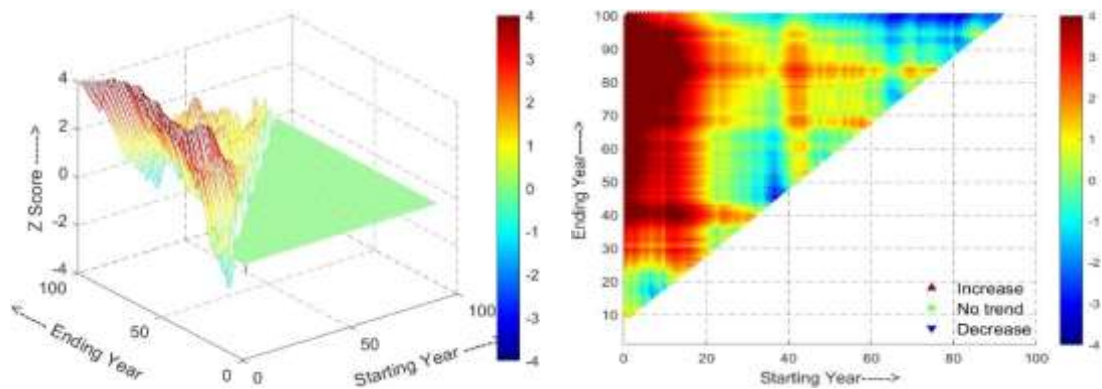
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(c)

Figure 6.4 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the PRCPTOT trend in Asansol is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Asansol was at level of 0.05.



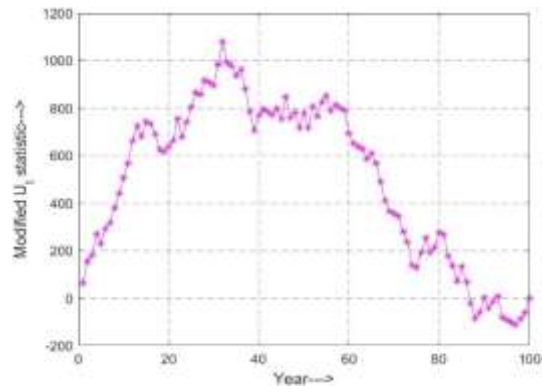
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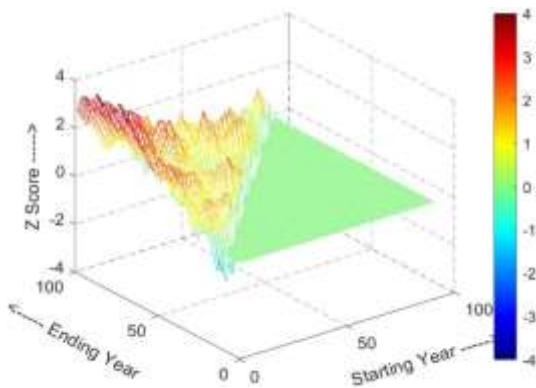
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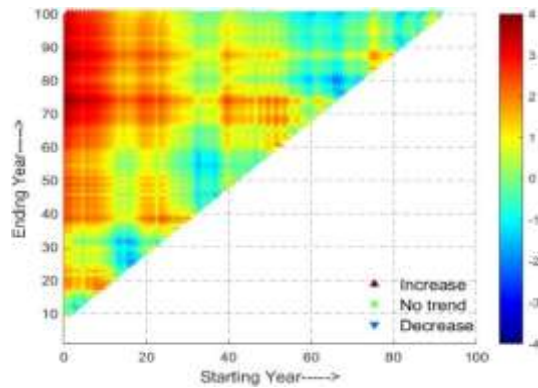
Figure 6.5 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the R10mm trend in Asansol is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Asansol was at level of 0.05.



(a)

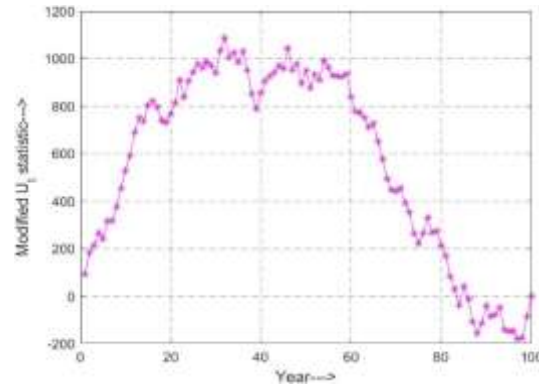


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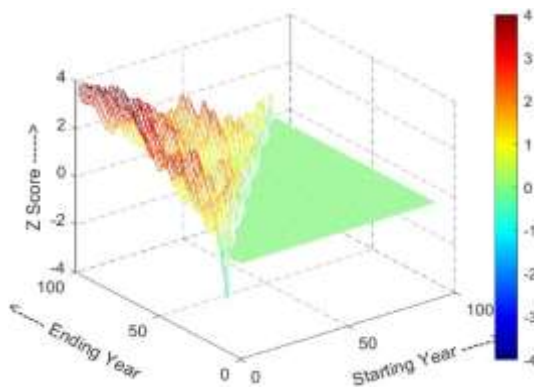


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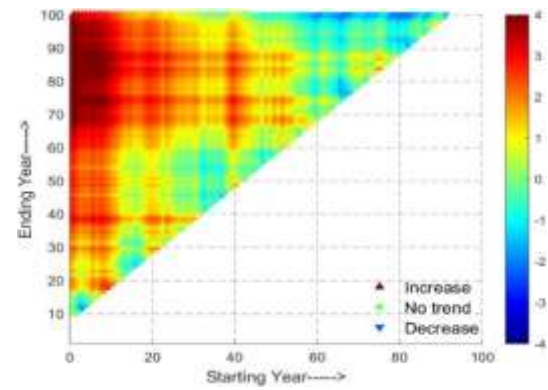
Figure 6.6 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the R20mm trend in Asansol is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Asansol was at level of 0.05.



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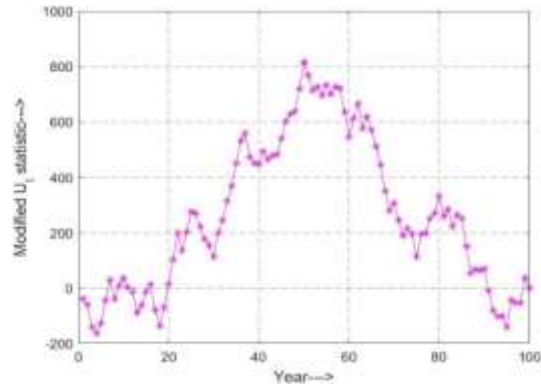


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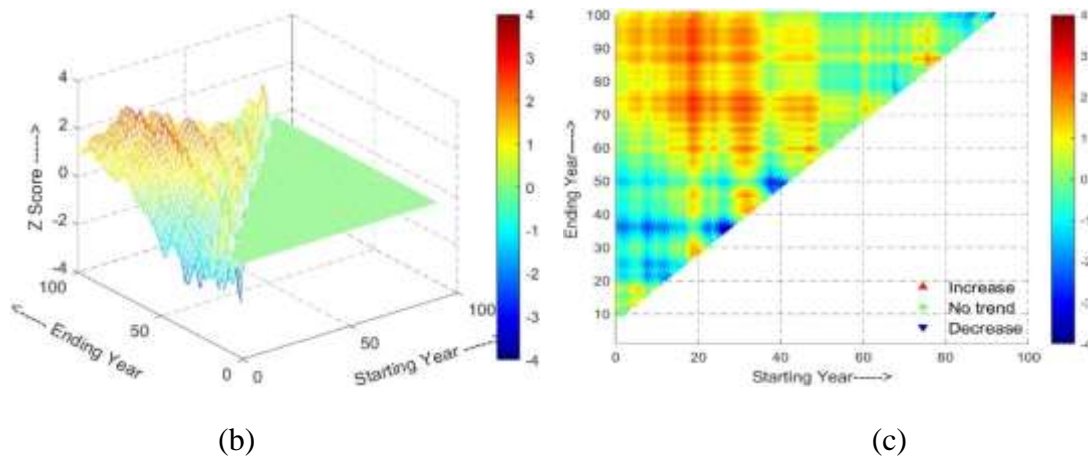


(c)

Figure 6.7 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the R_{95p} trend in Asansol is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in Asansol was at level of 0.05.



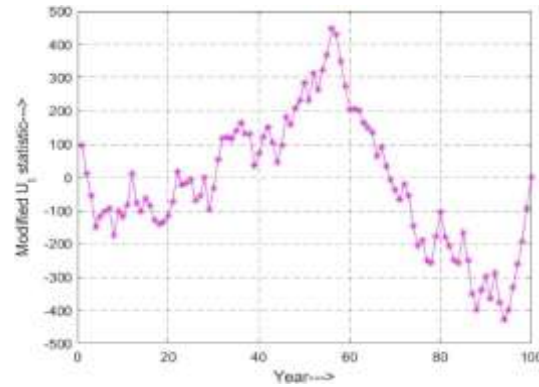
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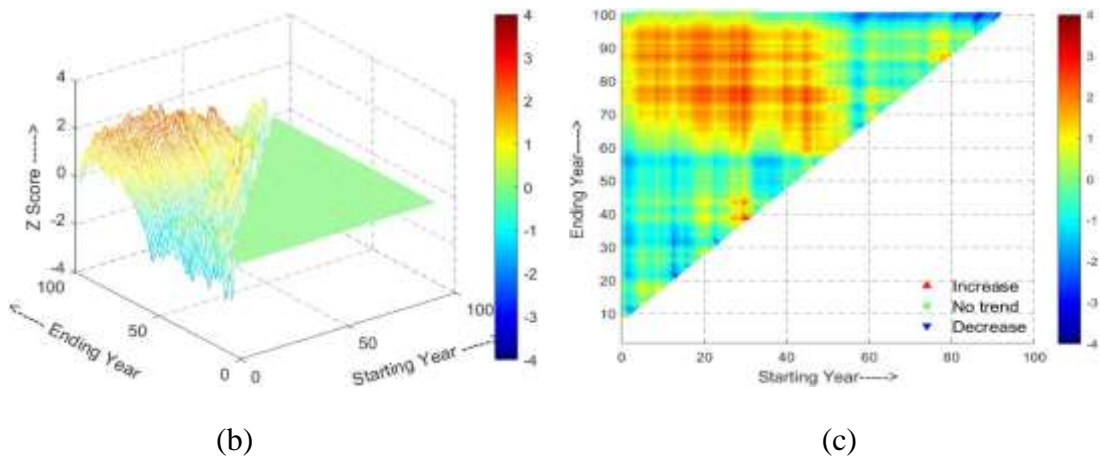
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Figure 6.8 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the R_{99p} trend in Asansol is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Asansol was at level of 0.05.



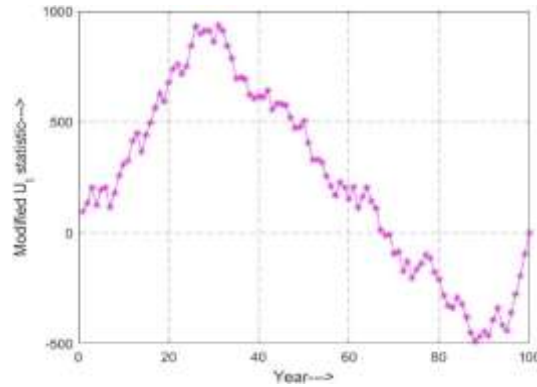
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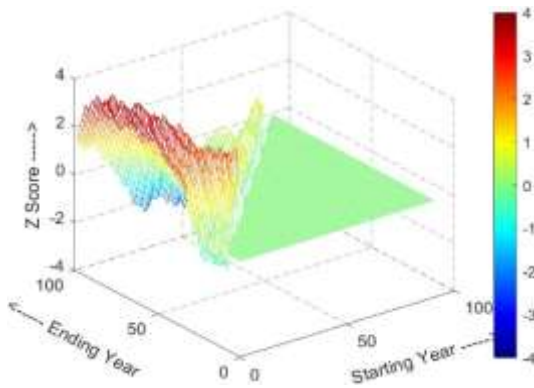
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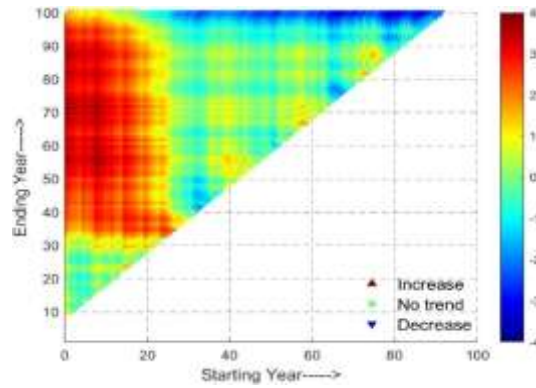
Figure 6.9 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the RX1day trend in Asansol is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Asansol was at level of 0.05.



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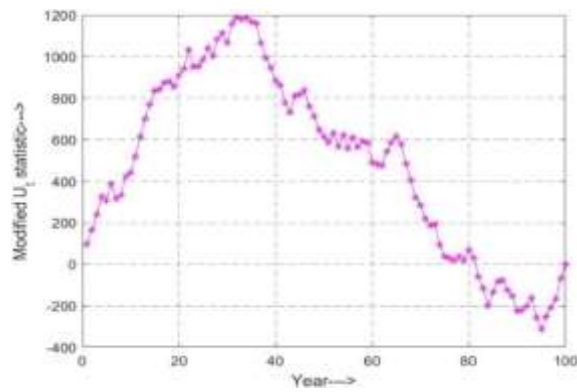


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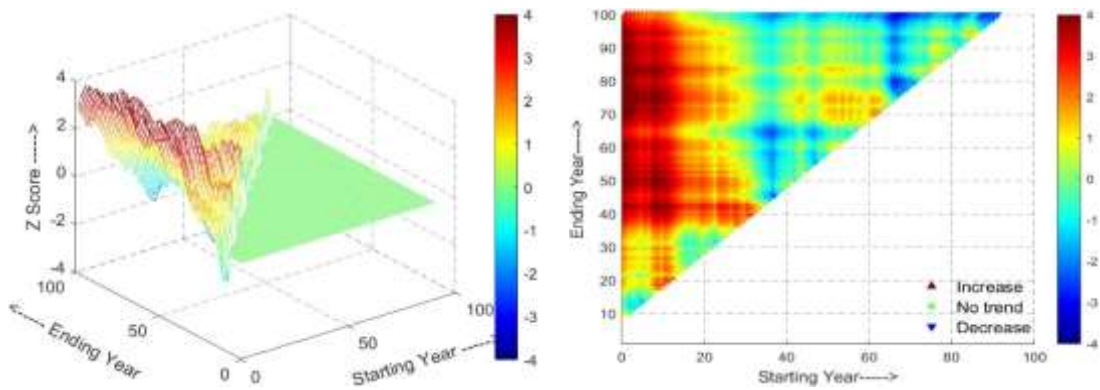


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Figure 6.10 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the RX5day trend in Asansol is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Asansol was at level of 0.05.



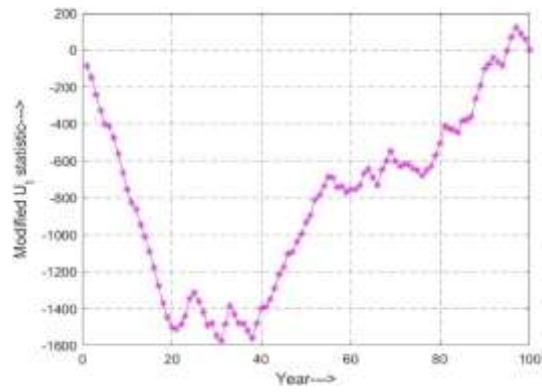
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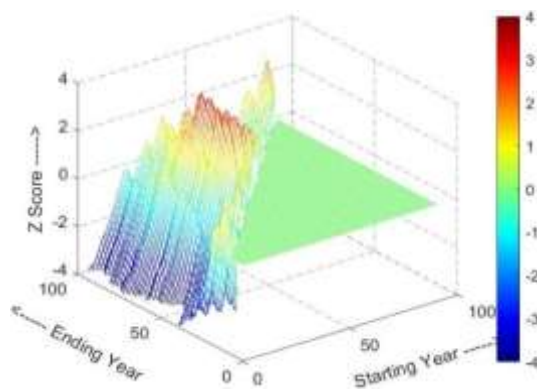
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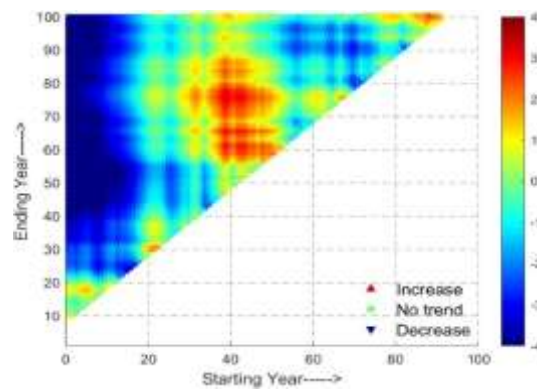
Figure 6.11(a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the SDII trend in Asansol is at level of 0.05. (c) The 2-D pattern of the SDII trend in Asansol was at level of 0.05.



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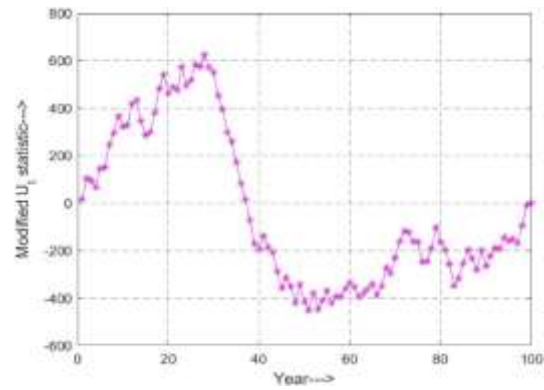


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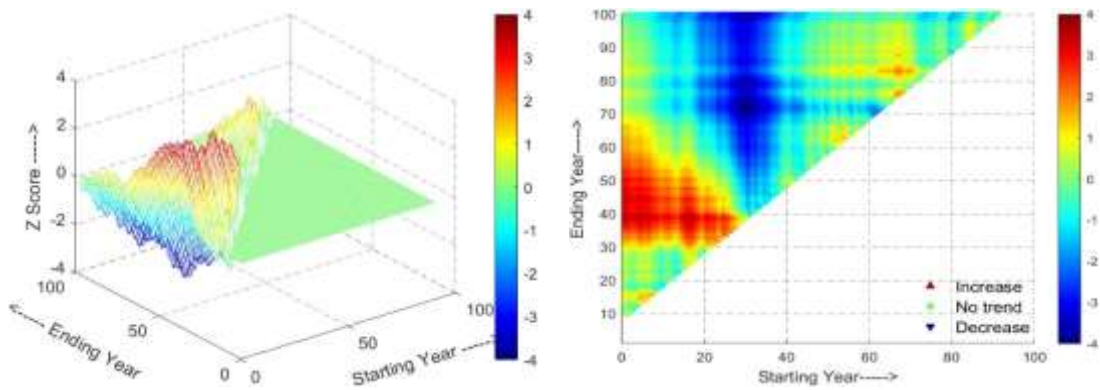


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Figure 6.12 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the TNN trend in Asansol is at level of 0.05. (c) The 2-D pattern of the TNN trend in Asansol was at level of 0.05.



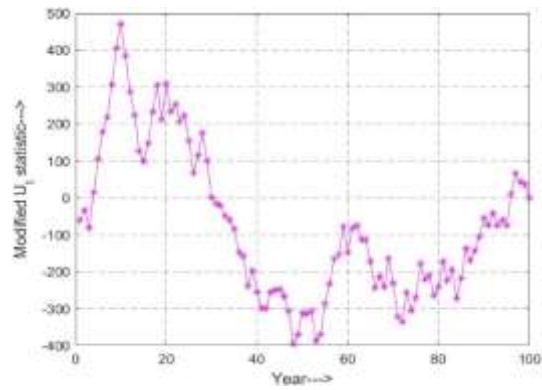
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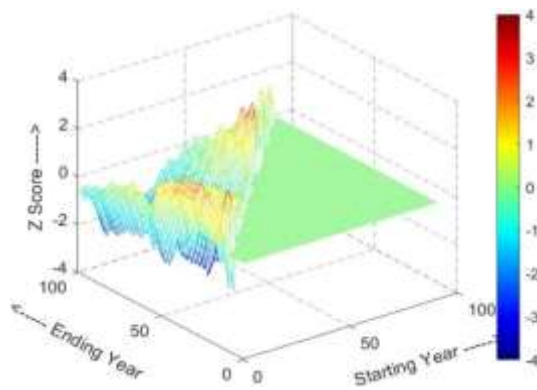
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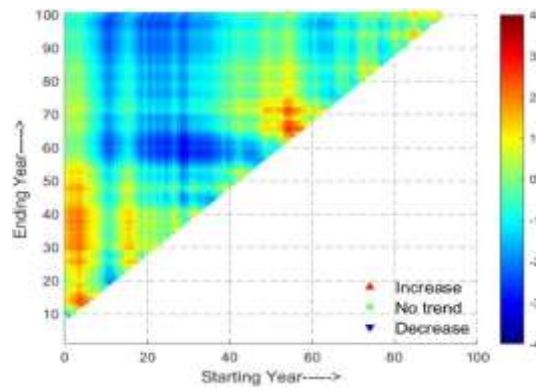
Figure 6.13(a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the TNX trend in Asansol is at level of 0.05. (c) The 2-D pattern of the TNX trend in Asansol was at level of 0.05.



(a)

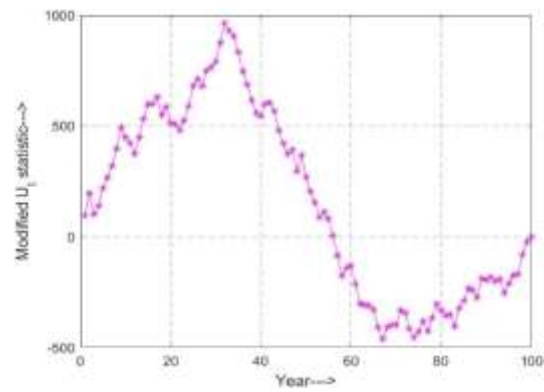


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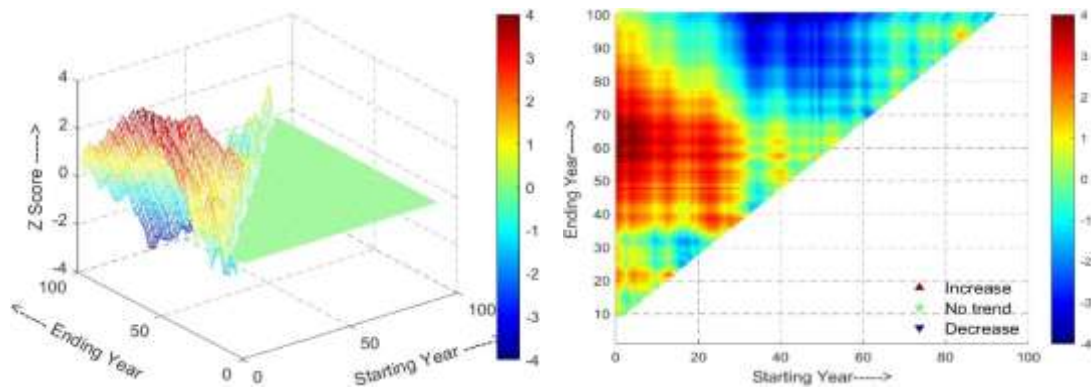


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Figure 6.14 (a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the TXN trend in Asansol is at level of 0.05. (c) The 2-D pattern of the TXN trend in Asansol was at level of 0.05.



(a)



(b)

(c)

Figure 6.15(a) Variation of modified U_t over the years to identify change points in Asansol. (b) The three-dimensional pattern of the TXX trend in Asansol is at level of 0.05. (c) The 2-D pattern of the TXX trend in Asansol was at level of 0.05.

6.2.2 Characteristics of Multiple Climatic Indices in Bagodar

Bagodhar station, located in the West Bengal portion of the Damodar River Basin (DRB), has been a significant focus for numerous research projects aimed at understanding long-term trends in extreme climate indices. This station was selected for a detailed analysis covering the period from 1923 to 2022. Figures 6.16(b-c) to 6.30(b-c) present both two-dimensional and three-dimensional visualizations of extreme climate variables observed at Bagodhar. In these figures, peaks and valleys emerge, with peaks indicating the intensity and direction of climate trends, while valleys reflect fluctuations over time. These patterns demonstrate that the extreme climate indices at Bagodhar have undergone considerable change during this period. The shaded zones, representing different climate phases, illustrate troughs in the lower portion of the triangular shapes and crests in the upper portions, indicating the dynamic nature of the trends. The color bar on the right side of Figures 6.16(c) to 6.30(c) shows a clear depiction of rainfall trends: blue for a decreasing trend, red for an increasing trend, and green for periods of stability.

Between 1923 and 1950, Bagodhar exhibited a decreasing rainfall trend, highlighted by blue shades in the figures. From 1950 to 1990, an increasing trend was observed, represented by red shades, while green areas denote stable periods with no significant trend. Analyzing clusters of trend shifts helps pinpoint critical moments where significant changes in extreme climate indices occurred. The statistical analysis in Figures 6.16(c) to 6.30(c) reinforces the reliability of these observations, making the trend analysis robust and dependable.

These results are invaluable for planners and policymakers, particularly in understanding how rainfall patterns shift over time critical knowledge for managing agricultural practices and water resources in the region. Since agriculture is the primary livelihood for the majority of the population in this area, understanding these rainfall dynamics is essential. By identifying key change points and representing rainfall trends in three dimensions, this research significantly enhances the understanding of climate variability in Bagodhar and its potential impacts on the region's agricultural productivity.

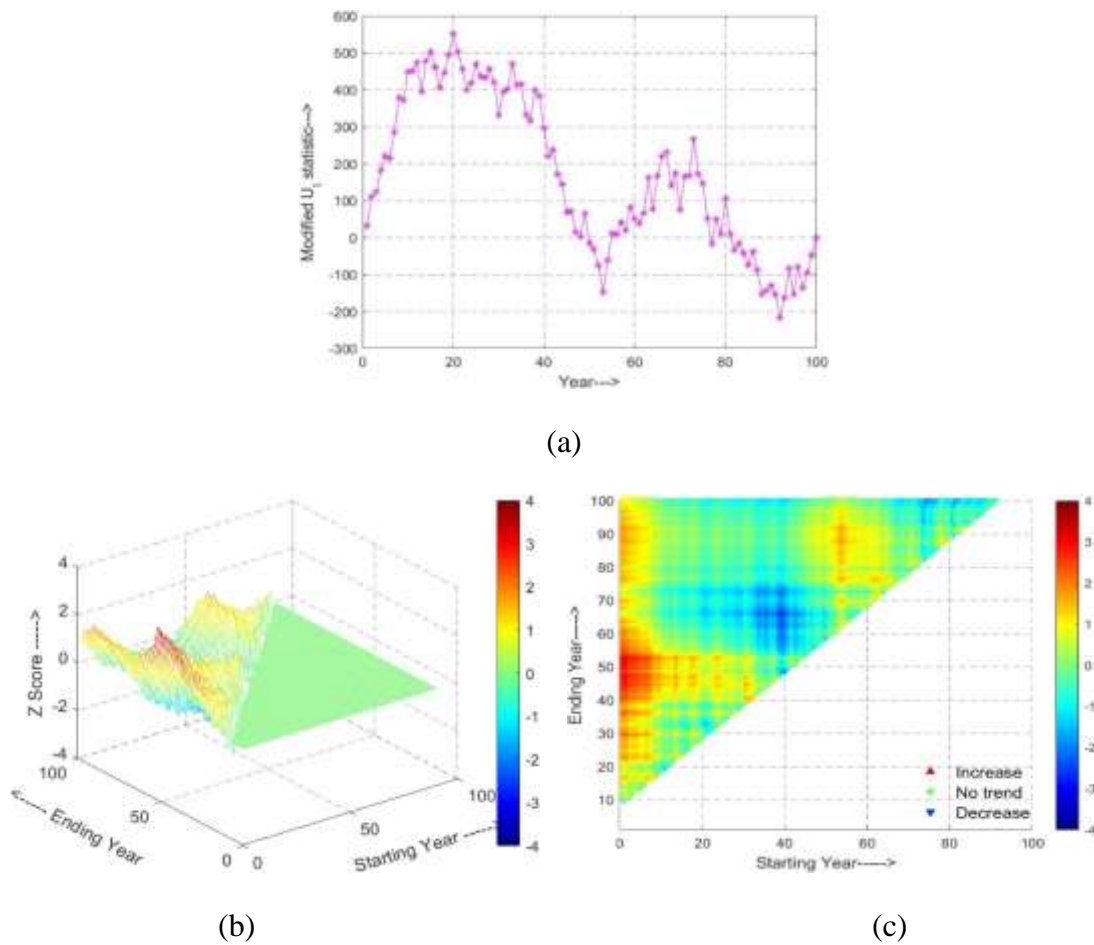
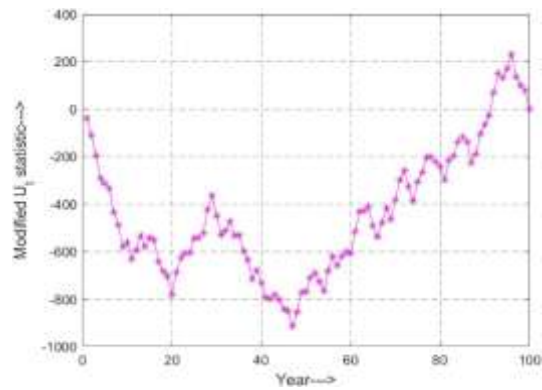
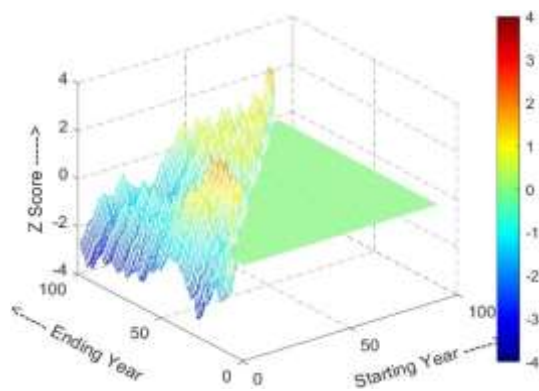


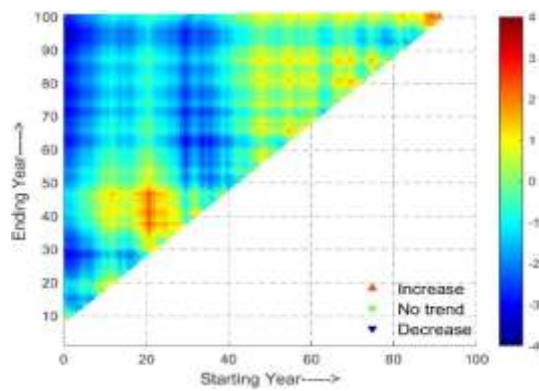
Figure 6.16 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the CDD trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the CDD trend in Bagodar was at level of 0.05.



(a)

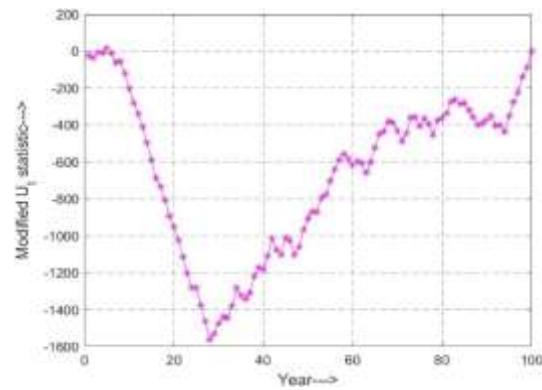


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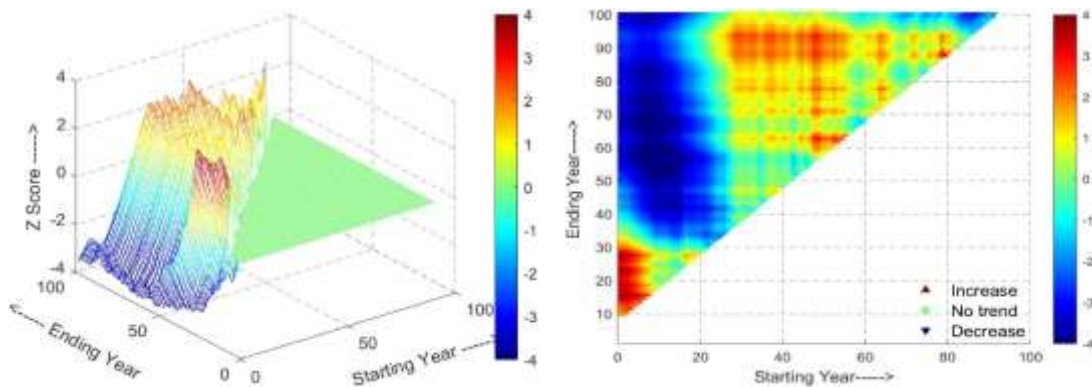


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Figure 6.17(a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the CWD trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the CWD trend in Bagodar was at level of 0.05.



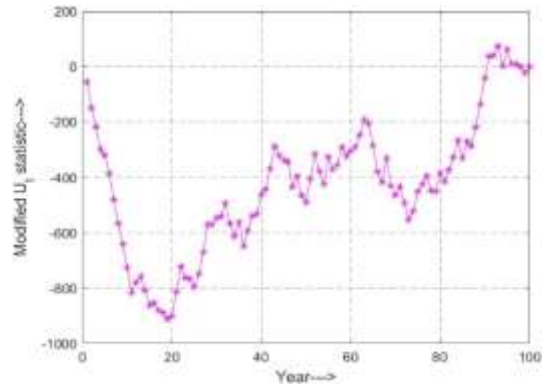
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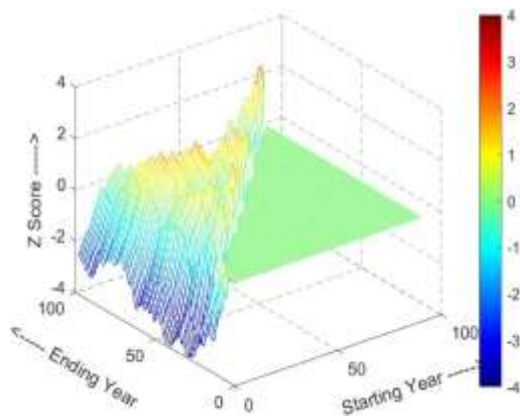
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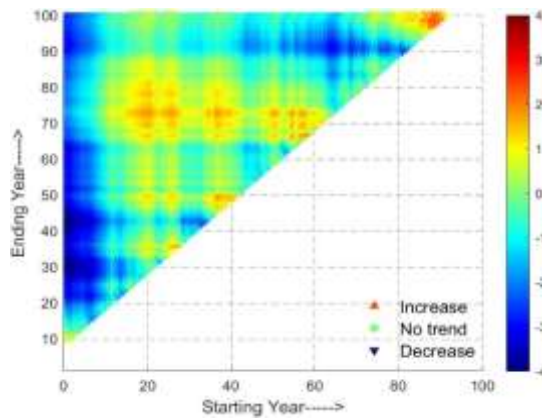
Figure 6.18 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the DTR trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the DTR trend in Bagodar was at level of 0.05.



(a)



(b)



(c)

Figure 6.19 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the PRCPTOT trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Bagodar was at level of 0.05.

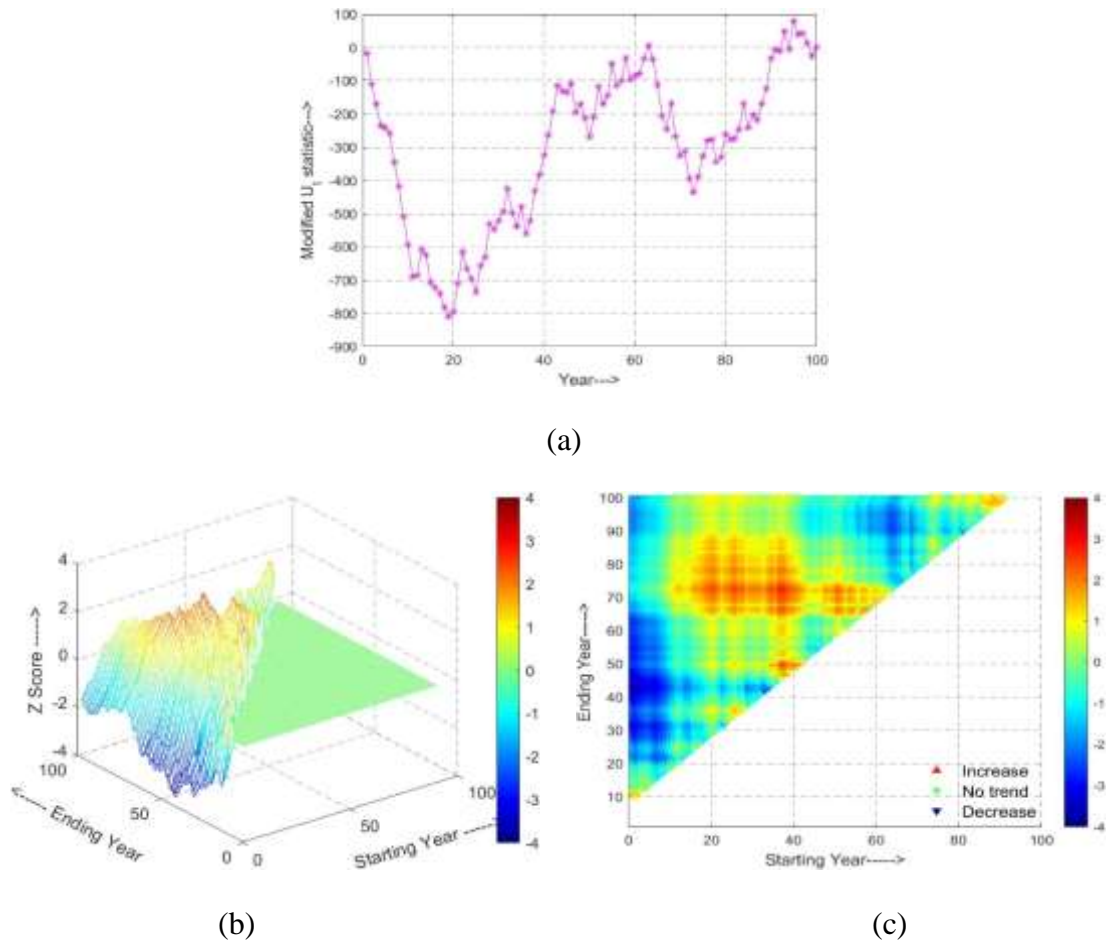
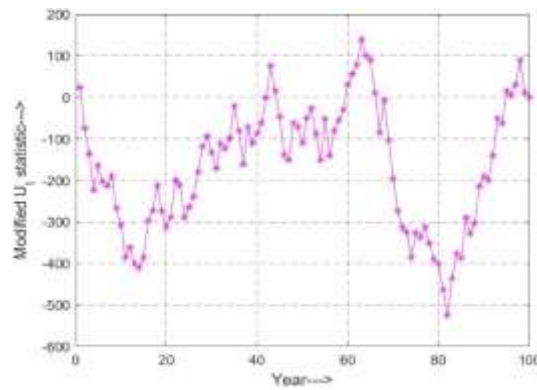
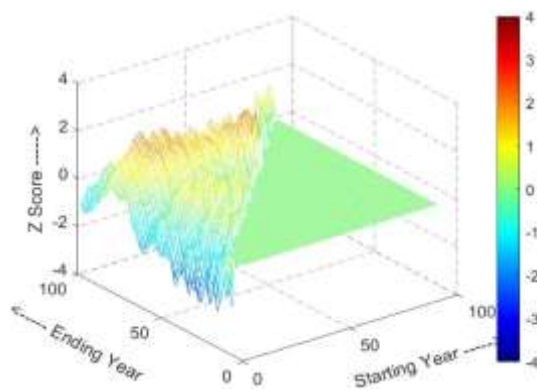


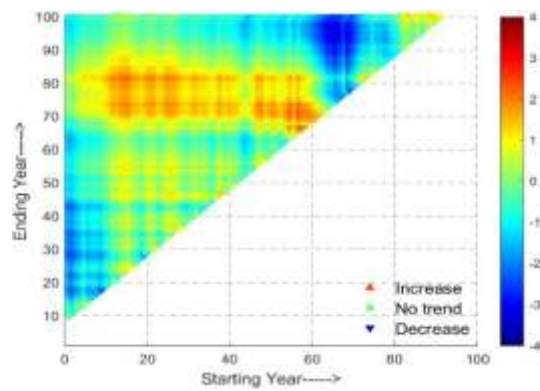
Figure 6.20(a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the R10mm trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Bagodar was at level of 0.05.



(a)



(b)



(c)

Figure 6.21(a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the R20mm trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Bagodar was at level of 0.05.

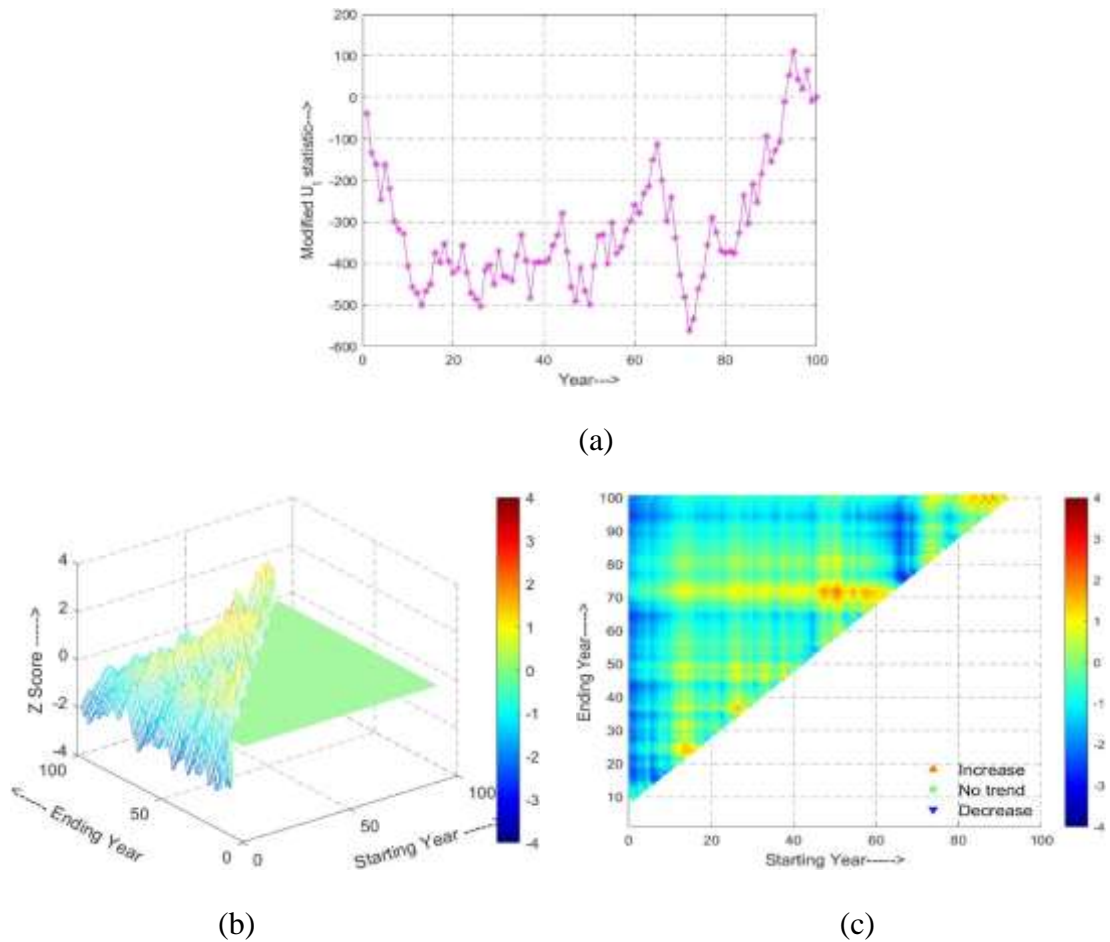
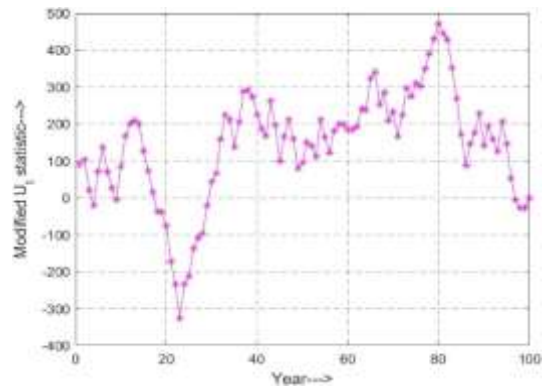
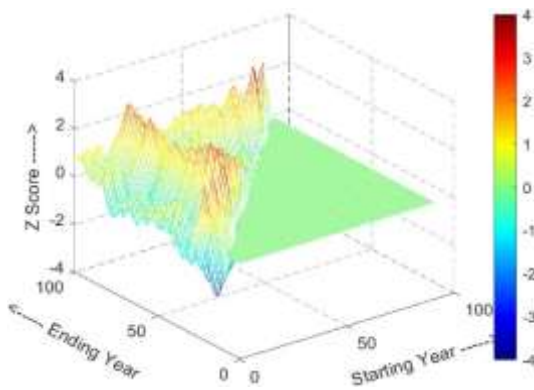


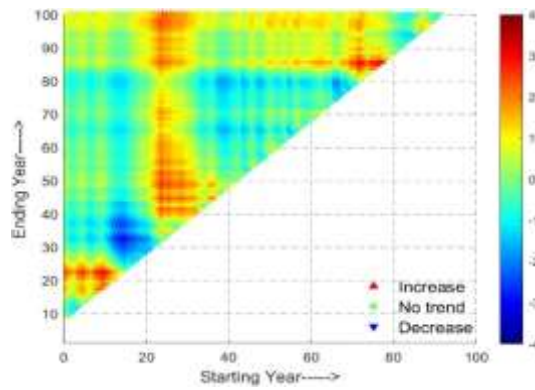
Figure 6.22 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the R95p trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the R95p trend in Bagodar was at level of 0.05.



(a)



(b)



(c)

Figure 6.23 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the R_{99p} trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Bagodar was at level of 0.05.

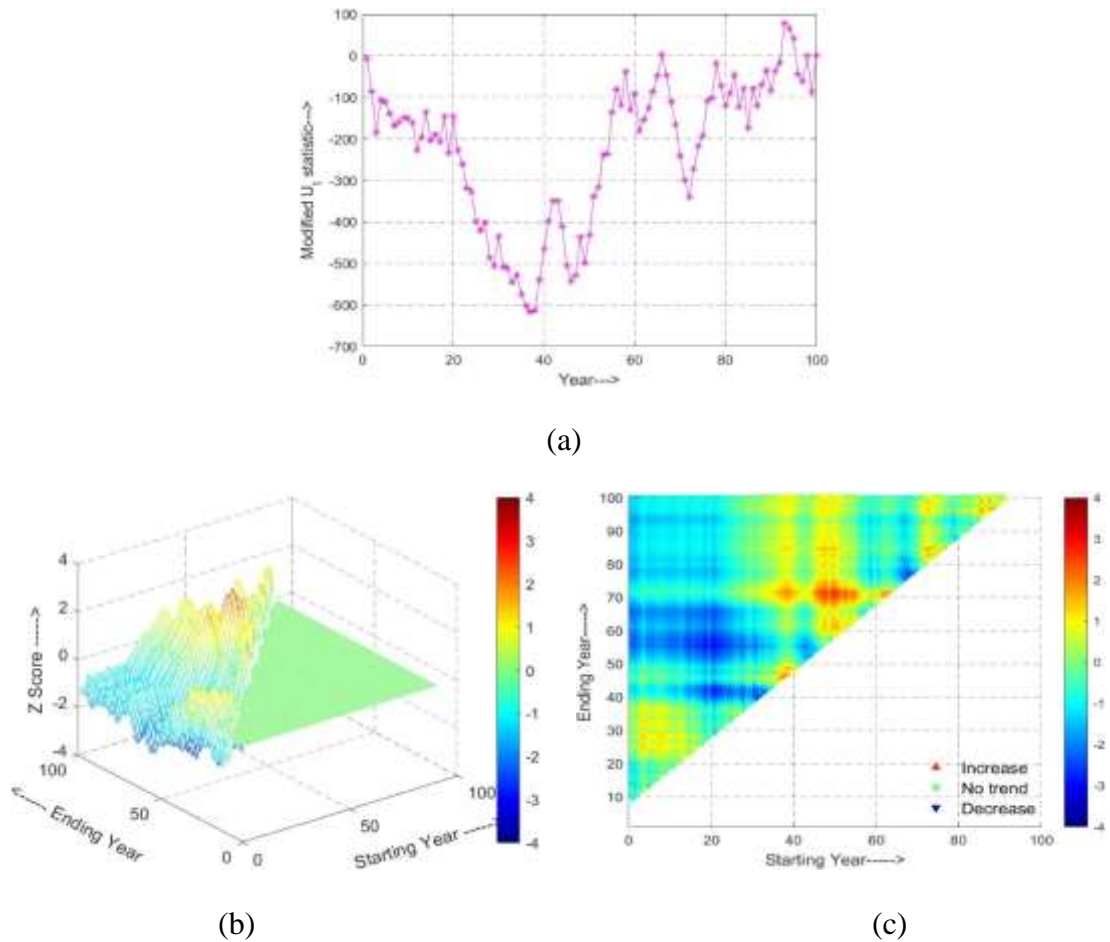
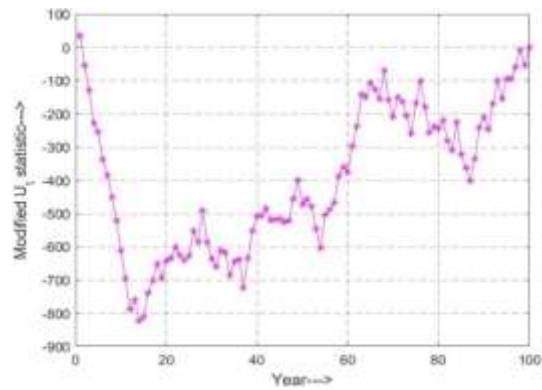
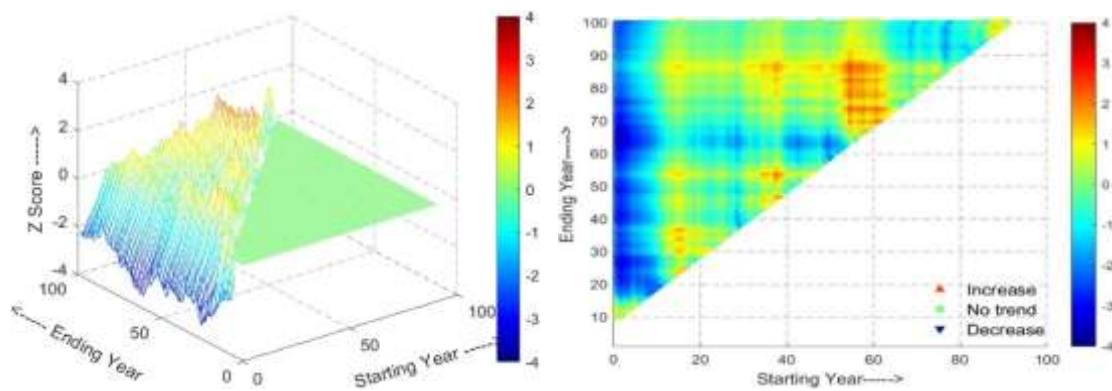


Figure 6.24 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the RX1Day trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the RX1Day trend in Bagodar was at level of 0.05.



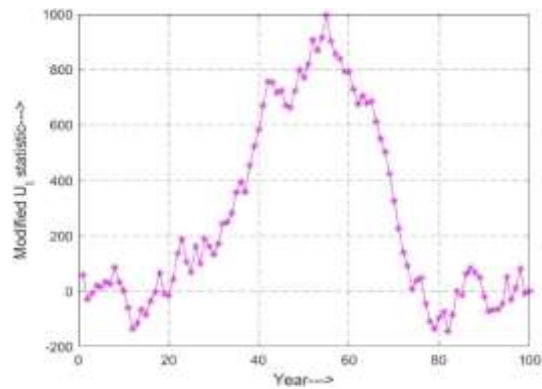
(a)



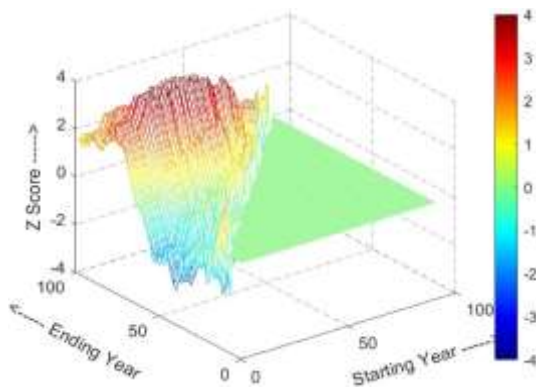
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(c)

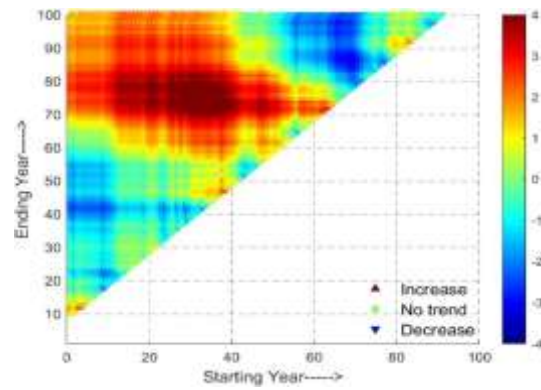
Figure 6.25 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the RX5Day trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the RX5Day trend in Bagodar was at level of 0.05.



(a)

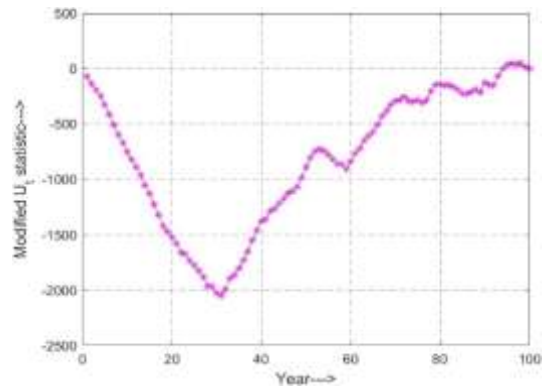


(b)

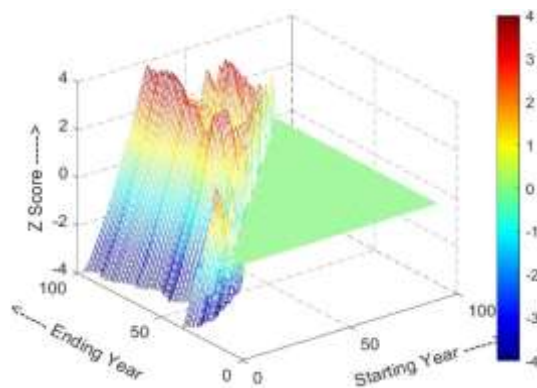


(c)

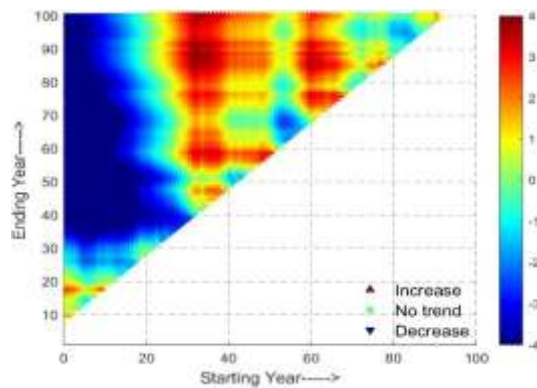
Figure 6.26 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the SDII trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the SDII trend in Bagodar was at level of 0.05.



(a)



(b)



(c)

Figure 6.27(a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the TNN trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the TNN trend in Bagodar was at level of 0.05.

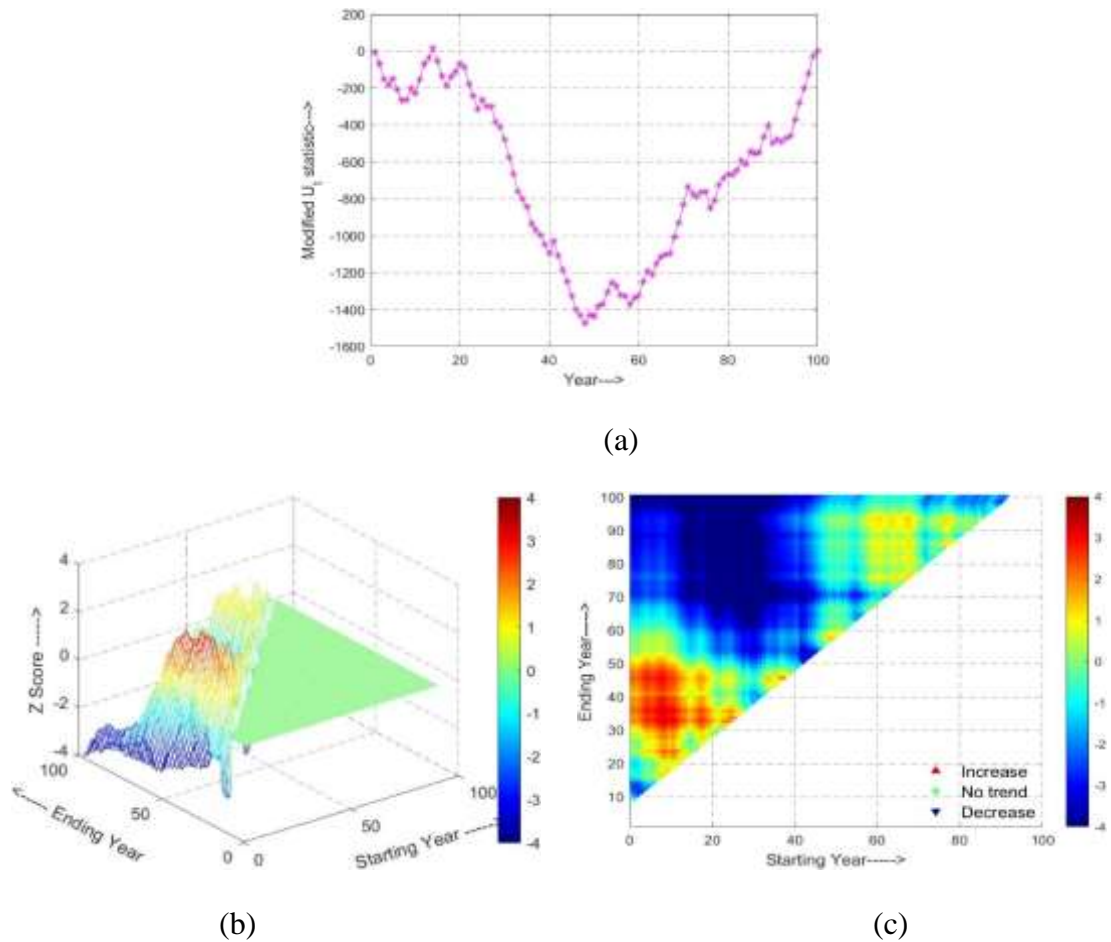


Figure 6.28 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the TNx trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the TNx trend in Bagodar was at level of 0.05.

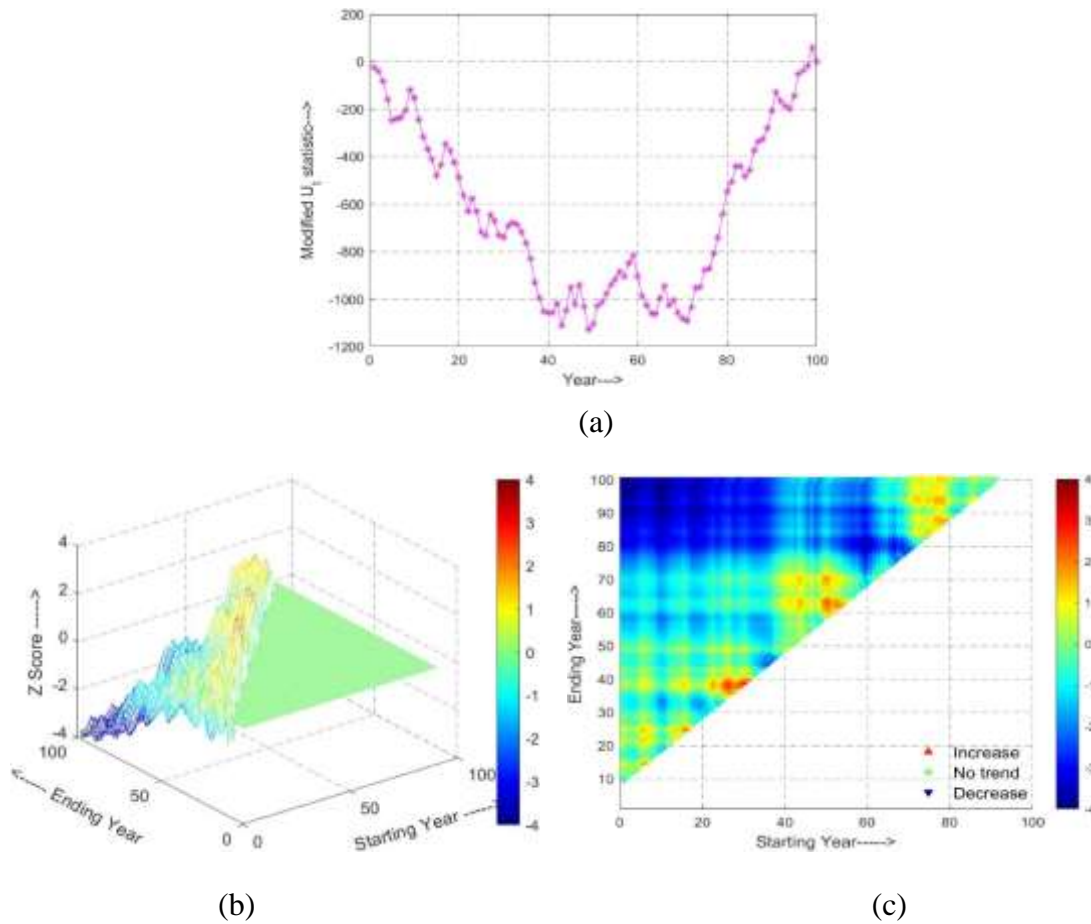


Figure 6.29 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the TX_n trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the TX_n trend in Bagodar was at level of 0.05.

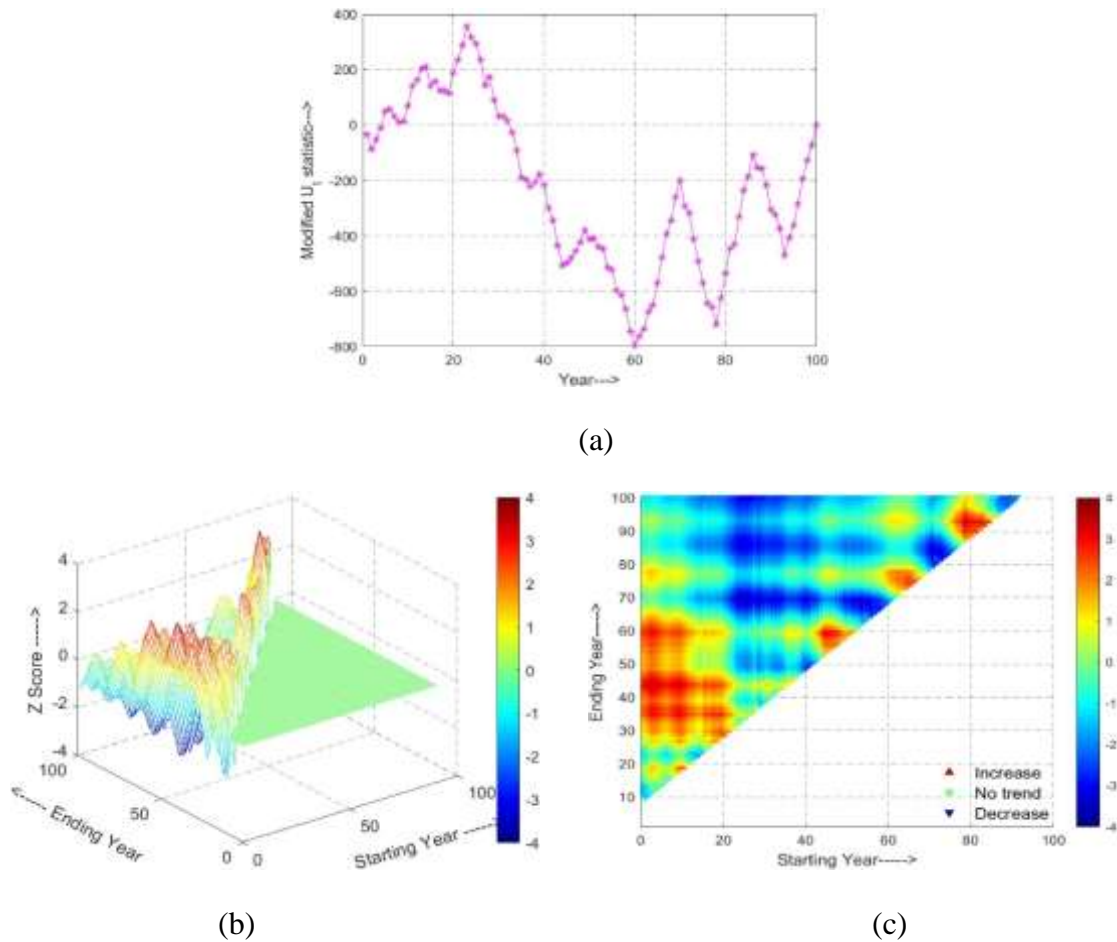


Figure 6.30 (a) Variation of modified U_t over the years to identify change points in Bagodar. (b) The three-dimensional pattern of the TXx trend in Bagodar is at level of 0.05. (c) The 2-D pattern of the TXx trend in Bagodar was at level of 0.05.

6.2.3 Characteristics of Multiple Climatic Indices in Bankura

Bankura station, situated within the West Bengal portion of the Damodar River Basin (DRB), has been the subject of extensive research to understand the long-term trends in extreme climate indices. This station was chosen for a comprehensive analysis spanning from 1923 to 2022. Figures 6.31(b-c) through 6.45(b-c) illustrate both two-dimensional and three-dimensional visualizations of the extreme climate variables recorded at Bankura. The figures reveal a series of peaks and valleys, with peaks representing the strength and direction of the climate trends, and valleys indicating periods of fluctuation. These visualizations indicate that the pattern of extreme climate indices at Bankura has shifted significantly over time. Different shaded zones in the figures capture various stages of these changes, showing troughs in the lower parts of the triangular shape and crests in the upper regions, reflecting the dynamic nature of the trends. A color bar alongside the figure's highlights rainfall trends, with blue symbolizing a decline, red indicating an increase, and green representing sTable, trend-free periods.

From 1923 to 1950, a declining rainfall trend is observed at Bankura, marked by the blue shades in the figures. Between 1950 and 1990, the trend shifts to an increase, shown in red, while green areas indicate periods of stability where no significant trend is detected. The analysis of clustered patterns helps pinpoint crucial moments of trend changes, offering a clearer understanding of the shifts in extreme climate indices. The statistical data shown in Figures 6.31(c) through 6.45(c) reinforce the reliability of these observations, making the findings robust and comprehensive.

The findings of this study are highly significant for local planners and policymakers, particularly in terms of understanding how rainfall patterns are evolving, which is vital for agricultural management and water resource planning in the region. Since a large portion of the population in Bankura depends on agriculture, understanding these rainfall trends is crucial for ensuring sustainable practices. By identifying critical change points and presenting the rainfall patterns in a three-dimensional format, this research deepens the understanding of climate variability in Bankura and its implications for regional agriculture and development strategies.

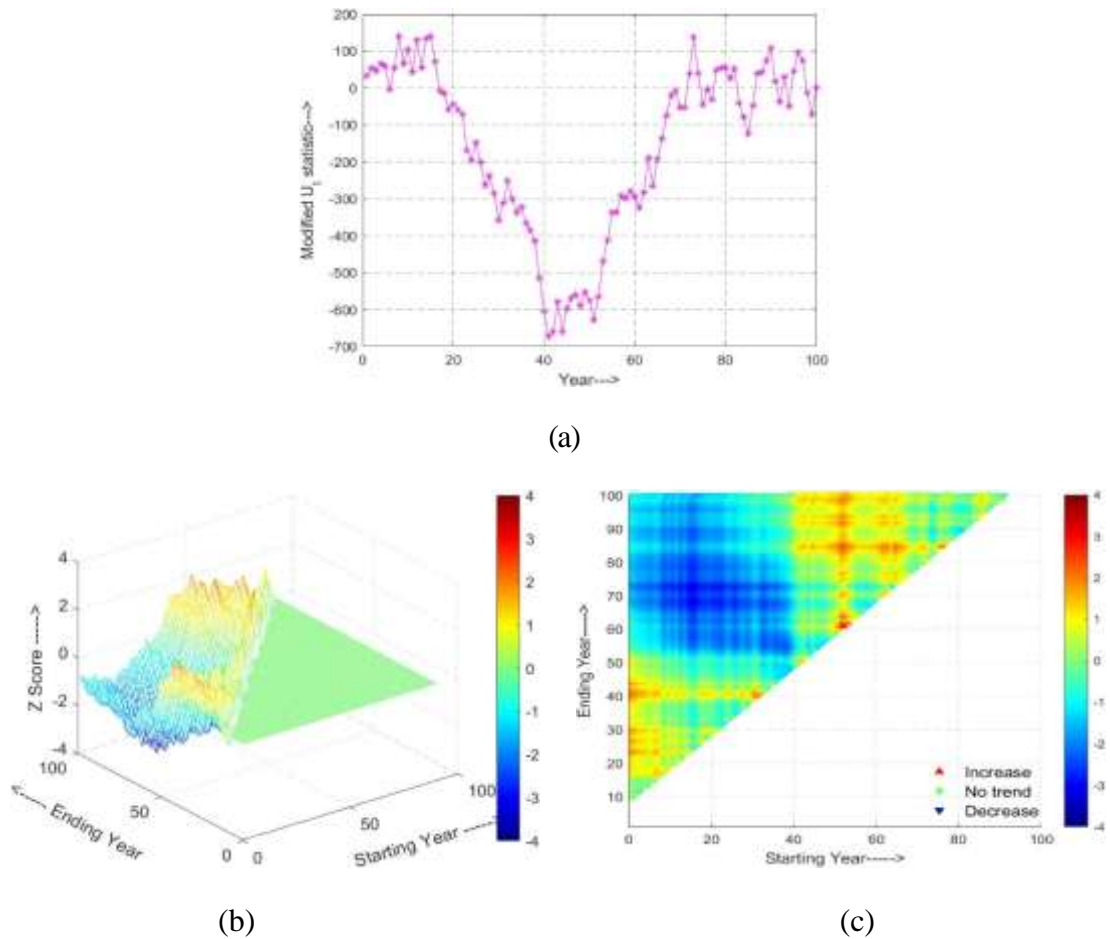
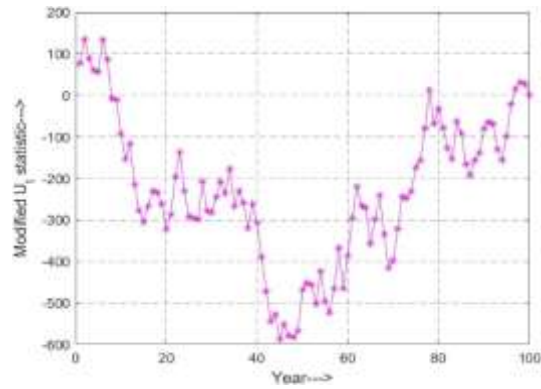
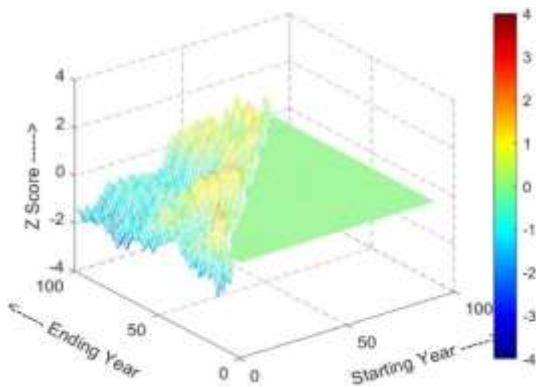


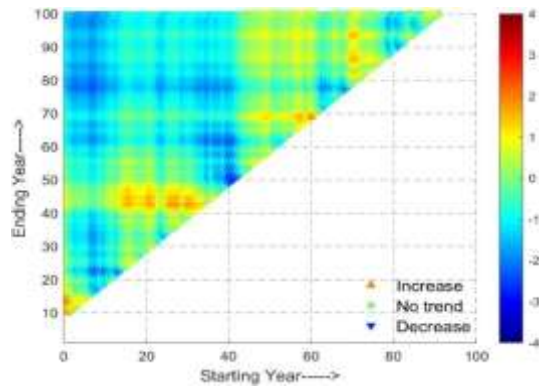
Figure 6.31 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the CDD trend in Bankura is at level of 0.05. (c) The 2-D pattern of the CDD trend in Bankura was at level of 0.05.



(a)



(b)



(c)

Figure 6.32 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the CWD trend in Bankura is at level of 0.05. (c) The 2-D pattern of the CWD trend in Bankura was at level of 0.05.

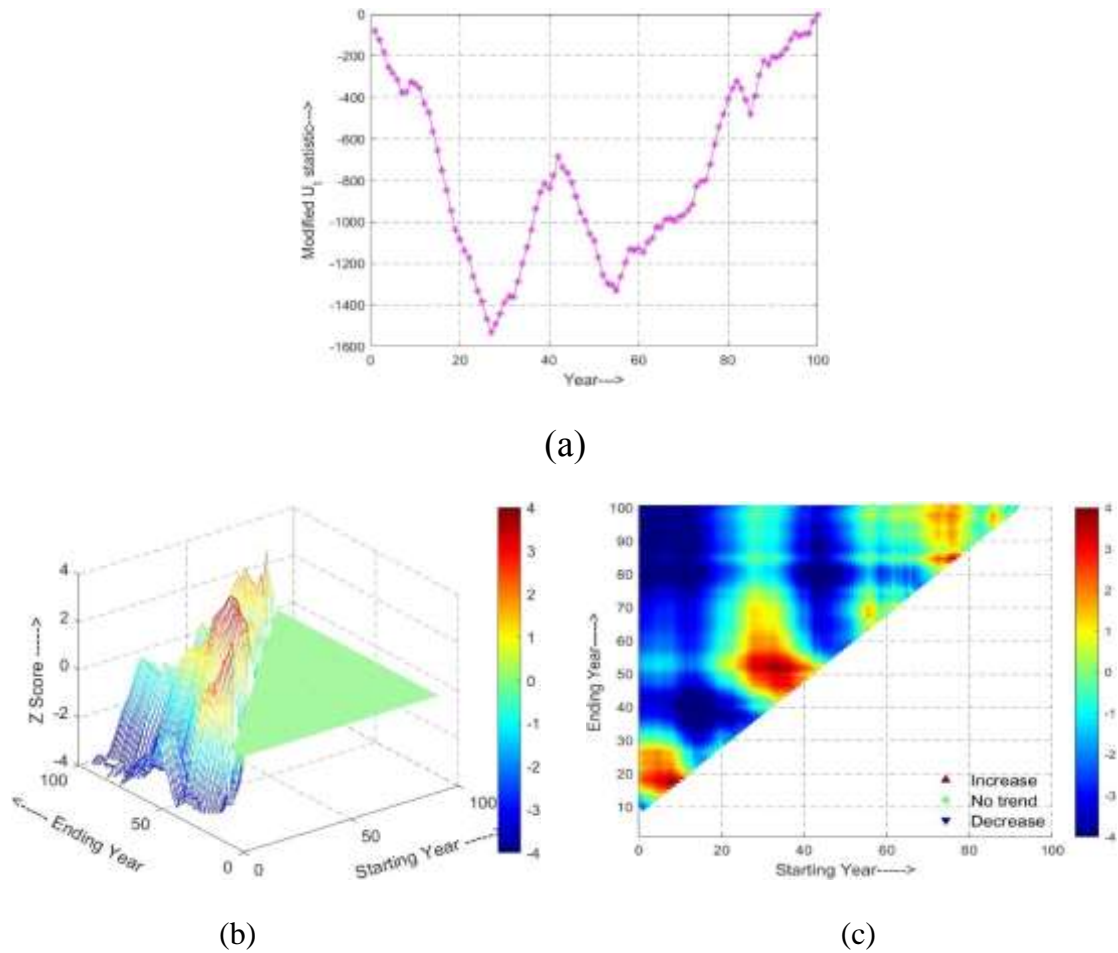
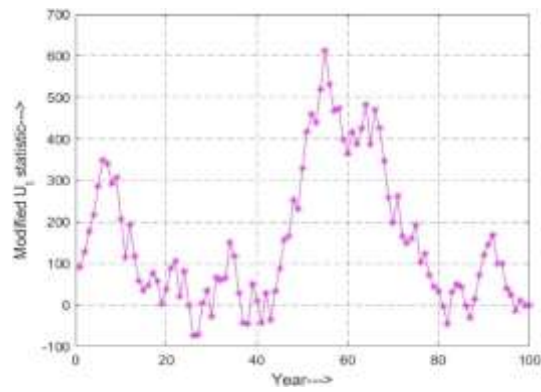
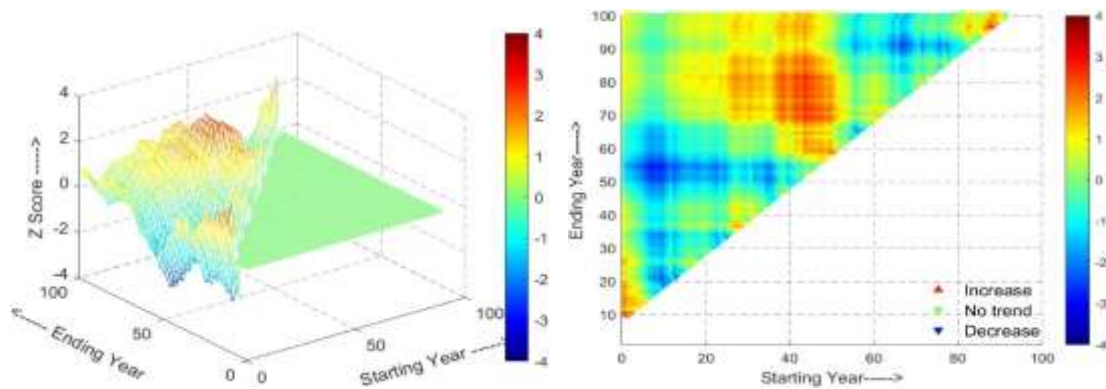


Figure 6.33 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the DTR trend in Bankura is at level of 0.05. (c) The 2-D pattern of the DTR trend in Bankura was at level of 0.05.



(a)



(b)

(c)

Figure 6.34 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the PRCPTOT trend in Bankura is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Bankura was at level of 0.05.

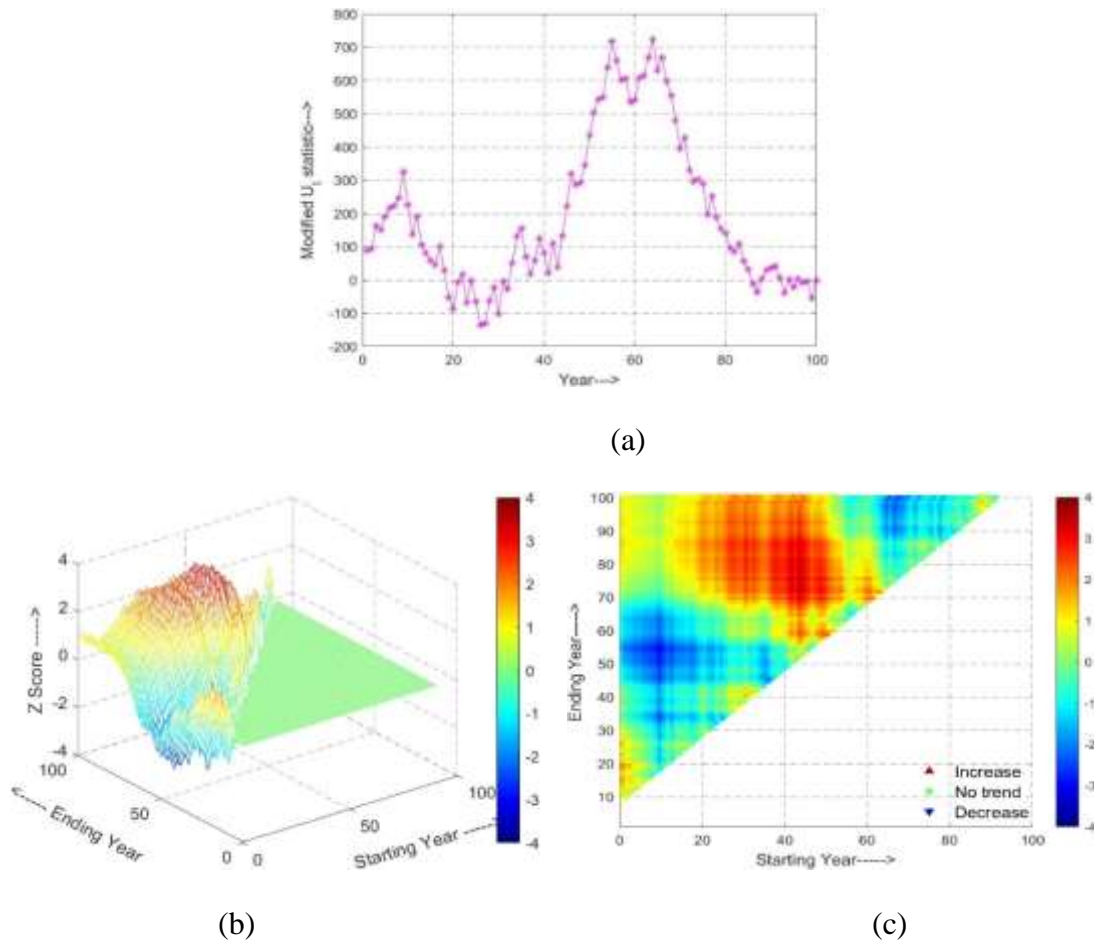
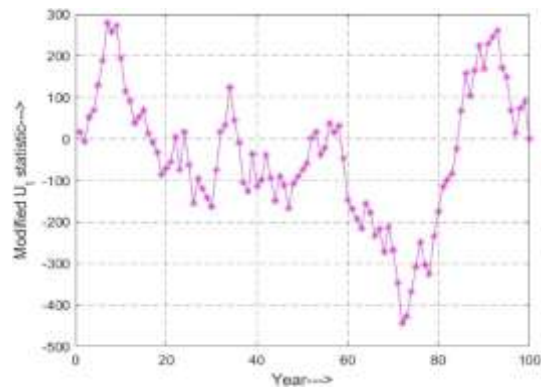
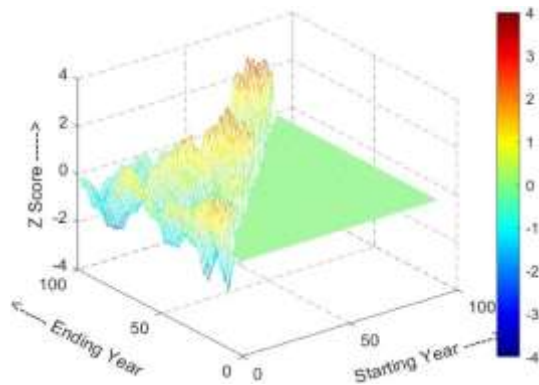


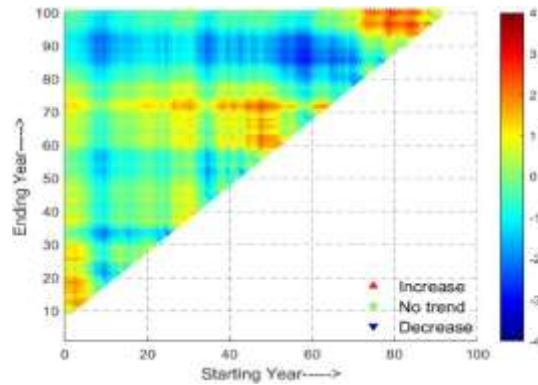
Figure 6.35 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the R10mm trend in Bankura is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Bankura was at level of 0.05.



(a)

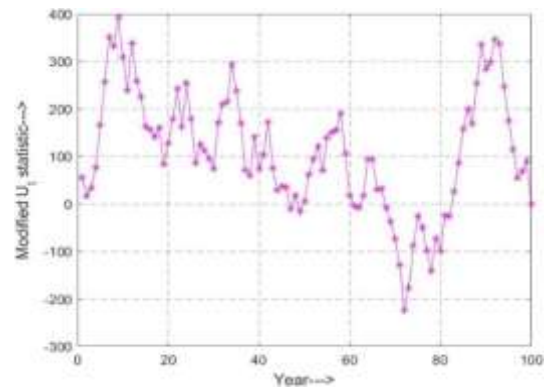


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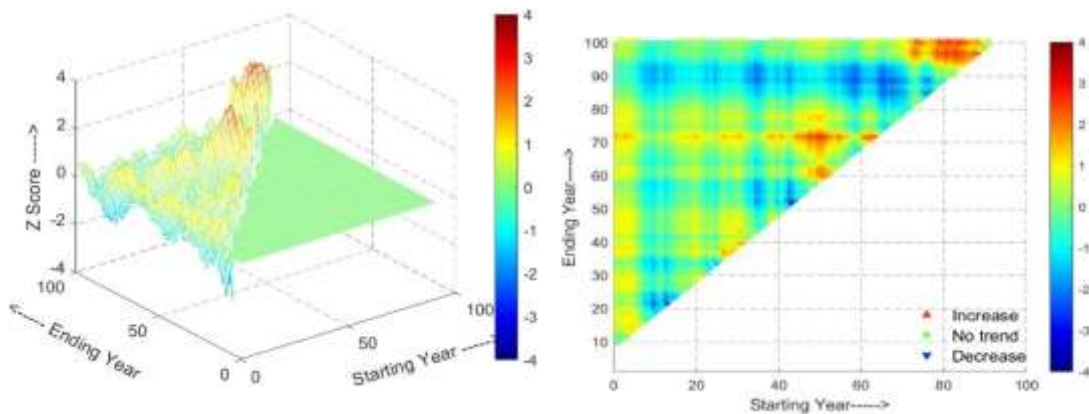


(c)

Figure 6.36 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the R20mm trend in Bankura is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Bankura was at level of 0.05.



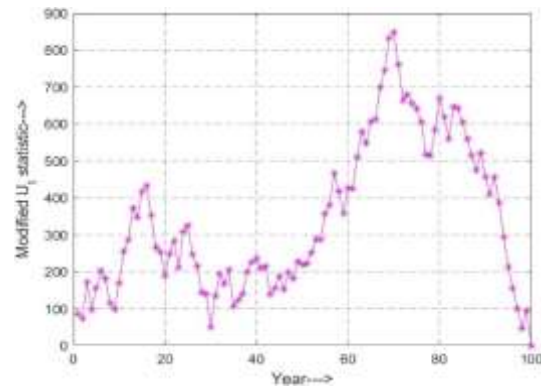
(a)



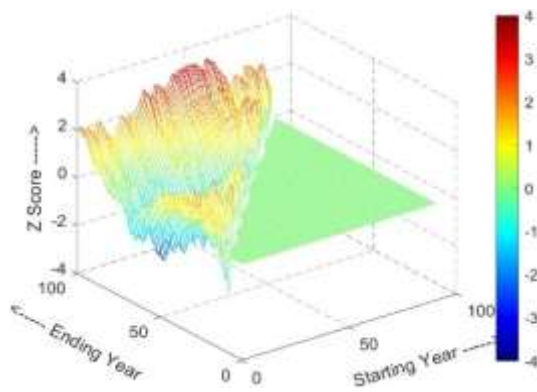
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(c)

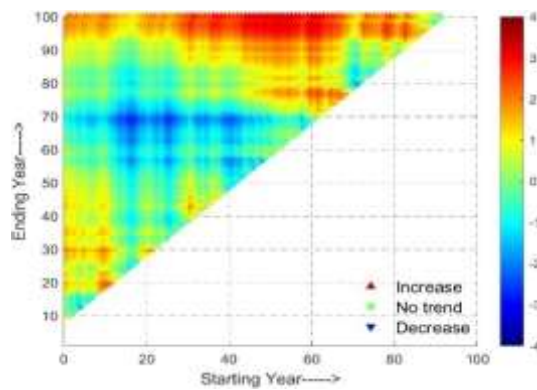
Figure 6.37 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the R95p trend in Bankura is at level of 0.05. (c) The 2-D pattern of the R95p trend in Bankura was at level of 0.05.



(a)



(b)



(c)

Figure 6.38(a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the R99p trend in Bankura is at level of 0.05. (c) The 2-D pattern of the R99p trend in Bankura was at level of 0.05.

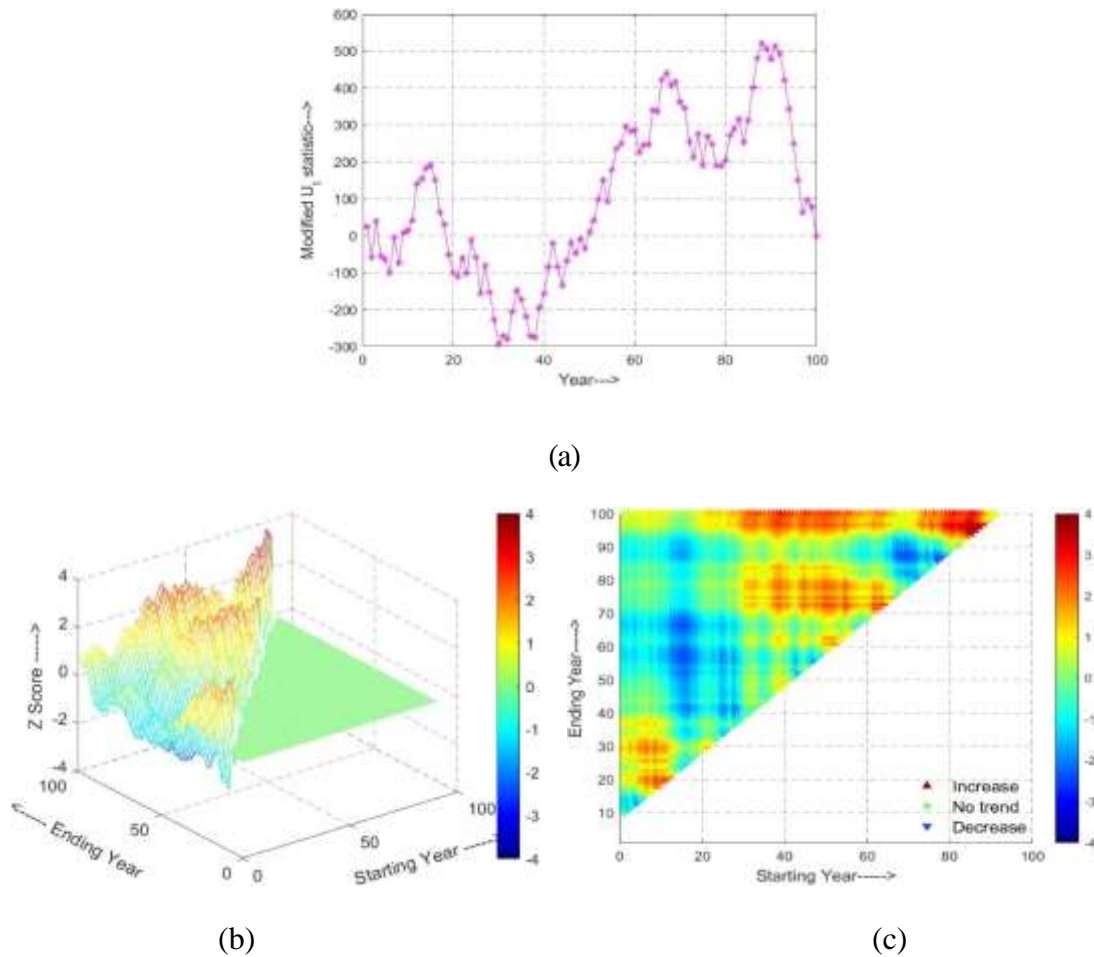
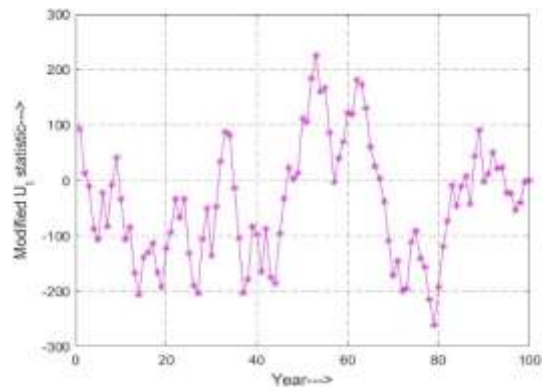
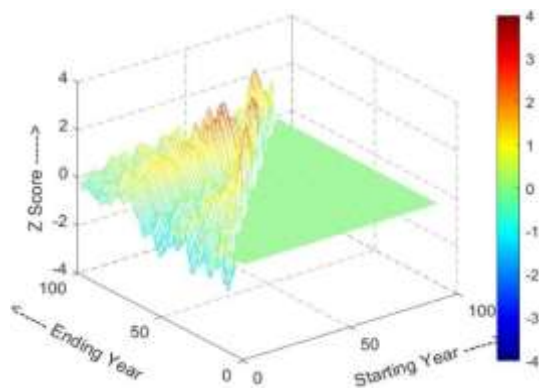


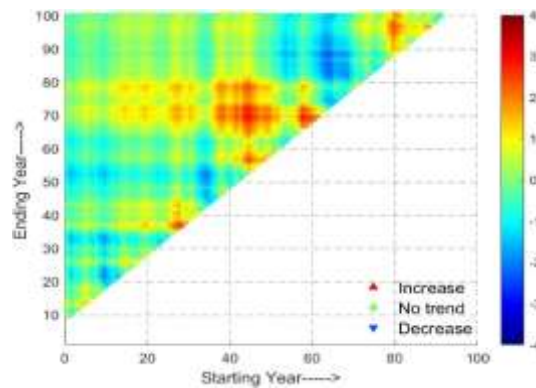
Figure 6.39 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the RX1day trend in Bankura is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Bankura was at level of 0.05.



(a)



(b)



(c)

Figure 6.40 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the RX5day trend in Bankura is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Bankura was at level of 0.05.

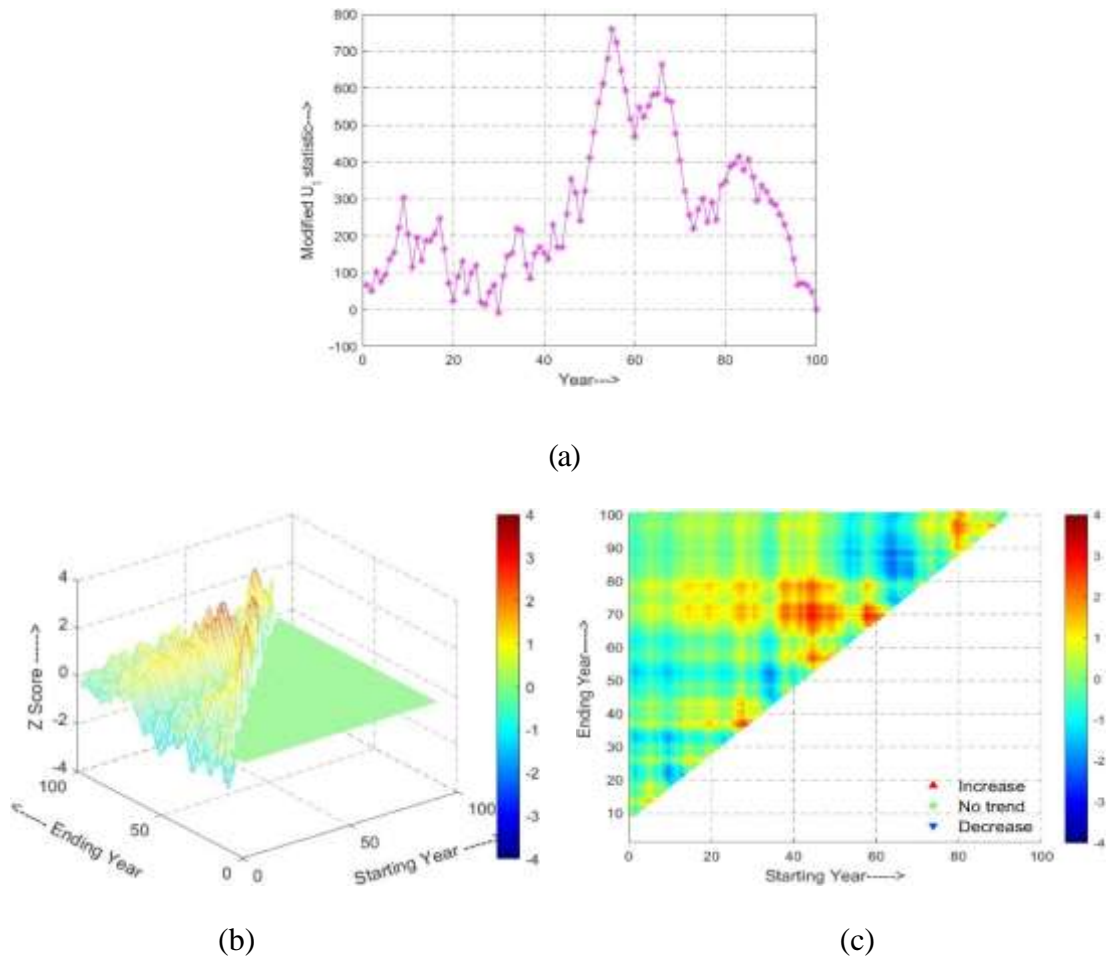
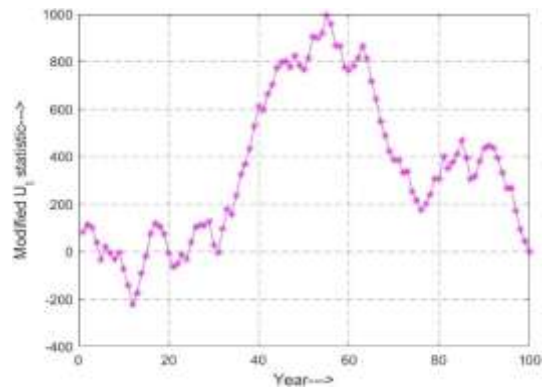
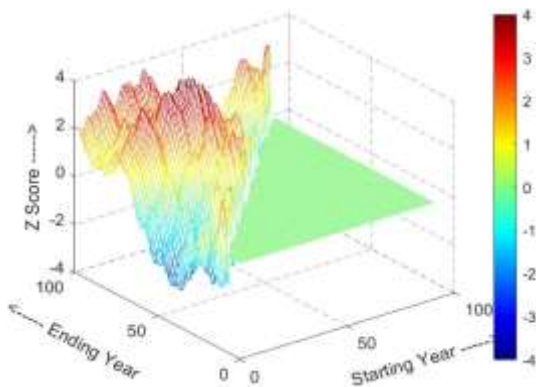


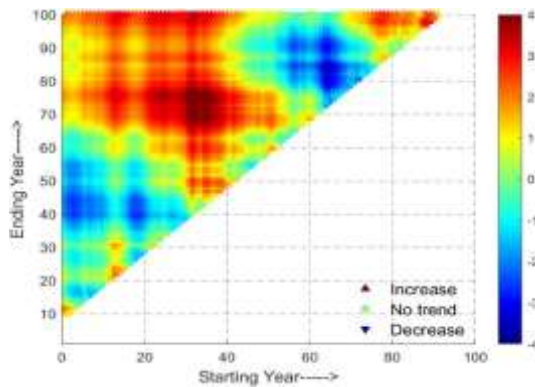
Figure 6.41 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the SDII trend in Bankura is at level of 0.05. (c) The 2-D pattern of the SDII trend in Bankura was at level of 0.05.



(a)



(b)



(c)

Figure 6.42 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the TNN trend in Bankura is at level of 0.05. (c) The 2-D pattern of the TNN trend in Bankura was at level of 0.05.

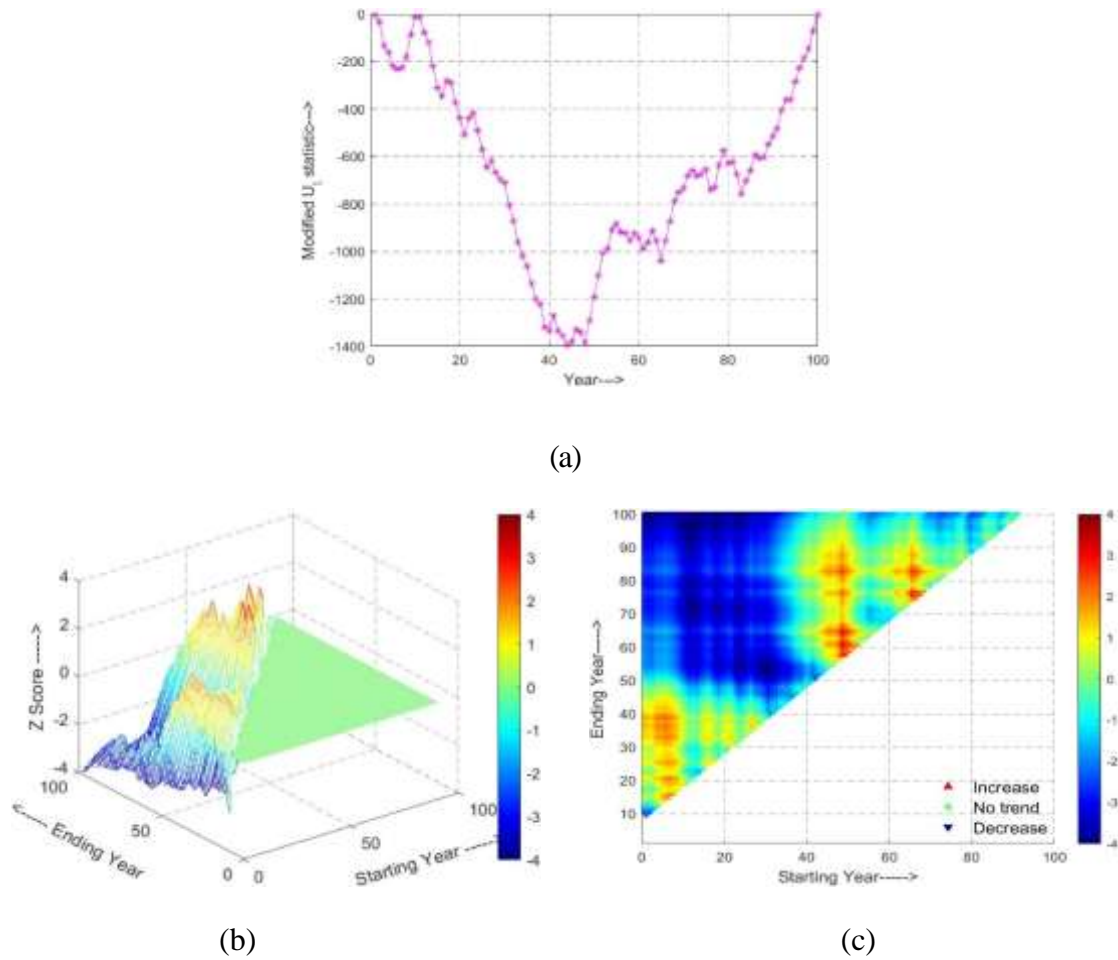
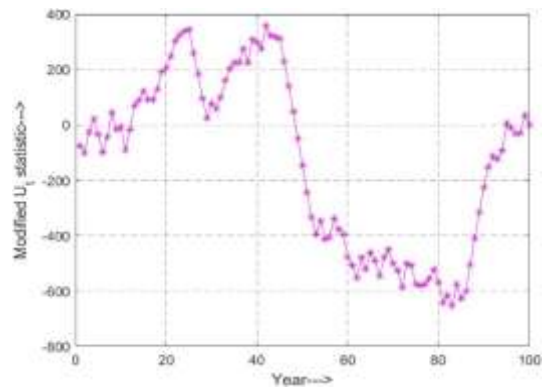
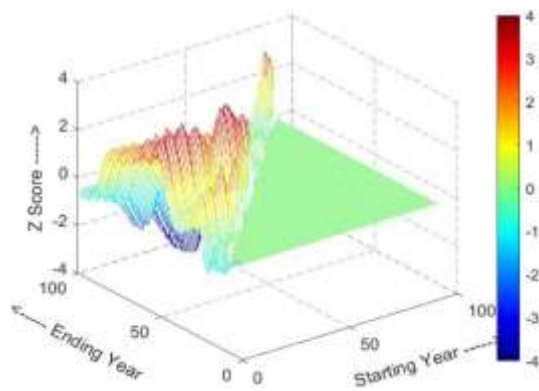


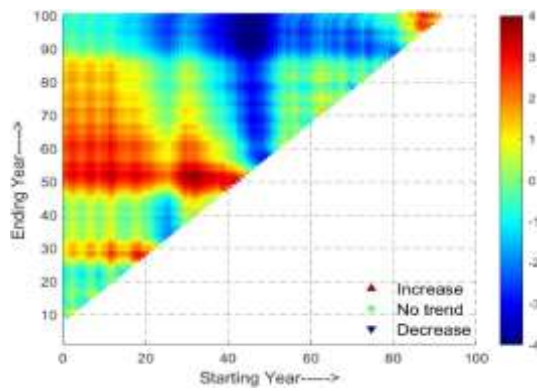
Figure 6.43 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the TNX trend in Bankura is at level of 0.05. (c) The 2-D pattern of the TNX trend in Bankura was at level of 0.05.



(a)



(b)



(c)

Figure 6.44 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the TXN trend in Bankura is at level of 0.05. (c) The 2-D pattern of the TXN trend in Bankura was at level of 0.05.

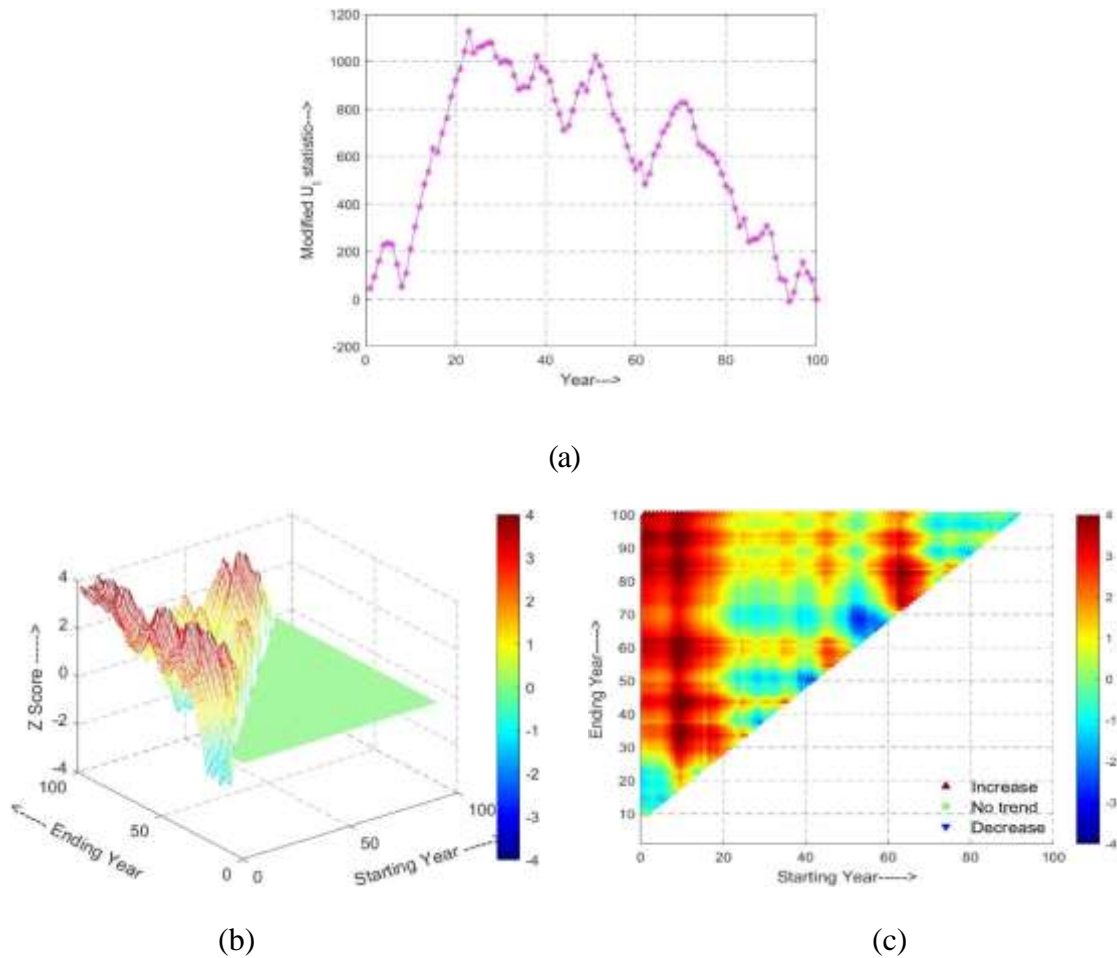


Figure 6.45 (a) Variation of modified U_t over the years to identify change points in Bankura. (b) The three-dimensional pattern of the TXX trend in Bankura is at level of 0.05. (c) The 2-D pattern of the TXX trend in Bankura was at level of 0.05.

6.2.4 Characteristics of Multiple Climatic Indices in Bardhaman

Bardhaman stations, located in the West Bengal portion of the DRB, have been the site of numerous research projects. This station was chosen to analyze the trend of extreme climate indices within the basin for long-term trend analysis. Figure 6.46(b-c)-6.60 (b-c) depicts three and two-dimensional views of the extreme climate variables pattern observed in the Bardhaman station from 1923 to 2022. The initial portion of Figure 6.46 (b) - 6.60 (b) displays peaks and valleys of magnitudes. These peaks signify a trend, and their height indicates the strength or intensity of the trend's direction. The

presence of crests and troughs suggests fluctuations in the trend over time. Therefore, it can be observed that the pattern of extreme climate indices in Bardhaman has changed throughout the period. Figure 6.46 (b) - 6.60 (b) can be characterized by roughly different shade zones containing multiple troughs in the lower portion of the triangular shape, and various crests in the upper portion. The right-side bar in Figure 6.46 (c) – 6.60 (c) indicates the increasing and decreasing trend based on the color shades, clearly visualizing that the blue color denotes a decreasing rainfall trend. In contrast, green denotes no trend zone on the triangular shape, and red indicates an increasing rainfall trend. Bardhaman detected a decreasing trend observed until 1950, as visualized in Figure 6.46 (c) – 6.60 (c), with different shades of the color bar. An increasing trend was observed from 1950 to 1990, as shown in Figure 6.46 (c) – 6.60 (c), with red shades of color in the triangular section, while green denotes no trend condition. One interesting aspect that can be derived from analyzing clusters of sizes is the ability to pinpoint the moments when extreme climate indices trends shift. The statistics presented in Figure 6.46 (c) – 6.60 (c) suggest that the information provided in Figures 6.46 (a)-6.60 (a) and Figures 6.46 (b)-6.60 (b) is reliable and appropriate to consider.

(Halder et al., 2023) Studied long-term trend analysis of rainfall in almost all districts of West- Bengal and found that Bardhaman observed a declining annual rainfall trend from 1901-2020. This study shows both the increase and decrease trend of the annual rainfall of Bardhaman from 1923 to 2022. Regarding trend analysis, our results differ. The results have been shown in 2-D and 3-D figures to visualize the pattern of trends. It indicates the nature of trends with the help of different shades of color in the bar. The rainfall trends and change point detection at Bardhaman station were also analyzed.

Nevertheless, a modified version of the PMW test was introduced in this research to detect multiple change points of trend. Minor research has been implemented over Bardhaman based on trend detection and change point analysis. However, this study detects multiple change points with clearly displayed graphs in Figure 6.46(a)- 6.60(a). This boosts the study's significance and increases the researchers' influence. Planners must understand the nature of rainfall patterns and how they change, which is also advantageous for agricultural purposes. Since agriculture employs most of the population in this area, understanding the features of the rainfall pattern is crucial. Rainfall patterns were characterized in three dimensions, and several places around the basin were found to be change points.

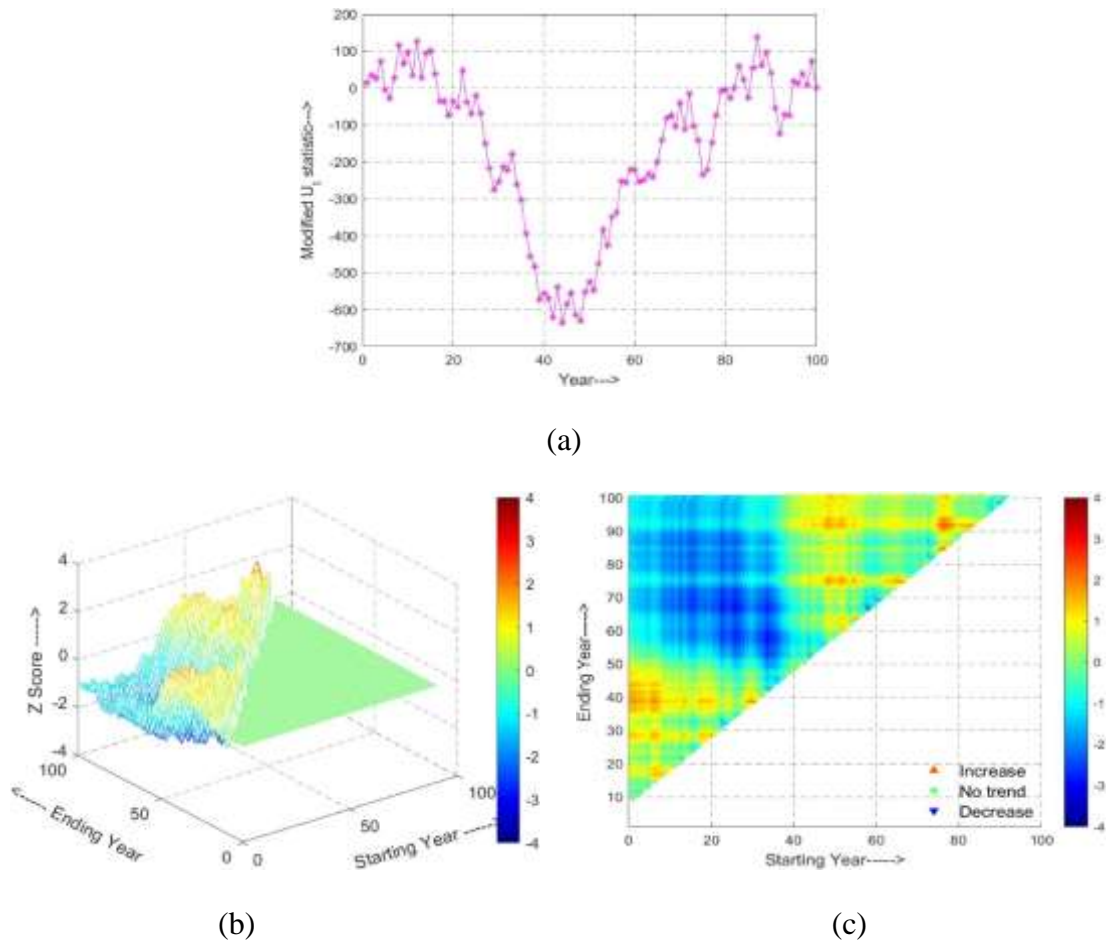
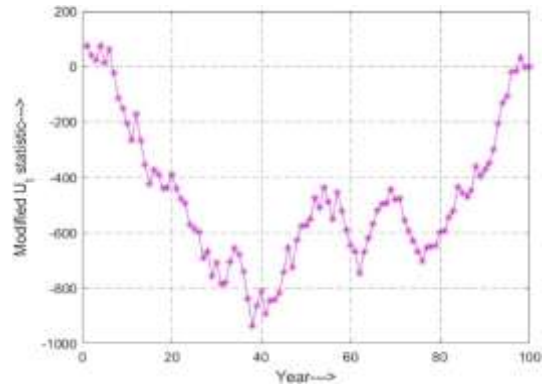
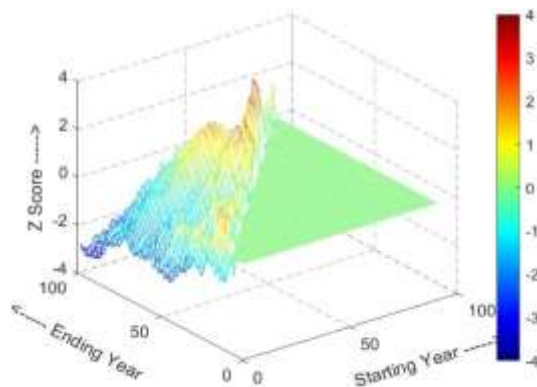


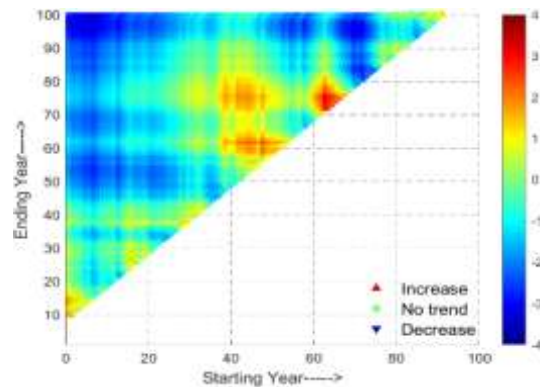
Figure 6.46 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the CDD trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the CDD trend in Bankura was at level of 0.05.



(a)

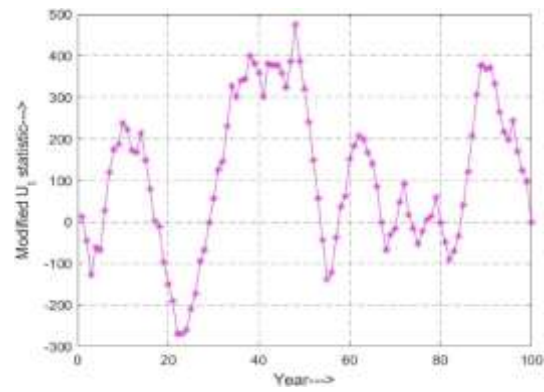


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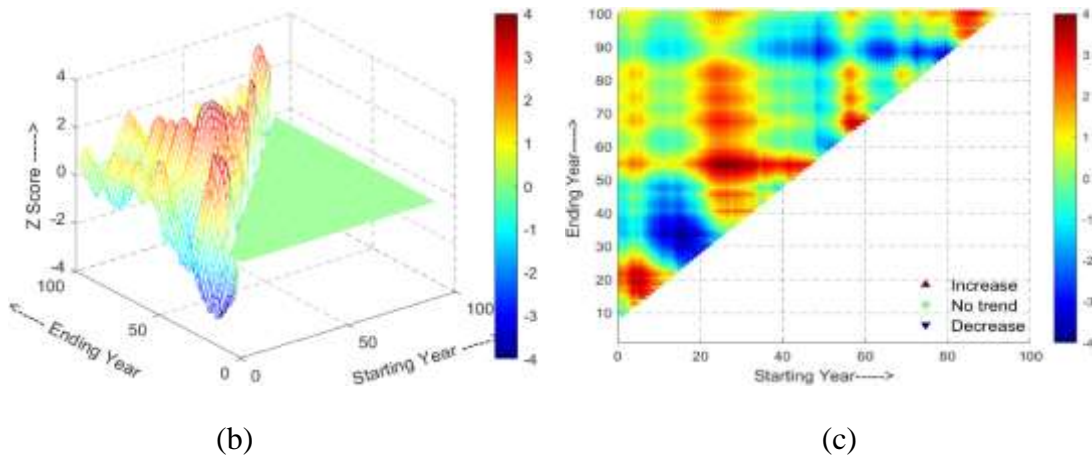


(c)

Figure 6.47 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the CWD trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the CWD trend in Bankura was at level of 0.05.



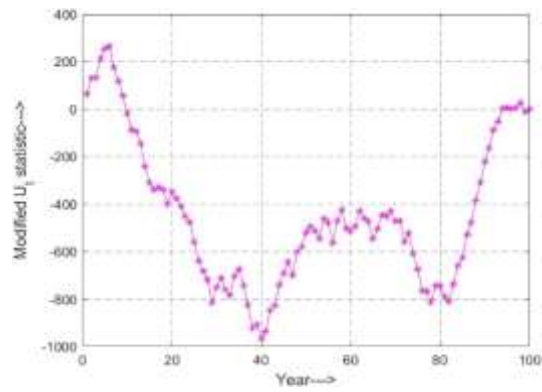
(a)



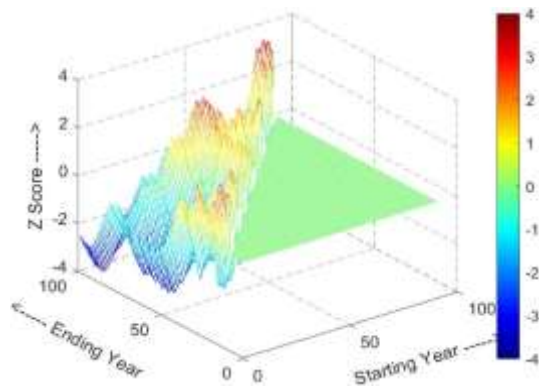
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(c)

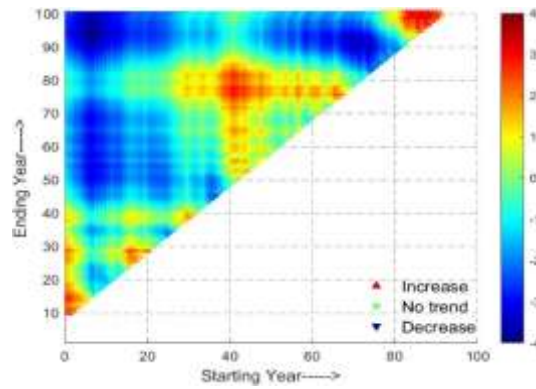
Figure 6.48 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the DTR trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the DTR trend in Bankura was at level of 0.05.



(a)

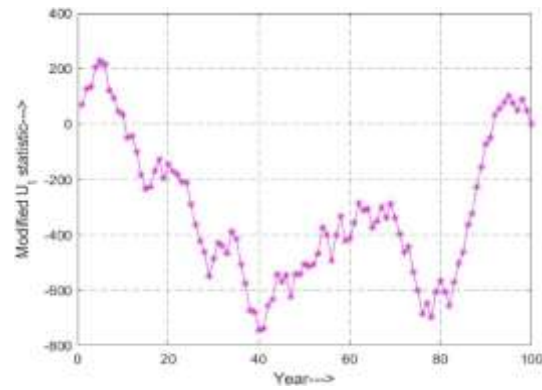


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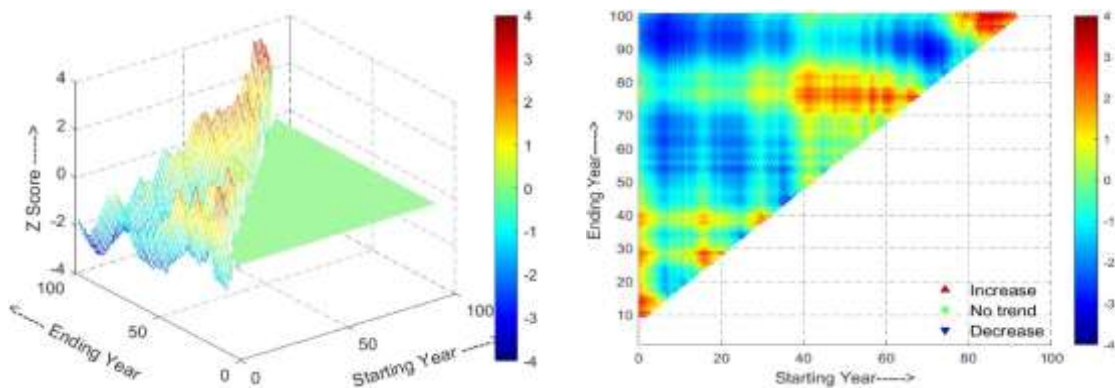


(c)

Figure 6.49 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the PRCPTOT trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Bardhaman was at level of 0.05.



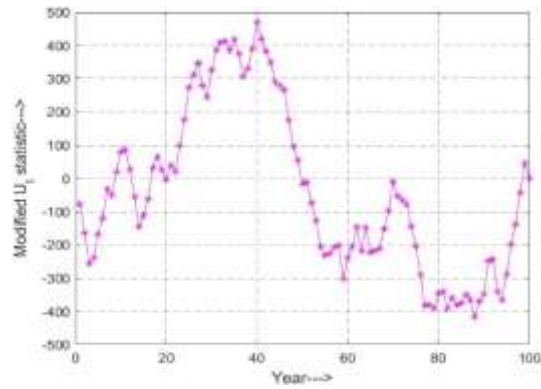
(a)



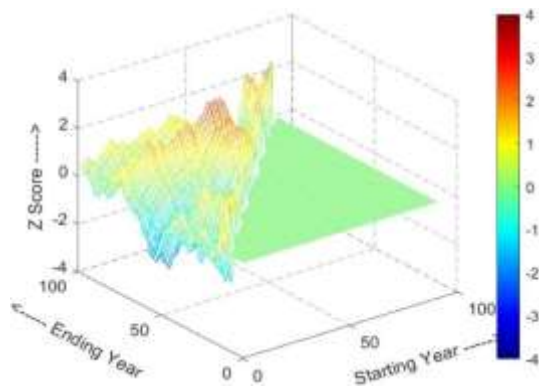
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(c)

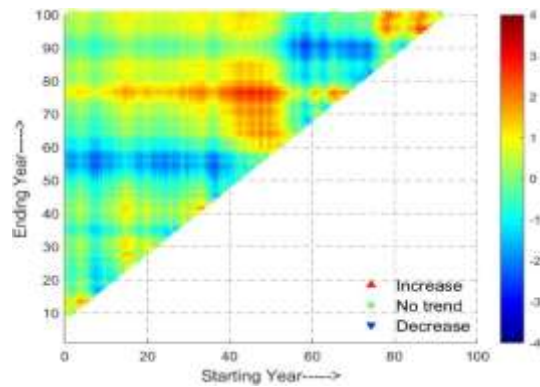
Figure 6.50 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the R10mm trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Bardhaman was at level of 0.05.



(a)

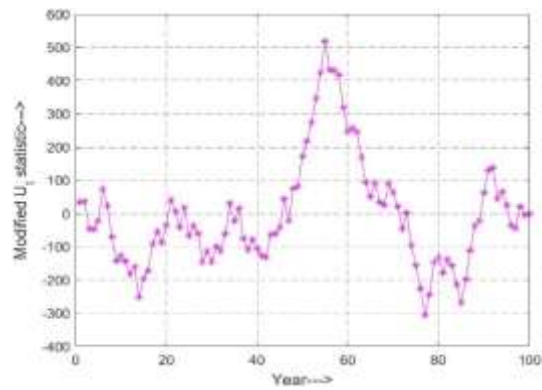


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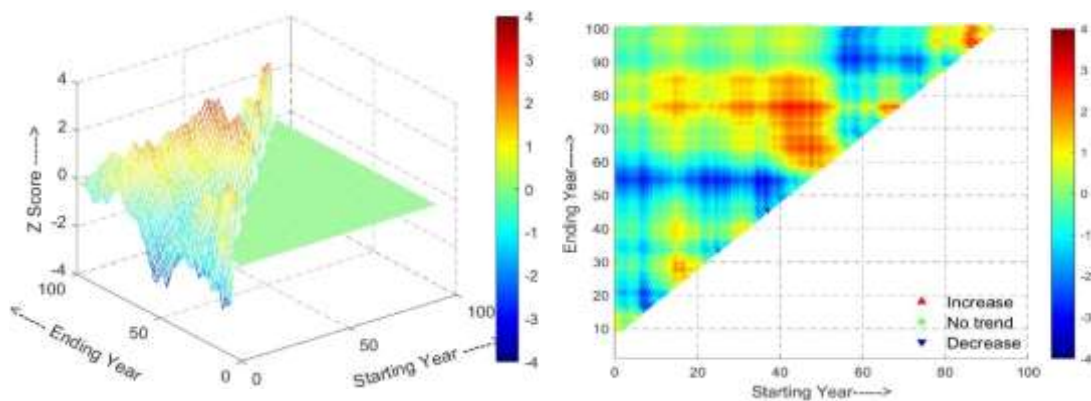


(c)

Figure 6.51 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the R20mm trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Bardhaman was at level of 0.05.



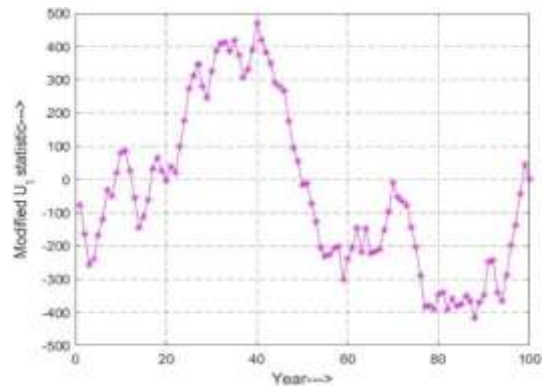
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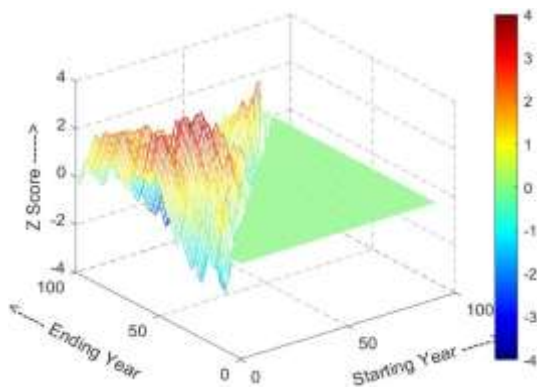
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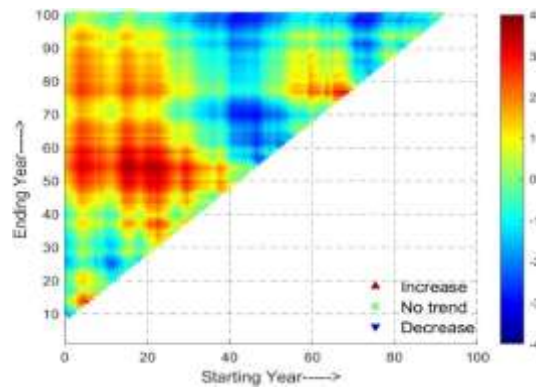
Figure 6.52 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the R95p trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the R95p trend in Bardhaman was at level of 0.05.



(a)



(b)



(c)

Figure 6.53 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the R99p trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the R99p trend in Bardhaman was at level of 0.05.

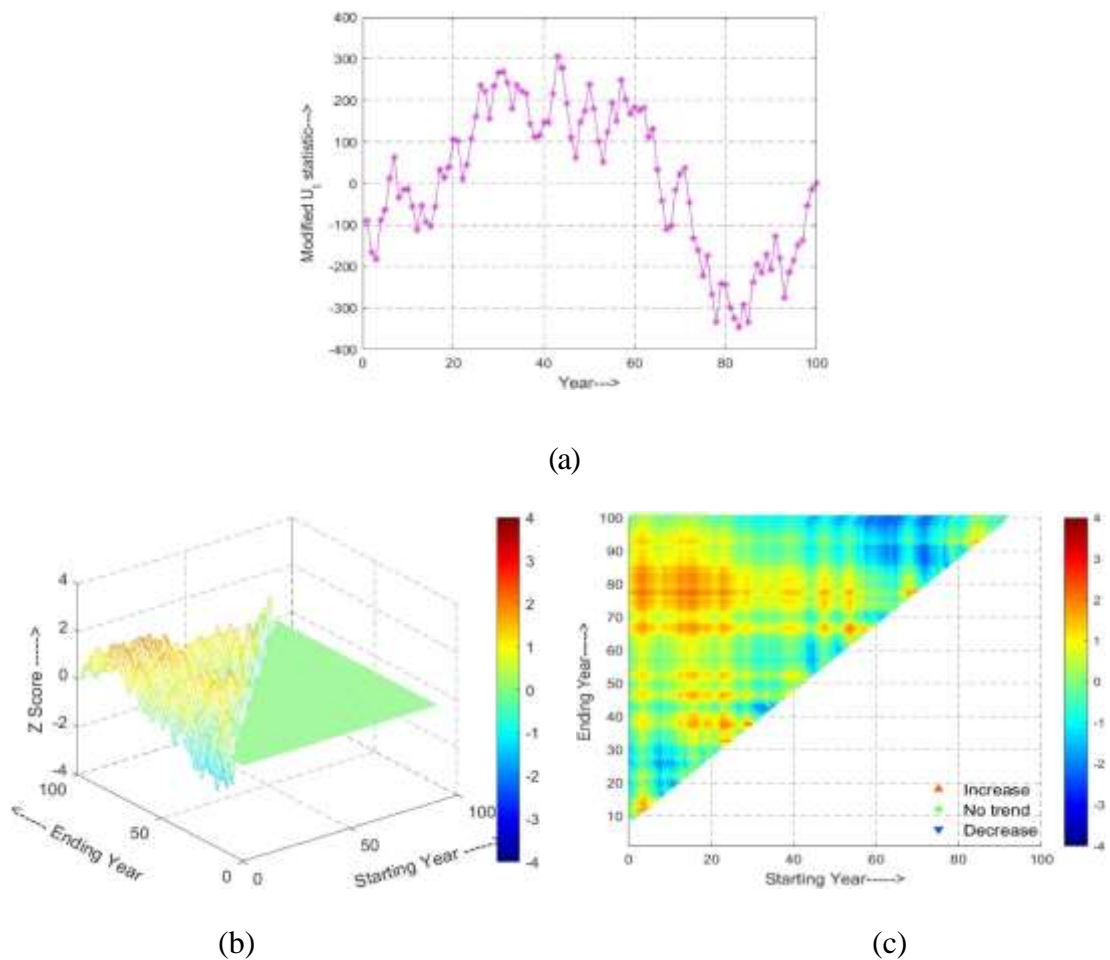
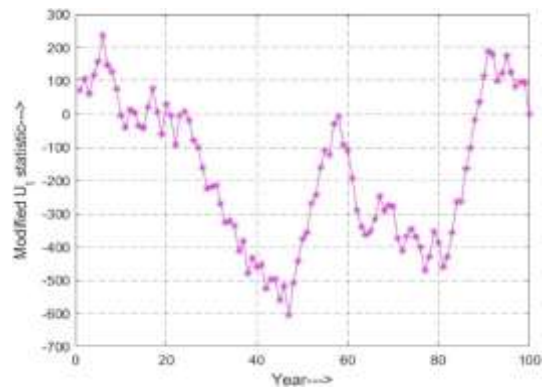
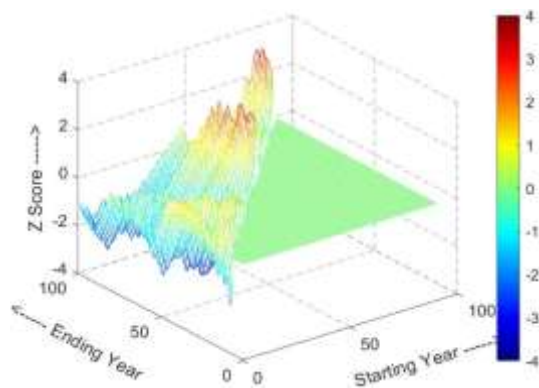


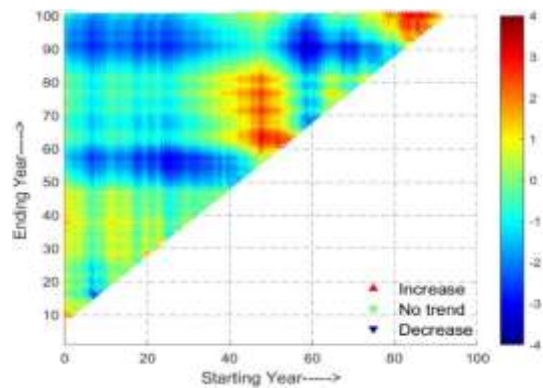
Figure 6.54 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the RX1day trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Bardhaman was at level of 0.05.



(a)

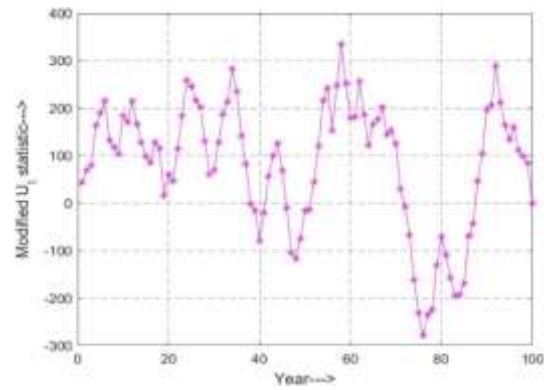


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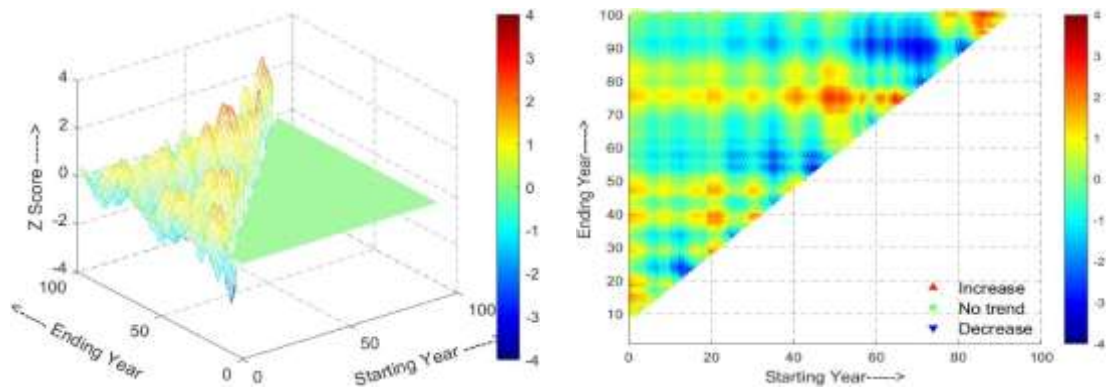


(c)

Figure 6.55 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the RX5day trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Bardhaman was at level of 0.05.



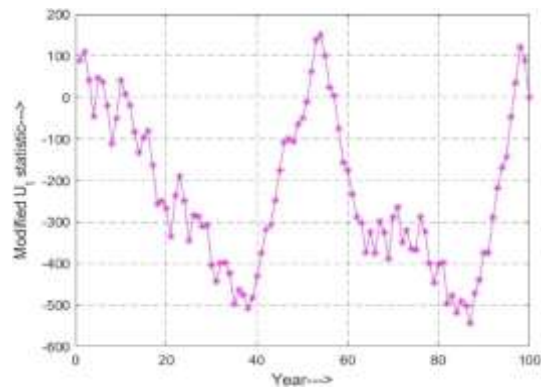
(a)



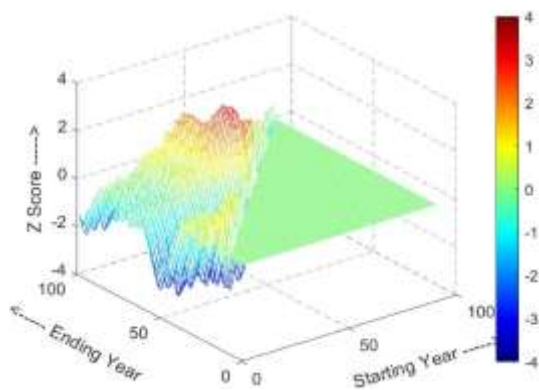
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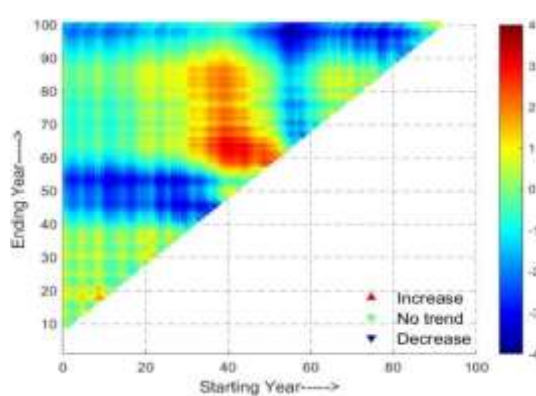
Figure 6.56 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the SDII trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the SDII trend in Bardhaman was at level of 0.05.



(a)



(b)



(c)

Figure 6.57 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the TNN trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the TNN trend in Bardhaman was at level of 0.05.

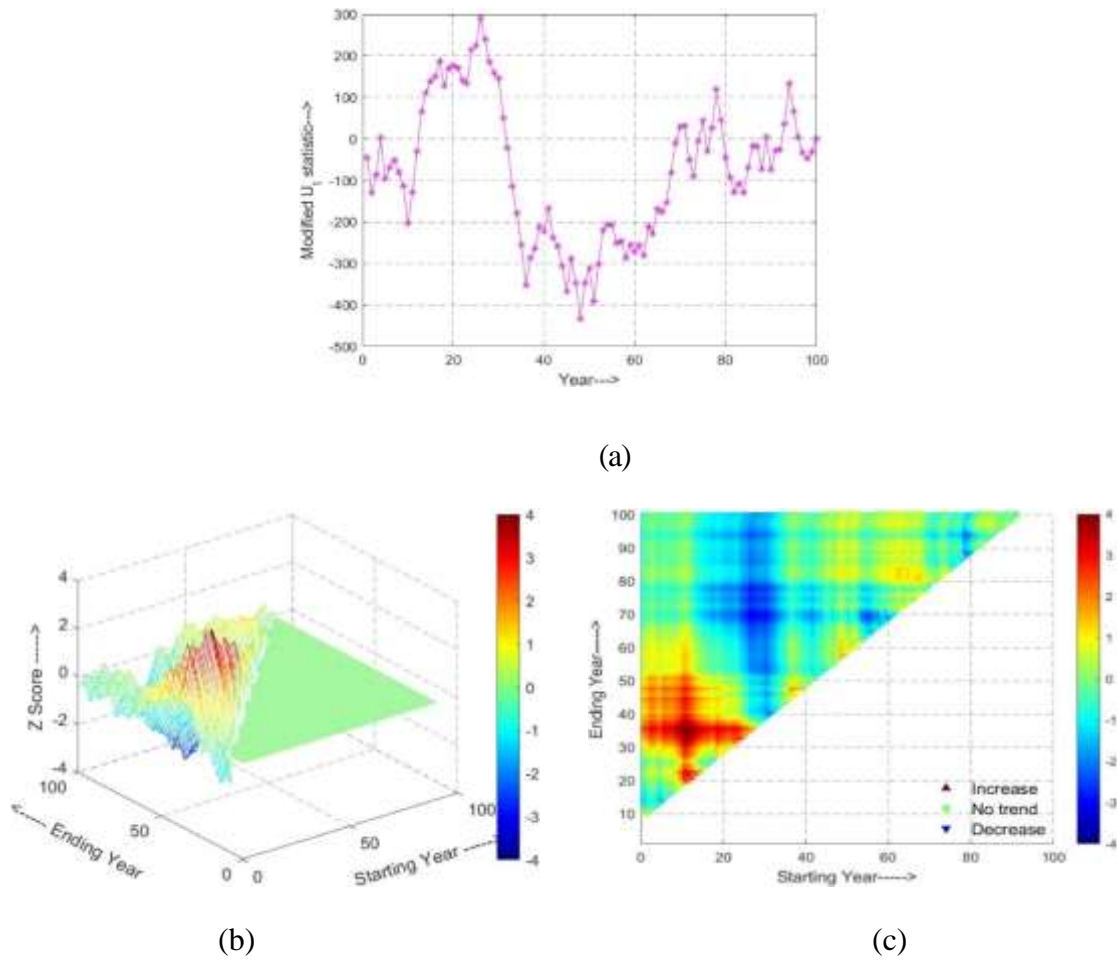
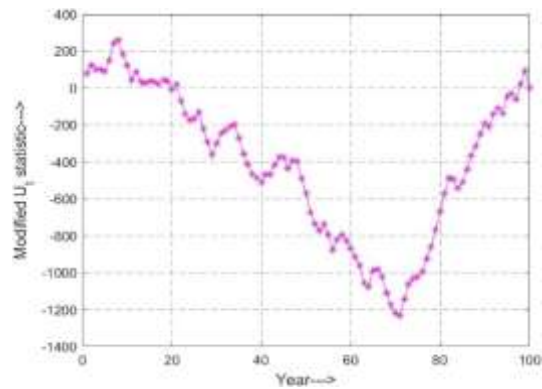
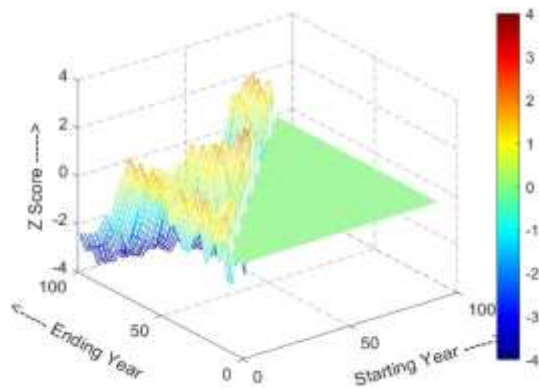


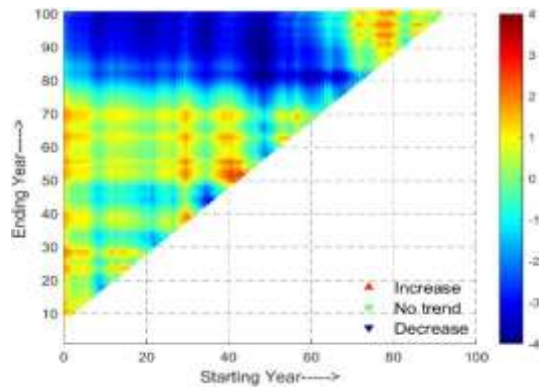
Figure 6.58 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the TN_x trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the TN_x trend in Bardhaman was at level of 0.05.



(a)



(b)



(c)

Figure 6.59 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the TXN trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the TXN trend in Bardhaman was at level of 0.05.

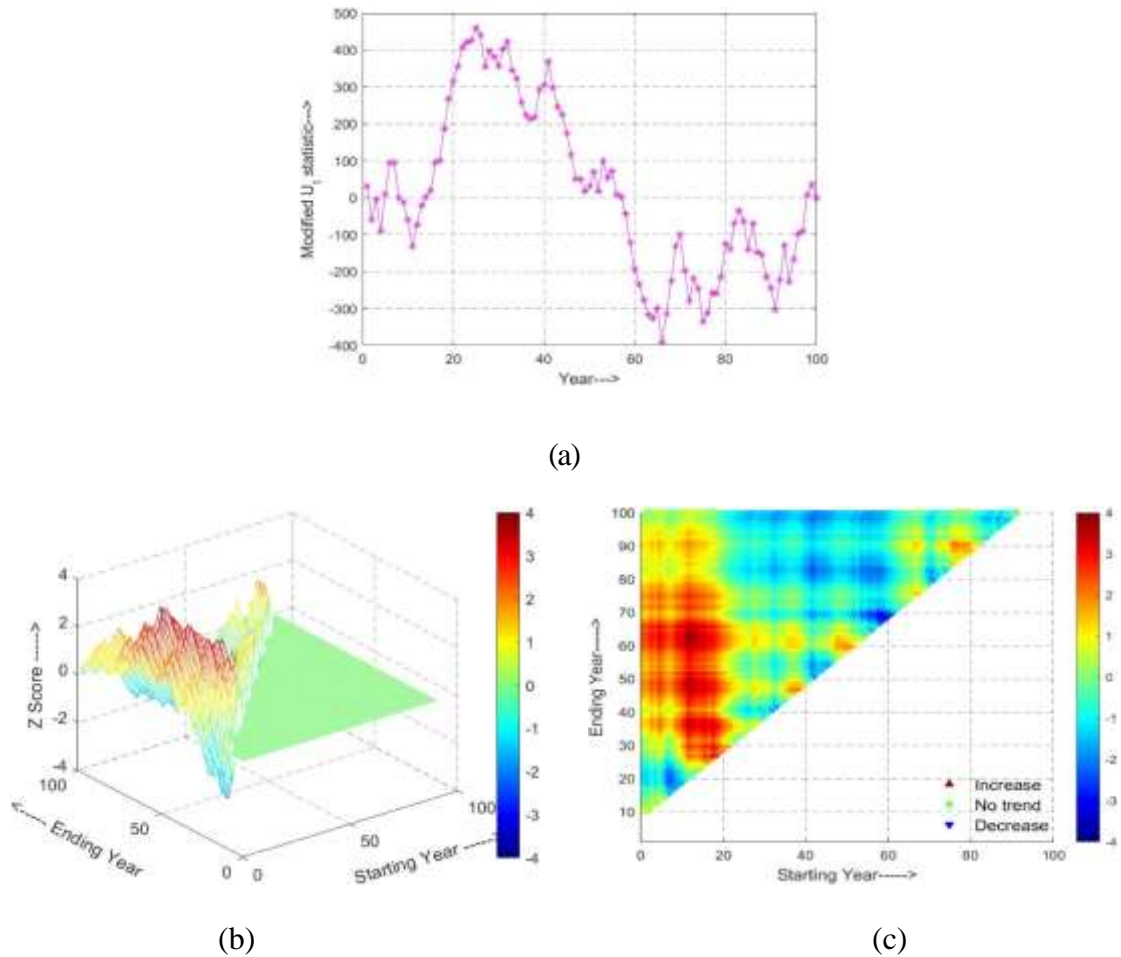


Figure 6.60 (a) Variation of modified U_t over the years to identify change points in Bardhaman. (b) The three-dimensional pattern of the TXX trend in Bardhaman is at level of 0.05. (c) The 2-D pattern of the TXX trend in Bardhaman was at level of 0.05.

6.2.5 Characteristics of Multiple Climatic Indices in Bokaro

Bokaro station, located in the West Bengal portion of the Damodar River Basin (DRB), has been the focus of extensive research aimed at analyzing long-term trends in extreme climate indices. The station was selected for a detailed analysis covering the period from 1923 to 2022. Figures 6.61(b-c) to 6.75(b-c) provide two-dimensional and three-dimensional visual representations of the extreme climate variables recorded at Bokaro. These figures reveal distinct peaks and valleys, with the peaks indicating the strength and direction of trends, and the valleys representing fluctuations in these trends over time. The data clearly shows that the pattern of extreme climate indices at Bokaro has changed significantly throughout the analyzed period. The figures use shaded zones to illustrate these shifts, with troughs in the lower portions and crests in the upper portions of the triangular shapes, reflecting the dynamic nature of the trends. The color bar accompanying the figures makes it easy to identify rainfall trends, where blue denotes a decreasing trend, red indicates an increasing trend, and green signifies periods of stability with no discernible trend.

From 1923 to 1950, Bokaro exhibited a declining rainfall trend, as depicted by the blue shading in the figures. This trend reversed from 1950 to 1990, with an increasing pattern shown in red, while green shades highlight periods of no significant change. The clustering of trend shifts offers insights into key moments when extreme climate indices began to change, providing a clearer understanding of these trends. The statistics presented in Figures 6.61(c) to 6.75(c) confirm the accuracy and reliability of the visualized data, making it a valuable tool for understanding climate patterns in Bokaro.

These findings are highly significant for planners and decision-makers, particularly when it comes to understanding how rainfall patterns are evolving, which has important implications for agricultural and water resource management in the region. Since a large portion of the population in Bokaro depends on agriculture, understanding these climate trends is essential for sustainable planning. By identifying key change points and presenting the data in three-dimensional models, this study deepens the understanding of climate variability in Bokaro and its potential impact on agriculture and resource planning.

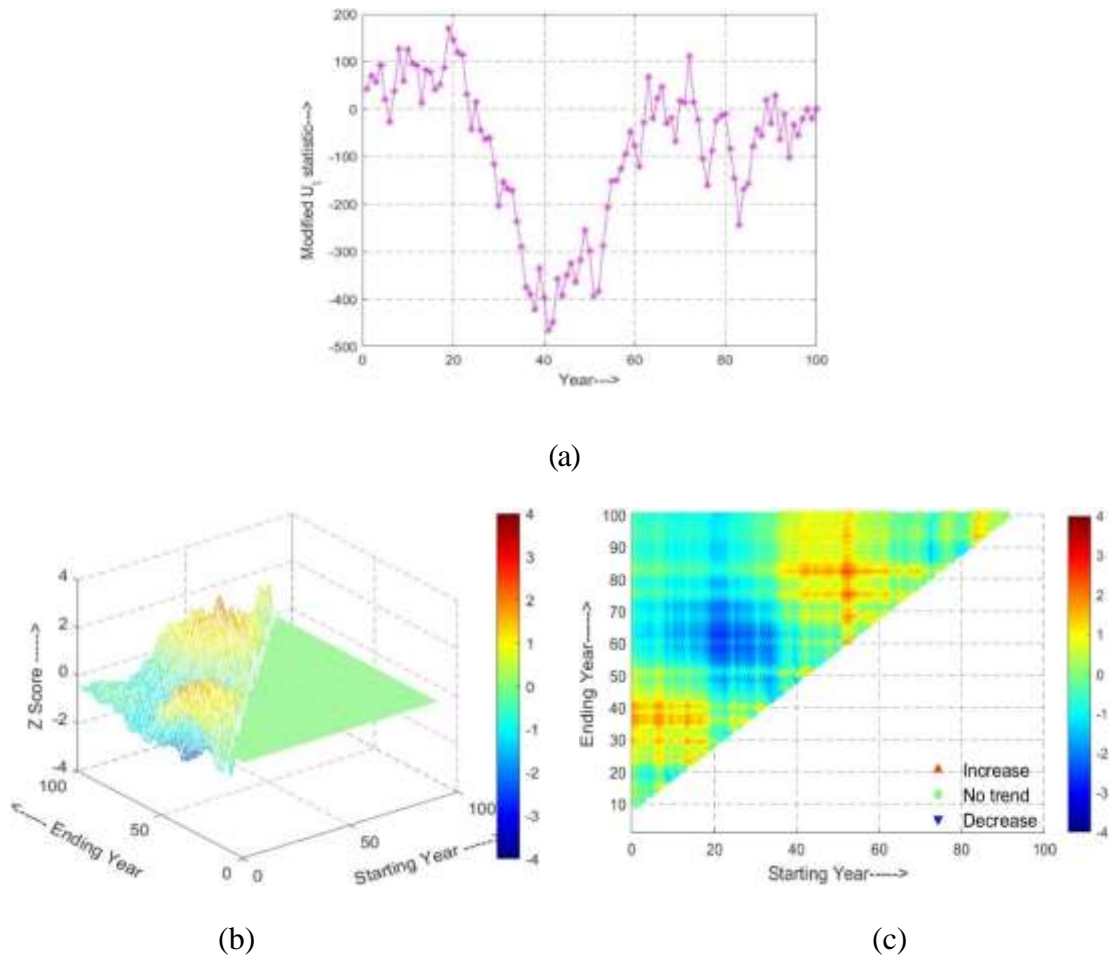
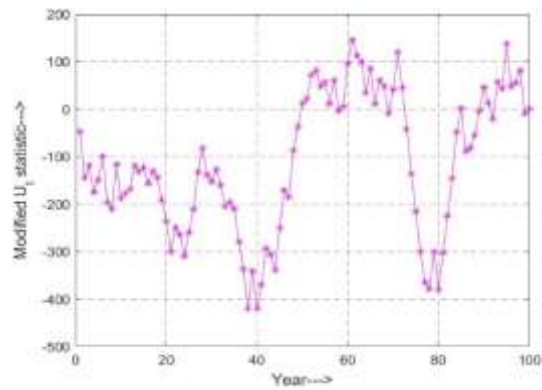
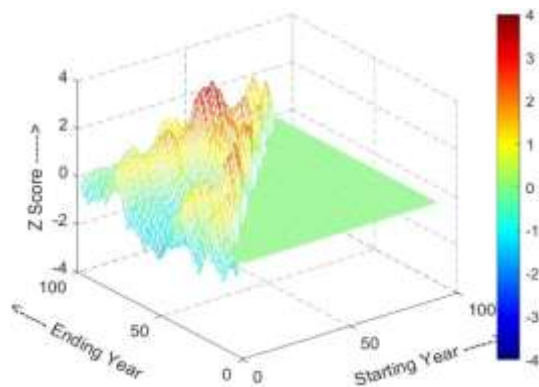


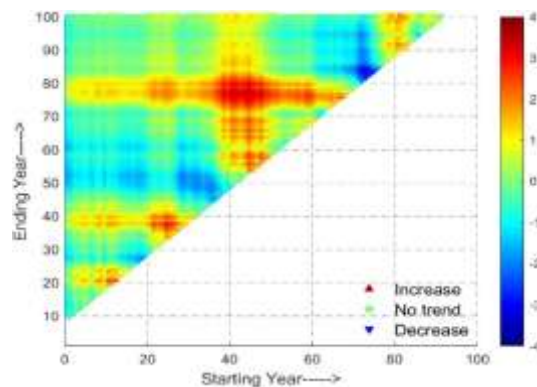
Figure 6.61(a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the CDD trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the CDD trend in Bokaro was at level of 0.05.



(a)

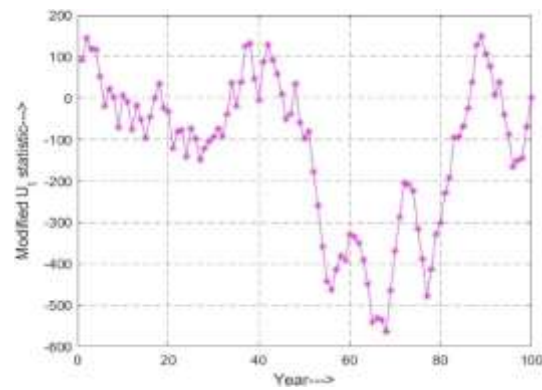


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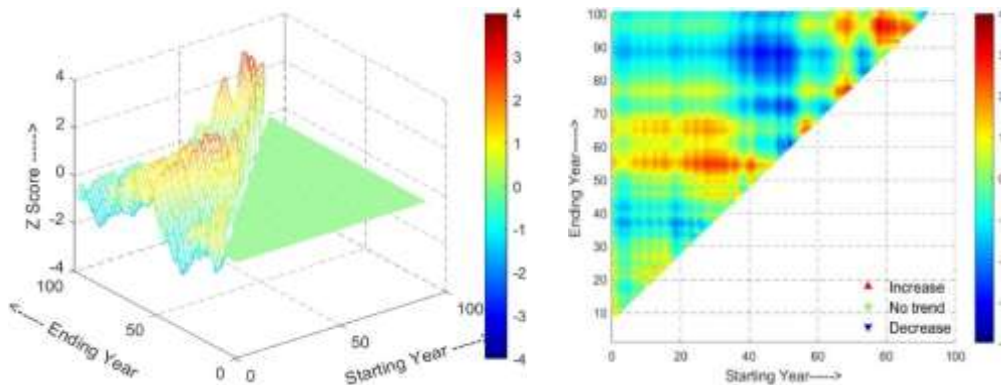


(c)

Figure 6.62 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the CWD trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the CWD trend in Bokaro was at level of 0.05.



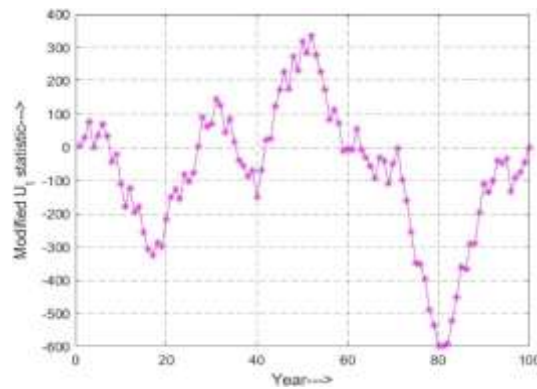
(a)



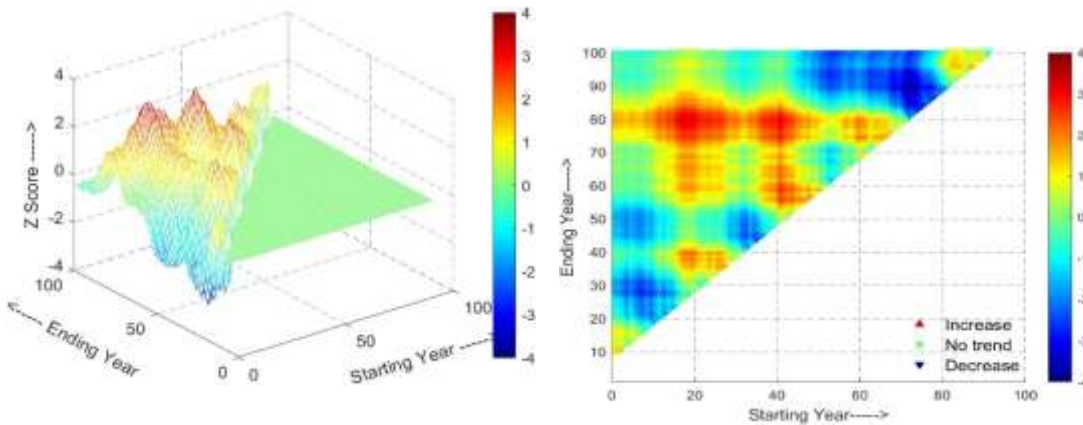
(b)

(c)

Figure 6.63 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the DTR trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the DTR trend in Bokaro was at level of 0.05.



(a)



(b)

(c)

Figure 6.64 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the PRCPTOT trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Bokaro was at level of 0.05.

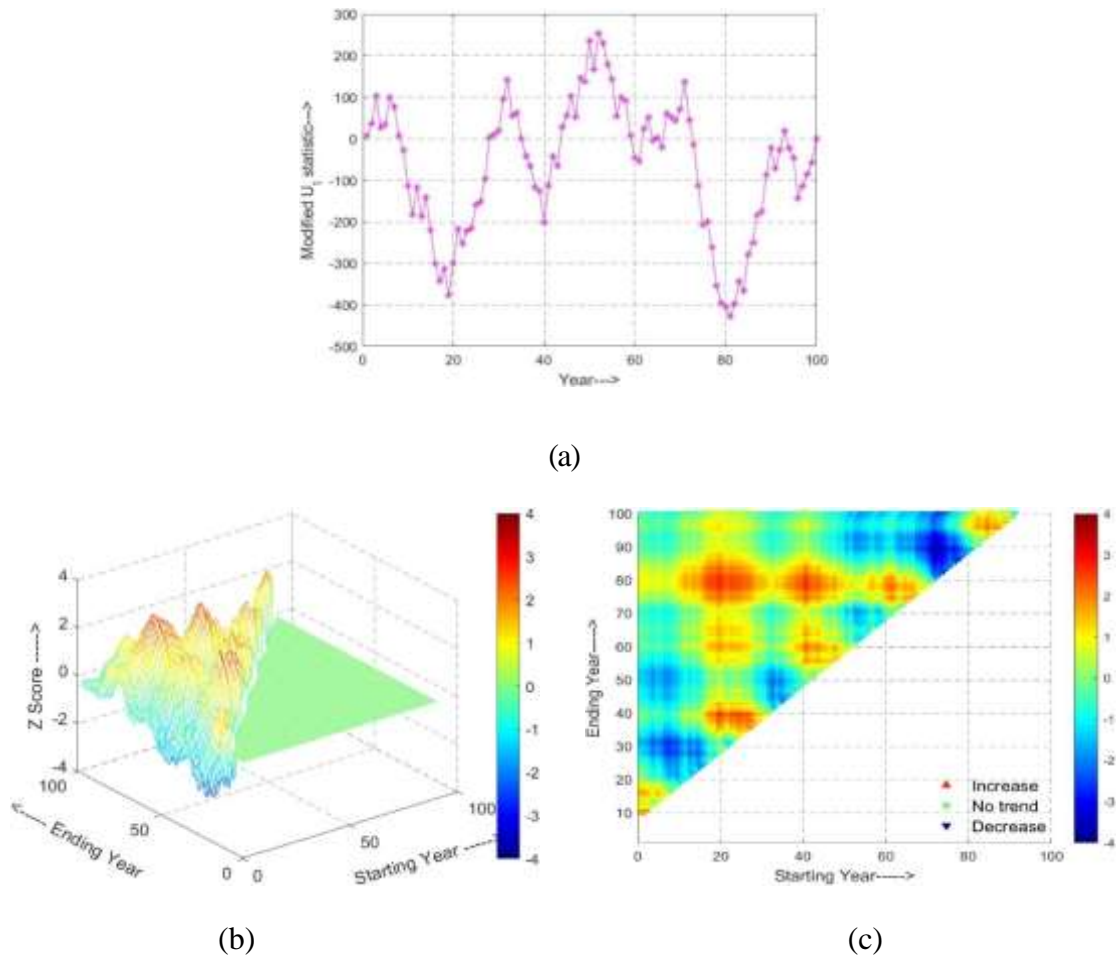
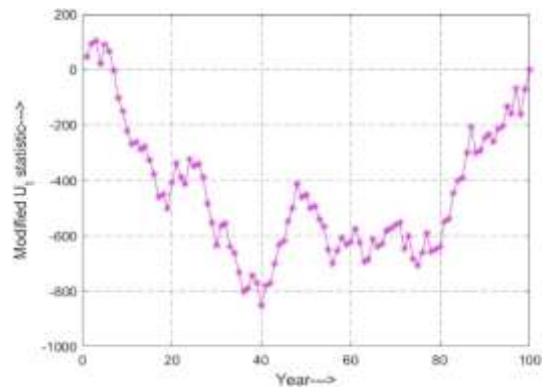
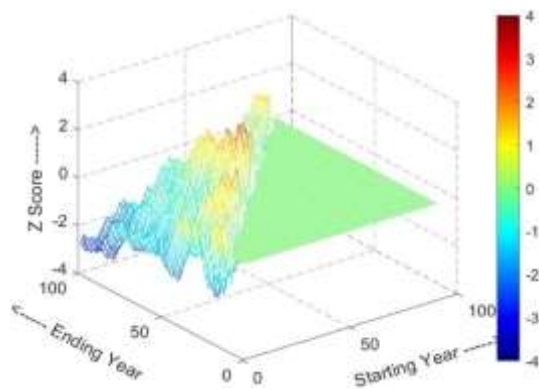


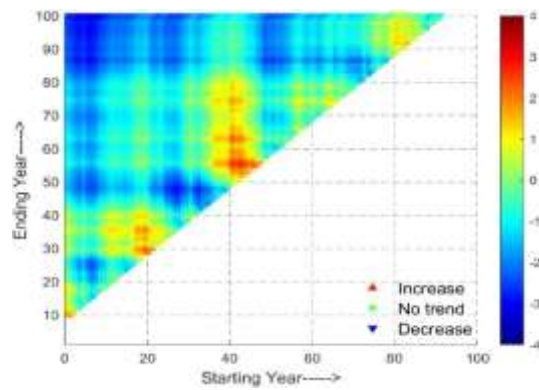
Figure 6.65 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the R10mm trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Bokaro was at level of 0.05.



(a)



(b)



(c)

Figure 6.66 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the R20mm trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Bokaro was at level of 0.05.

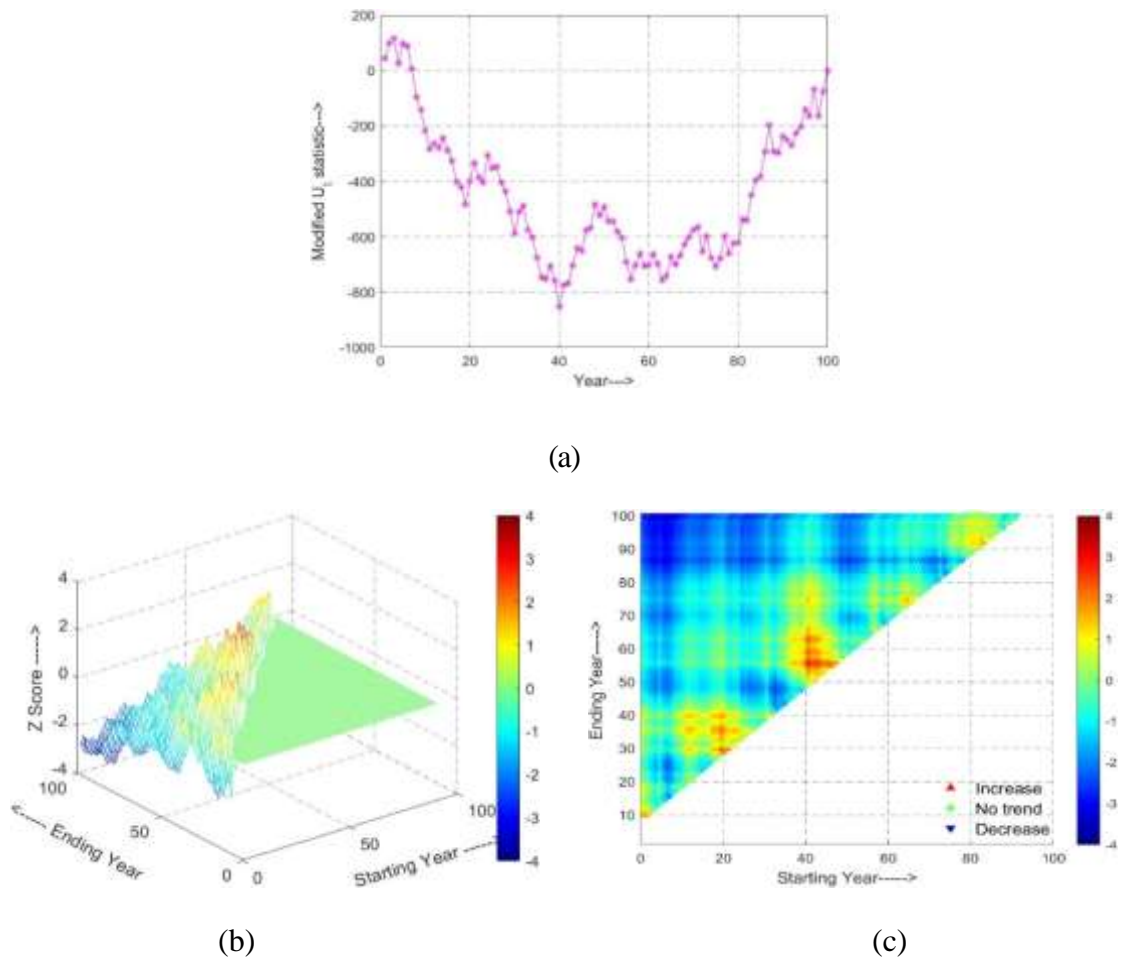
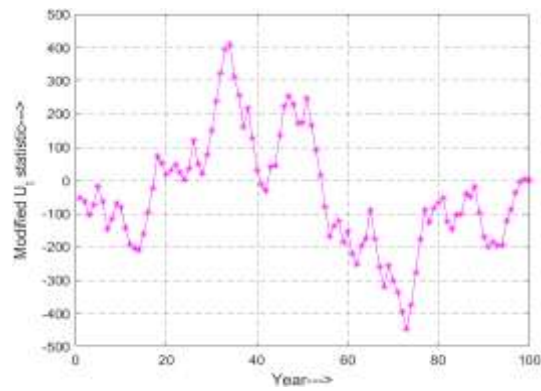
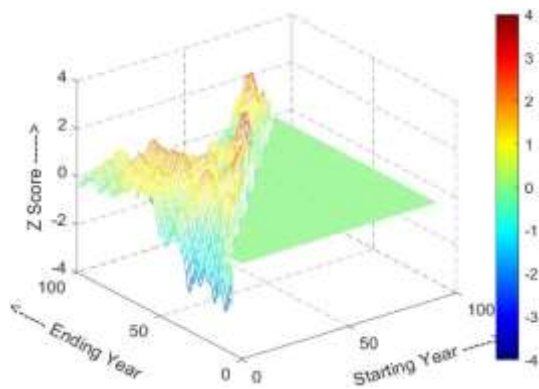


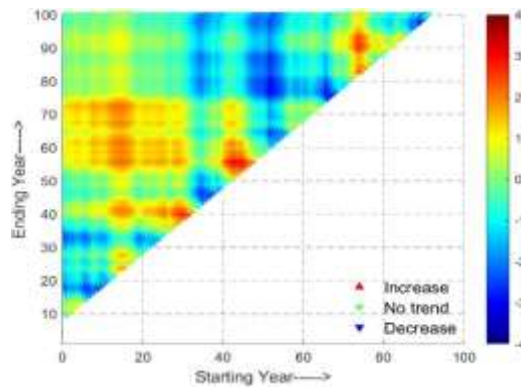
Figure 6.67 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the R95p trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the R95p trend in Bokaro was at level of 0.05.



(a)



(b)



(c)

Figure 6.68 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the R99p trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the R99p trend in Bokaro was at level of 0.05.

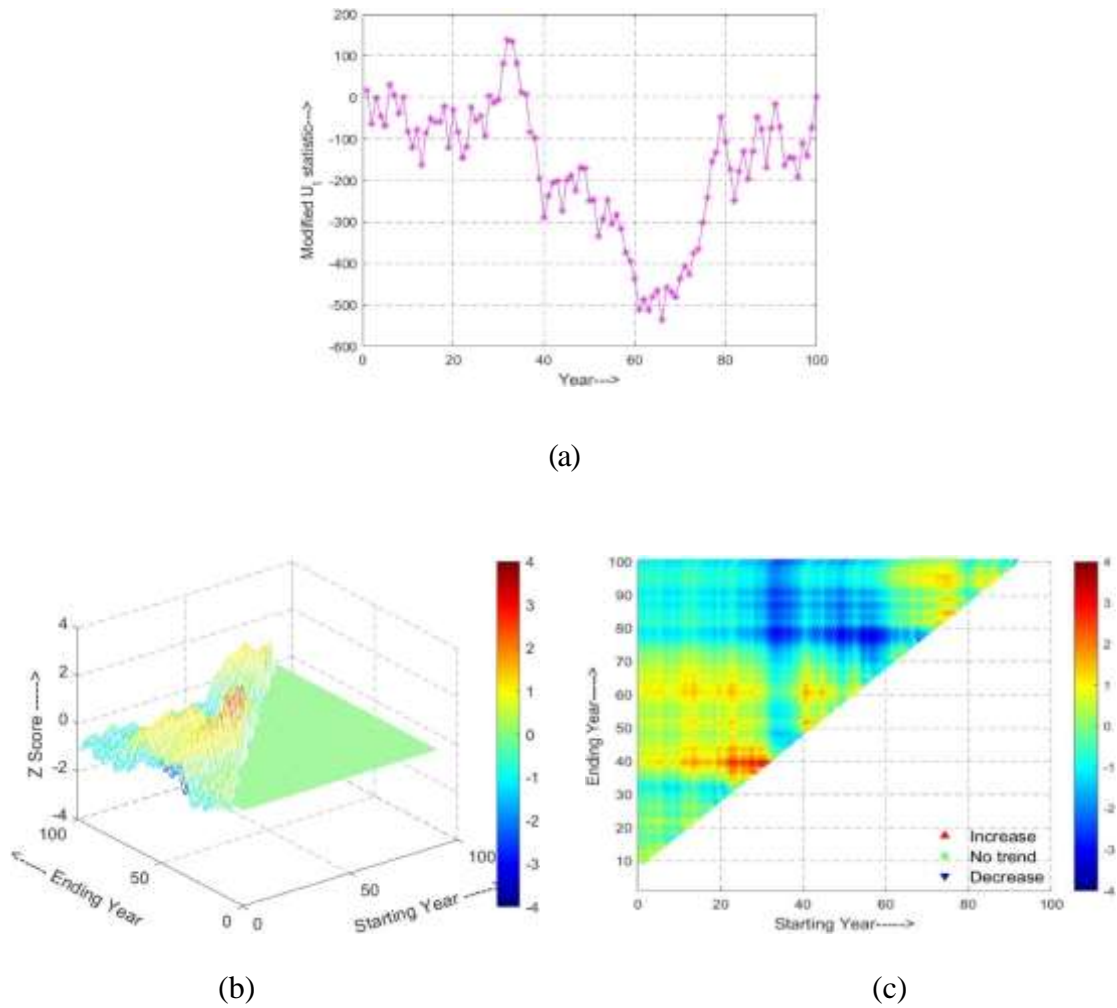
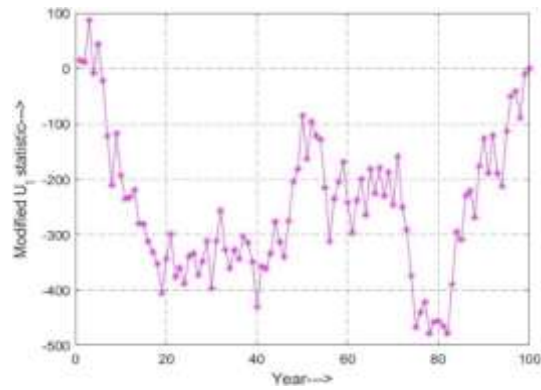
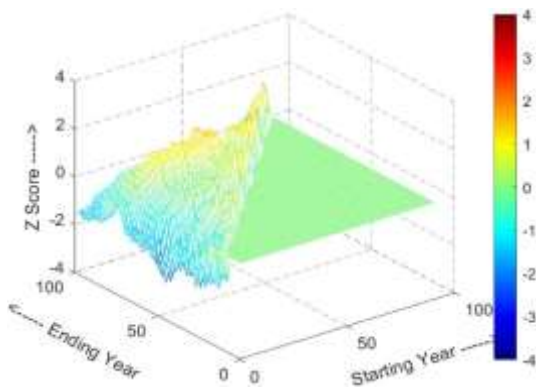


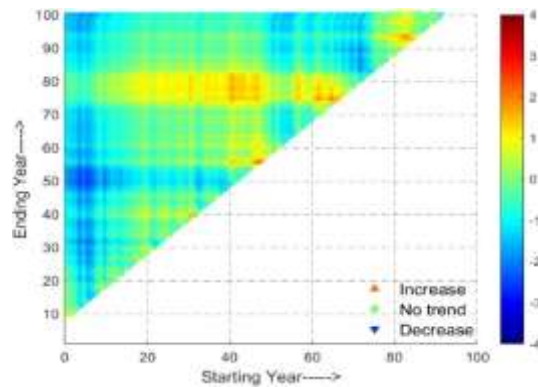
Figure 6.69 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the RX1day trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Bokaro was at level of 0.05.



(a)

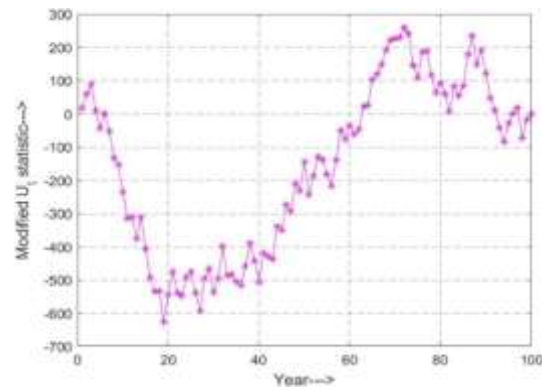


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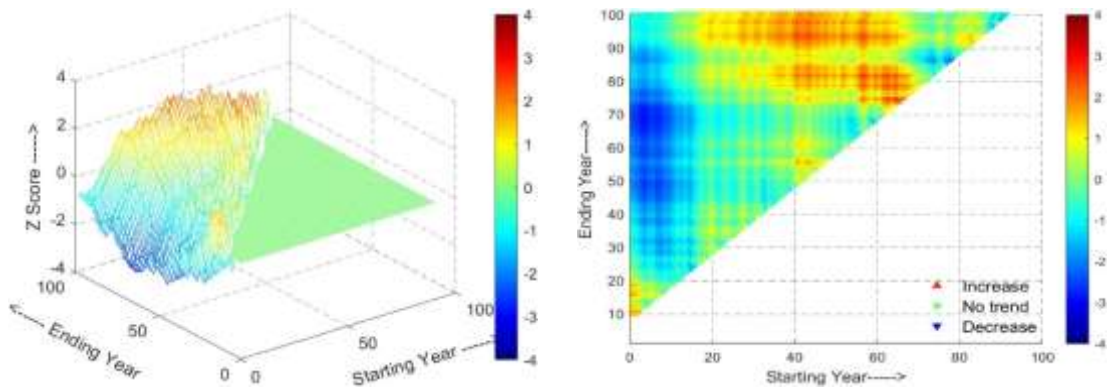


(c)

Figure 6.70 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the RX5day trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Bokaro was at level of 0.05.



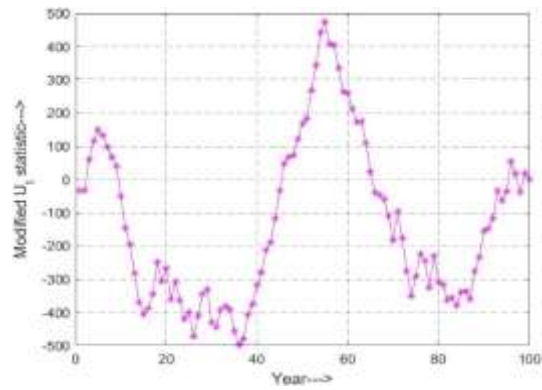
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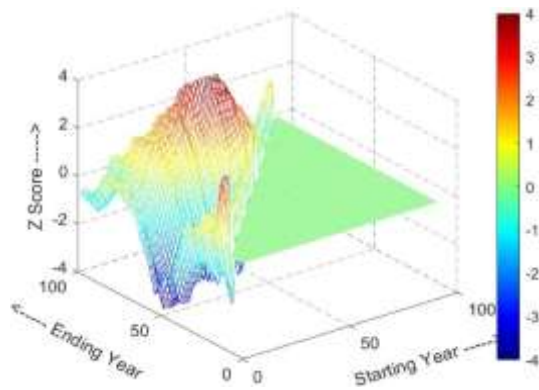
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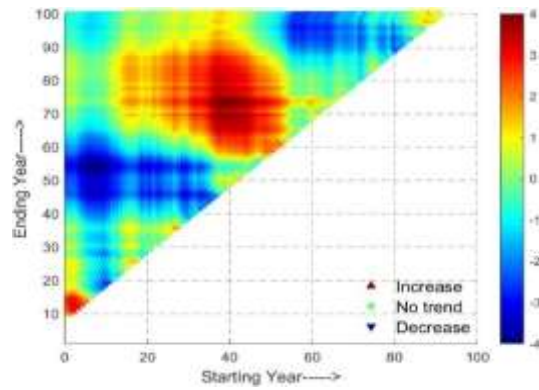
Figure 6.71 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the SDII trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the SDII trend in Bokaro was at level of 0.05.



(a)

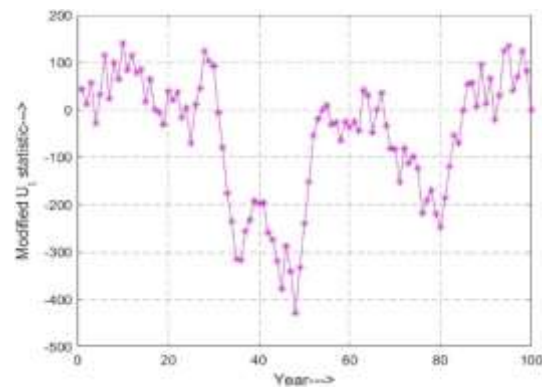


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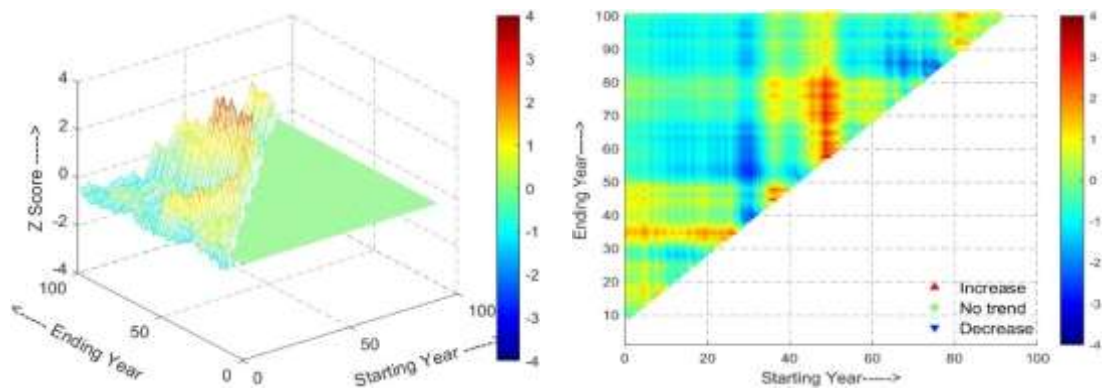


(c)

Figure 6.72 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the TNn trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the TNn trend in Bokaro was at level of 0.05.



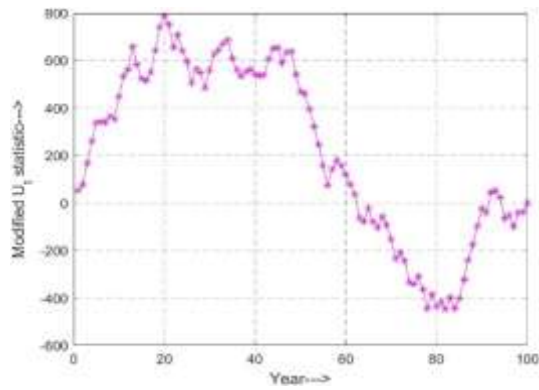
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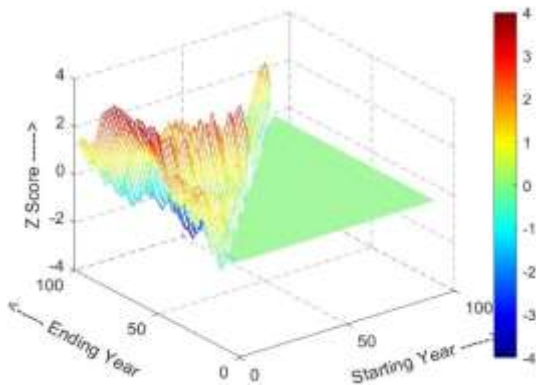
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(c)

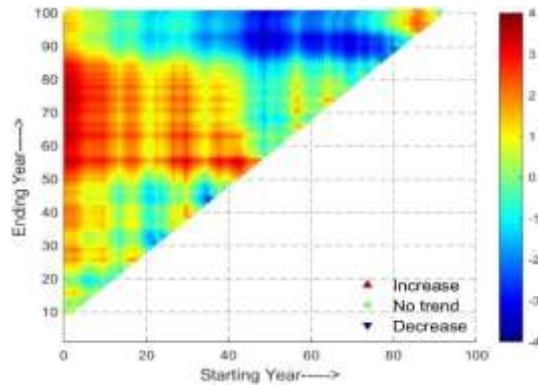
Figure 6.73 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the TNx trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the TNx trend in Bokaro was at level of 0.05.



(a)



(b)



(c)

Figure 6.74 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the TX_n trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the TX_n trend in Bokaro was at level of 0.05.

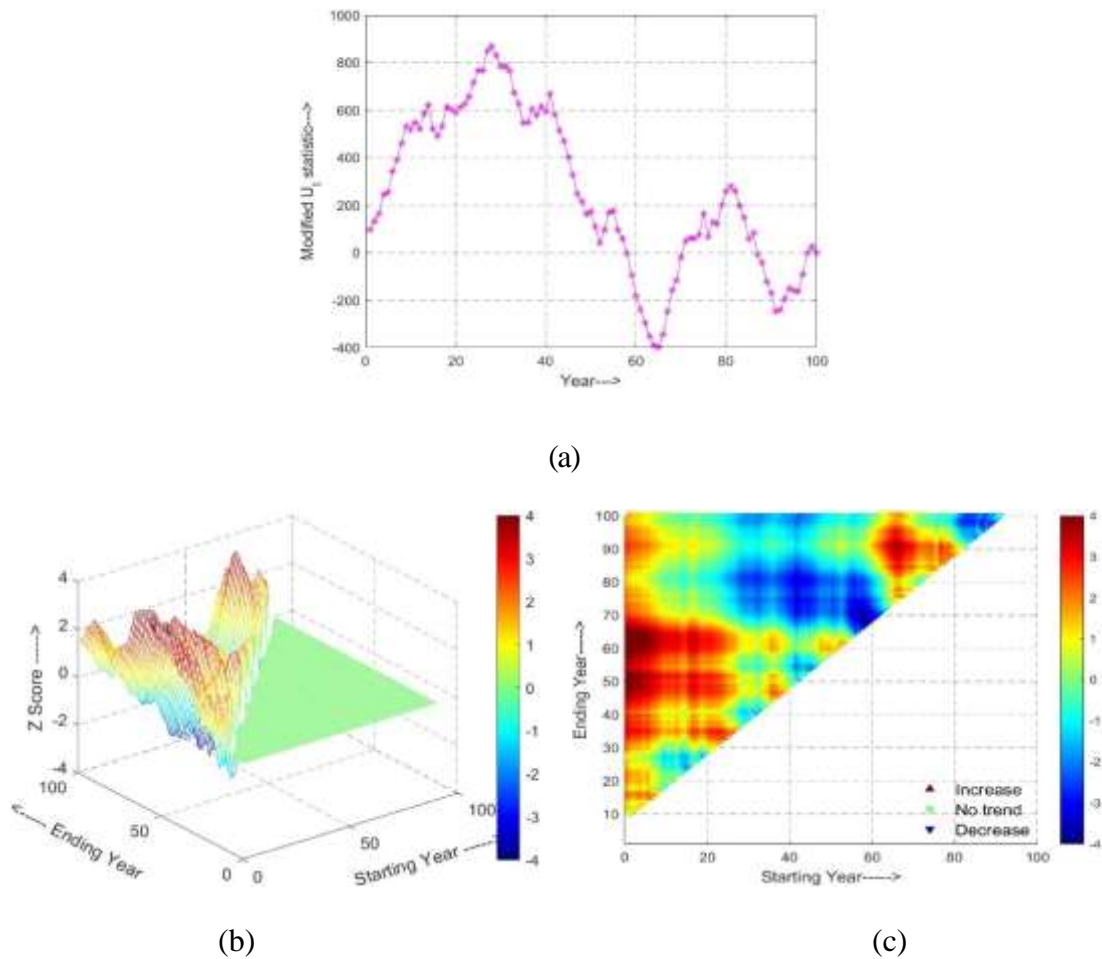


Figure 6.75 (a) Variation of modified U_t over the years to identify change points in Bokaro. (b) The three-dimensional pattern of the TXx trend in Bokaro is at level of 0.05. (c) The 2-D pattern of the TXx trend in Bokaro was at level of 0.05.

6.2.6 Characteristics of Multiple Climatic Indices in Dhanbad

Dhanbad station, located in the Jharkhand portion of the Damodar River Basin (DRB), has been the focus of extensive research aimed at analyzing long-term trends in extreme climate indices. This station was chosen for a comprehensive trend analysis spanning the years from 1923 to 2022. Figures 6.76(b-c) to 6.90(b-c) provide both two-dimensional and three-dimensional visualizations of extreme climate variables recorded at Dhanbad. The early sections of these figures depict a series of peaks and valleys, where the peaks reflect the intensity and direction of climate trends, and the valleys represent fluctuations over time. These patterns clearly demonstrate significant shifts in extreme climate indices throughout the study period. The visualizations, highlighted by distinct color zones, show troughs in the lower portion of the triangular shapes and crests in the upper portion, illustrating the dynamic nature of these climate trends. The color bar on the right side of Figures 6.76(c) to 6.90(c) depicts increasing rainfall trends in red, decreasing trends in blue, and stable periods in green.

From 1923 to 1950, Dhanbad experienced a declining rainfall trend, as indicated by the blue shading in the figures. However, an increasing trend was observed between 1950 and 1990, represented by red shades, while green zones highlight periods of stability with no significant trend. Through clustering analysis, researchers were able to identify key moments when major shifts in the climate occurred. The statistical data presented in Figures 6.76(c) to 6.90(c) validate the accuracy of these visualized trends, reinforcing the credibility of the analysis.

A broader long-term trend analysis conducted by Halder et al. (2023), which covered various districts across West Bengal and Jharkhand, also revealed a declining trend in annual rainfall for Dhanbad from 1901 to 2020. This study further visualizes both the increase and decrease in annual rainfall trends for Dhanbad, utilizing advanced 2D and 3D figures to capture the evolving rainfall patterns. Additionally, the research introduced a modified version of the PMW test to detect multiple change points in the trends, providing more detailed insights compared to previous studies, which primarily focused on broader trend detection.

The study's results are particularly valuable for policymakers and planners, as understanding the shifting nature of rainfall patterns is critical for managing agricultural

activities and water resources in the region. Given that a significant portion of Dhanbad's population depends on agriculture, understanding the variability in rainfall patterns is crucial for effective planning and resource management. By using three-dimensional representations and identifying critical change points in rainfall trends, this research offers deeper insights into the region's climate dynamics and its potential impact on agriculture and water management in Dhanbad.

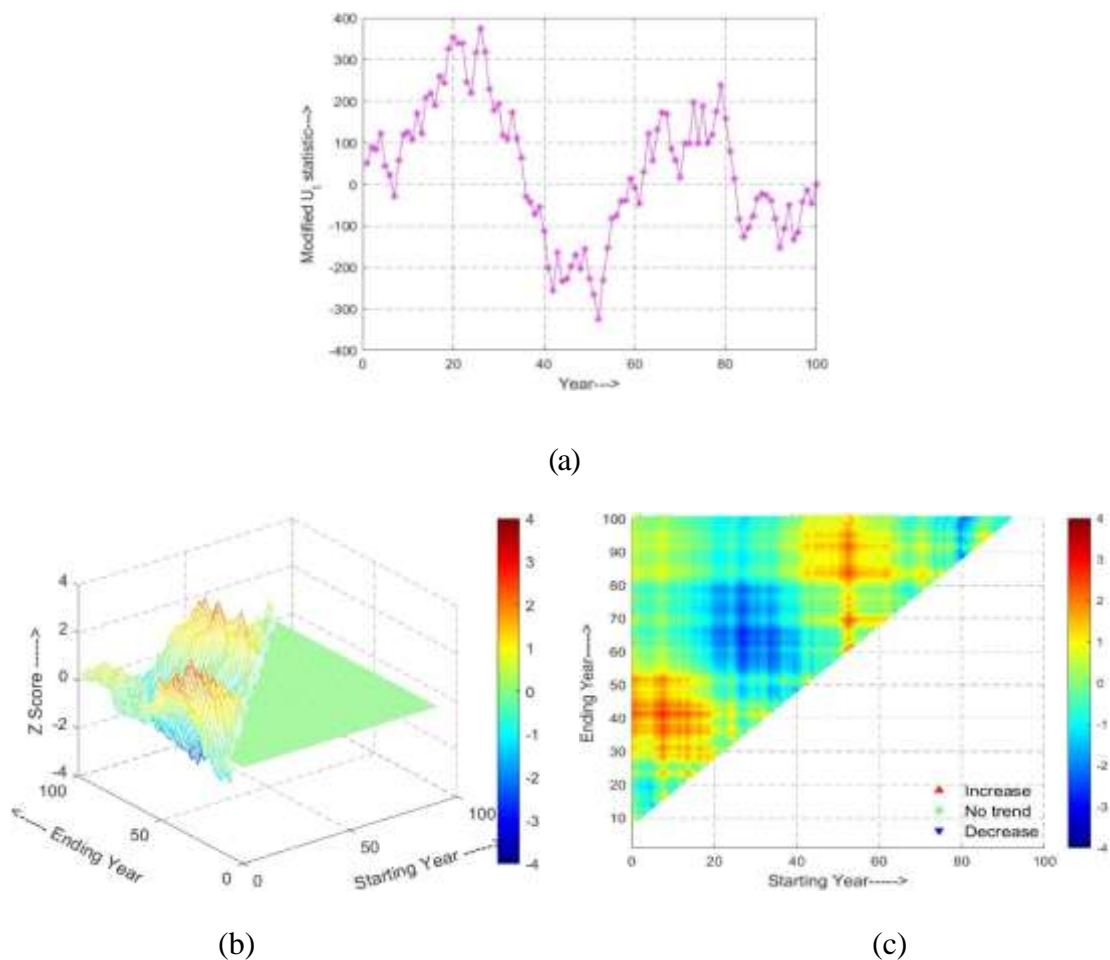
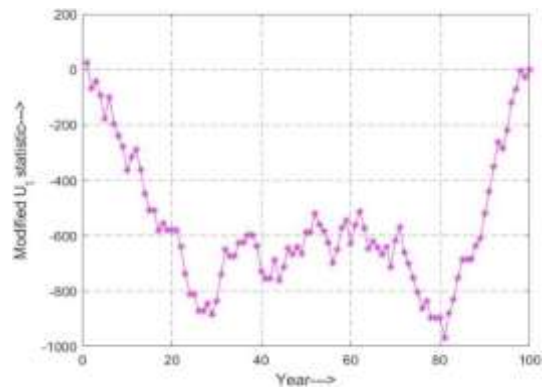
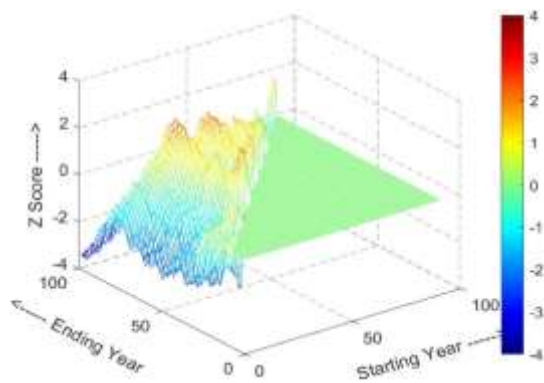


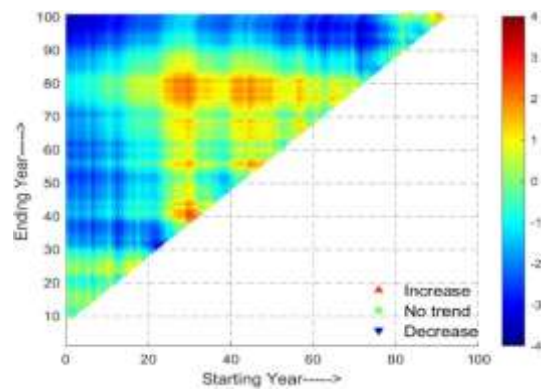
Figure 6.76 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the CDD trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the CDD trend in Dhanbad was at level of 0.05.



(a)



(b)



(c)

Figure 6.77 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the CWD trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the CWD trend in Dhanbad was at level of 0.05.

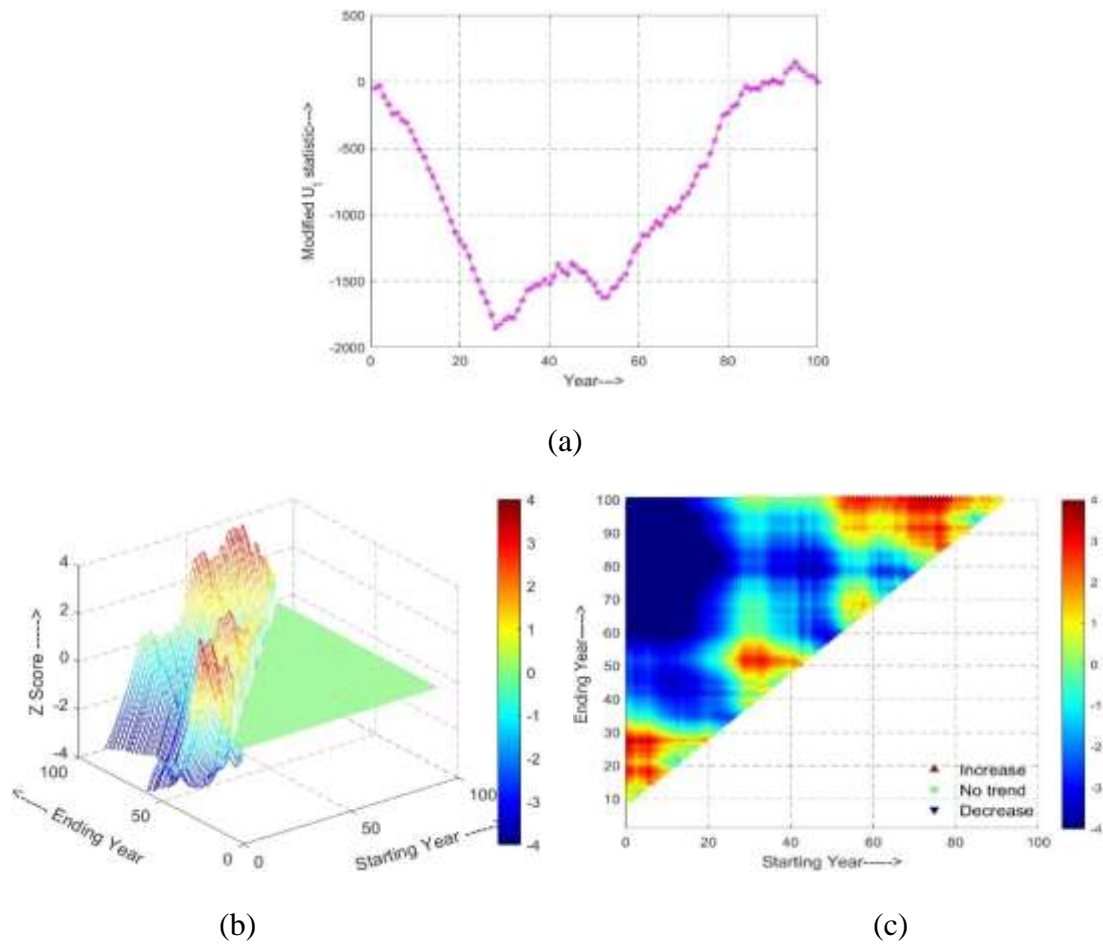
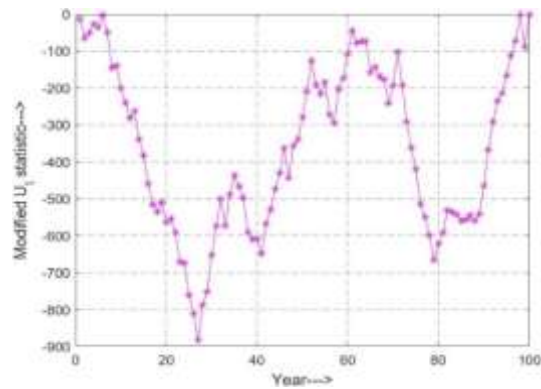
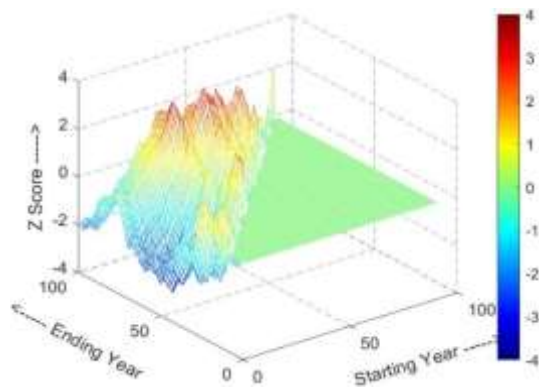


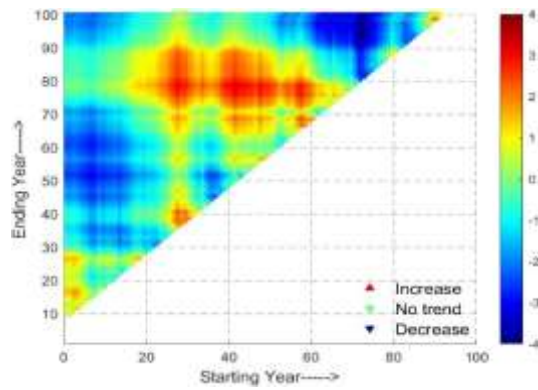
Figure 6.78 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the DTR trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the DTR trend in Dhanbad was at level of 0.05.



(a)



(b)



(c)

Figure 6.79 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the PRCPTOT trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Dhanbad was at level of 0.05.

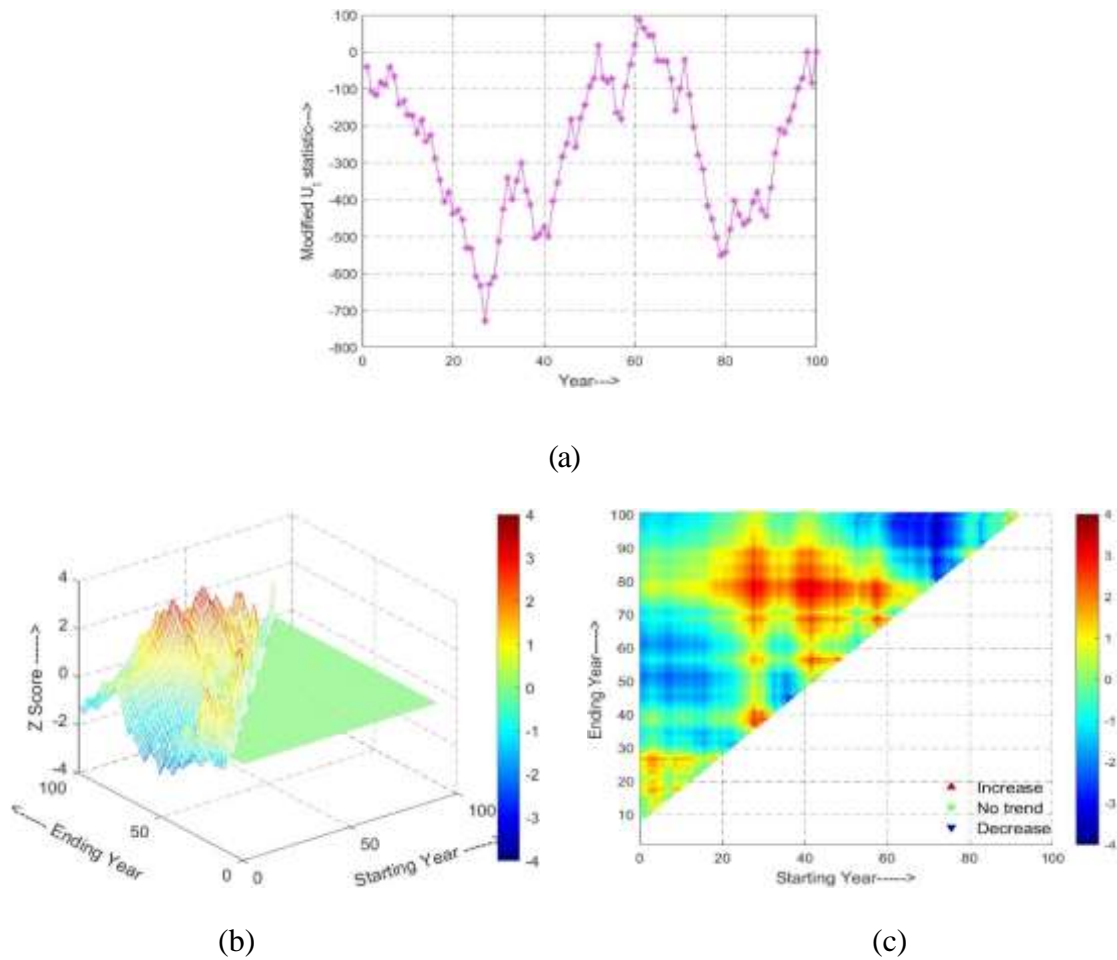
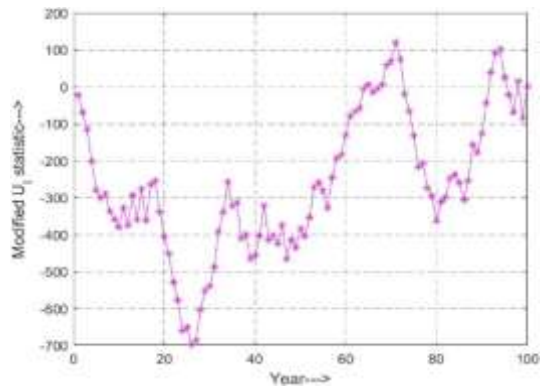
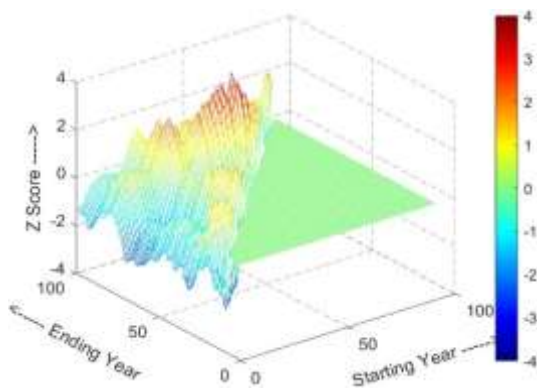


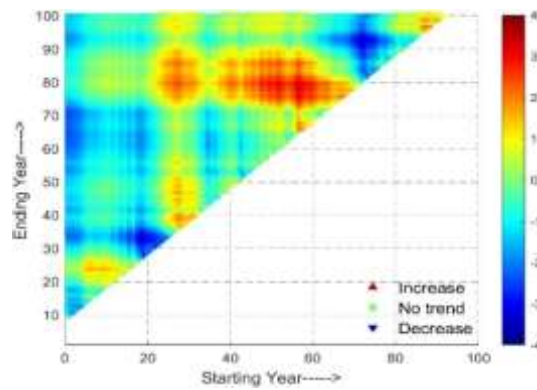
Figure 6.80 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the R10mm trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Dhanbad was at level of 0.05.



(a)



(b)



(c)

Figure 6.81 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the R20mm trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Dhanbad was at level of 0.05.

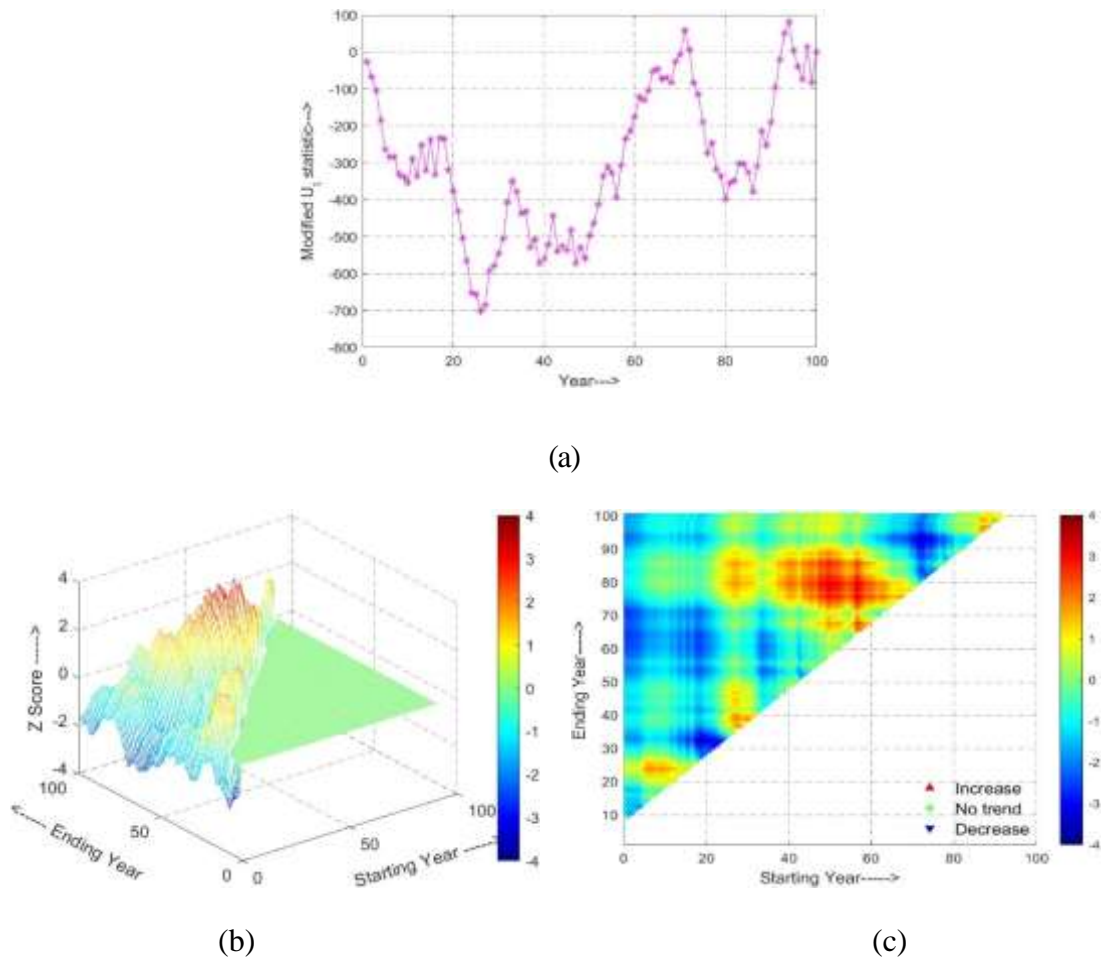


Figure 6.82 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the R_{95p} trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in Dhanbad was at level of 0.05.

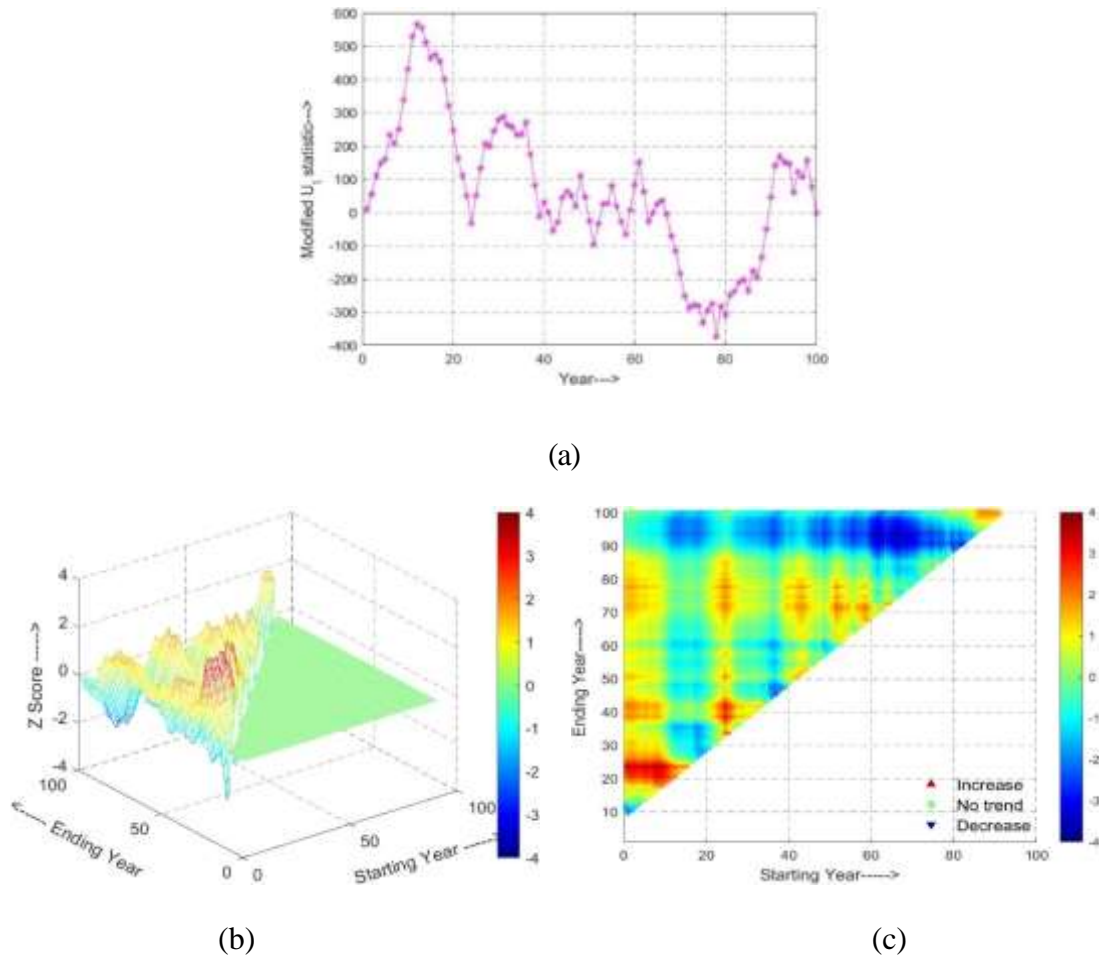


Figure 6.83 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the R_{99p} trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Dhanbad was at level of 0.05.

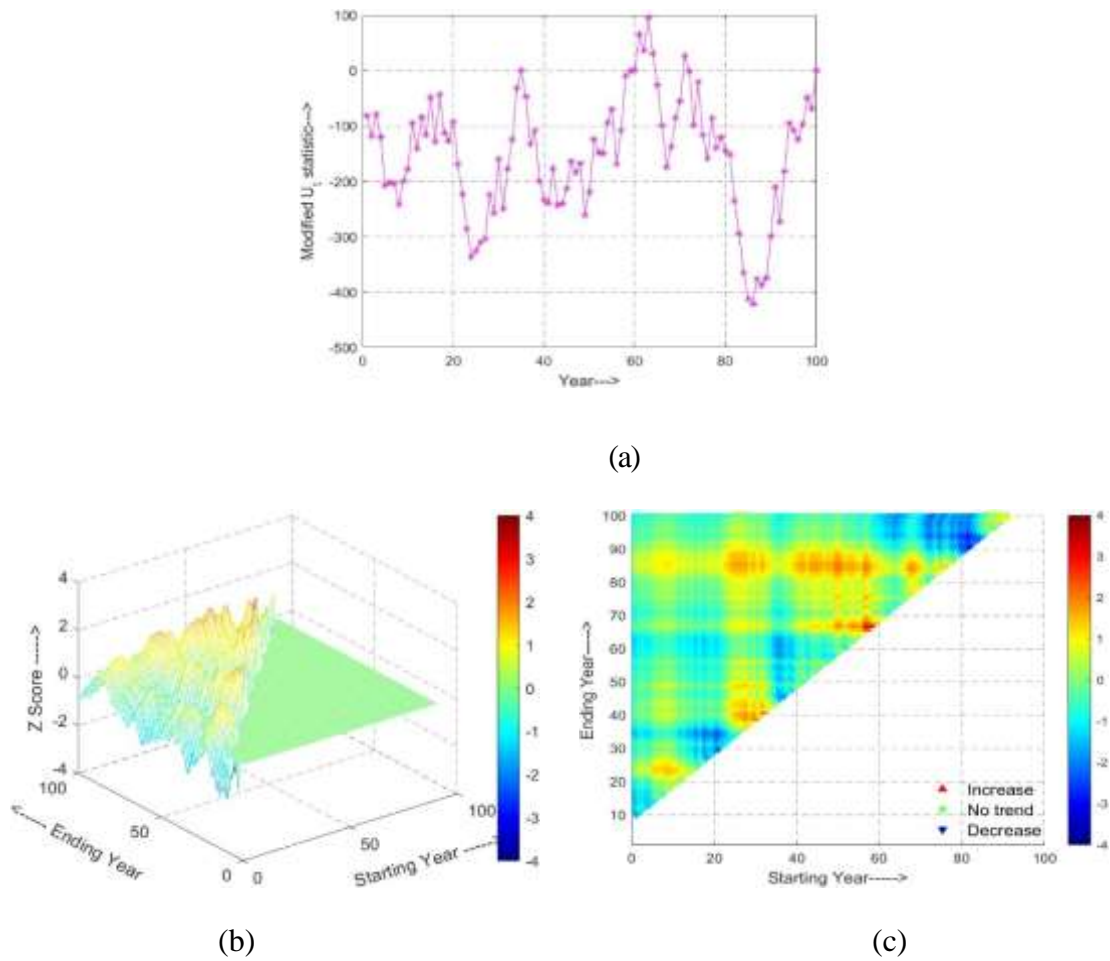
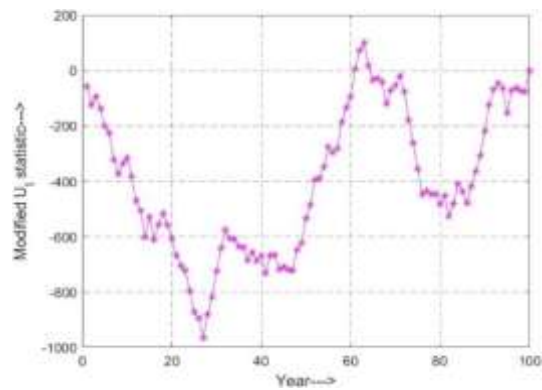
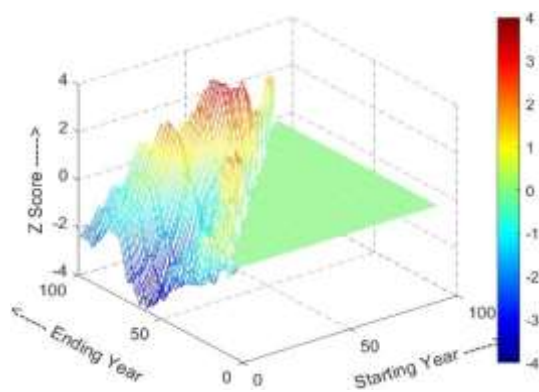


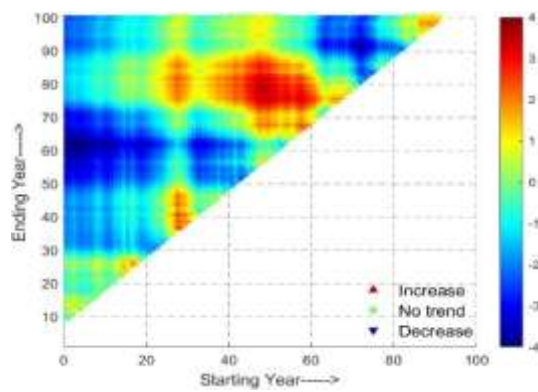
Figure 6.84 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the RX1day trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Dhanbad was at level of 0.05.



(a)



(b)



(c)

Figure 6.85 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the RX5day trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Dhanbad was at level of 0.05.

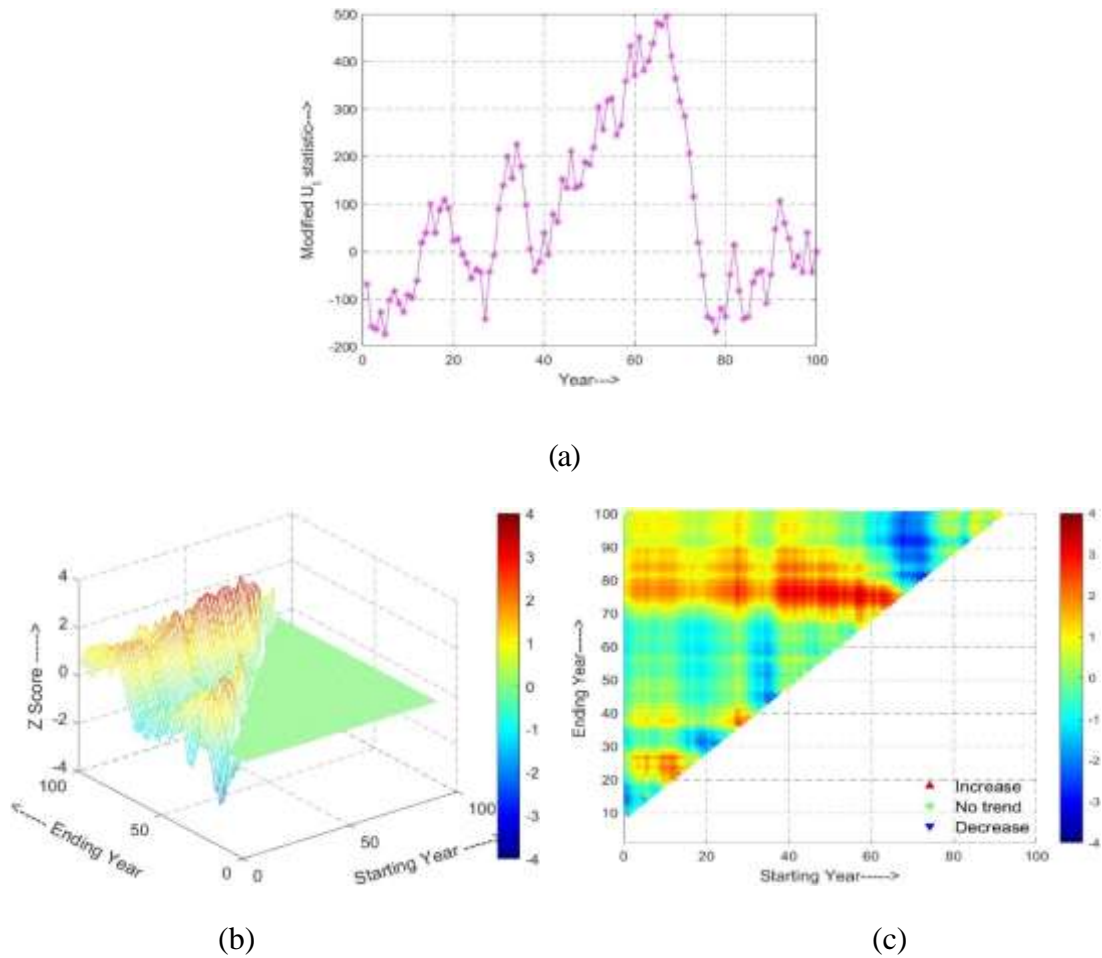
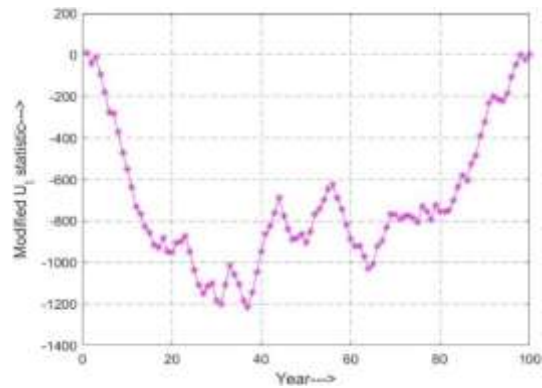
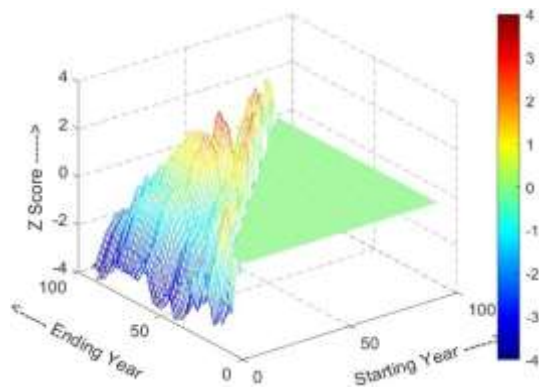


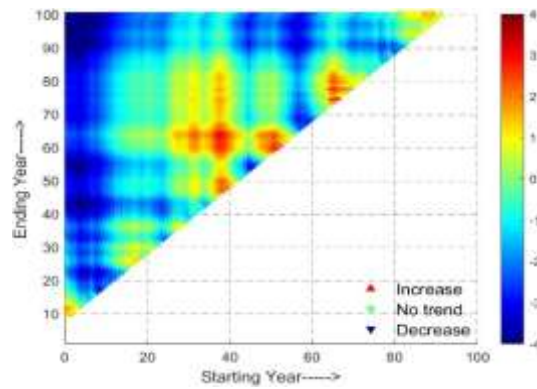
Figure 6.86 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the SDII trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the SDII trend in Dhanbad was at level of 0.05.



(a)



(b)



(c)

Figure 6.87 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the TNn trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the TNn trend in Dhanbad was at level of 0.05.

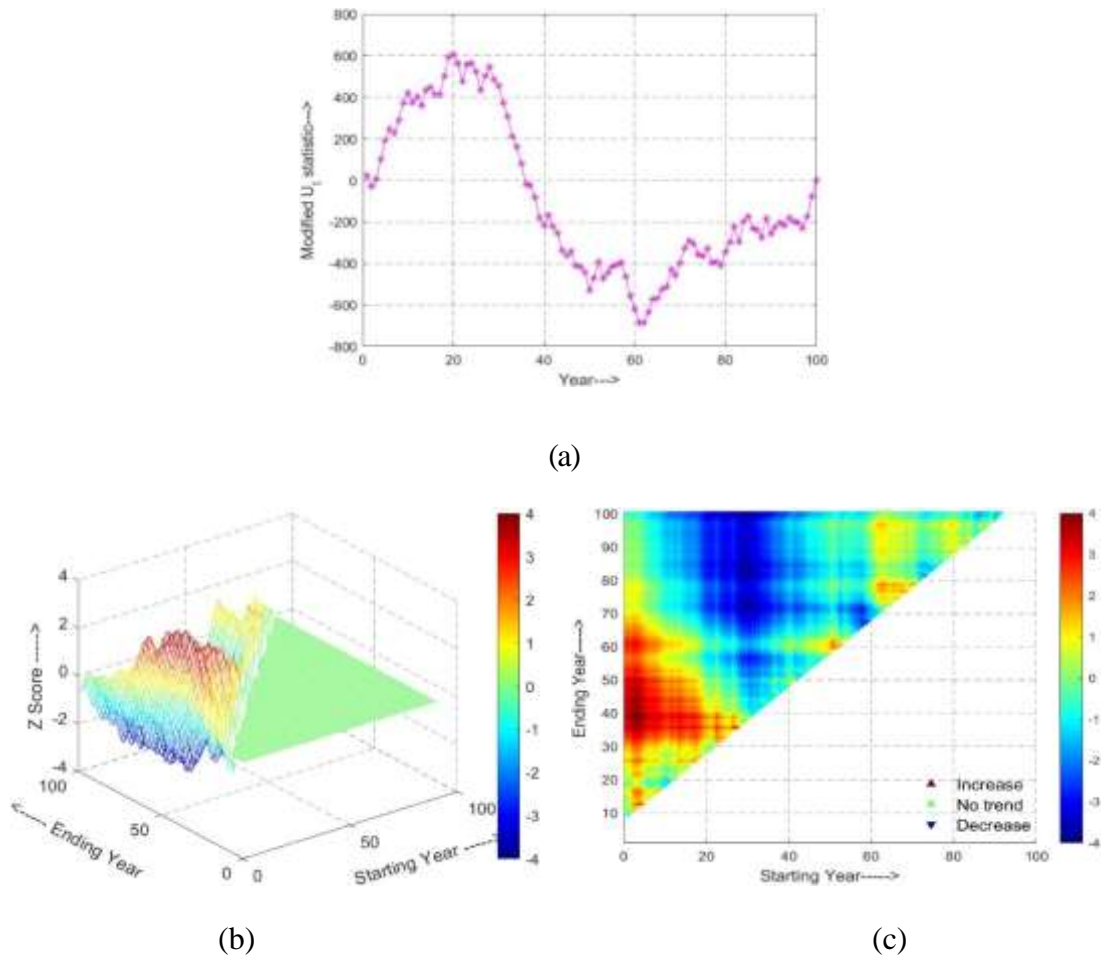
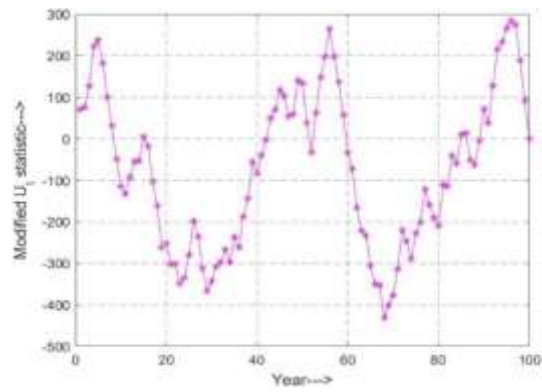
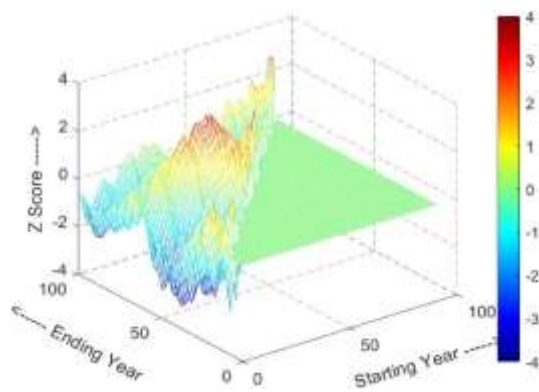


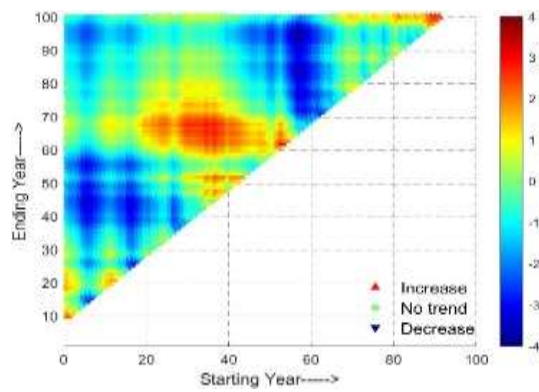
Figure 6.88 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the TNx trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the TNx trend in Dhanbad was at level of 0.05.



(a)

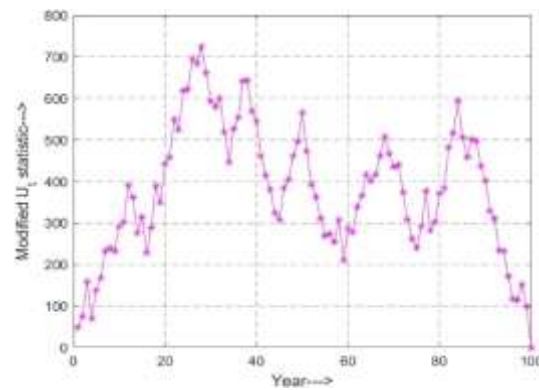


(b)

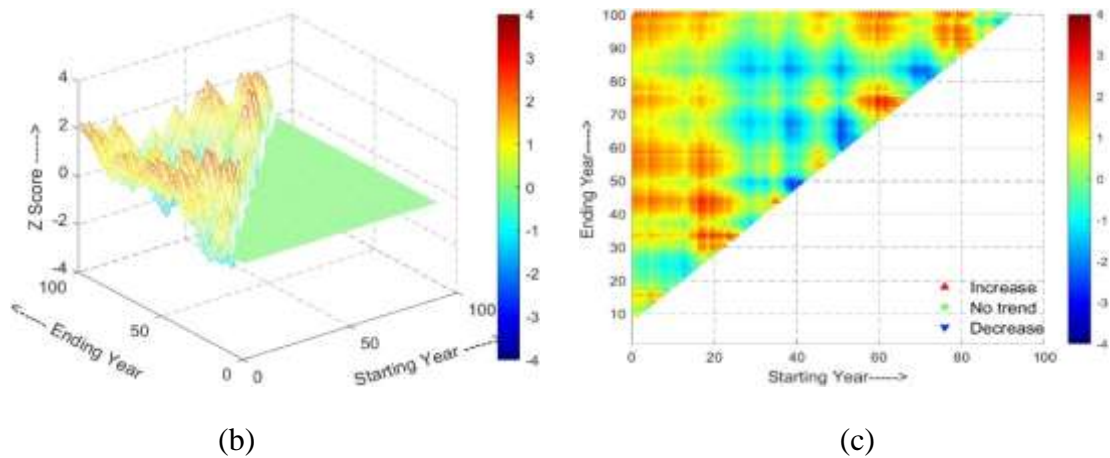


(c)

Figure 6.89 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the TXn trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the TXn trend in Dhanbad was at level of 0.05.



(a)



(b)

(c)

Figure 6.90 (a) Variation of modified U_t over the years to identify change points in Dhanbad. (b) The three-dimensional pattern of the TXx trend in Dhanbad is at level of 0.05. (c) The 2-D pattern of the TXx trend in Dhanbad was at level of 0.05.

6.2.7 Characteristics of Multiple Climatic Indices in Durgapur

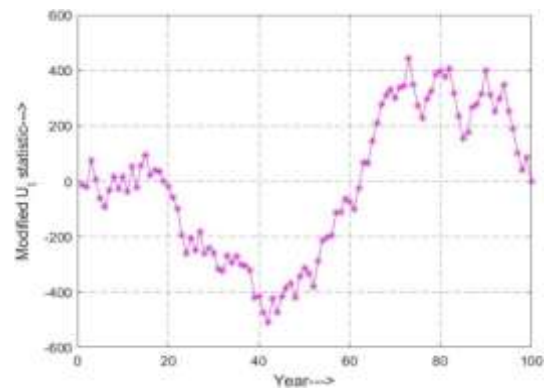
Durgapur station, situated in the West Bengal region of the Damodar River Basin (DRB), has been the subject of extensive research focusing on long-term trends in extreme climate indices. This station was selected for a detailed analysis covering the period from 1923 to 2022. Figures 6.1(b-c) through 6.15(b-c) present both two-dimensional and three-dimensional visualizations of

the extreme climate variables observed in Durgapur. The initial sections of these figures show peaks and troughs, where the peaks represent the intensity and direction of climate trends, while the troughs highlight fluctuations over time. These visualizations clearly indicate significant shifts in extreme climate indices throughout the analysis period. The figures, with their distinct color-shaded zones, depict troughs in the lower parts and crests in the upper portions of the triangular shapes, reflecting the dynamic nature of the observed climate trends. A color bar on the right side of Figures 6.1(c) to 6.15(c) illustrates these trends, with red denoting an increasing rainfall pattern, blue indicating a decreasing trend, and green signifying periods of no significant change.

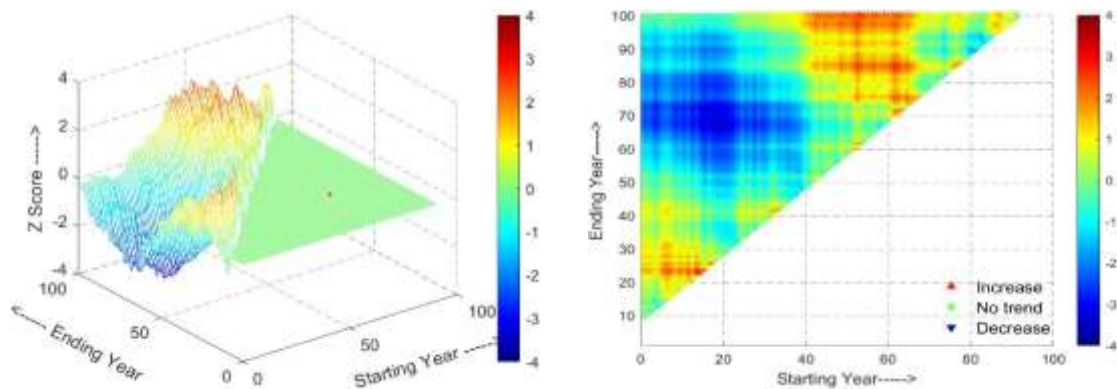
From 1923 to 1950, Durgapur experienced a declining trend in rainfall, as indicated by the blue shading in the figures. However, between 1950 and 1990, an increasing rainfall trend was observed, highlighted in red, while green areas represent periods of relative stability. By analyzing the clustering of these trends, researchers were able to pinpoint key moments when significant shifts occurred. The statistical analysis in Figures 6.1(c) through 6.15(c) confirms the accuracy and reliability of the visualized trends, adding further credibility to the findings.

This study builds on those findings by visualizing both increasing and decreasing rainfall trends from 1923 to 2022, employing advanced 2D and 3D models to capture the evolving rainfall patterns. Additionally, this research introduced a modified version of the PMW test to detect multiple change points in the rainfall trends, providing more detailed insights than previous studies, which primarily focused on general trend detection.

The insights from this research are highly valuable for local planners and policymakers, as understanding the changing nature of rainfall patterns is crucial for managing agriculture and water resources in the region. With a large portion of Durgapur's population dependent on agriculture, understanding rainfall variability is essential for sustainable agricultural practices and water management strategies. By using three-dimensional visualizations and identifying critical change points in rainfall trends, this study offers a deeper understanding of climate variability in Durgapur and its potential impact on regional agriculture and resource planning.



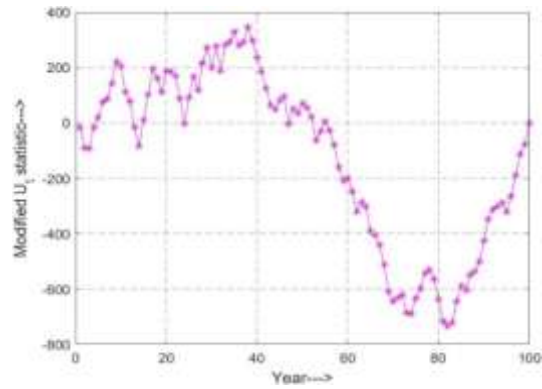
(a)



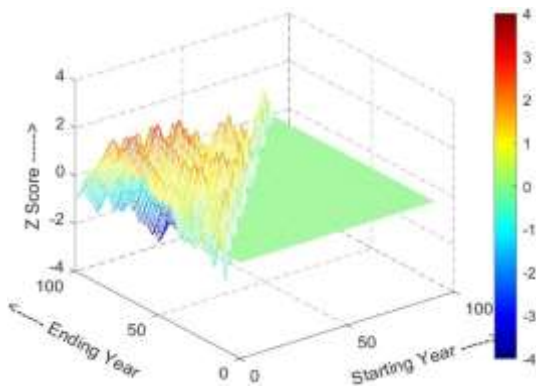
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(c)

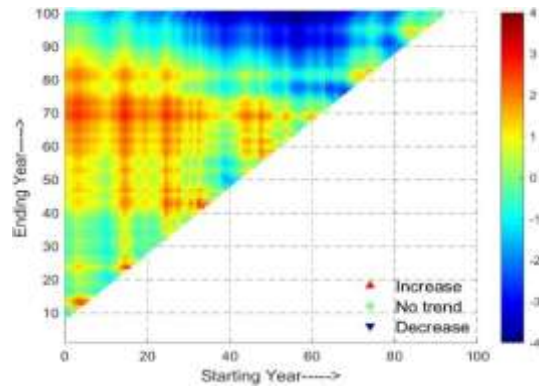
Figure 6.91(a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the CDD trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the CDD trend in Durgapur was at level of 0.05.



(a)

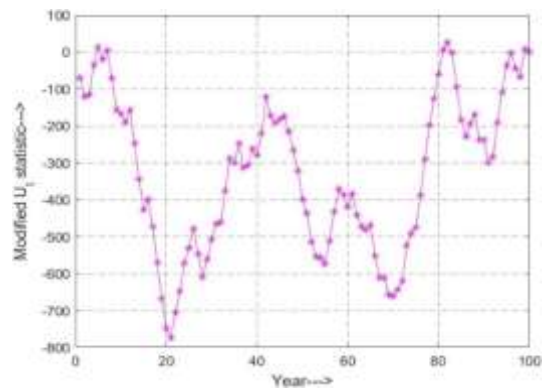


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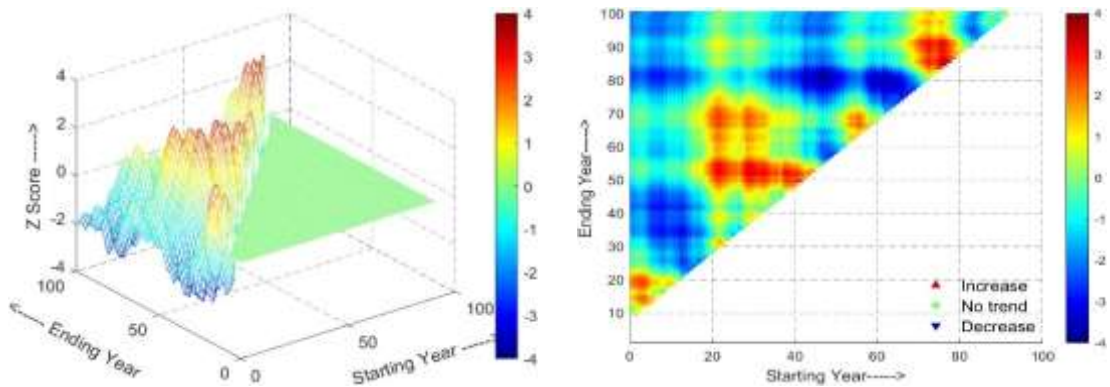


(c)

Figure 6.92 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the CWD trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the CWD trend in Durgapur was at level of 0.05.



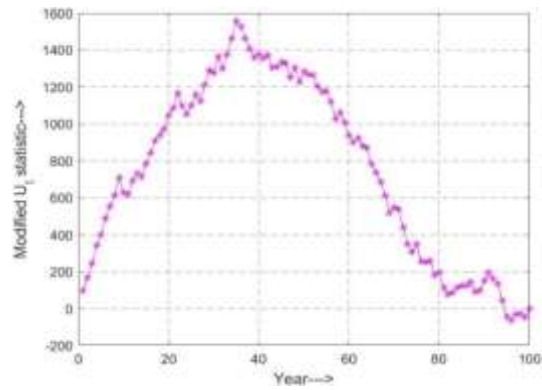
(a)



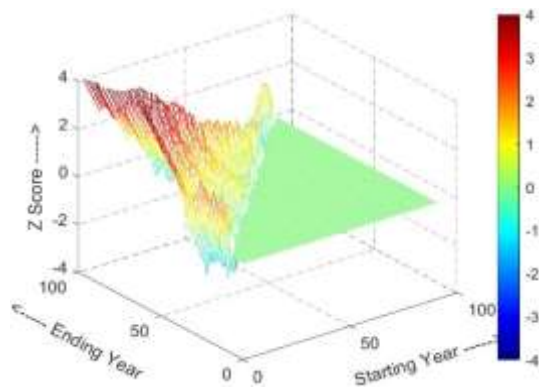
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(c)

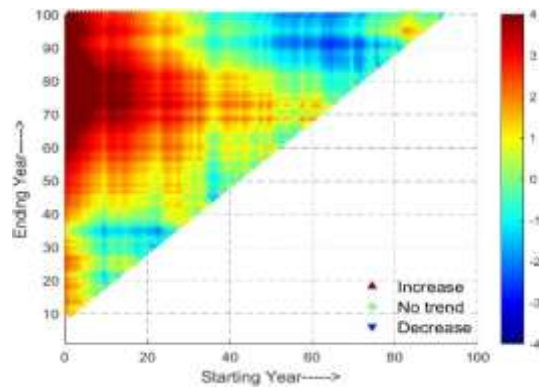
Figure 6.93 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the DTR trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the DTR trend in Durgapur was at level of 0.05.



(a)



(b)



(c)

Figure 6.94 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the PRCPTOT trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Durgapur was at level of 0.05.

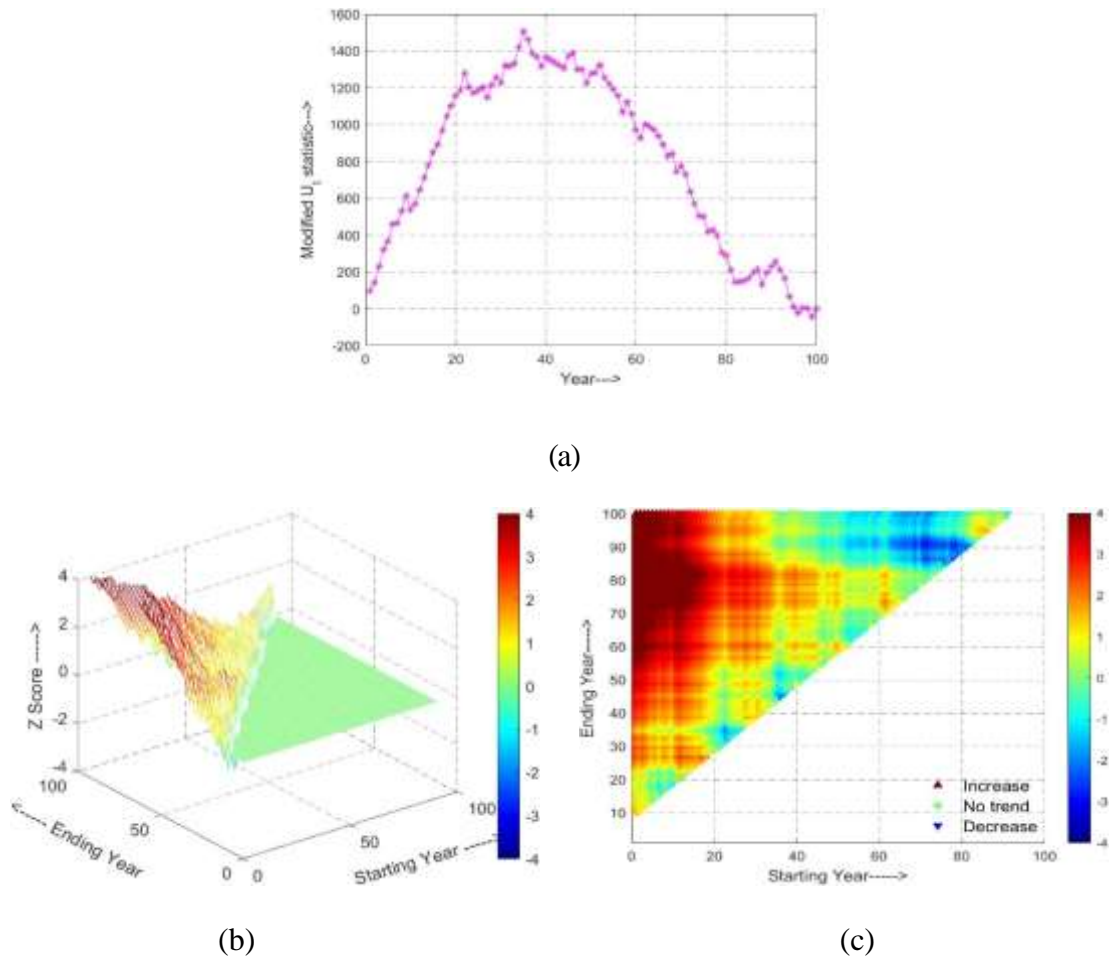
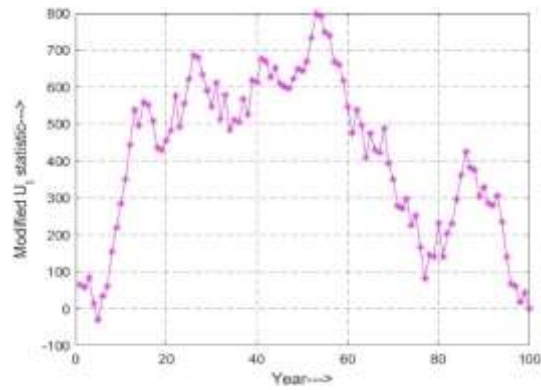
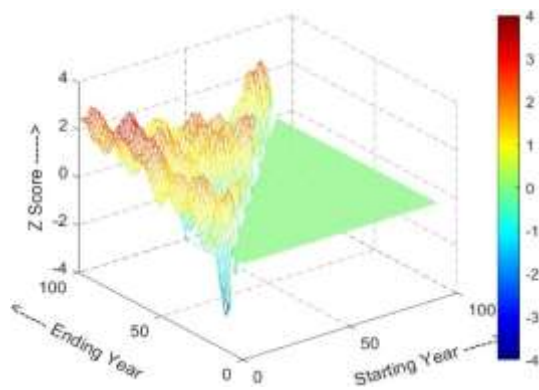


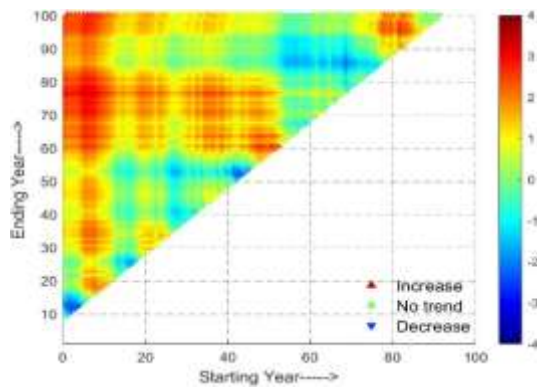
Figure 6.95 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the R10mm trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Durgapur was at level of 0.05.



(a)

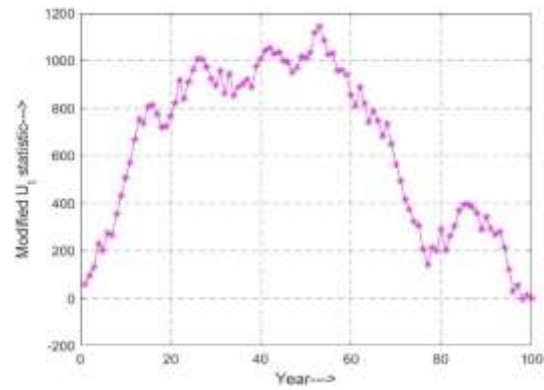


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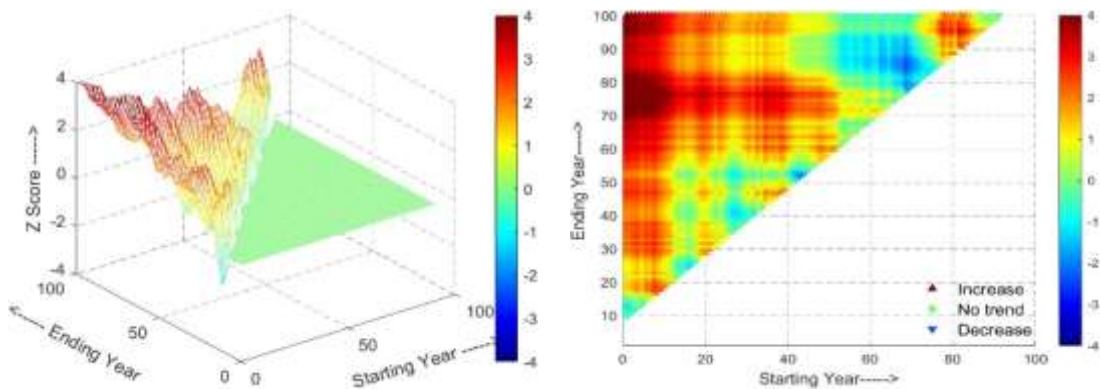


(c)

Figure 6.96 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the R20mm trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Durgapur was at level of 0.05.



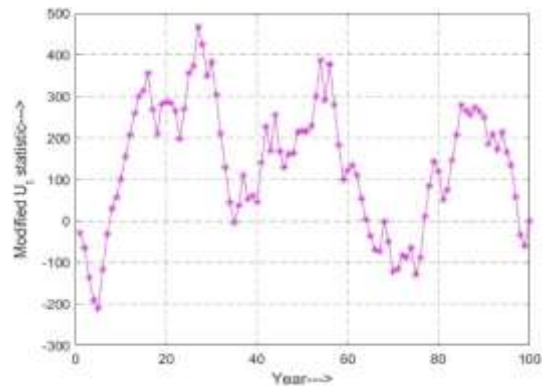
(a)



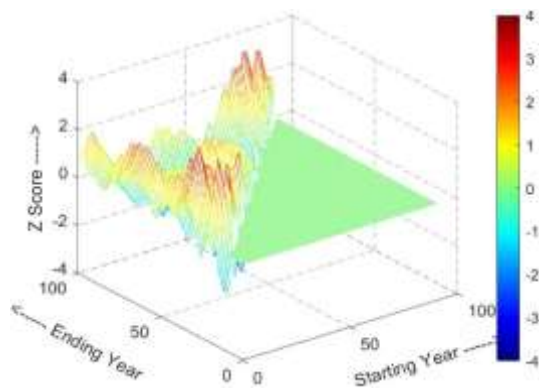
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(c)

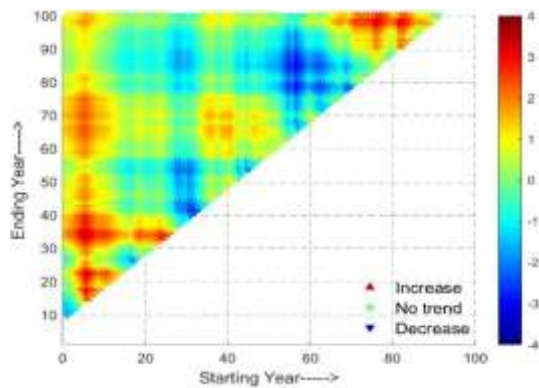
Figure 6.97 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the R95p trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the R95p trend in Durgapur was at level of 0.05.



(a)



(b)



(c)

Figure 6.98 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the R_{99p} trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Durgapur was at level of 0.05.

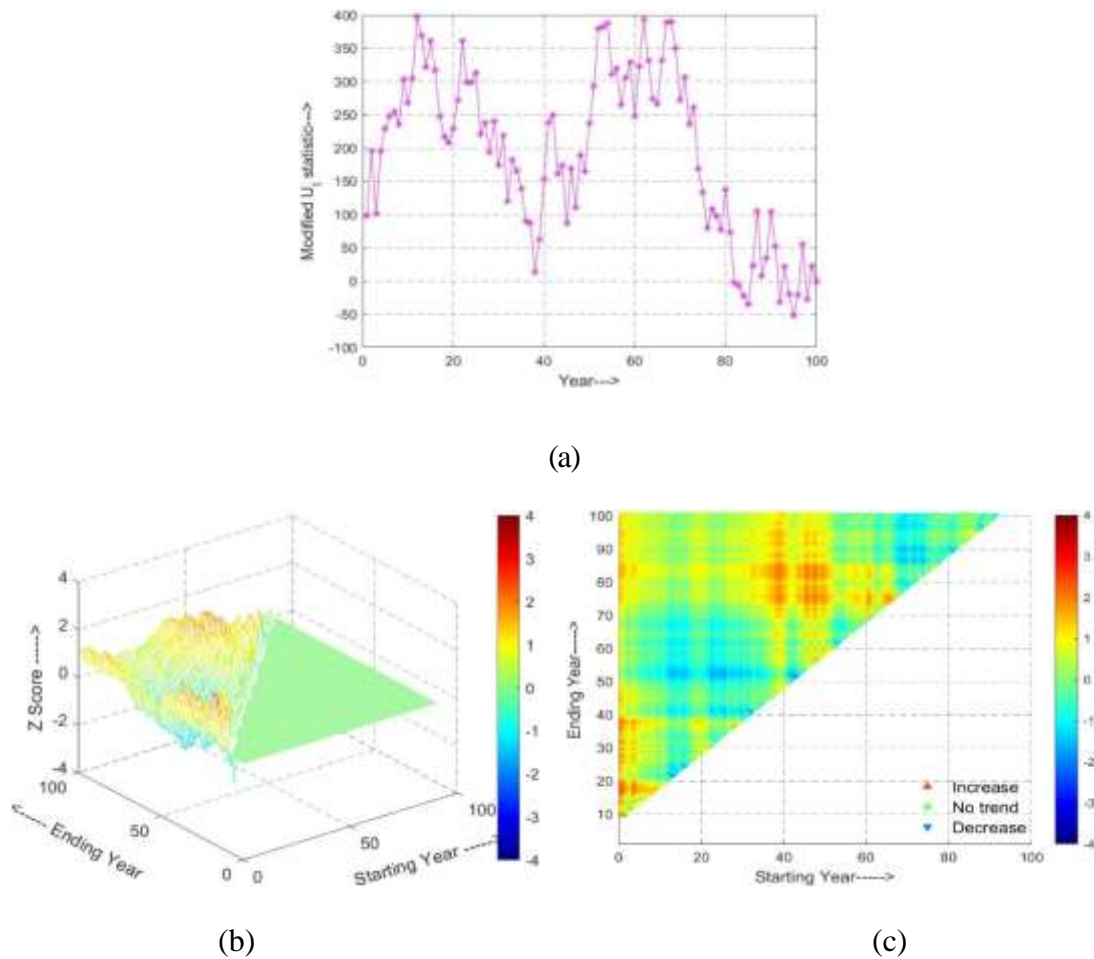
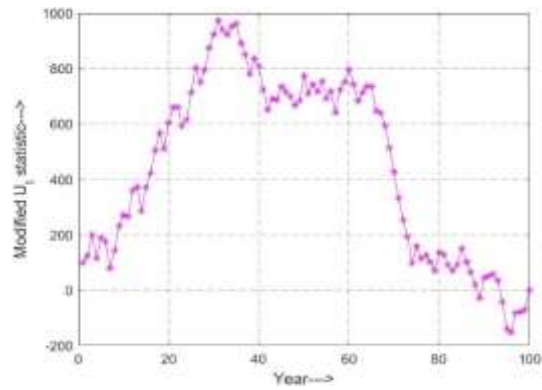
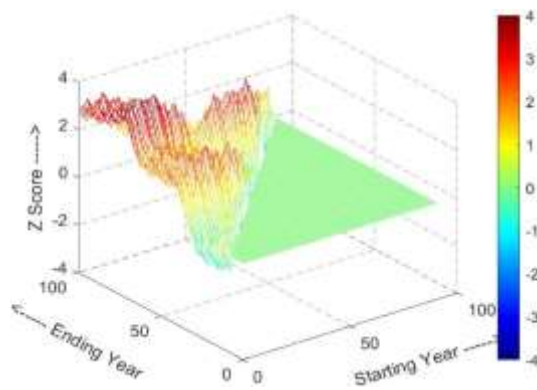


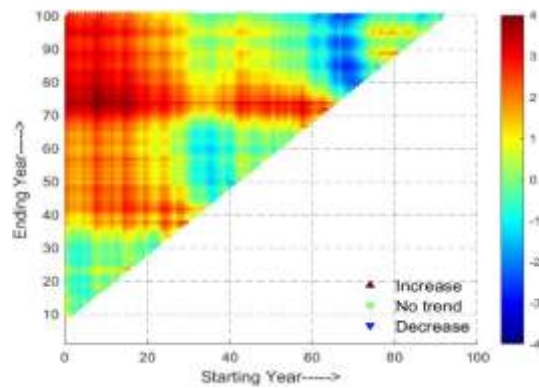
Figure 6.99 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the RX1day trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Durgapur was at level of 0.05.



(a)



(b)



(c)

Figure 6.100 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the RX5day trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Durgapur was at level of 0.05.

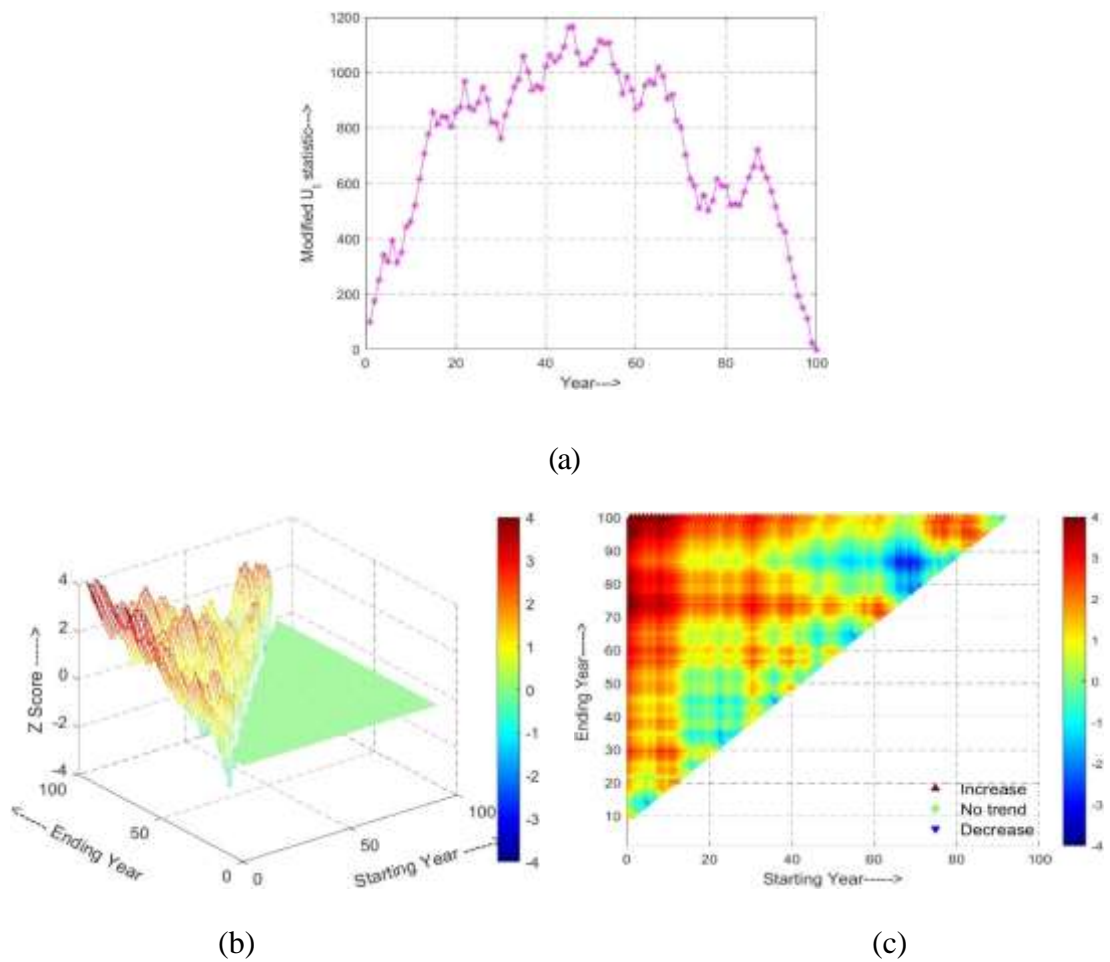
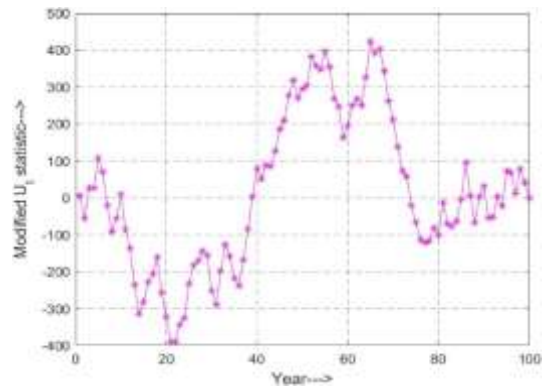
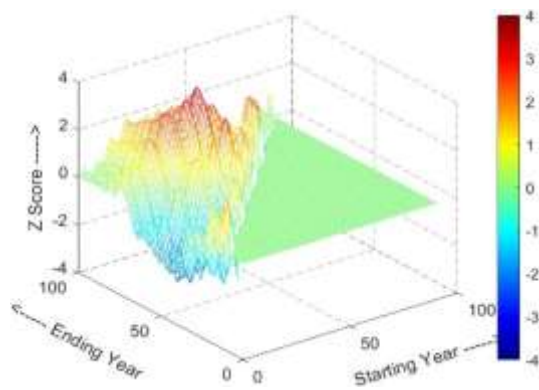


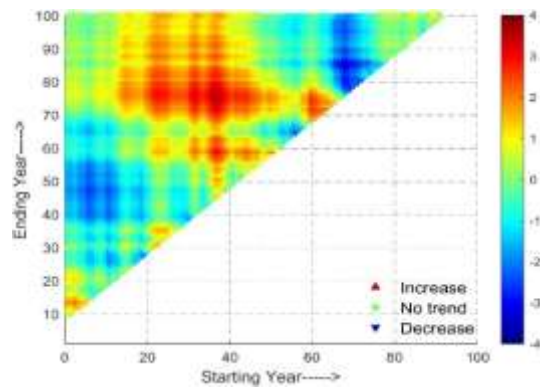
Figure 6.101 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the SDII trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the SDII trend in Durgapur was at level of 0.05.



(a)



(b)



(c)

Figure 6.102 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the TNn trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the TNn trend in Durgapur was at level of 0.05.

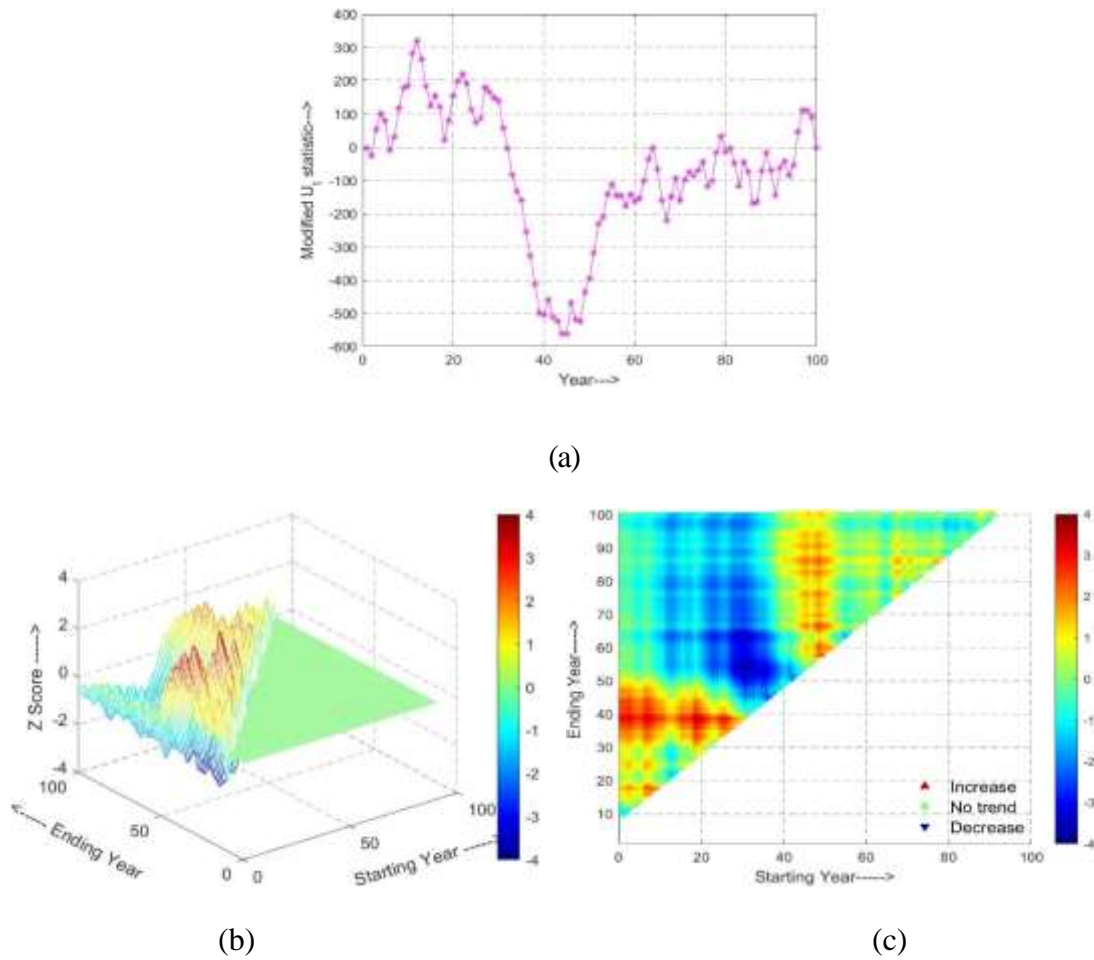
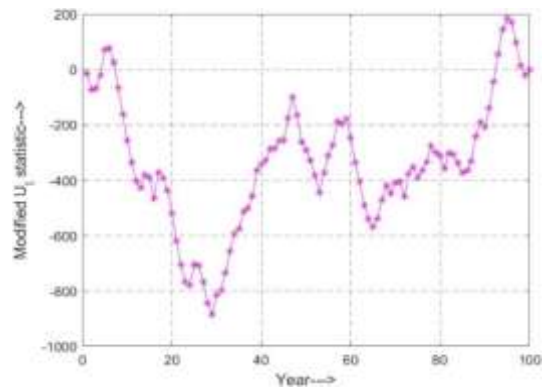
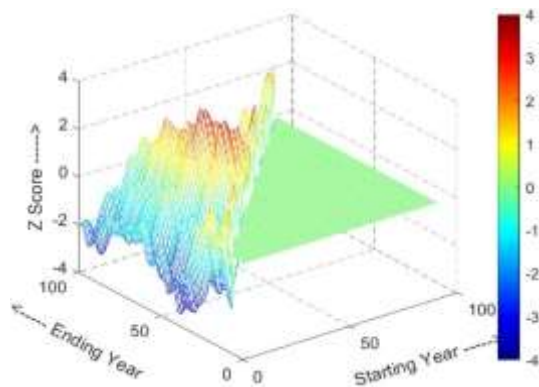


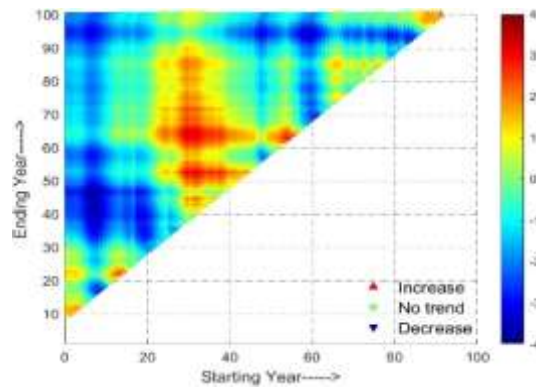
Figure 6.103 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the TNx trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the TNx trend in Durgapur was at level of 0.05.



(a)

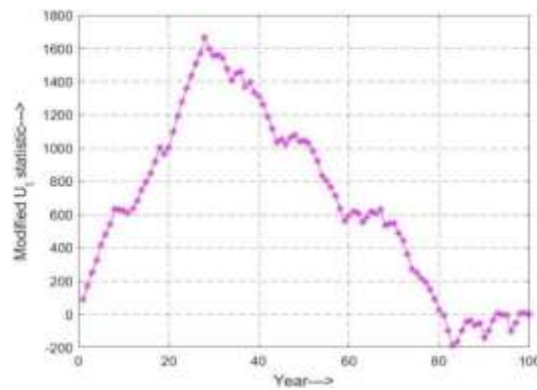


(b)

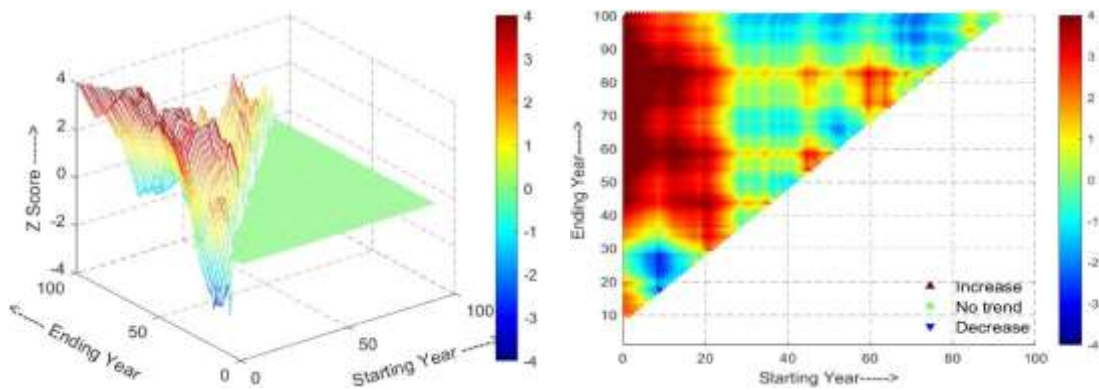


(c)

Figure 6.104 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the TX_n trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the TX_n trend in Durgapur was at level of 0.05.



(a)



(b)

(c)

Figure 6.105 (a) Variation of modified U_t over the years to identify change points in Durgapur. (b) The three-dimensional pattern of the TX_x trend in Durgapur is at level of 0.05. (c) The 2-D pattern of the TX_x trend in Durgapur was at level of 0.05.

6.2.8 Characteristics of Multiple Climatic Indices in East-Medinipur

East Medinipur station, located within the West Bengal region of the Damodar River Basin (DRB), has been a central focus of research examining long-term trends in extreme climate indices. This station was chosen for an in-depth analysis covering the period from 1923 to 2022. Figures 6.106(b-c) to 6.120(b-c) offer both two-dimensional and three-dimensional visual representations of the extreme climate variables recorded in East Medinipur. The early sections of these figures display patterns of peaks and troughs, where the peaks indicate the strength and direction of climate trends, and the troughs represent fluctuations over time. These visualizations highlight significant changes in extreme climate indices over the analyzed period. The figures, with their

Chapter 6

distinct shading, show troughs in the lower sections and crests in the upper parts of the triangular shapes, illustrating the evolving nature of the trends. The accompanying color bar in Figures 6.106(c) to 6.120(c) helps to visualize rainfall patterns, where red signifies an increasing trend, blue indicates a decreasing trend, and green shows periods of no significant change.

Between 1923 and 1950, East Medinipur experienced a declining trend in rainfall, as depicted by the blue shading in the figures. From 1950 to 1990, however, the station saw an increasing trend, represented by red hues, while green areas indicate periods of trend stability. By clustering the trends, researchers could identify key moments when significant shifts occurred in the climate patterns. The statistical data in Figures 6.106(c) through 6.120(c) support the accuracy of the visualized trends, reinforcing the reliability of the analysis.

This study extends those findings by illustrating both the increasing and decreasing trends in annual rainfall from 1923 to 2022, using advanced 2D and 3D models to better capture the evolving patterns. Additionally, the study introduced a modified version of the PMW test to identify multiple change points in the trends, providing more detailed insights compared to earlier research that focused mainly on overall trend detection.

These findings are particularly valuable for planners and policymakers in East Medinipur, as understanding shifts in rainfall patterns is critical for managing agriculture and water resources. Since a significant portion of the local population relies on agriculture, knowledge of changing rainfall trends is essential for sustainable agricultural and water management practices. By employing three-dimensional visualizations and detecting key change points, this research offers deeper insights into climate variability in East Medinipur and its potential effects on the region's agricultural and resource planning strategies.

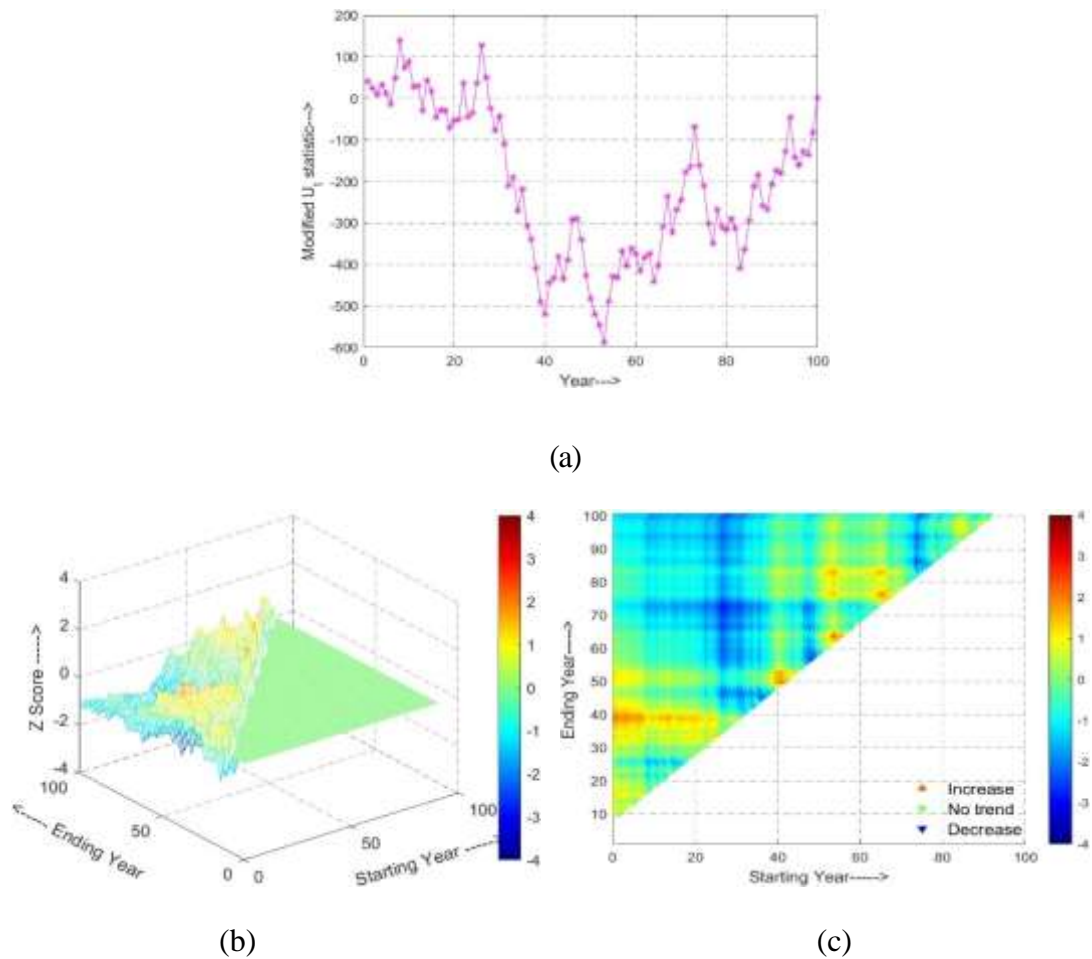
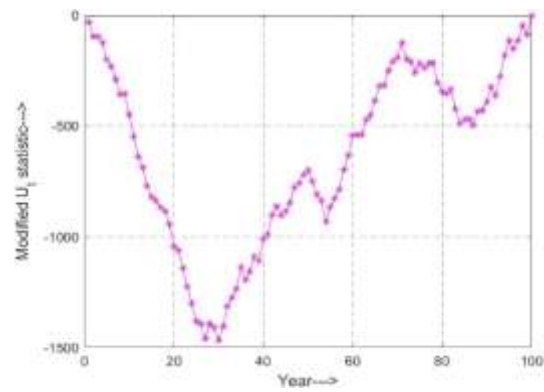
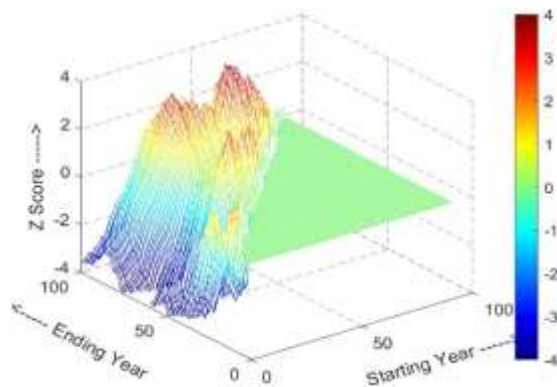


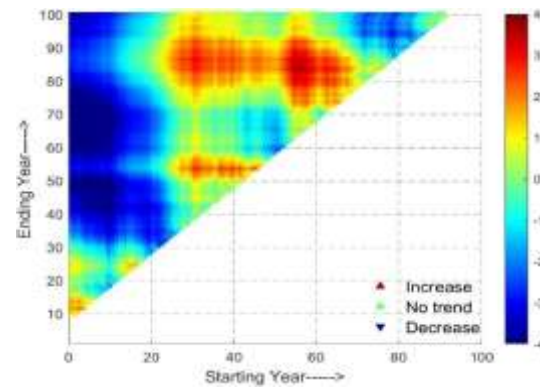
Figure 6.106 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the CDD trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the CDD trend in East-Medinipur was at level of 0.05



(a)

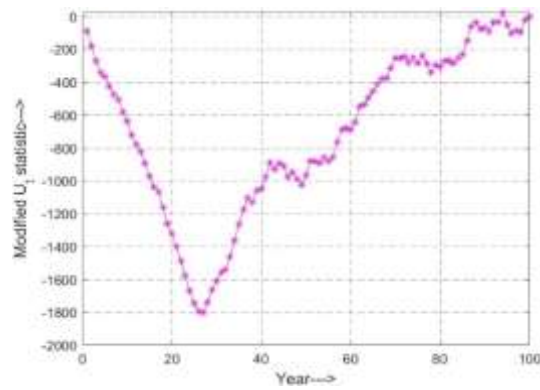


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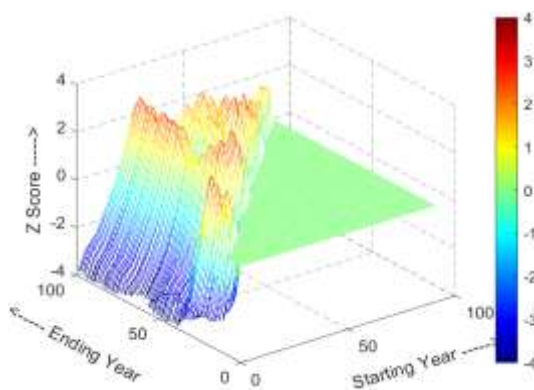


(c)

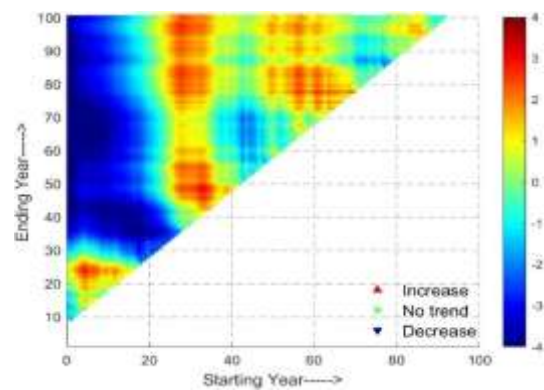
Figure 6.107 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the CWD trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the CWD trend in East-Medinipur was at level of 0.05



(a)

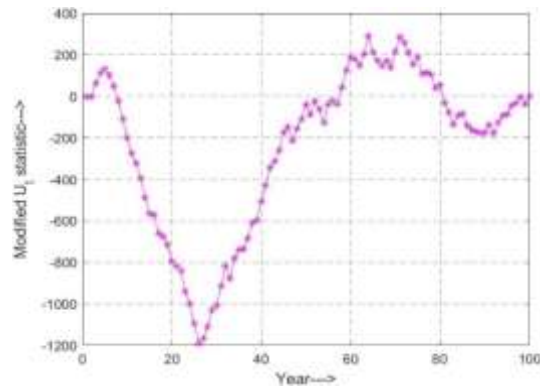


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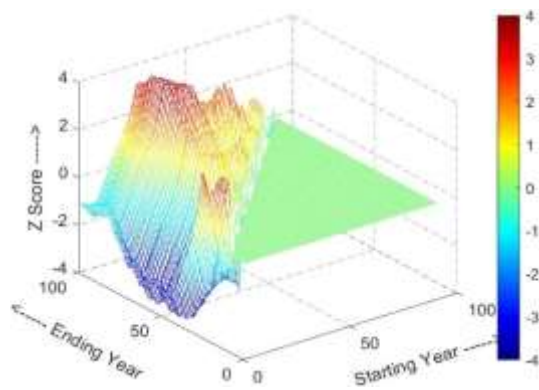


(c)

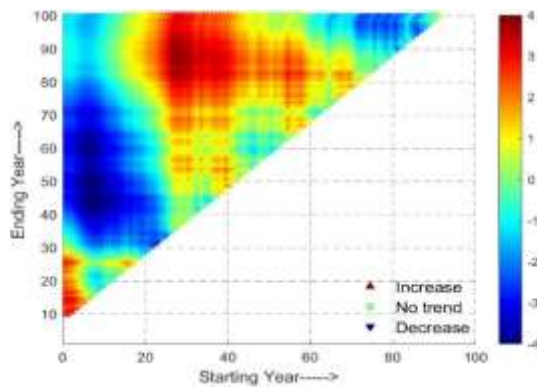
Figure 6.108 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the DTR trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the DTR trend in East-Medinipur was at level of 0.05



(a)

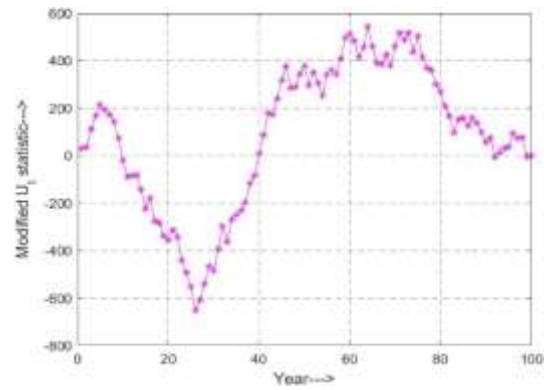


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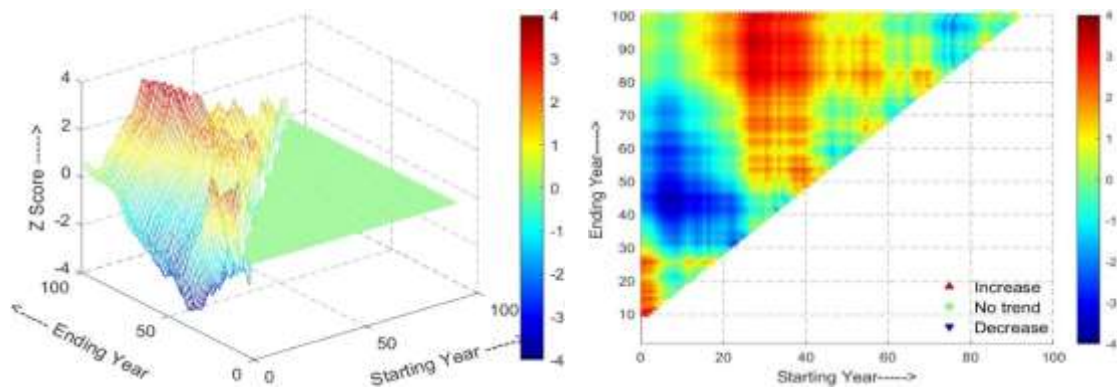


(c)

Figure 6.109 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the PRCPTOT trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in East-Medinipur was at level 0.05



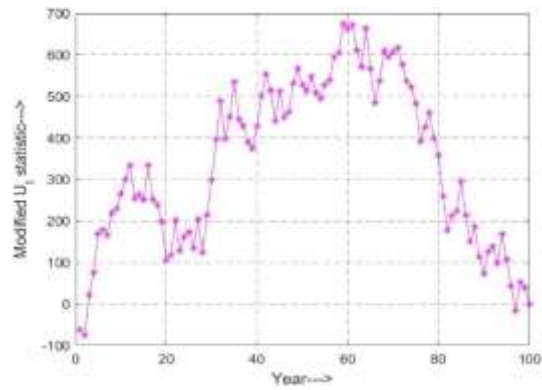
(a)



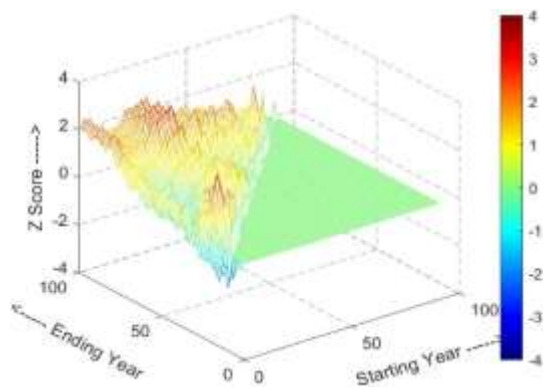
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(c)

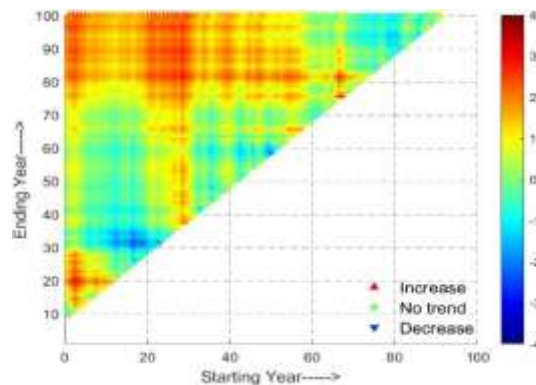
Figure 6.110 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the R10mm trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the R10mm trend in East-Medinipur was at level 0.05



(a)



(b)



(c)

Figure 6.111(a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the R20mm trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the R20mm trend in East-Medinipur was at level of 0.05

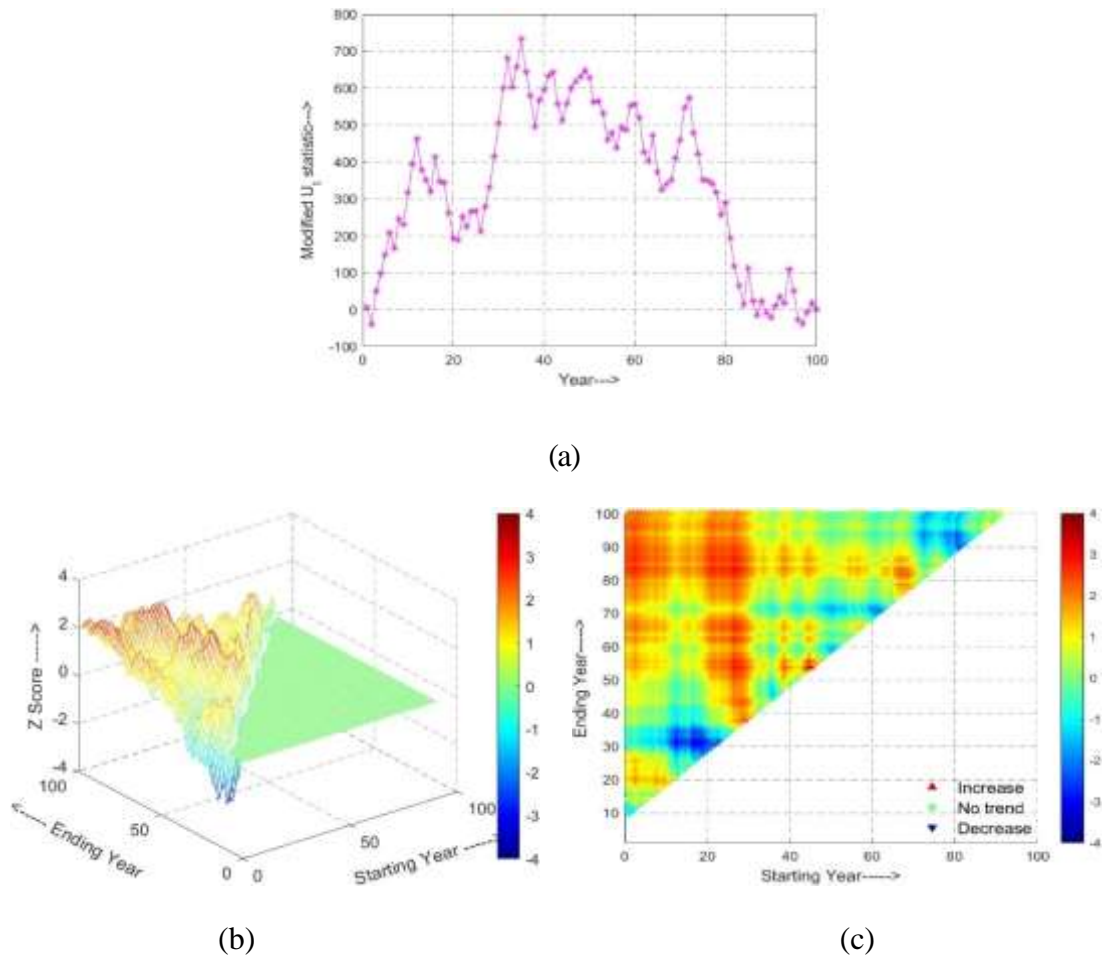
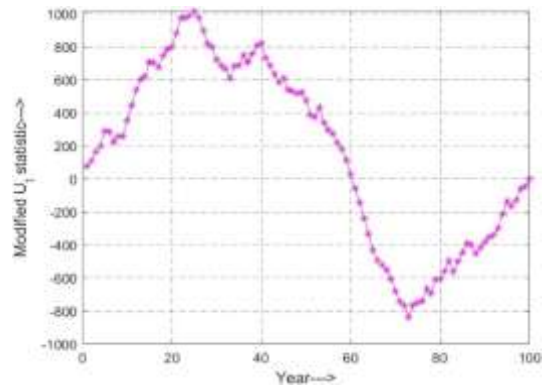
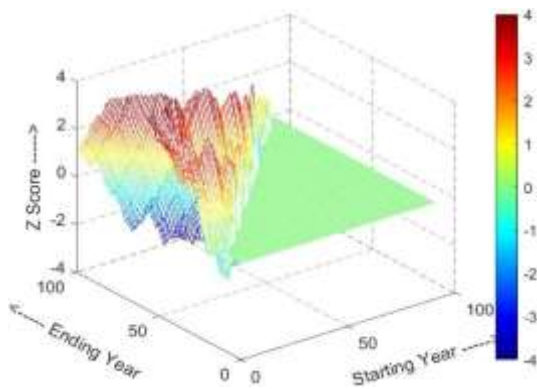


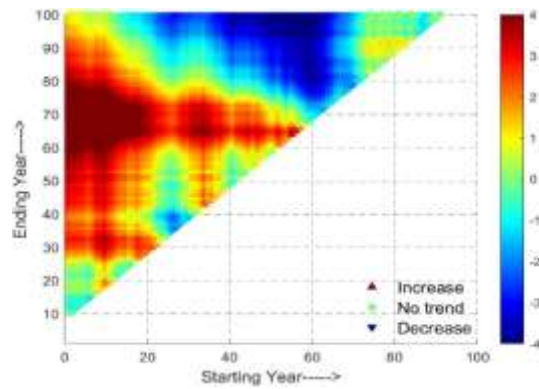
Figure 6.112 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the R_{95p} trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in East-Medinipur was at level of 0.05



(a)

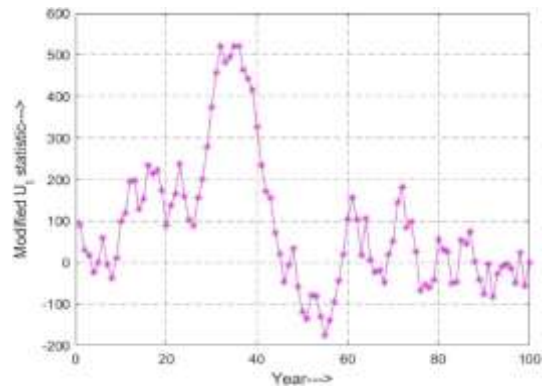


(b)

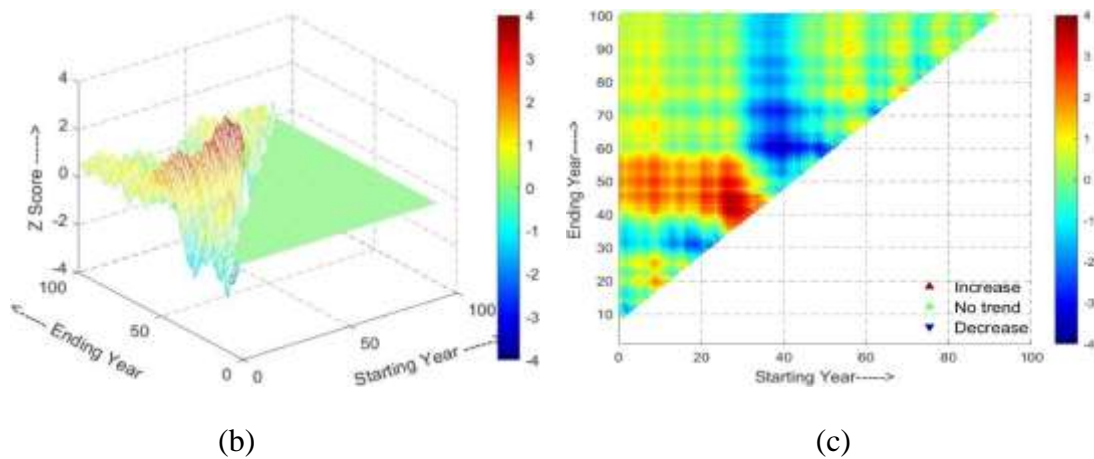


(c)

Figure 6.113 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the R_{99p} trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in East-Medinipur was at level of 0.05



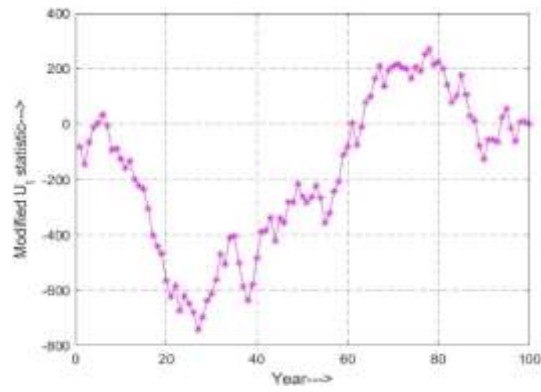
(a)



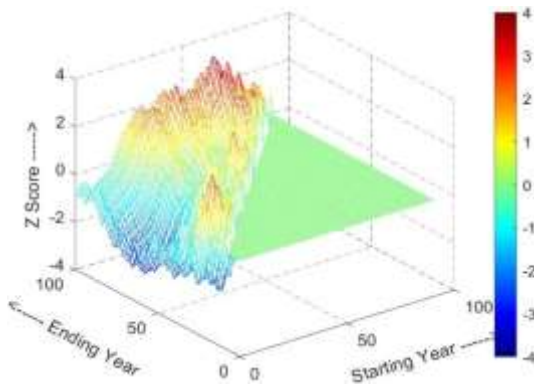
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(c)

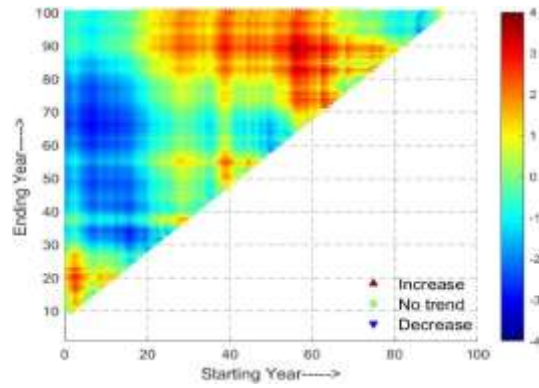
Figure 6.114 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the RX1day trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the RX1day trend in East-Medinipur was at level of 0.05



(a)



(b)



(c)

Figure 6.115 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the RX5day trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the RX5day trend in East-Medinipur was at level of 0.05

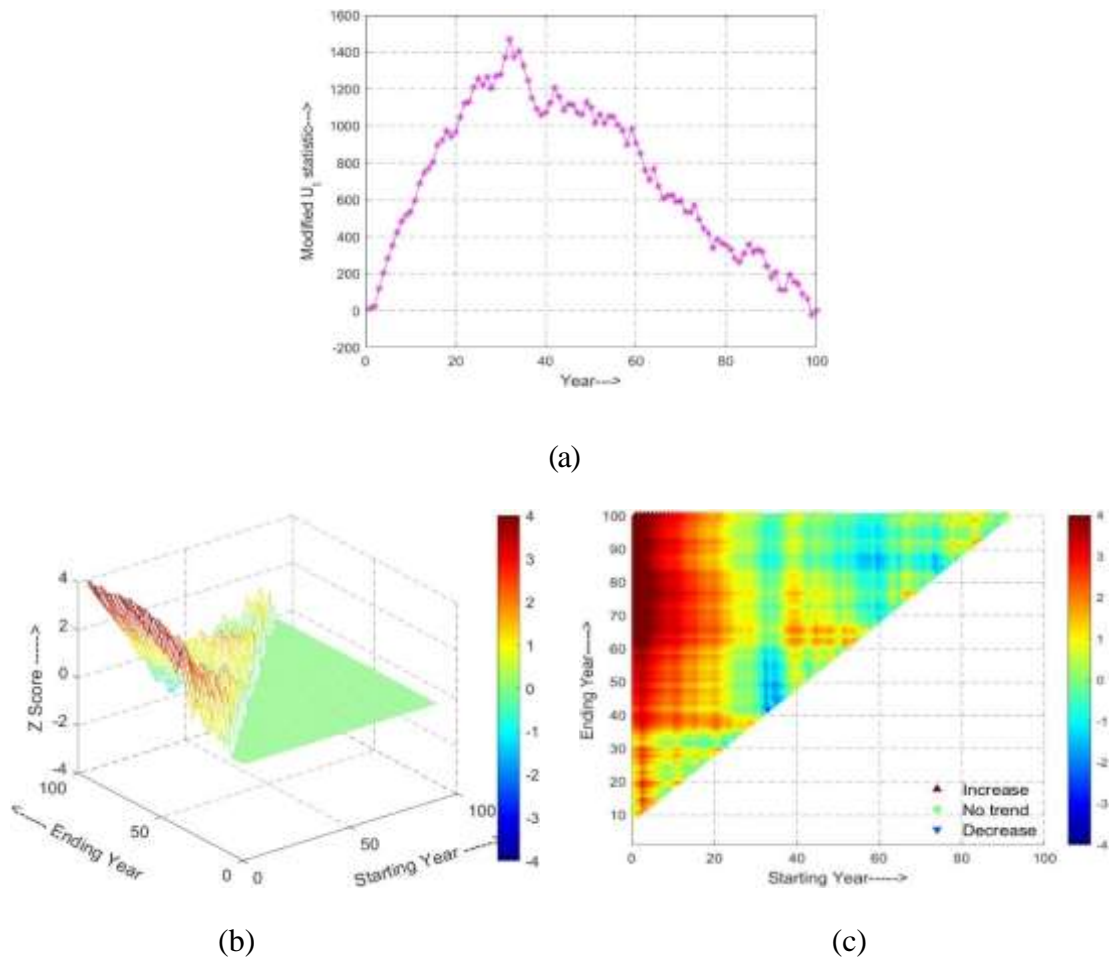
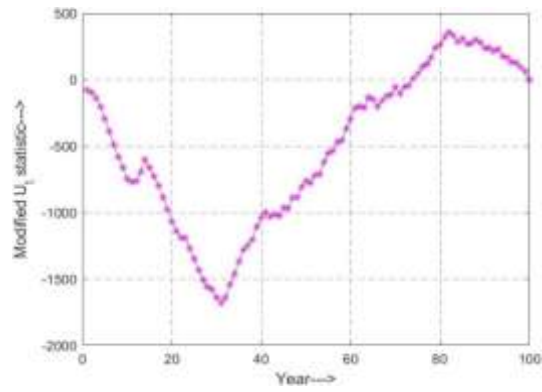
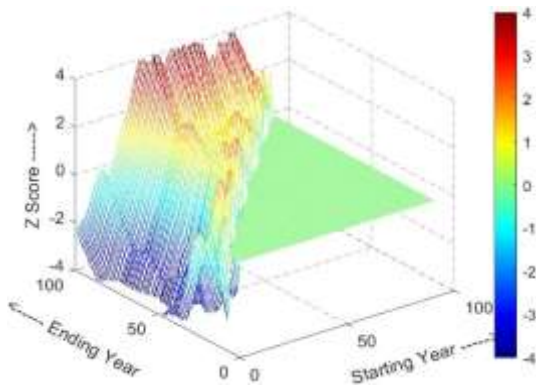


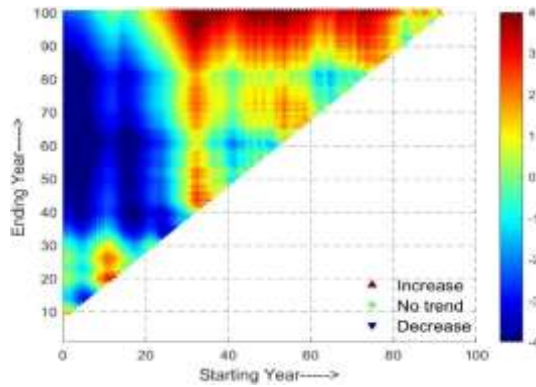
Figure 6.116 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the SDII trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the SDII trend in East-Medinipur was at level of 0.05



(a)

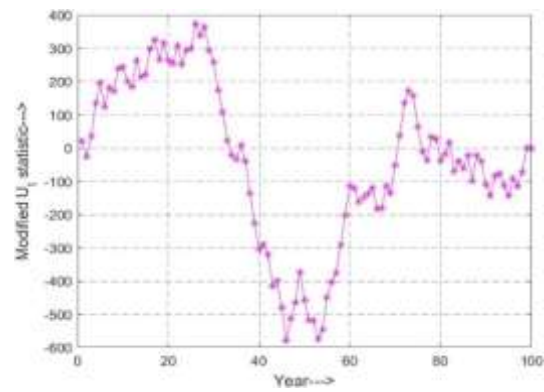


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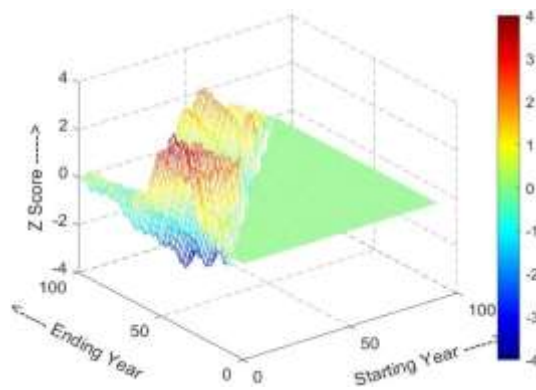


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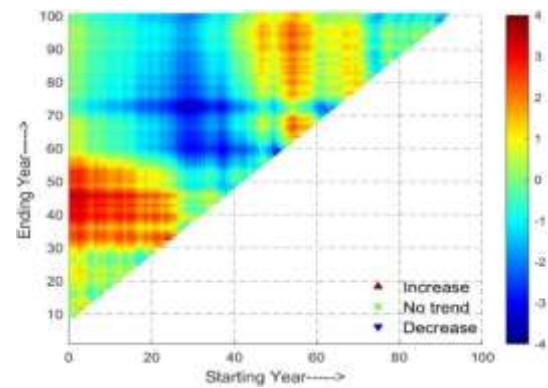
Figure 6.117 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the TNN trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the TNN trend in East-Medinipur was at level of 0.05



(a)

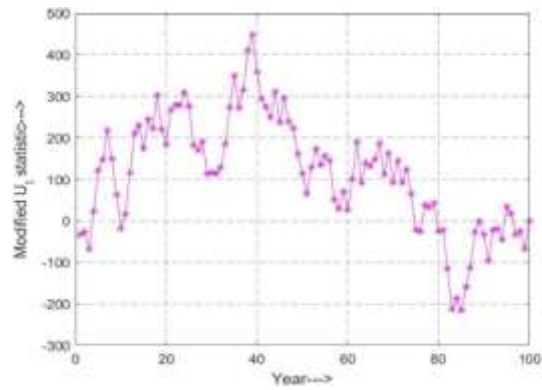


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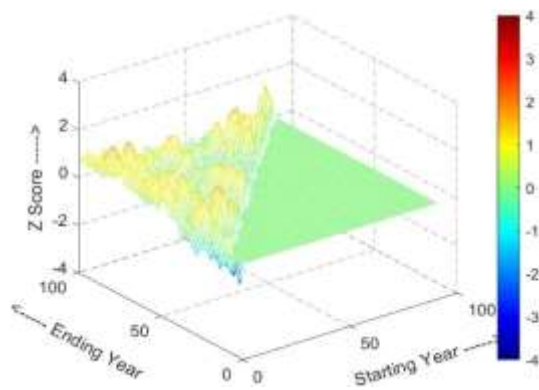


(c)

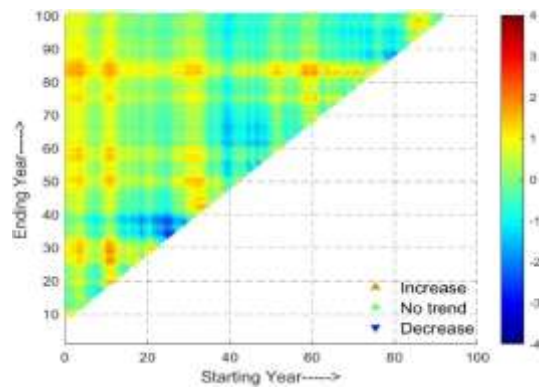
Figure 6.118 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the TN_x trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the TN_x trend in East-Medinipur was at level of 0.05



(a)



(b)



(c)

Figure 6.119 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the TX_n trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the TX_n trend in East-Medinipur was at level of 0.05

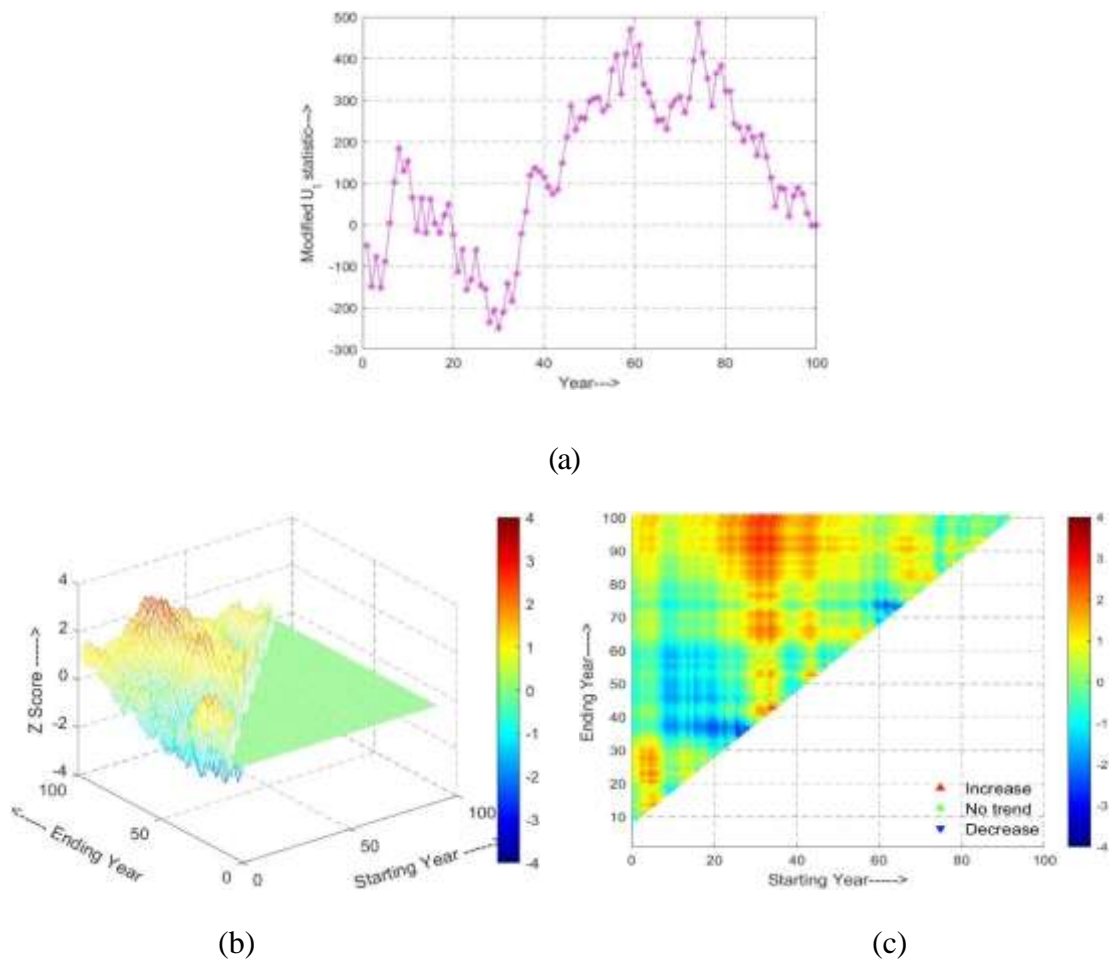


Figure 6.120 (a) Variation of modified U_t over the years to identify change points in East-Medinipur. (b) The three-dimensional pattern of the TXx trend in East-Medinipur is at level of 0.05. (c) The 2-D pattern of the TXx trend in East-Medinipur was at level of 0.05

6.2.9 Characteristics of Multiple Climatic Indices in Giridih

Giridih station, located in the Jharkhand region of the Damodar River Basin (DRB), has been a primary focus of research analyzing long-term trends in extreme climate indices. This station was chosen for a comprehensive analysis covering the period from 1923 to 2022. Figures 6.121(b-c) to 6.135(b-c) present both two-dimensional and three-dimensional visual representations of the extreme climate variables observed at Giridih. The early sections of these figures depict patterns of peaks and troughs, with peaks indicating the intensity and direction of climate trends, while the troughs highlight fluctuations over time. These visualizations illustrate significant changes in extreme climate indices throughout the analyzed period. The figures utilize different shaded

zones to represent these variations, where troughs appear in the lower sections and crests in the upper sections of the triangular shapes, reflecting the dynamic shifts in climate trends. The accompanying color bar in Figures 6.121(c) to 6.135(c) shows that red represents an increasing rainfall trend, blue indicates a decreasing trend, and green denotes periods with no significant changes.

From 1923 to 1950, Giridih experienced a decreasing trend in rainfall, as depicted by the blue shades in the figures. However, from 1950 to 1990, an increasing trend emerged, marked by red shading, while the green zones reflect periods of stability in the trends. By analyzing the clustering of these trends, researchers were able to identify key moments when significant shifts in climate patterns occurred. The statistical data displayed in Figures 6.121(c) to 6.135(c) confirm the accuracy and reliability of the visualized trends, adding credibility to the findings.

This study builds on those findings, illustrating both increasing and decreasing rainfall trends from 1923 to 2022, using advanced 2D and 3D models to better visualize the changes. Additionally, the study introduced a modified version of the PMW test to detect multiple change points in the trends, providing a more detailed analysis compared to previous studies that focused mainly on overall trends.

The findings from this research are crucial for planners and policymakers in the Giridih region. Understanding the evolving nature of rainfall patterns is vital for managing agricultural practices and water resources. Given that a significant portion of the population in Giridih depends on agriculture, recognizing these shifts in rainfall variability is essential for sustainable planning. By incorporating three-dimensional visualizations and identifying key change points in the trends, this study provides deeper insights into the region's climate dynamics and their potential impact on agricultural and water resource management in Giridih.

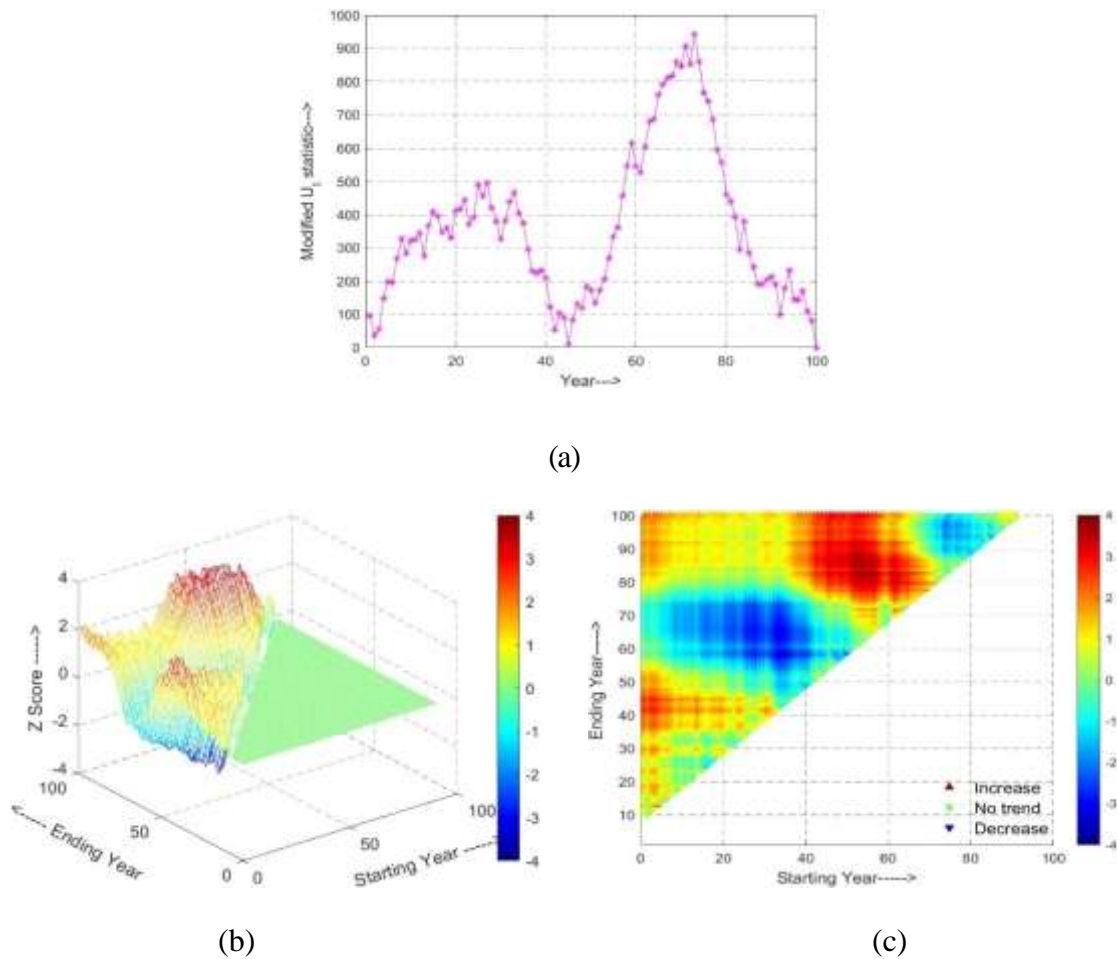
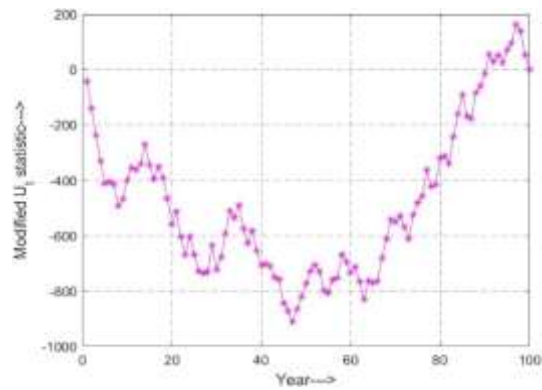
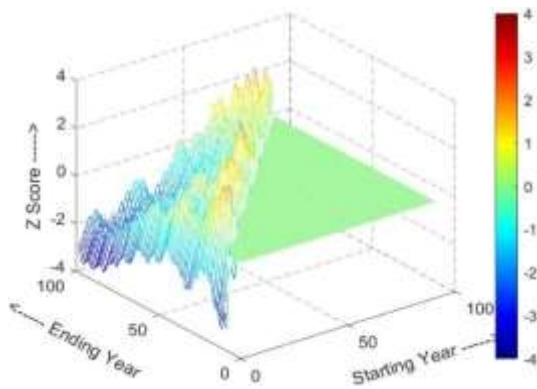


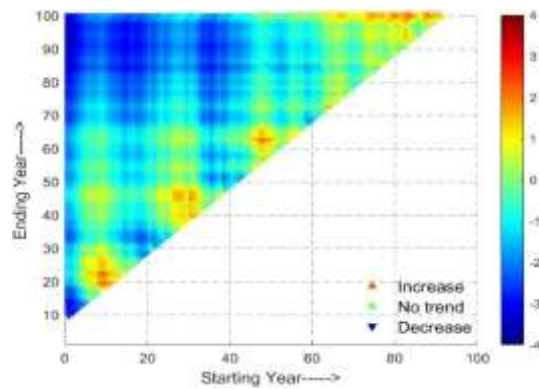
Figure 6.121 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the CDD trend in Giridih is at level of 0.05. (c) The 2-D pattern of the CDD trend in Giridih was at level of 0.05.



(a)

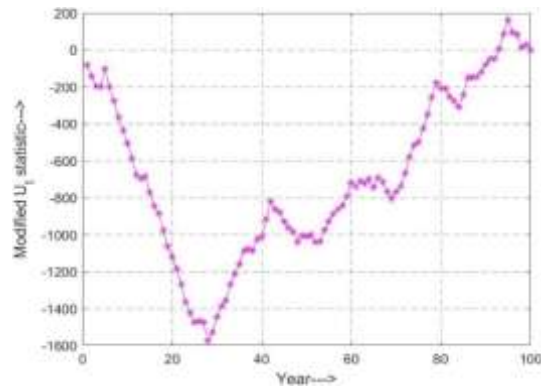


(b)

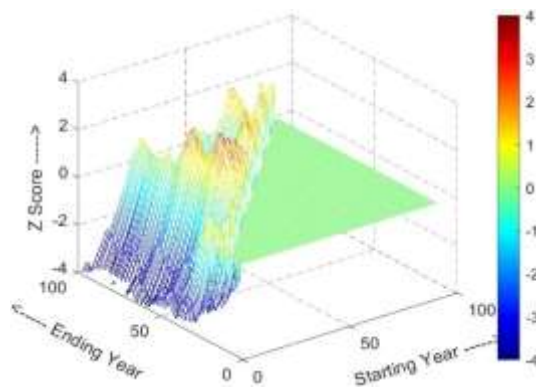


(c)

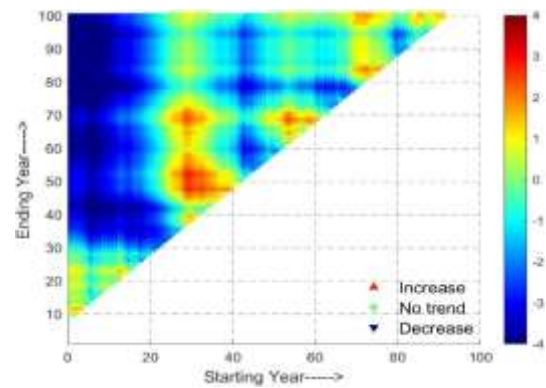
Figure 6.122 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the CWD trend in Giridih is at level of 0.05. (c) The 2-D pattern of the CWD trend in Giridih was at level of 0.05.



(a)

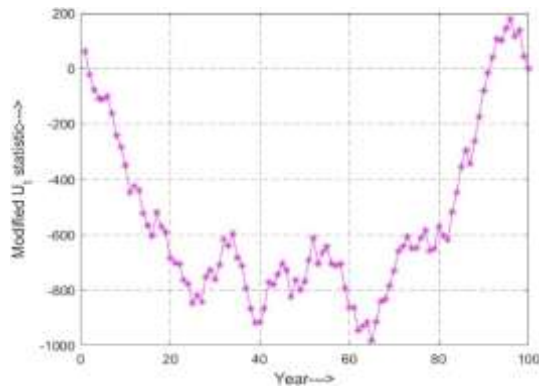


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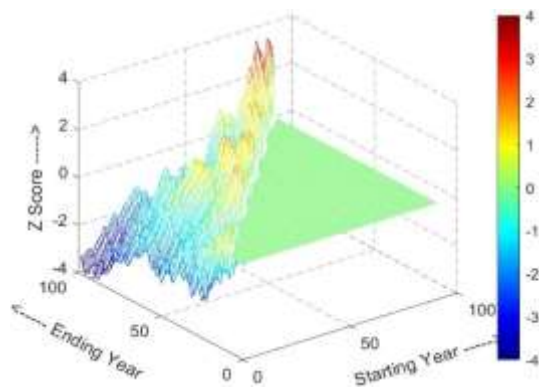


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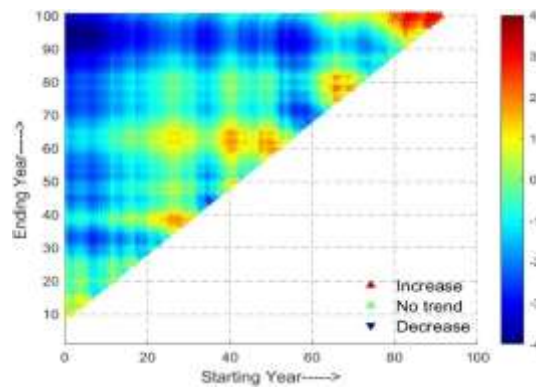
Figure 6.123 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the DTR trend in Giridih is at level of 0.05. (c) The 2-D pattern of the DTR trend in Giridih was at level of 0.05.



(a)



(b)



(c)

Figure 6.124 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the PRCPTOT trend in Giridih is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Giridih was at level of 0.05.

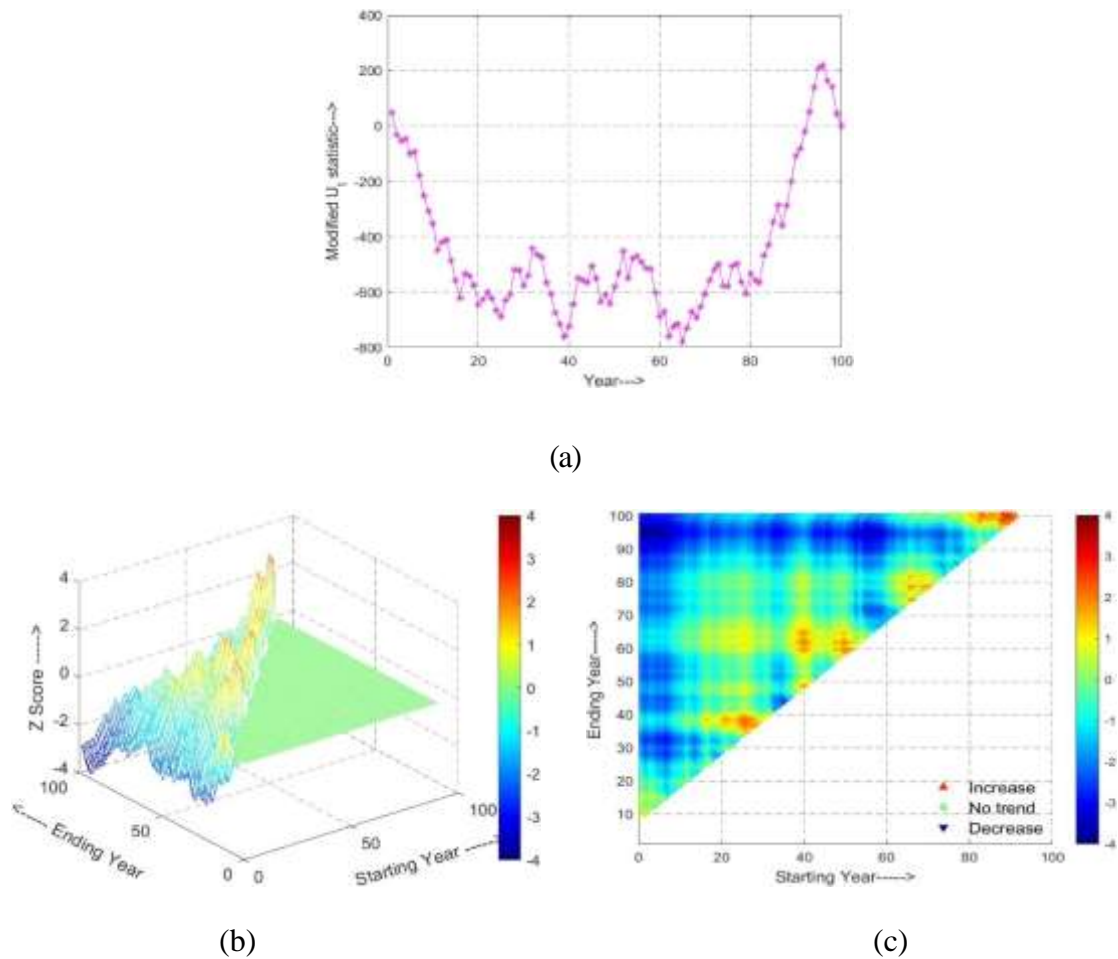
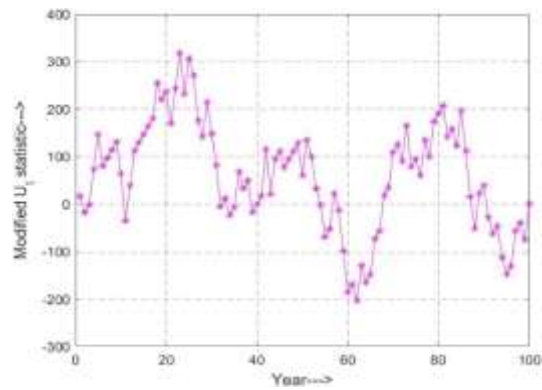
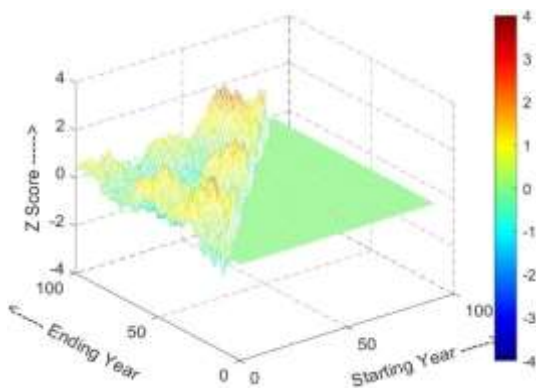


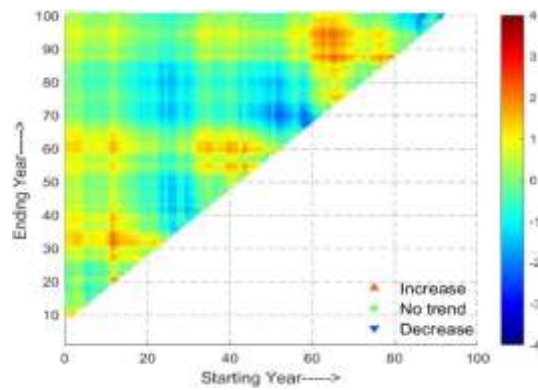
Figure 6.125 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the R10mm trend in Giridih is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Giridih was at level of 0.05.



(a)



(b)



(c)

Figure 6.126 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the R20mm trend in Giridih is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Giridih was at level of 0.05.

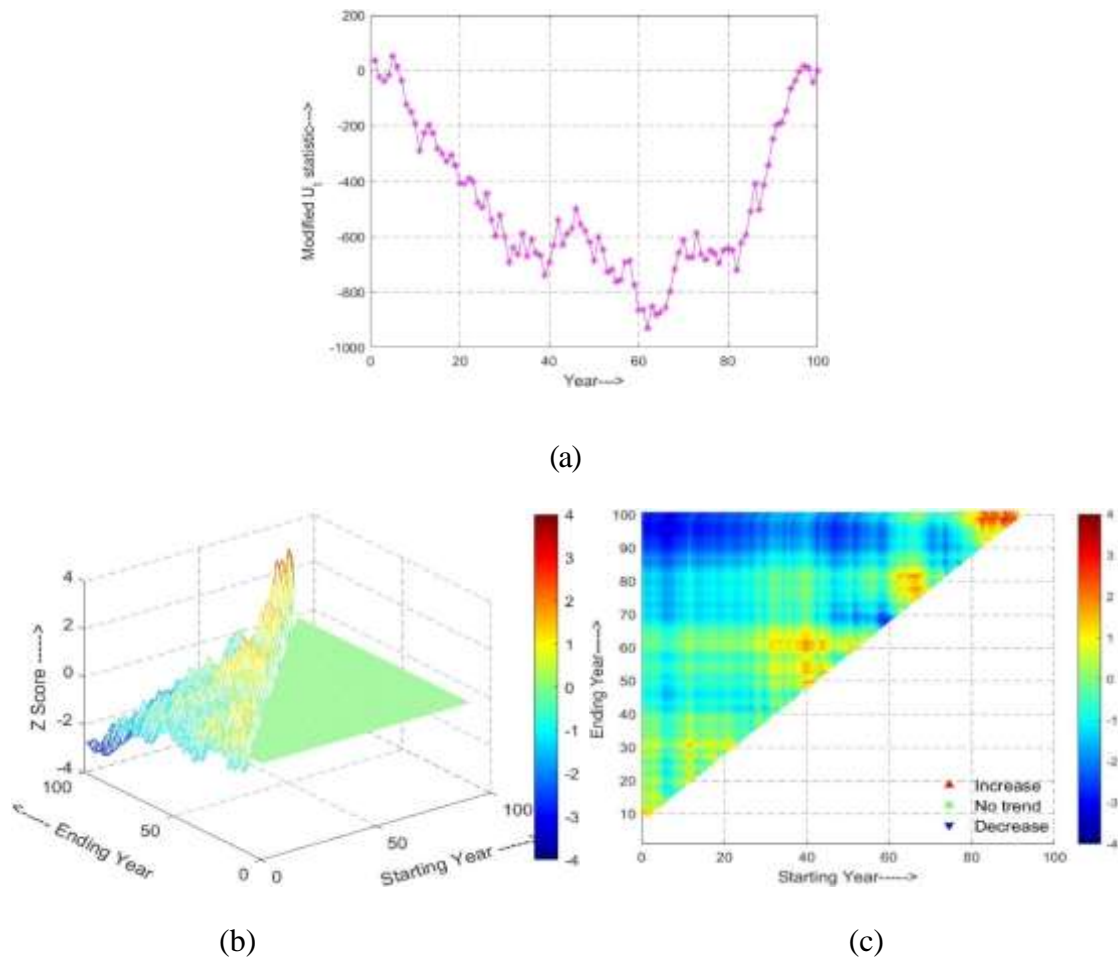


Figure 6.127 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the R_{95p} trend in Giridih is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in Giridih was at level of 0.05.

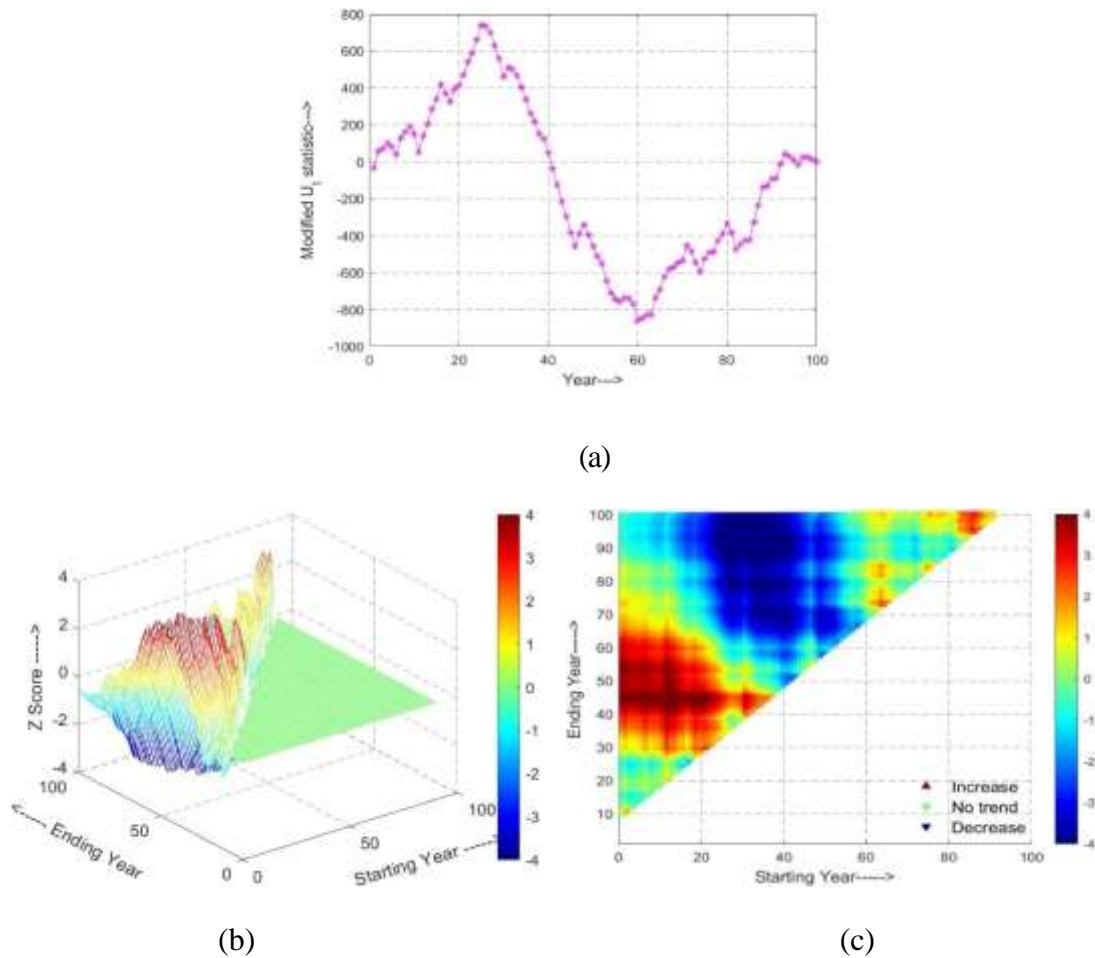


Figure 6.128 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the R_{99p} trend in Giridih is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Giridih was at level of 0.05.

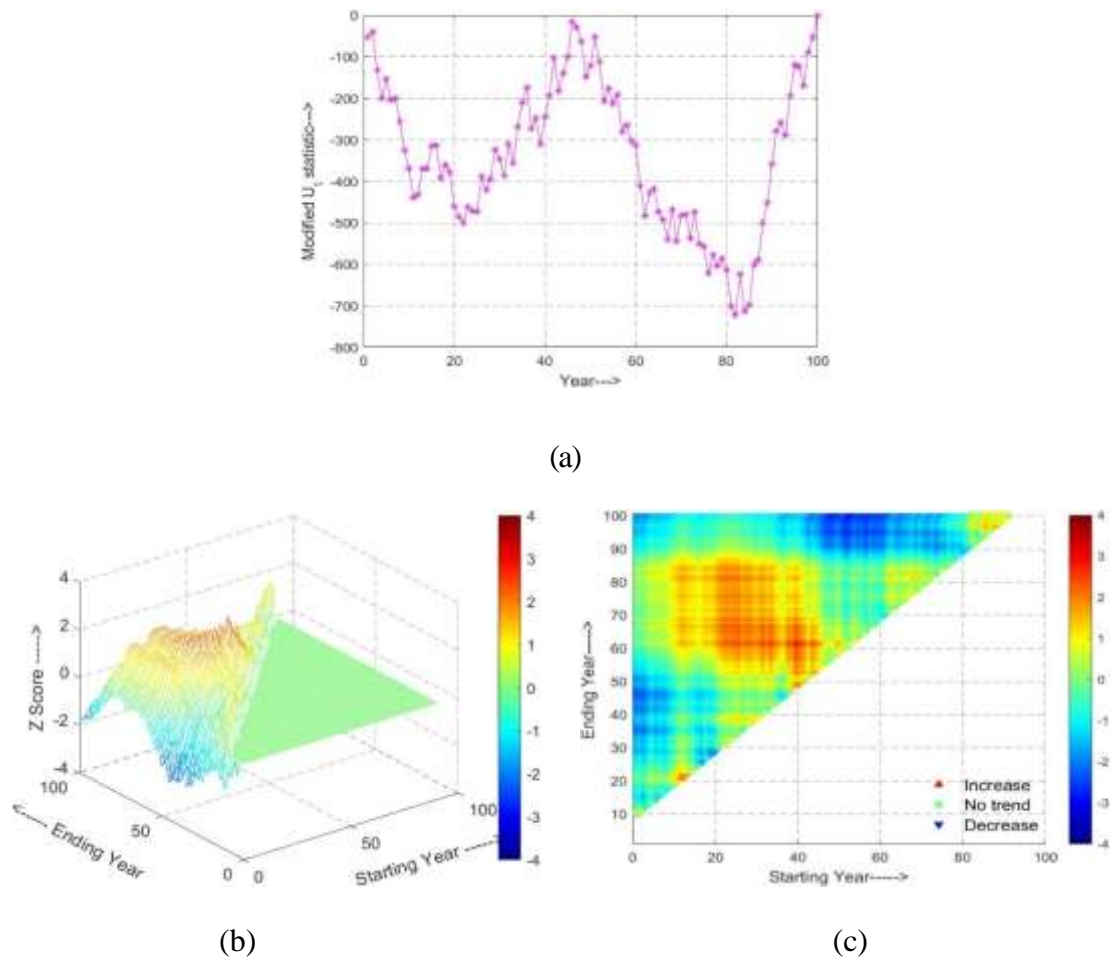
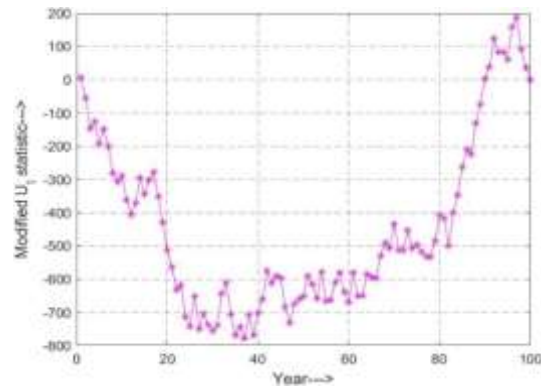
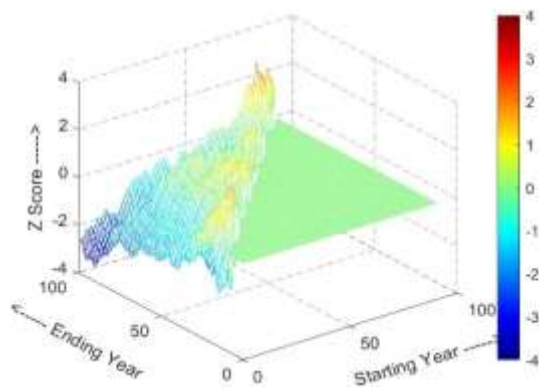


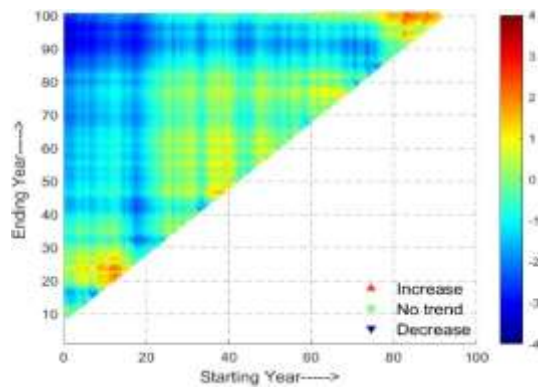
Figure 6.129 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the RX1day trend in Giridih is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Giridih was at level of 0.05.



(a)

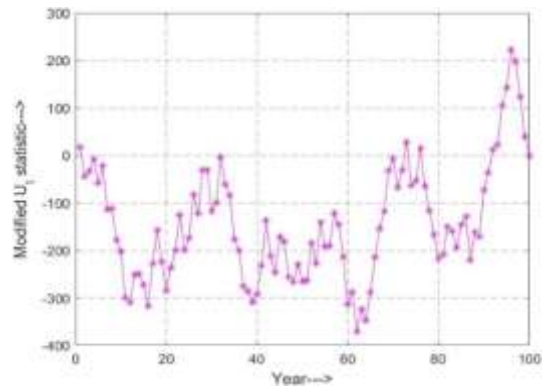


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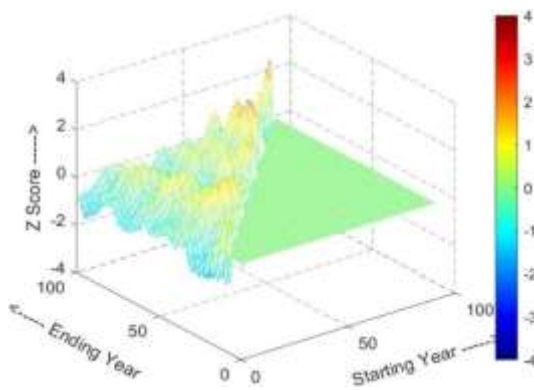


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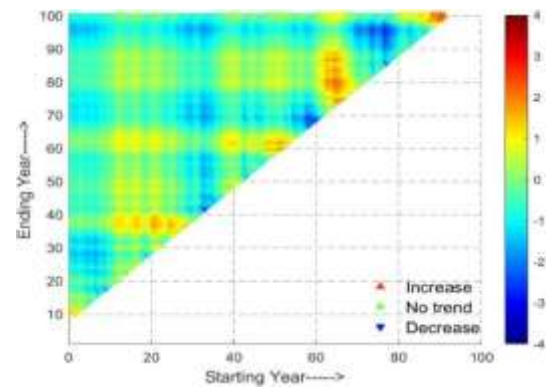
Figure 6.130 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the RX5day trend in Giridih is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Giridih was at level of 0.05.



(a)

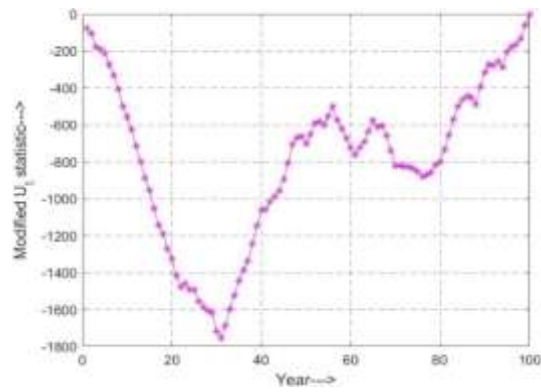


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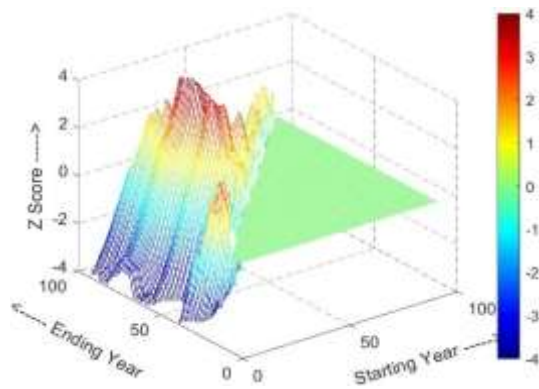


(c)

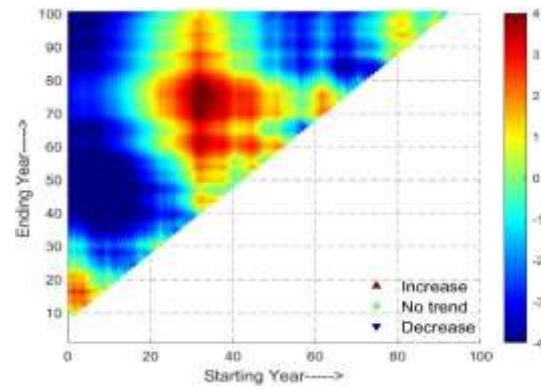
Figure 6.131 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the SDII trend in Giridih is at level of 0.05. (c) The 2-D pattern of the SDII trend in Giridih was at level of 0.05.



(a)



(b)



(c)

Figure 6.132 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the TNN trend in Giridih is at level of 0.05. (c) The 2-D pattern of the TNN trend in Giridih was at level of 0.05.

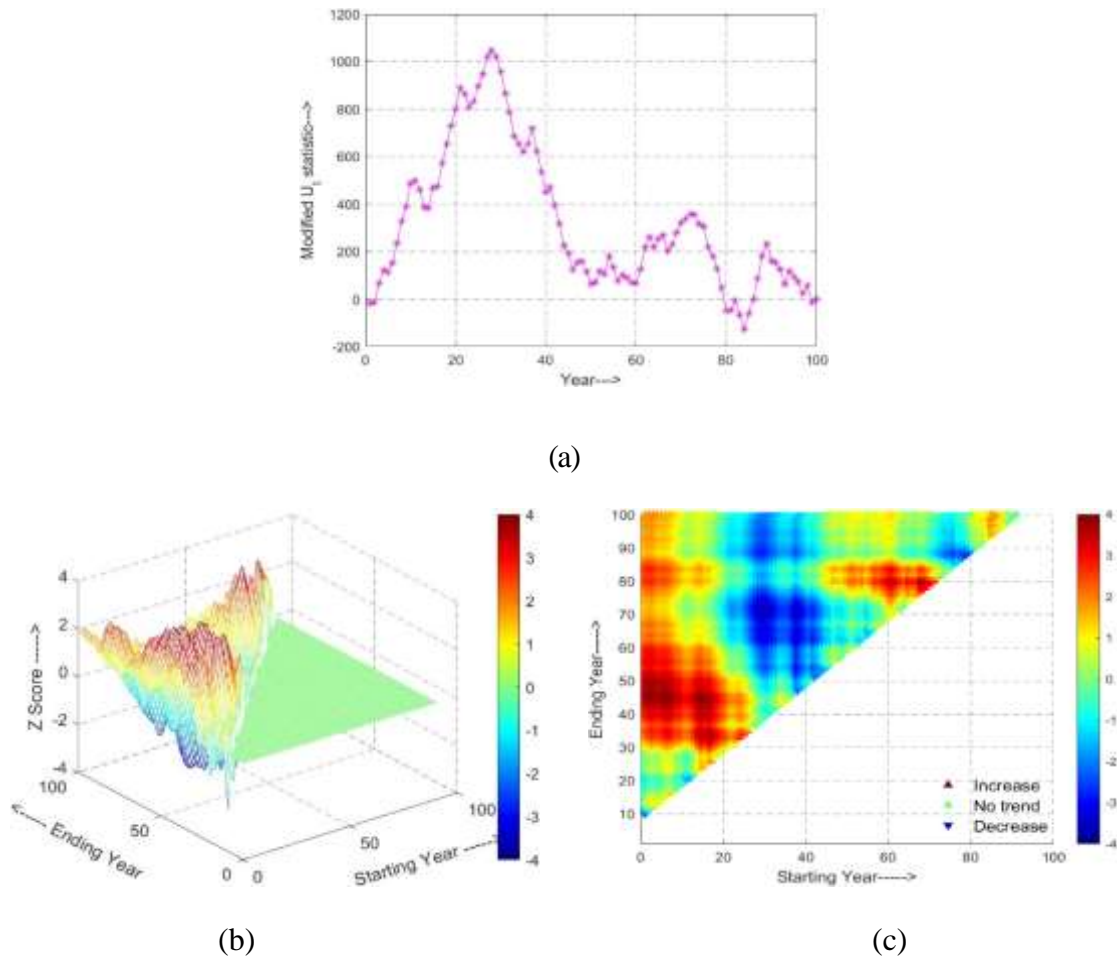
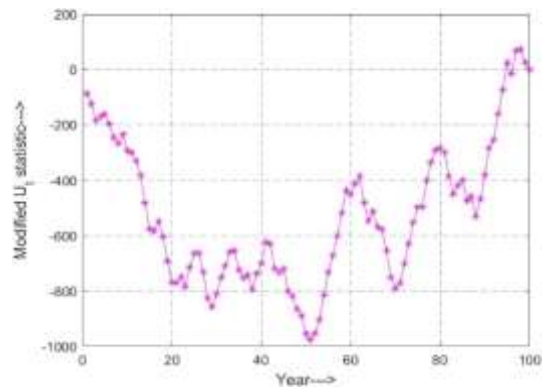
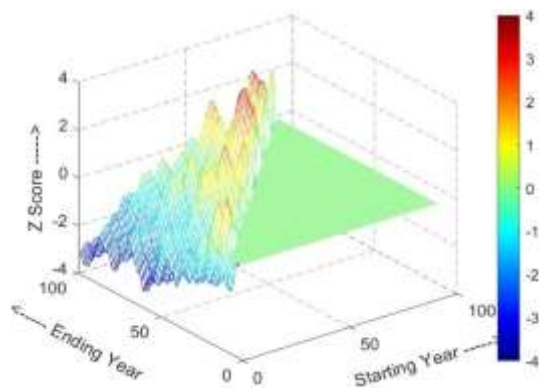


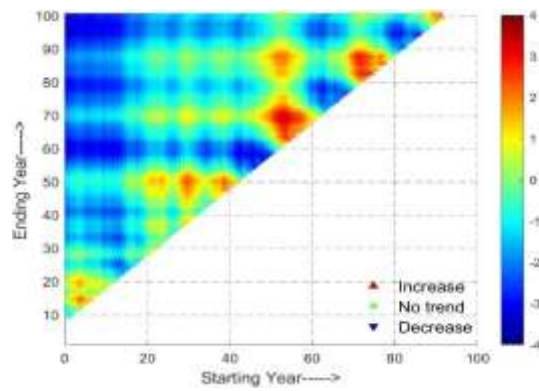
Figure 6.133 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the TNX trend in Giridih is at level of 0.05. (c) The 2-D pattern of the TNX trend in Giridih was at level of 0.05.



(a)



(b)



(c)

Figure 6.134 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the TXN trend in Giridih is at level of 0.05. (c) The 2-D pattern of the TXN trend in Giridih was at level of 0.05.

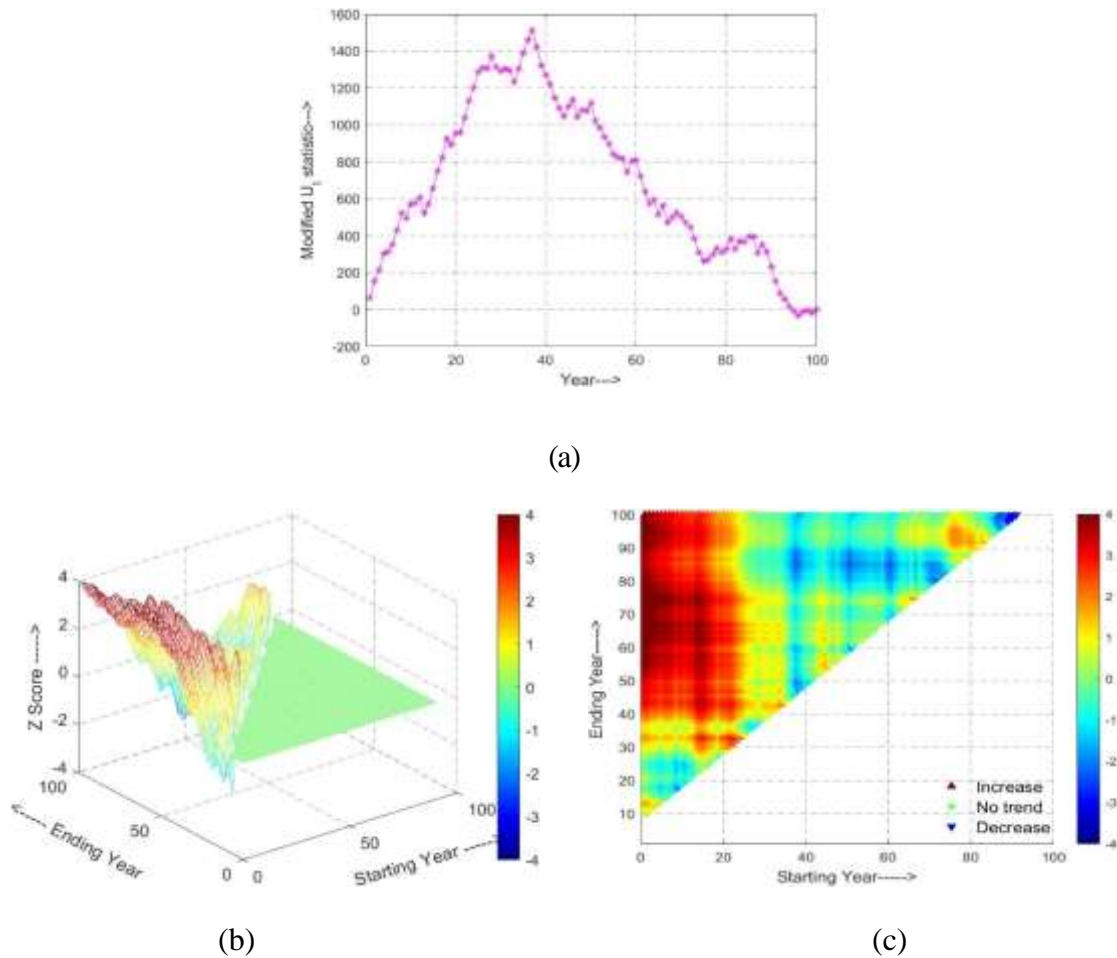


Figure 6.135 (a) Variation of modified U_t over the years to identify change points in Giridih. (b) The three-dimensional pattern of the TXX trend in Giridih is at level of 0.05. (c) The 2-D pattern of the TXX trend in Giridih was at level of 0.05..

6.2.10 Characteristics of Multiple Climatic Indices in Hazaribag

Hazaribagh station, situated in the Jharkhand region of the Damodar River Basin (DRB), has been a significant focus for research analyzing long-term trends in extreme climate indices. This station was selected for an in-depth analysis spanning from 1923 to 2022. Figures 6.136(b-c) to 6.150(b-c) present both two-dimensional and three-dimensional visualizations of the extreme climate variables recorded at Hazaribagh. The initial sections of these figures illustrate patterns of peaks and troughs, where peaks

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indicate the intensity and direction of climate trends, while troughs reflect fluctuations over time. These visual representations underscore notable changes in extreme climate indices throughout the study period. The figures utilize various shaded zones to depict these variations, with troughs appearing in the lower sections and crests in the upper portions of the triangular shapes, showcasing the dynamic nature of the climate trends. The accompanying color bar in Figures 6.136(c) to 6.150(c) indicates that red represents an increasing rainfall trend, blue signifies a decreasing trend, and green denotes periods of no significant change.

From 1923 to 1950, Hazaribagh exhibited a declining trend in rainfall, as evidenced by the blue shading in the figures. However, between 1950 and 1990, an increasing trend was noted, marked by red hues, while green areas represent periods of stability in the rainfall patterns. By analyzing the clustering of these trends, researchers could pinpoint key moments when significant shifts occurred in the climate patterns. The statistical data displayed in Figures 6.136(c) to 6.150(c) affirm the accuracy and reliability of these visualized trends, bolstering the credibility of the analysis.

The insights from this research are particularly valuable for planners and policymakers in the Hazaribagh region, as understanding the evolving nature of rainfall patterns is crucial for effective agricultural management and water resource planning. Since a significant portion of Hazaribagh's population depends on agriculture, recognizing shifts in rainfall variability is essential for sustainable farming practices. By integrating three-dimensional visualizations and identifying key change points in rainfall trends, this study contributes valuable insights into climate dynamics in Hazaribagh and their potential impacts on agricultural and resource management strategies.

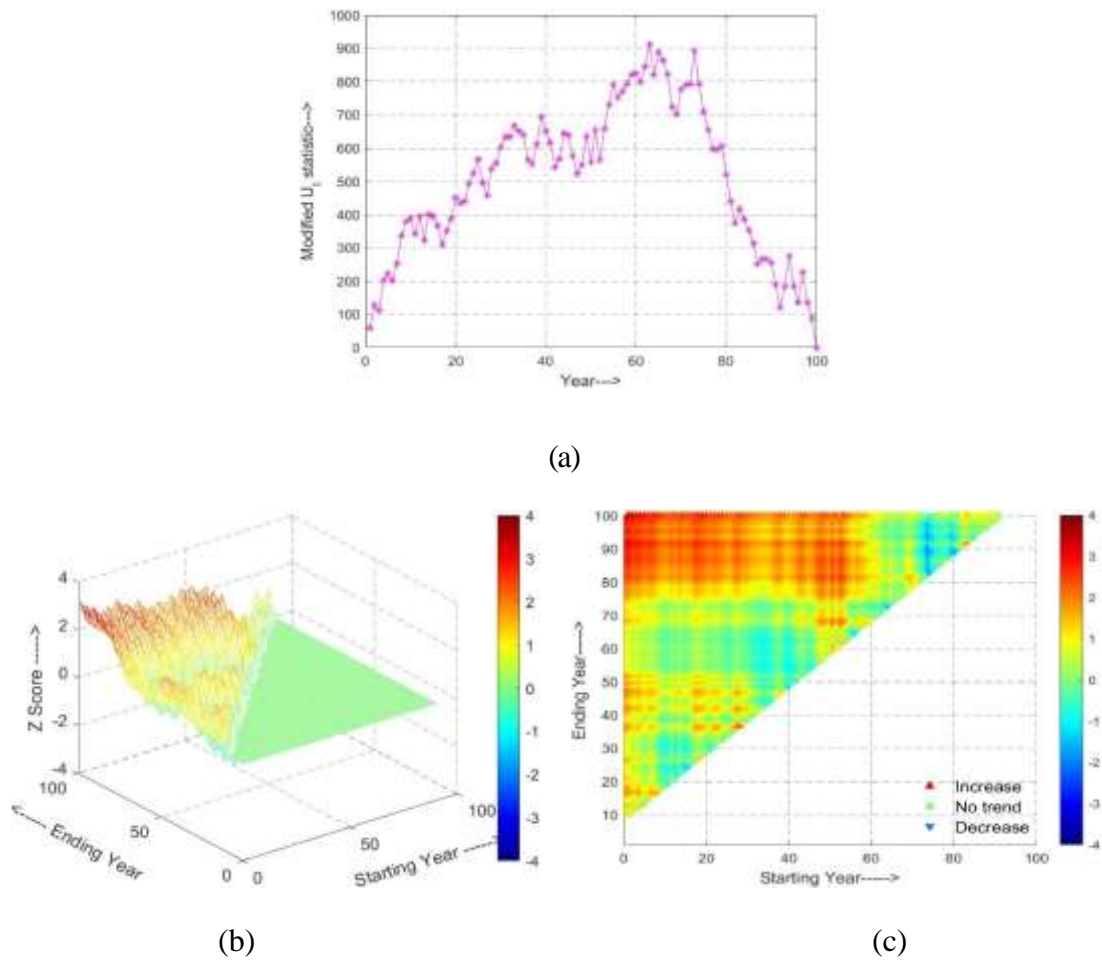
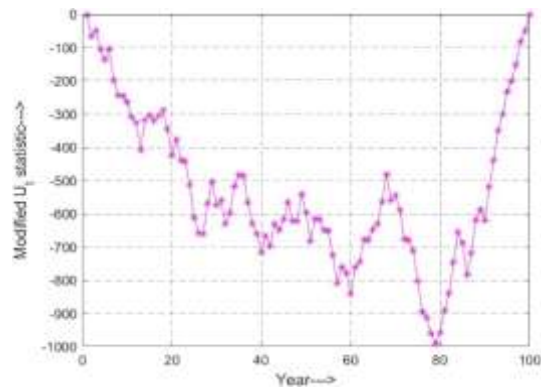
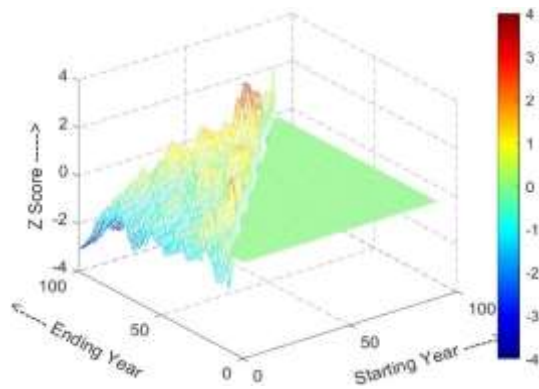


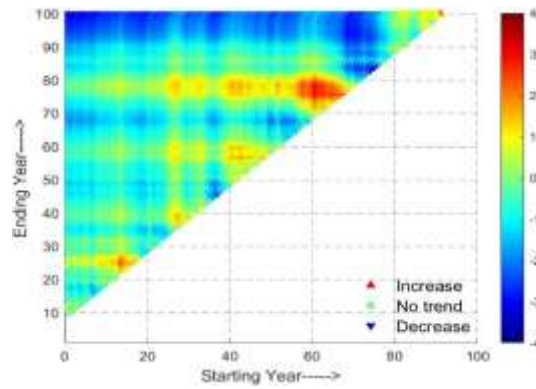
Figure 6.136 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the CDD trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the CDD trend in Hazaribag was at level of 0.05.



(a)



(b)



(c)

Figure 6.137 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the CWD trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the CWD trend in Hazaribag was at level of 0.05.

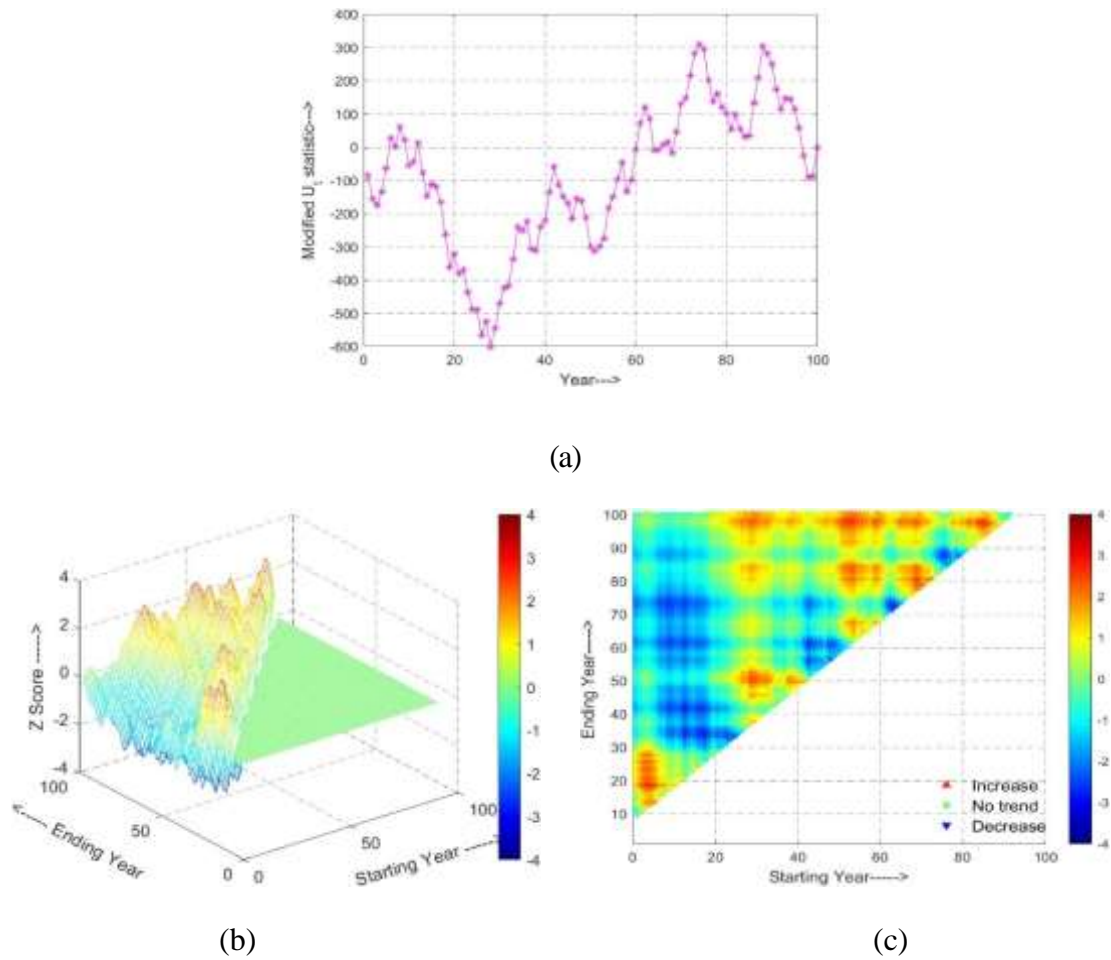
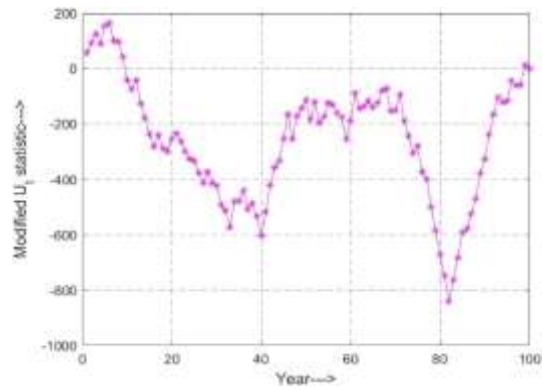
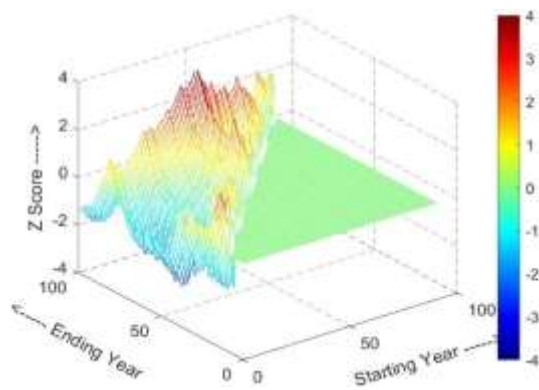


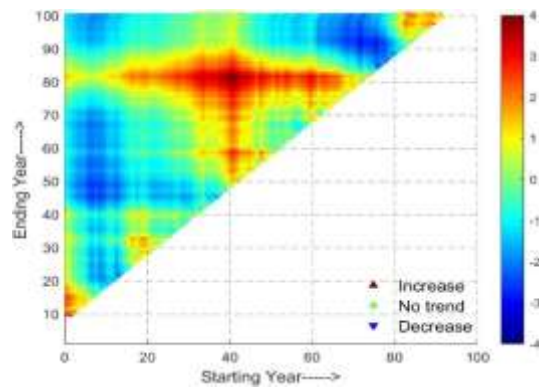
Figure 6.138 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the DTR trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the DTR trend in Hazaribag was at level of 0.05.



(a)



(b)



(c)

Figure 6.139 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the PRCPTOT trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Hazaribag was at level of 0.05.

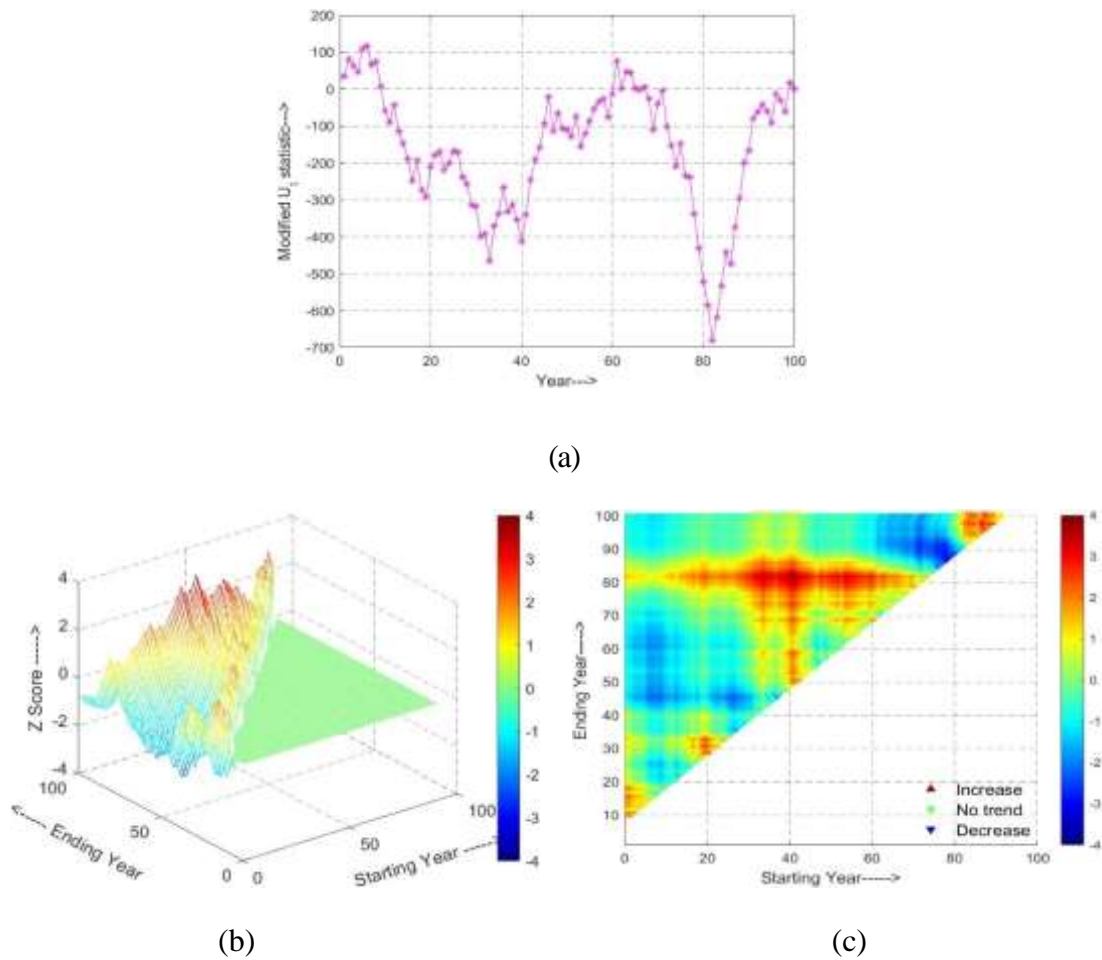
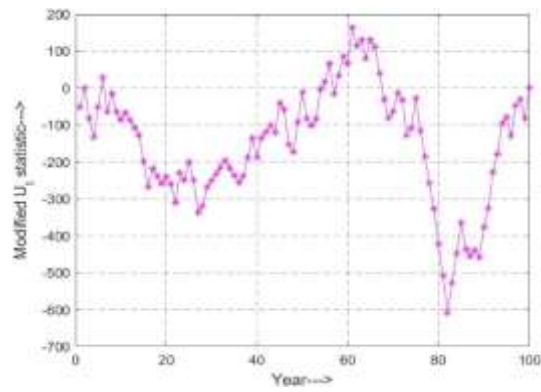
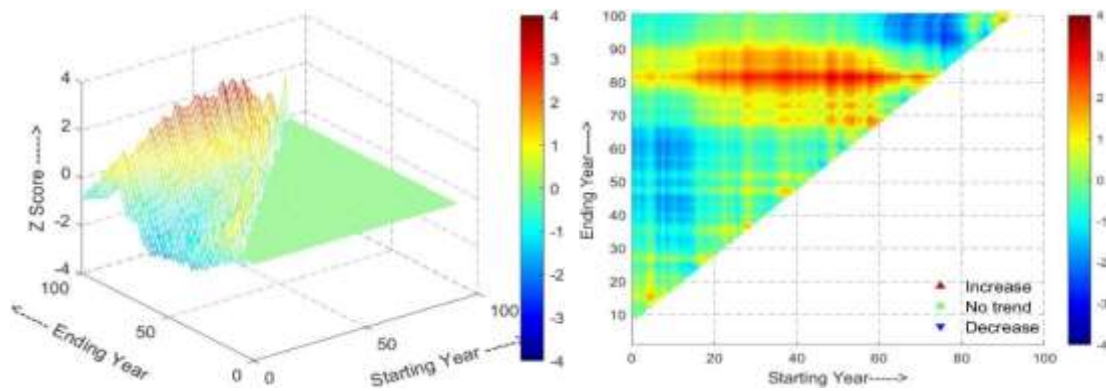


Figure 6.140 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the R10mm trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Hazaribag was at level of 0.05.



(a)



(b)

(c)

Figure 6.141 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the R20mm trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Hazaribag was at level of 0.05.

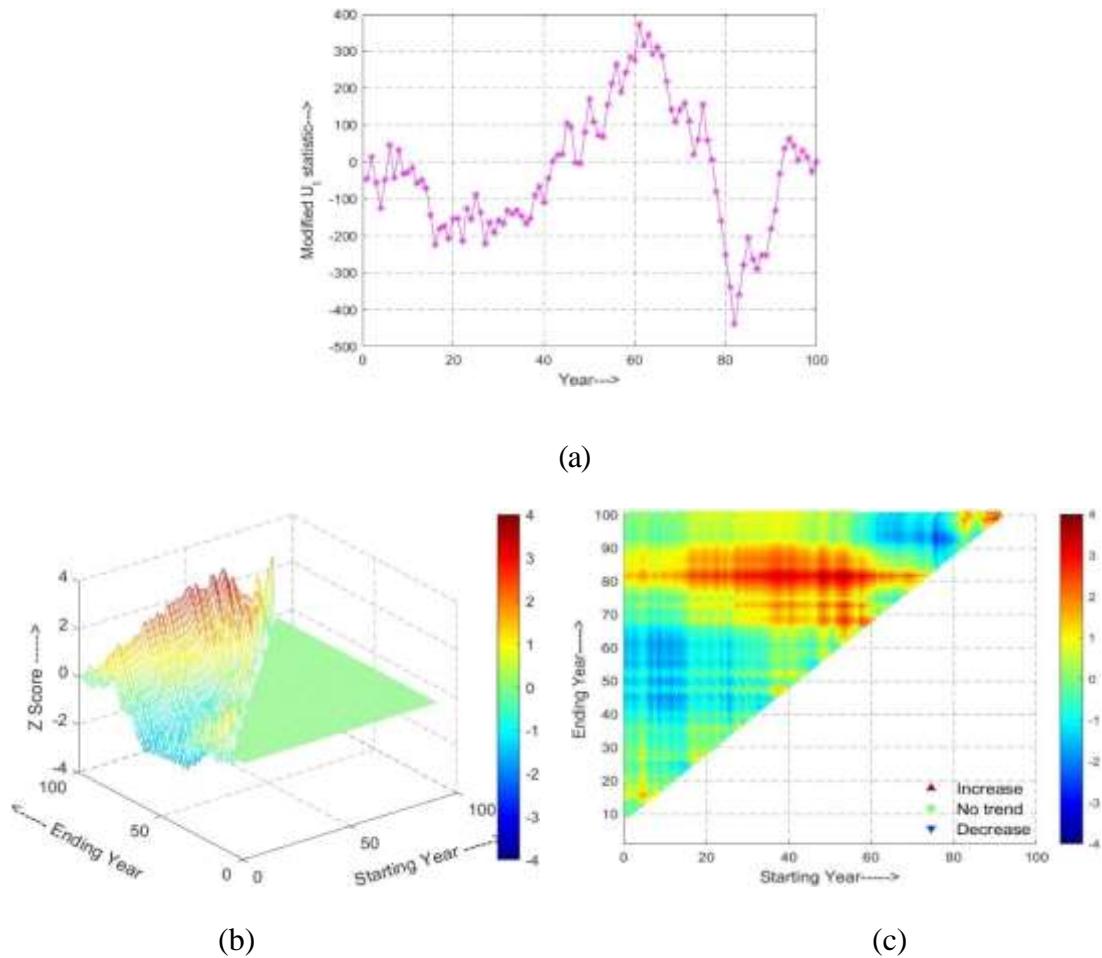
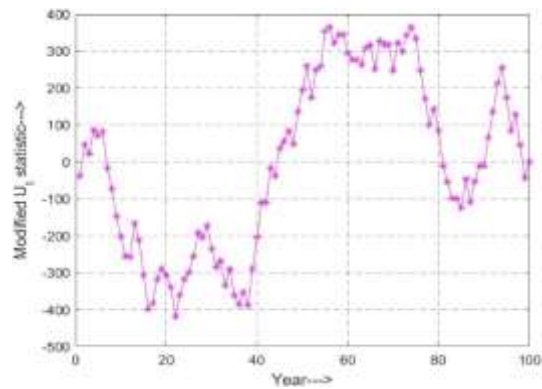
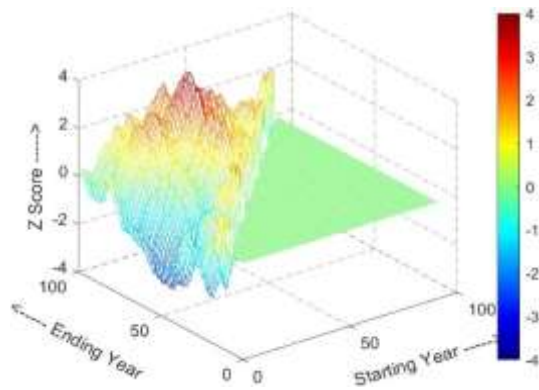


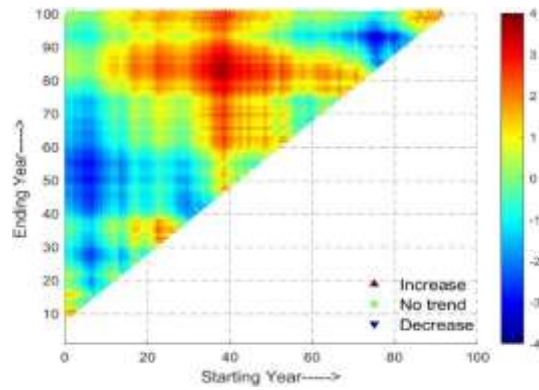
Figure 6.142 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the R_{95p} trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in Hazaribag was at level of 0.05.



(a)

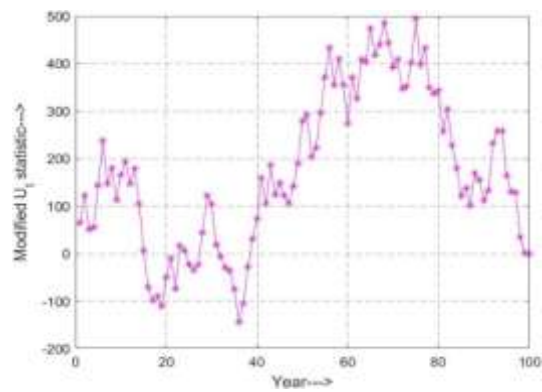


(b)

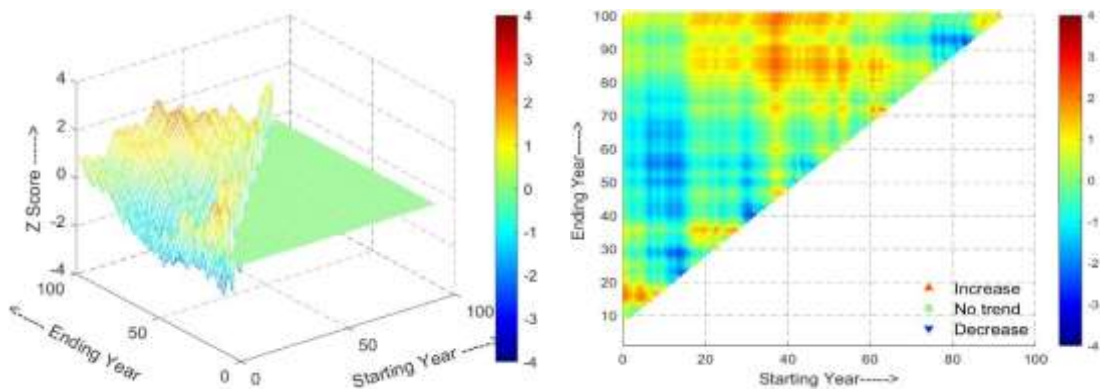


(c)

Figure 6.143 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the $R99p$ trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the $R99p$ trend in Hazaribag was at level of 0.05.



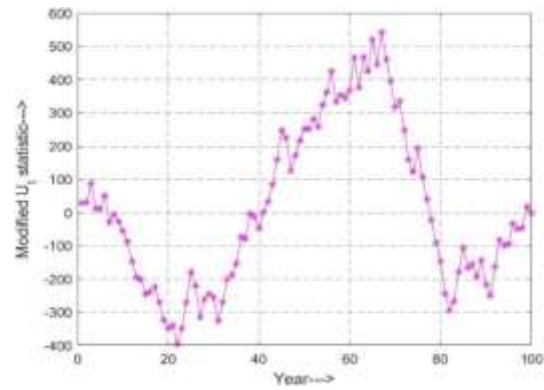
(a)



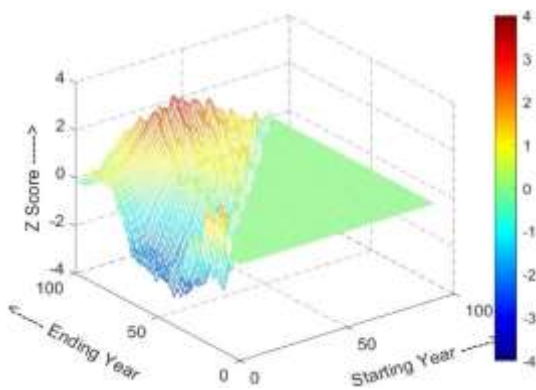
(b)

(c)

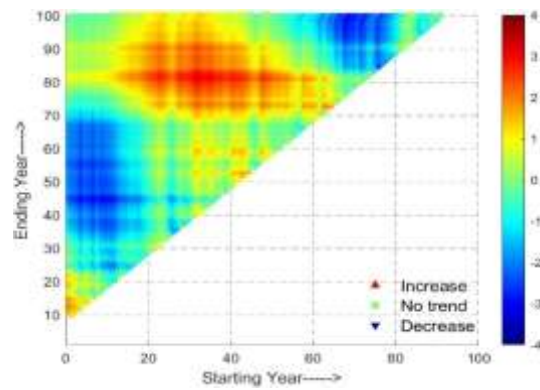
Figure 6.144 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the RX1day trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Hazaribag was at level of 0.05.



(a)



(b)



(c)

Figure 6.145 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the RX5day trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Hazaribag was at level of 0.05.

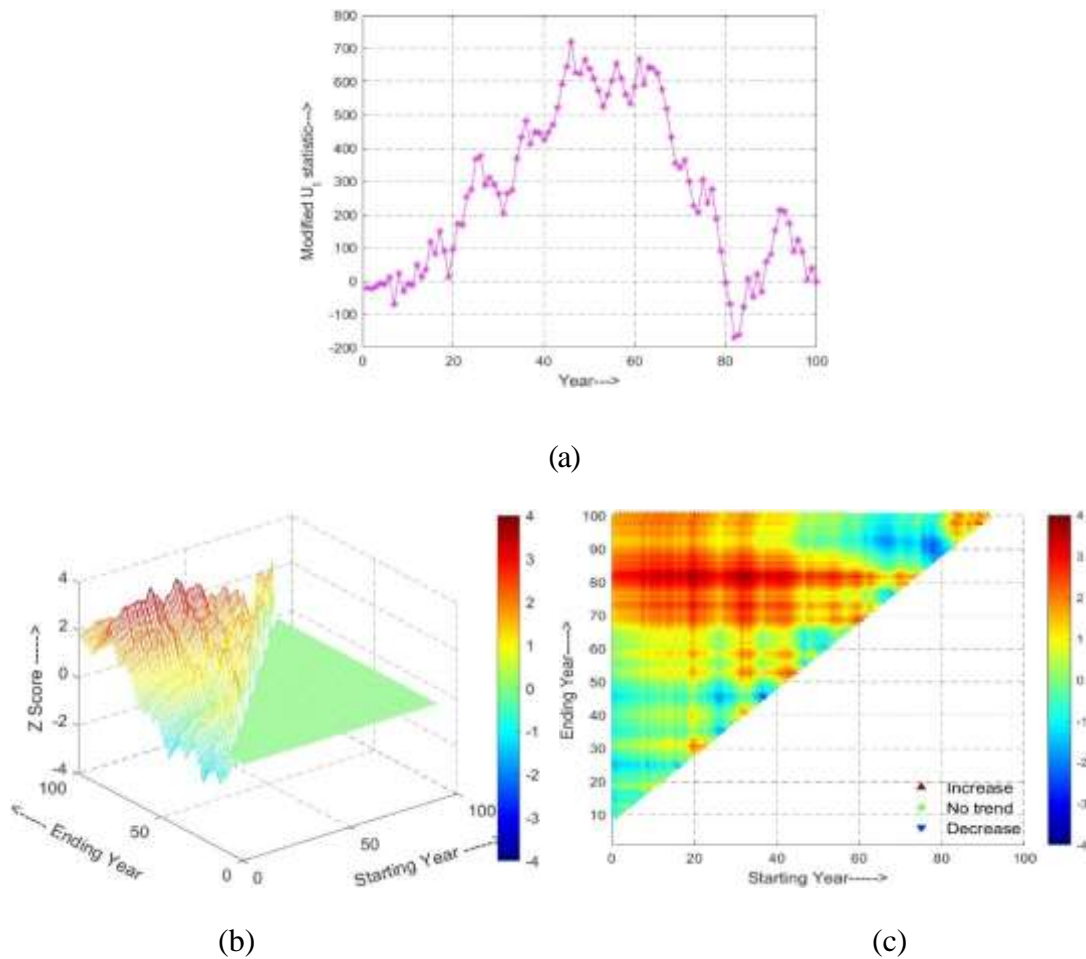
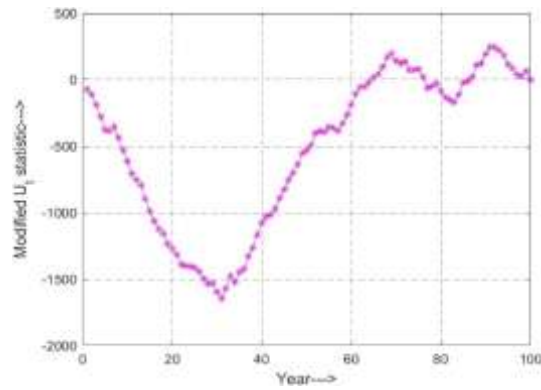
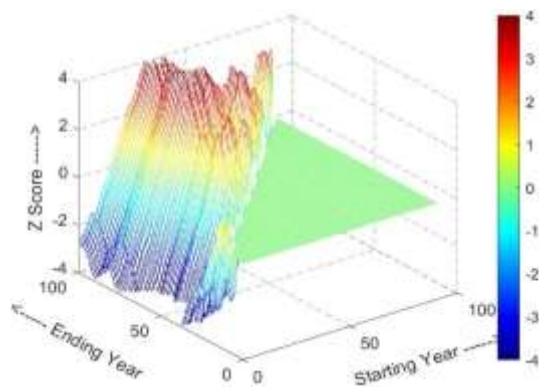


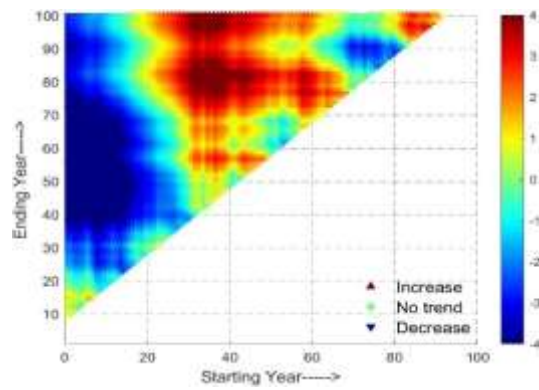
Figure 6.146 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the SDII trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the SDII trend in Hazaribag was at level of 0.05.



(a)

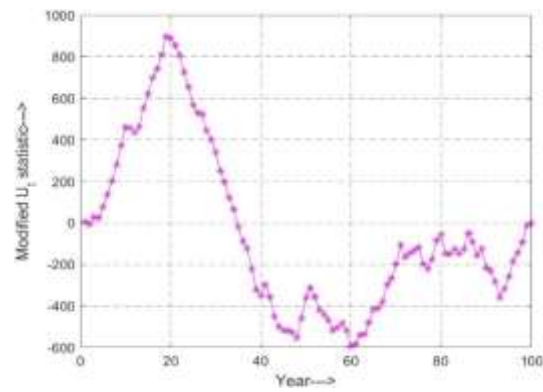


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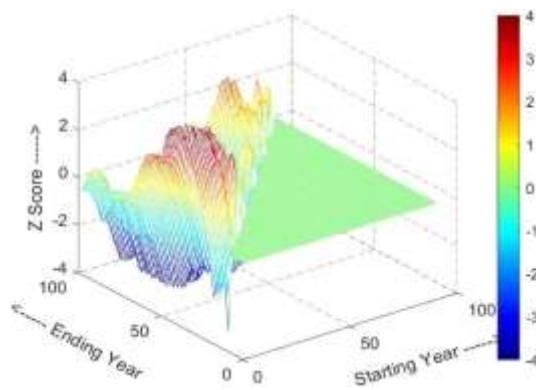


(c)

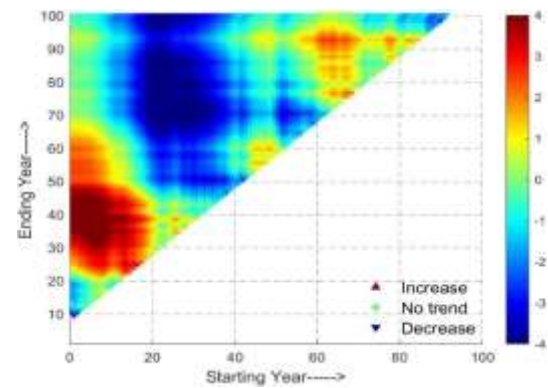
Figure 6.147 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the TNN trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the TNN trend in Hazaribag was at level of 0.05.



(a)

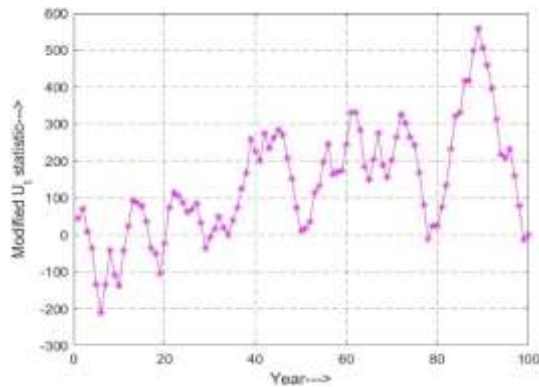


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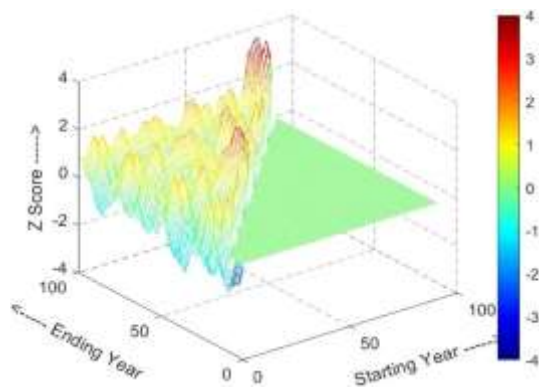


(c)

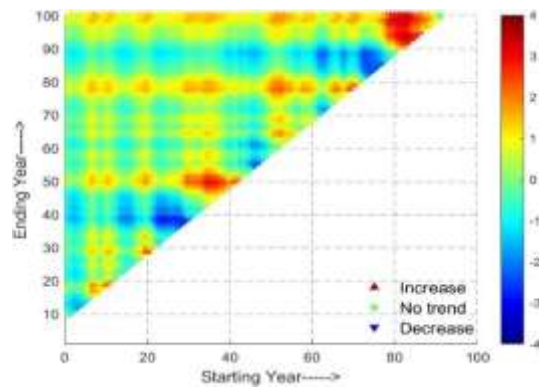
Figure 6.148 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the TNX trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the TNX trend in Hazaribag was at level of 0.05.



(a)



(b)



(c)

Figure 6.149 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the TXN trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the TXN trend in Hazaribag was at level of 0.05.

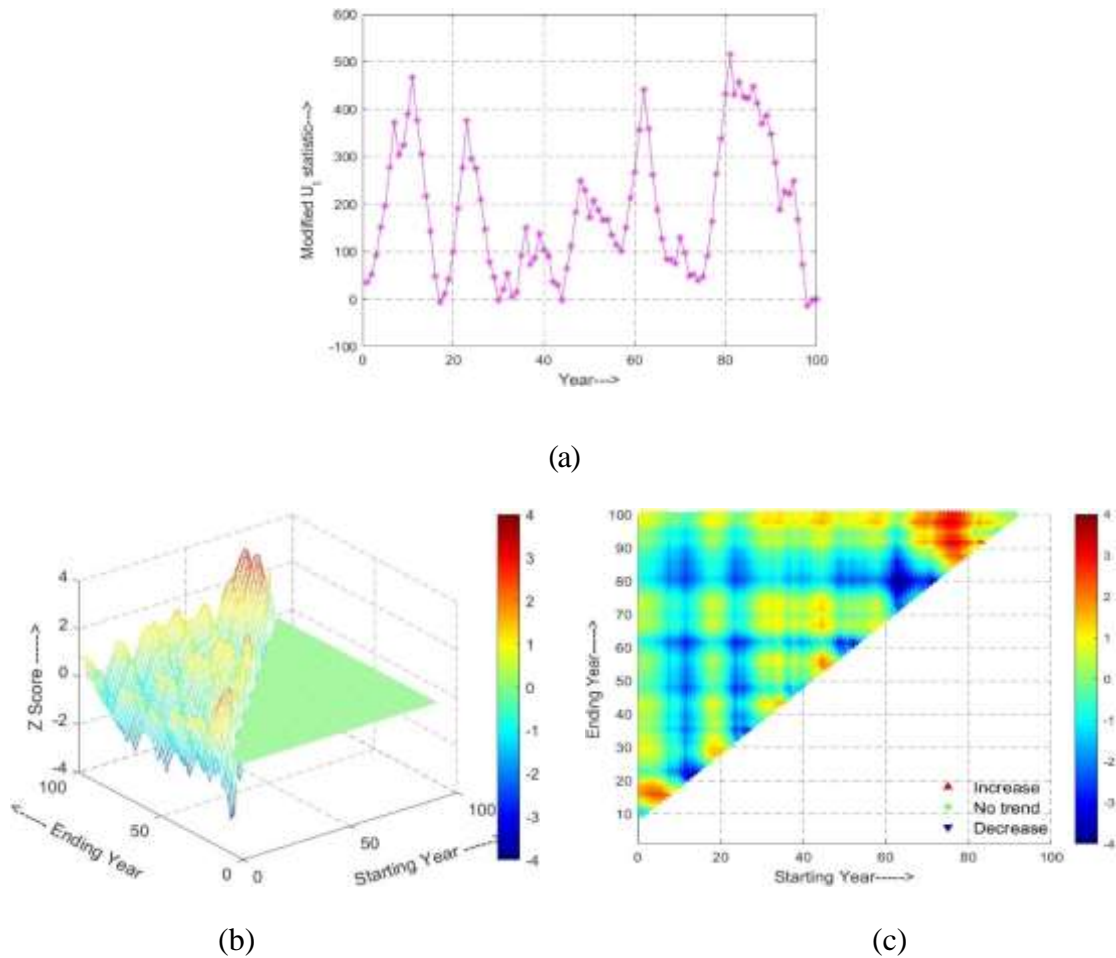


Figure 6.150 (a) Variation of modified U_t over the years to identify change points in Hazaribag. (b) The three-dimensional pattern of the TXX trend in Hazaribag is at level of 0.05. (c) The 2-D pattern of the TXX trend in Hazaribag was at level of 0.05.

6.2.11 Characteristics of Multiple Climatic Indices in Koderma

Koderma station, located within the Jharkhand region of the Damodar River Basin (DRB), has become a crucial site for research focused on long-term trends in extreme climate indices. This station was specifically selected for a detailed analysis covering the years 1923 to 2022. Figures 6.151(b-c) to 6.165(b-c) provide both two-dimensional and three-dimensional visual representations of the extreme climate variables observed at Koderma. The early sections of these figures reveal patterns characterized by peaks

and troughs, where peaks denote the intensity and direction of climate trends, while troughs indicate fluctuations over time. These visualizations highlight significant changes in extreme climate indices throughout the study period. The figures employ various shaded zones to represent these variations, with troughs appearing in the lower sections and crests in the upper portions of the triangular shapes, effectively illustrating the dynamic nature of climate trends. The accompanying color bar in Figures 6.151(c) to 6.165(c) indicates that red corresponds to an increasing rainfall trend, blue signifies a decreasing trend, and green reflects periods of no substantial change.

From 1923 to 1950, Koderma displayed a downward trend in rainfall, as shown by the blue shading in the figures. In contrast, an upward trend was noted from 1950 to 1990, represented by red hues, while green areas illustrate periods of stability in the rainfall patterns. By analyzing the clustering of these trends, researchers were able to identify key moments of significant shifts in climate patterns. The statistical data presented in Figures 6.161(c) to 6.165(c) affirm the accuracy and reliability of these visualized trends, thereby enhancing the overall credibility of the analysis.

A broader study by Halder et al. (2023), which examined rainfall trends across various districts in Jharkhand and West Bengal, also reported a declining annual rainfall trend for Koderma from 1901 to 2020. This research further extends those findings by visualizing both increasing and decreasing rainfall trends from 1923 to 2022, utilizing advanced 2D and 3D models to effectively capture the evolving patterns. Additionally, this study introduced a modified version of the PMW test to identify multiple change points in the trends, offering a more comprehensive analysis compared to previous studies that primarily focused on basic trend detection.

Given that a significant portion of the Koderma population relies on agriculture, recognizing rainfall variability is crucial for sustainable farming practices. By incorporating three-dimensional visualizations and pinpointing key change points in rainfall trends, this study provides valuable insights into the climate dynamics of Koderma and their potential impacts on agricultural and resource management strategies.

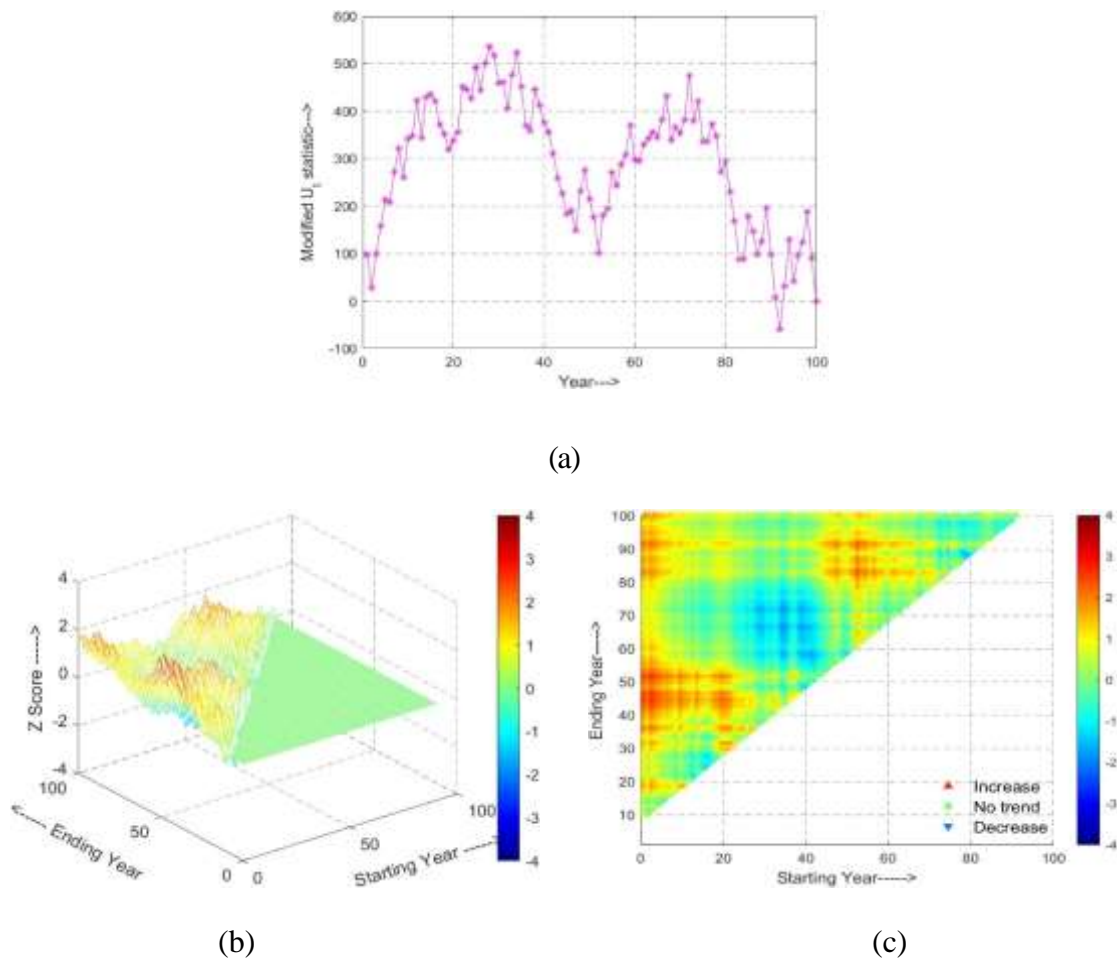
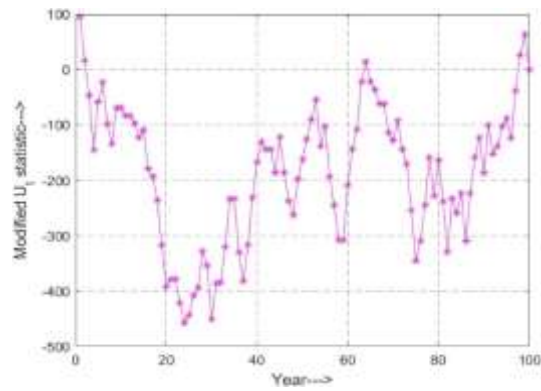
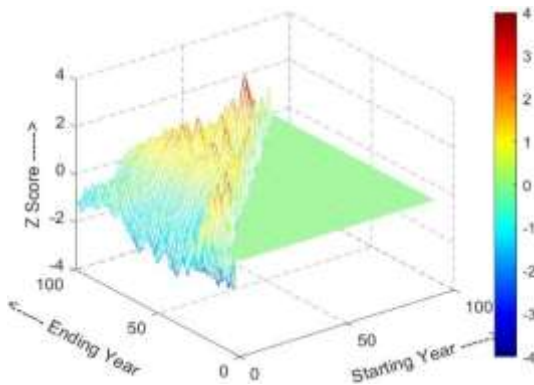


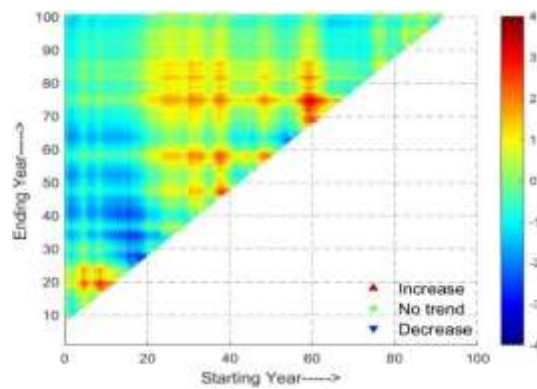
Figure 6.151 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the CDD trend in Koderma is at level of 0.05. (c) The 2-D pattern of the CDD trend in Koderma was at level of 0.05.



(a)



(b)



(c)

Figure 6.152 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the CWD trend in Koderma is at level of 0.05. (c) The 2-D pattern of the CWD trend in Koderma was at level of 0.05.

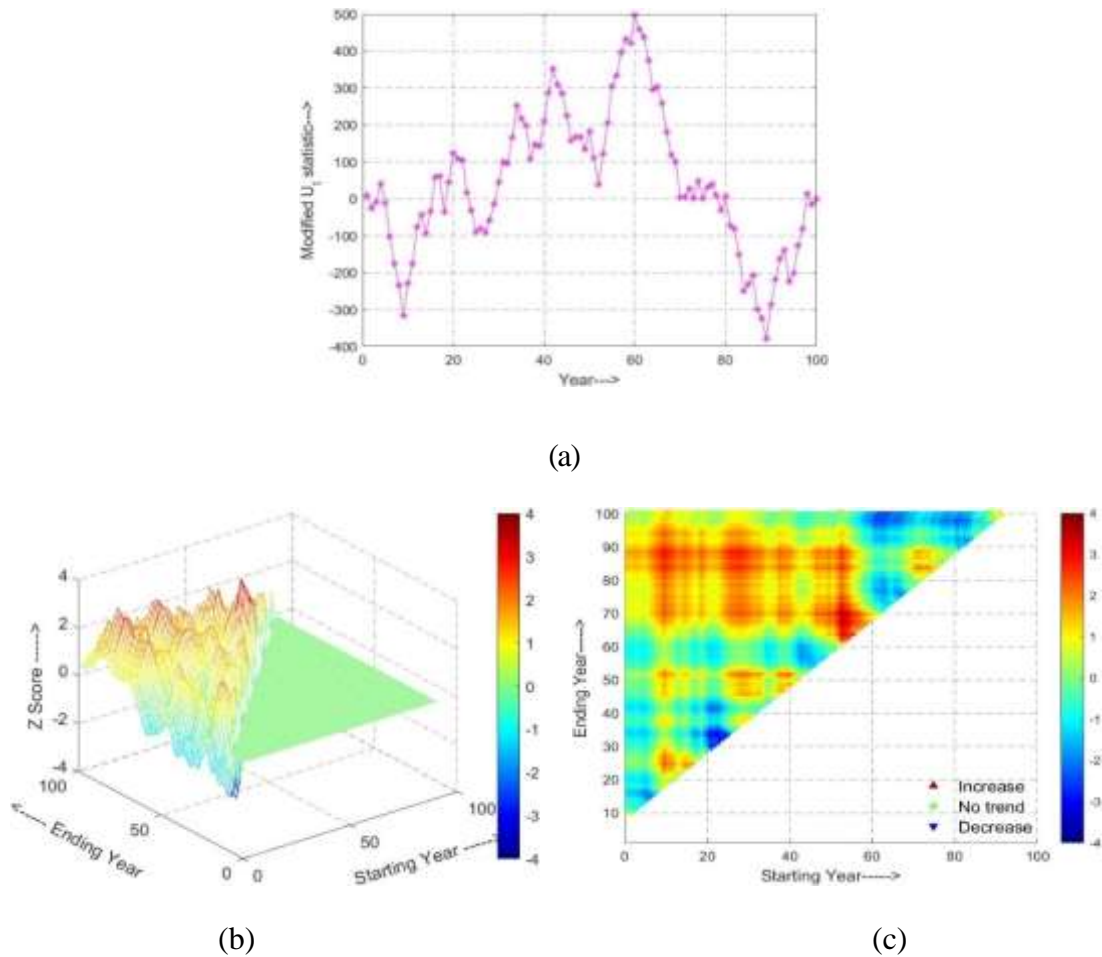


Figure 6.153 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the DTR trend in Koderma is at level of 0.05. (c) The 2-D pattern of the DTR trend in Koderma was at level of 0.05.

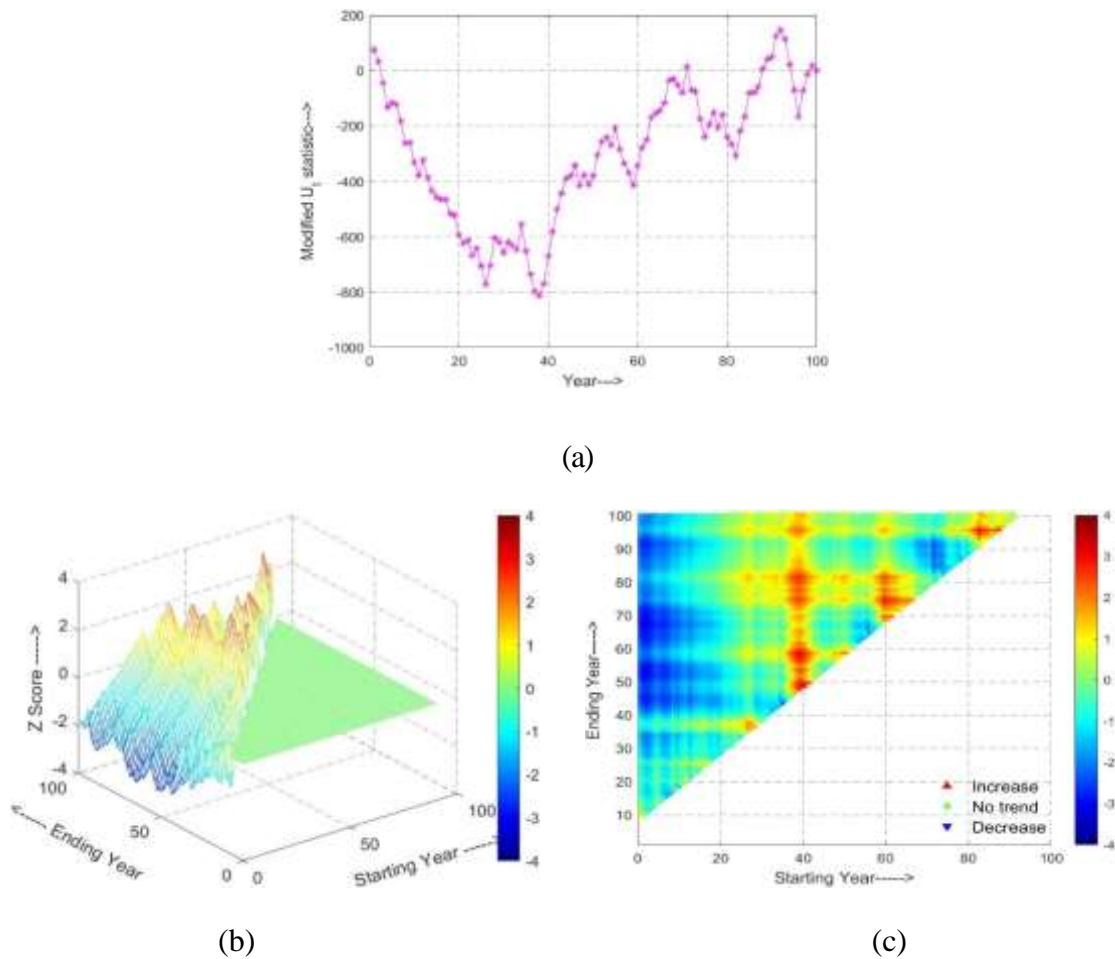


Figure 6.154 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the PRCPTOT trend in Koderma is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Koderma was at level of 0.05.

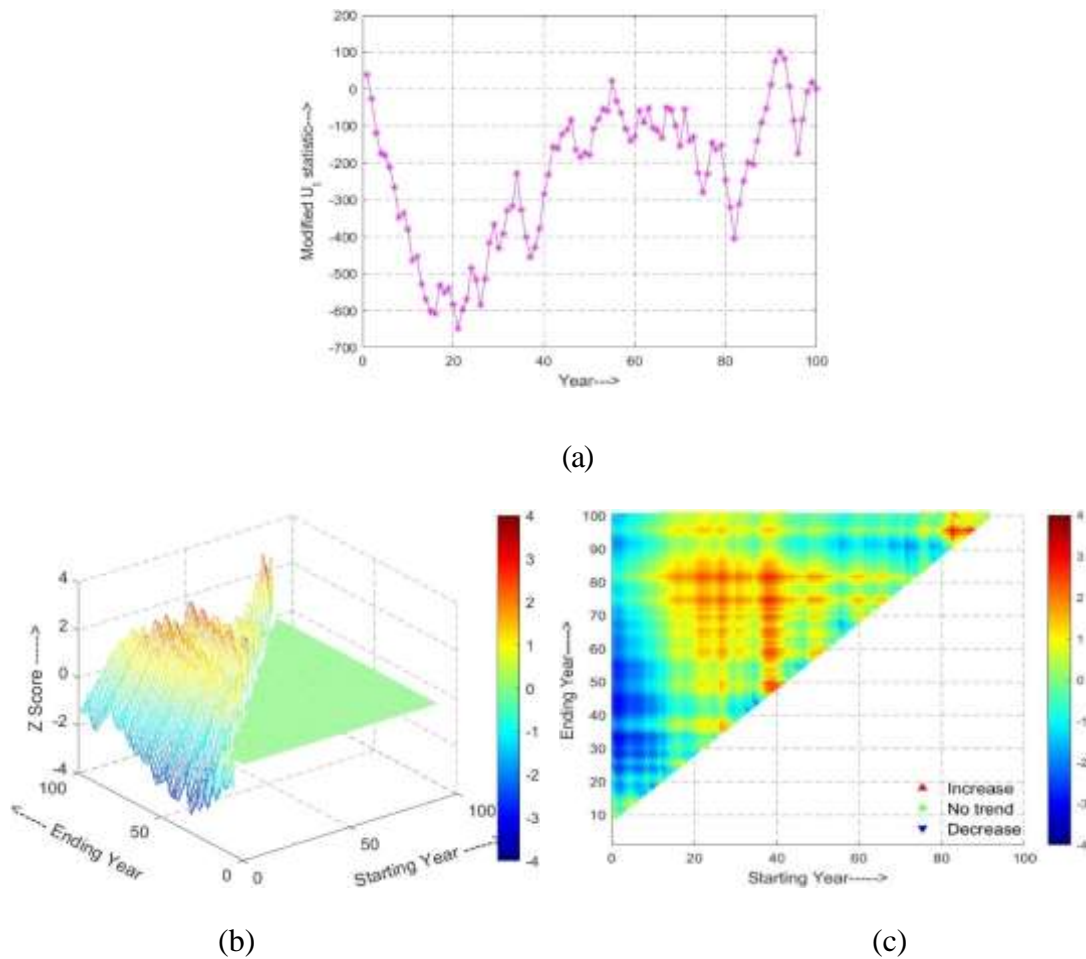
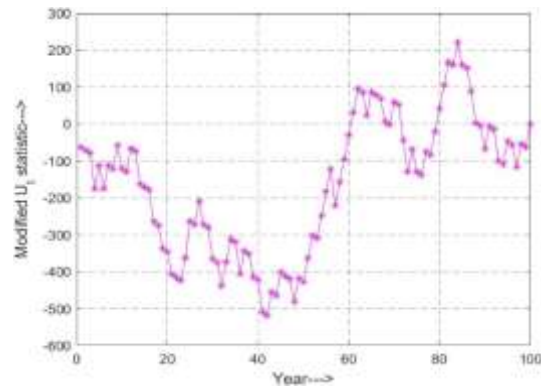
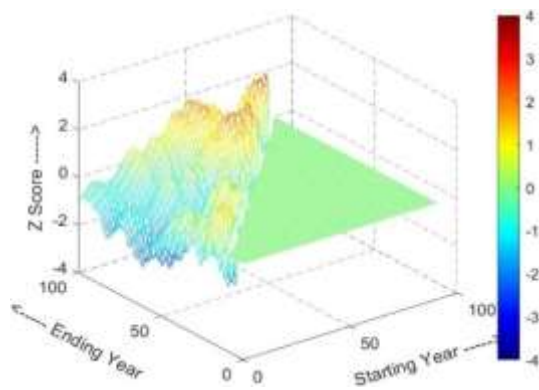


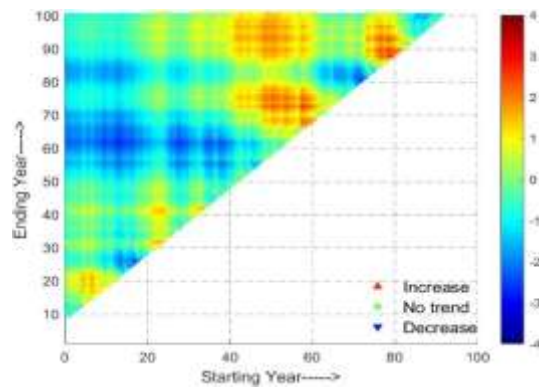
Figure 6.155 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the R10mm trend in Koderma is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Koderma was at level of 0.05.



(a)



(b)



(c)

Figure 6.156 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the R20mm trend in Koderma is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Koderma was at level of 0.05.

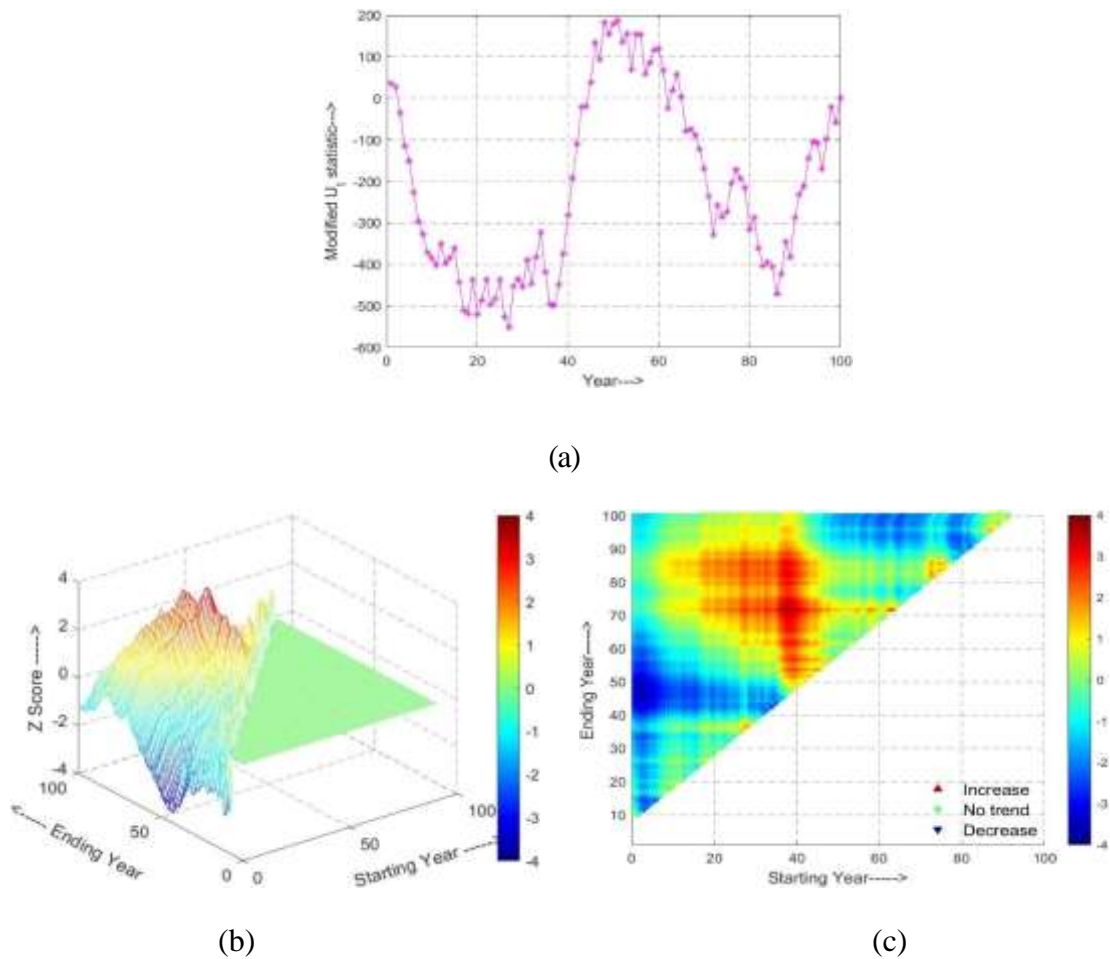
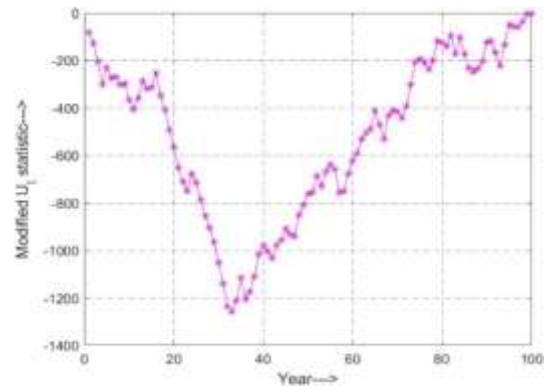
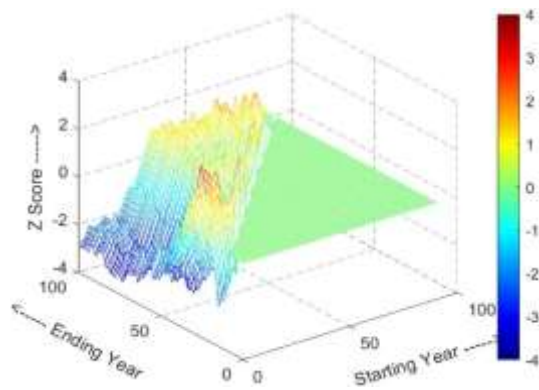


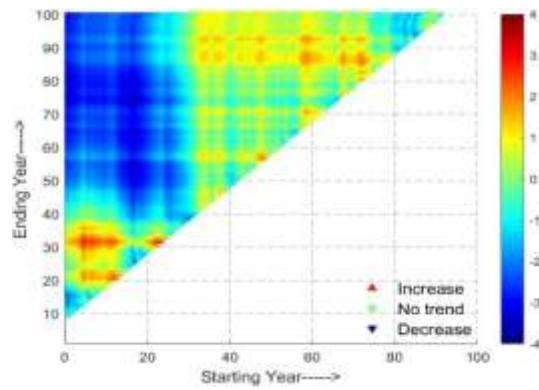
Figure 6.157 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the R95p trend in Koderma is at level of 0.05. (c) The 2-D pattern of the R95p trend in Koderma was at level of 0.05.



(a)



(b)



(c)

Figure 6.158 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the R_{99p} trend in Koderma is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Koderma was at level of 0.05.

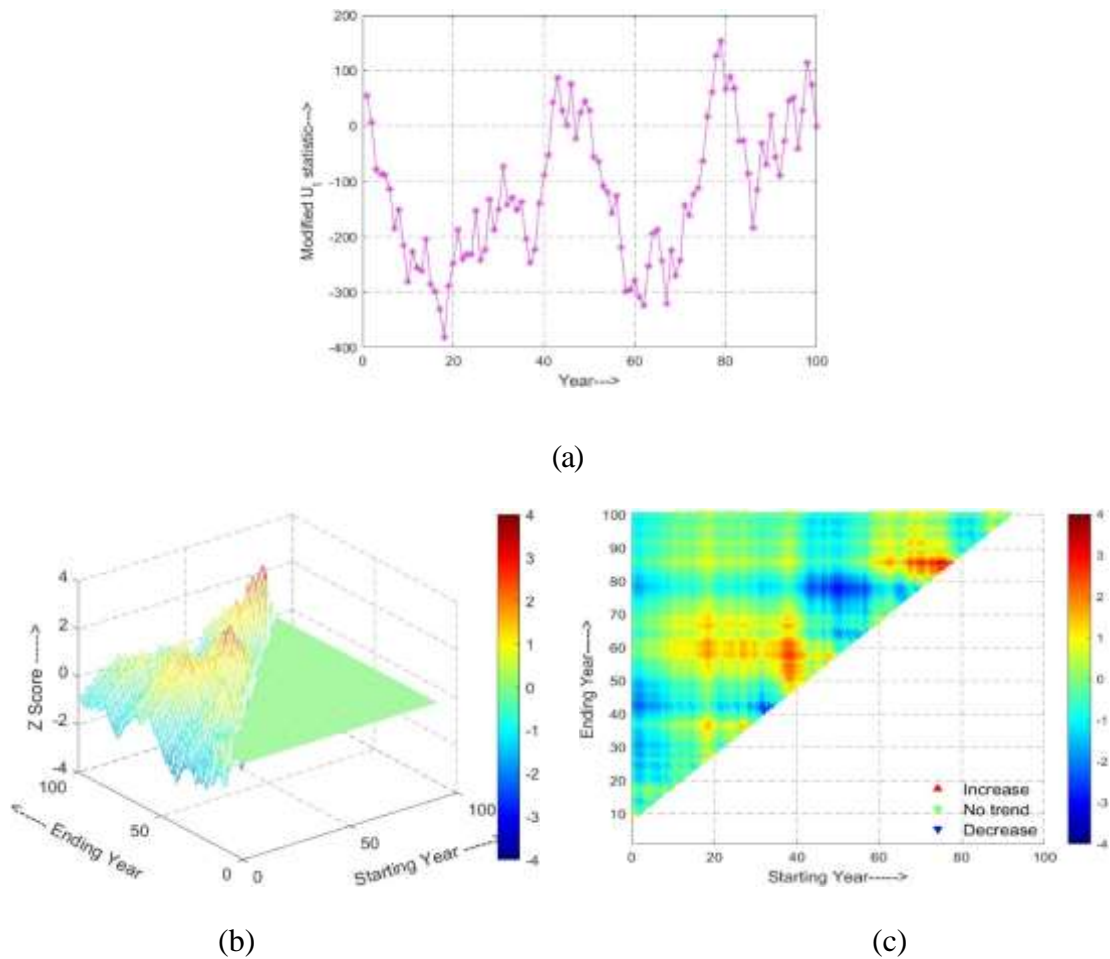
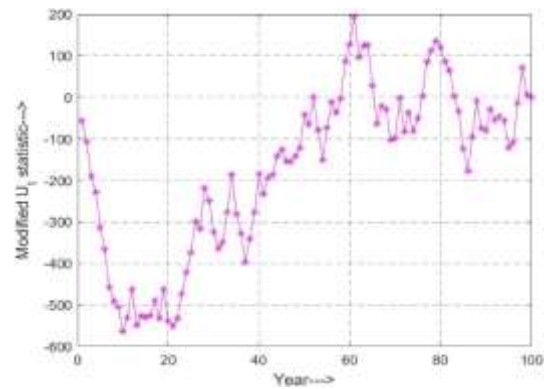
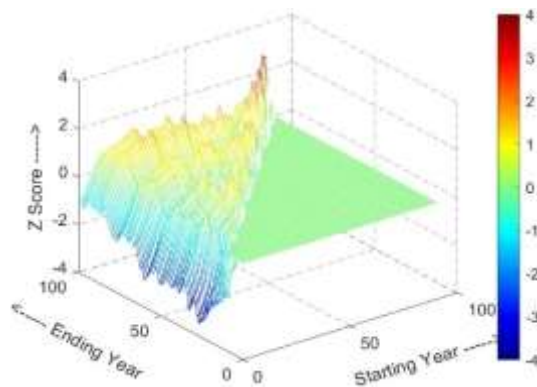


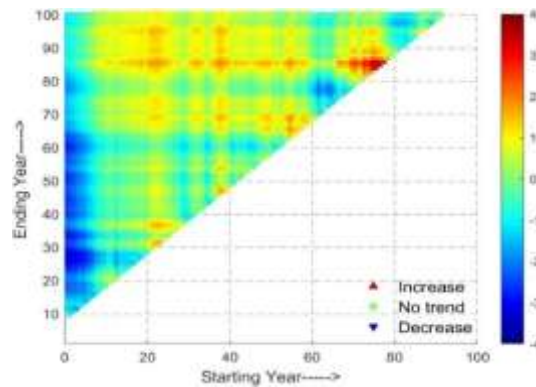
Figure 6.159 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the RX1day trend in Koderma is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Koderma was at level of 0.05.



(a)



(b)



(c)

Figure 6.160 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the RX5day trend in Koderma is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Koderma was at level of 0.05.

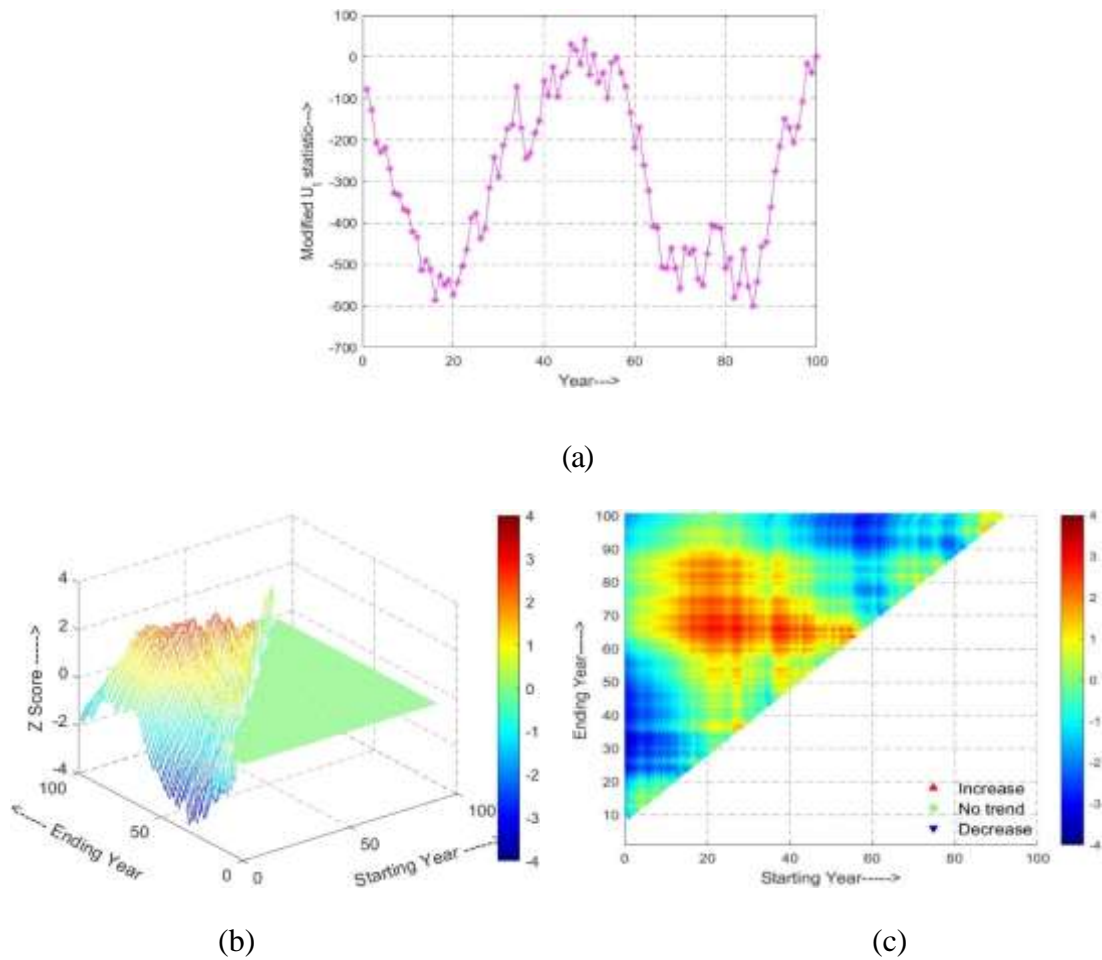
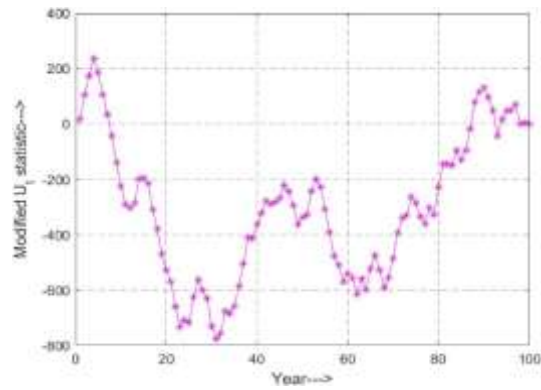
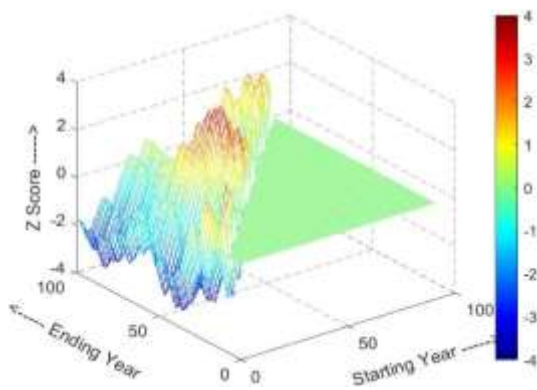


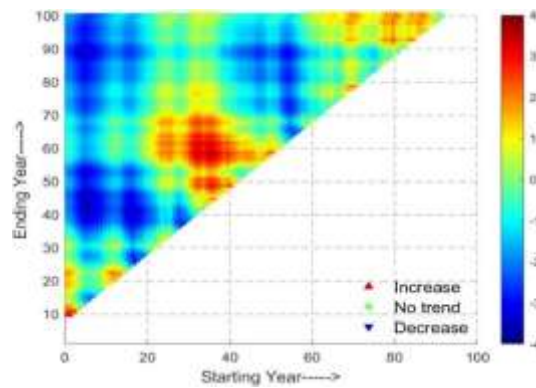
Figure 6.161 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the SDII trend in Koderma is at level of 0.05. (c) The 2-D pattern of the SDII trend in Koderma was at level of 0.05.



(a)



(b)



(c)

Figure 6.162 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the TNn trend in Koderma is at level of 0.05. (c) The 2-D pattern of the TNn trend in Koderma was at level of 0.05.

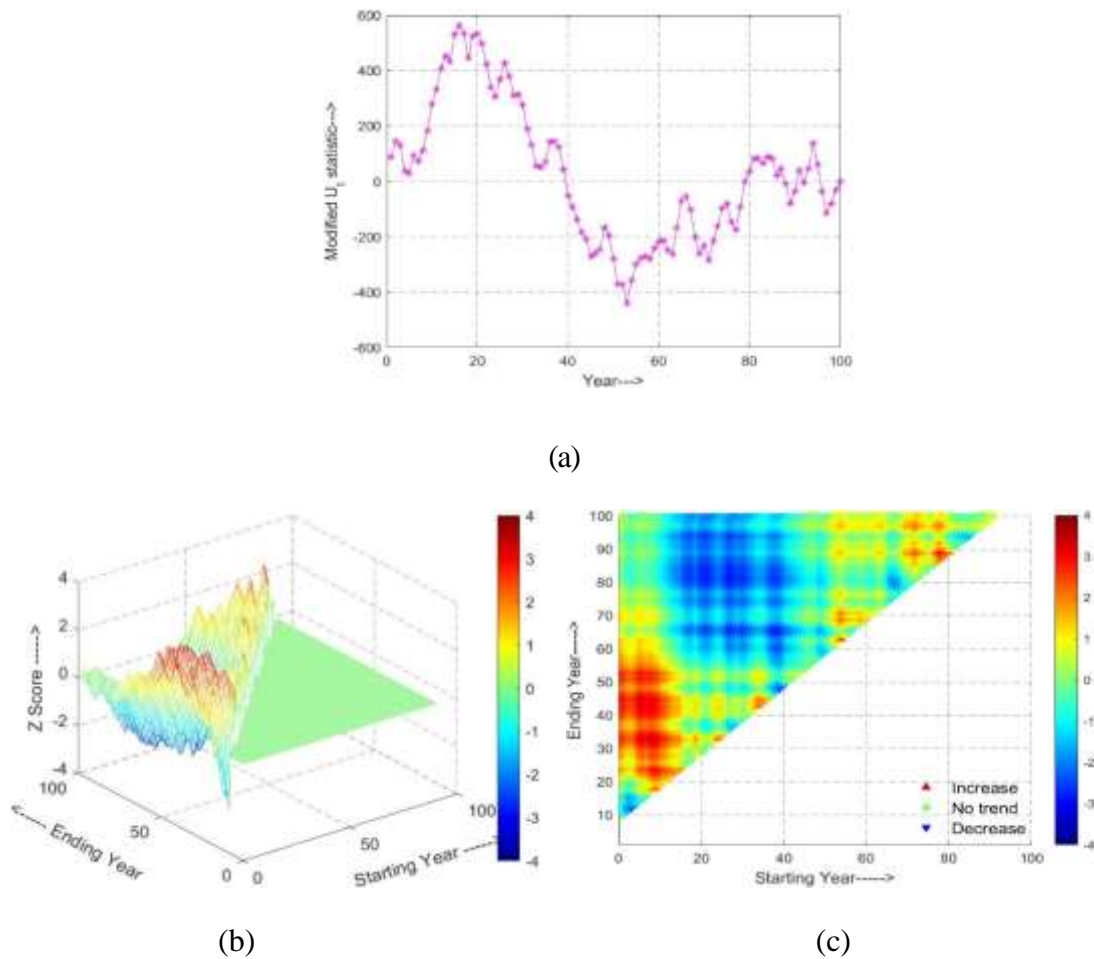
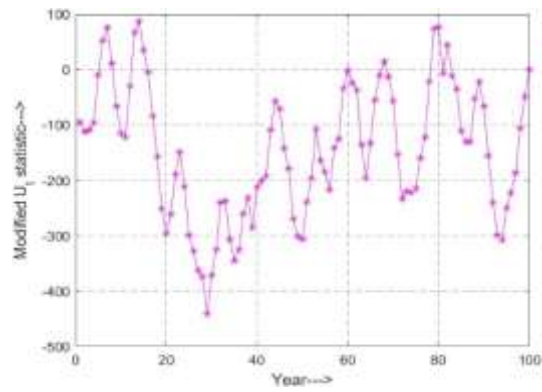
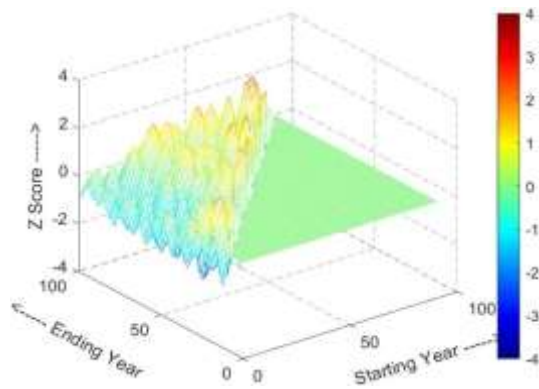


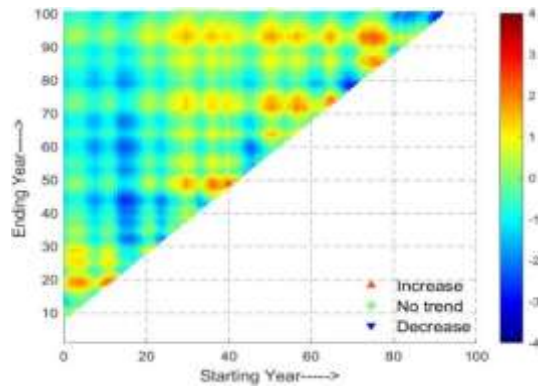
Figure 6.163 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the TNx trend in Koderma is at level of 0.05. (c) The 2-D pattern of the TNx trend in Koderma was at level of 0.05.



(a)



(b)



(c)

Figure 6.164 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the TX_n trend in Koderma is at level of 0.05. (c) The 2-D pattern of the TX_n trend in Koderma was at level of 0.05.

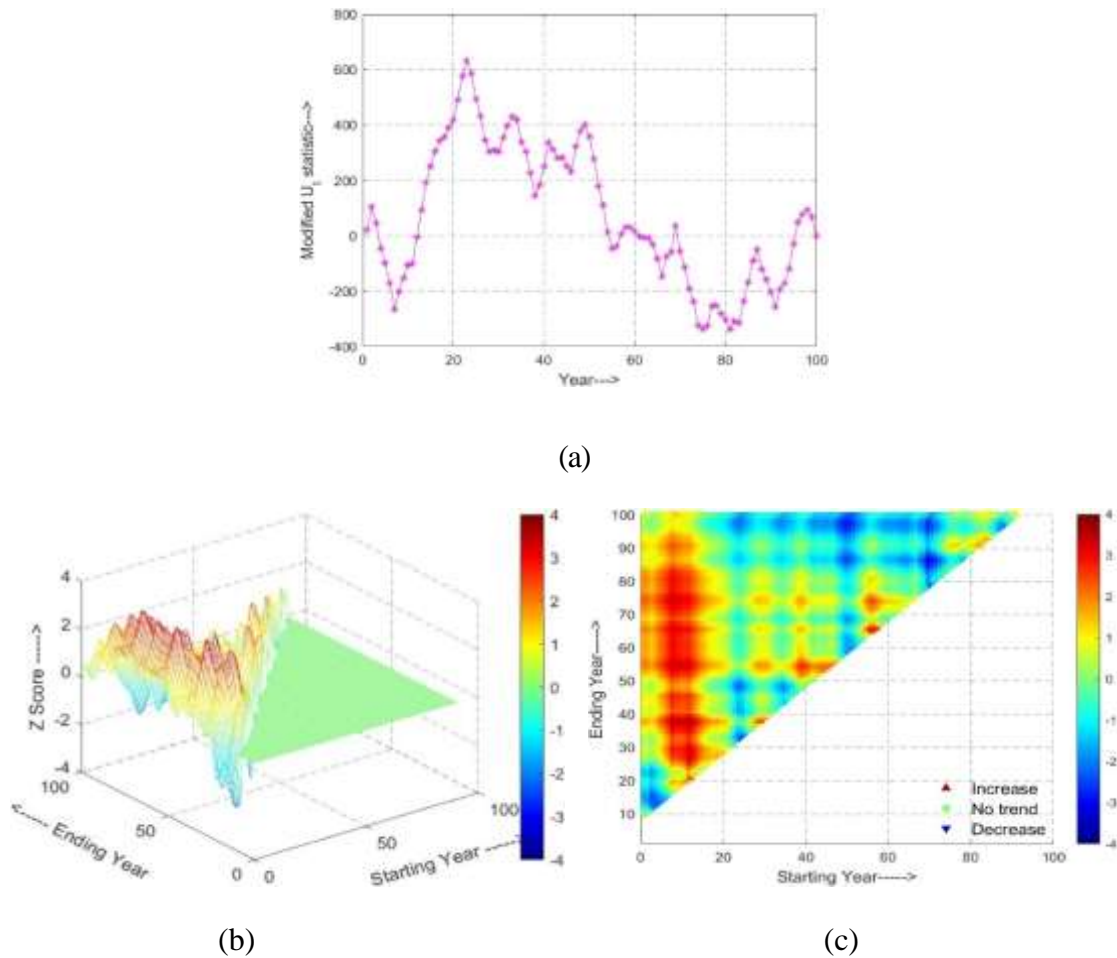


Figure 6.165 (a) Variation of modified U_t over the years to identify change points in Koderma. (b) The three-dimensional pattern of the TXX trend in Koderma is at level of 0.05. (c) The 2-D pattern of the TXX trend in Koderma was at level of 0.05.

6.2.12 Characteristics of Multiple Climatic Indices in Purulia

Purulia station, located in the West Bengal portion of the Damodar River Basin (DRB), has become an important site for research focused on long-term trends in extreme climate indices. This station was specifically selected for an extensive analysis covering the period from 1923 to 2022. Figures 6.166(b-c) to 6.180(b-c) offer both two-dimensional and three-dimensional visual representations of the extreme climate variables recorded at Purulia. The initial segments of these figures reveal patterns

characterized by peaks and troughs, where peaks signify the intensity and direction of climate trends, while troughs indicate fluctuations over time. These visualizations emphasize significant changes in extreme climate indices throughout the study period. The figures employ various shaded zones to depict these variations, with troughs appearing in the lower sections and crests in the upper portions of the triangular shapes, effectively illustrating the dynamic nature of climate trends. The accompanying color bar in Figures 6.166(c) to 6.180(c) indicates that red represents an increasing rainfall trend, blue denotes a decreasing trend, and green signifies periods of no substantial change.

From 1923 to 1950, Purulia exhibited a downward trend in rainfall, as illustrated by the blue shading in the figures. Conversely, between 1950 and 1990, an increasing trend was observed, marked by red hues, while green areas reflect periods of stability in rainfall patterns. By analyzing the clustering of these trends, researchers were able to identify key moments of significant shifts in climate patterns. The statistical data shown in Figures 6.166(c) to 6.180(c) support the accuracy and reliability of these visualized trends, thereby enhancing the overall credibility of the analysis.

This research further expands upon those findings by visualizing both increasing and decreasing rainfall trends from 1923 to 2022, utilizing advanced 2D and 3D models to effectively illustrate the evolving patterns. Additionally, this study introduced a modified version of the PMW test to detect multiple change points in the trends, providing a more detailed analysis compared to earlier studies that primarily focused on basic trend detection.

The insights gained from this research are particularly significant for planners and policymakers in the Purulia region, as understanding the evolving nature of rainfall patterns is crucial for effective agricultural management and water resource planning. Given that a significant portion of Purulia's population relies on agriculture, recognizing shifts in rainfall variability is essential for sustainable farming practices. By incorporating three-dimensional visualizations and identifying key change points in rainfall trends, this study contributes valuable knowledge regarding climate dynamics in Purulia and their potential implications for agricultural and resource management strategies.

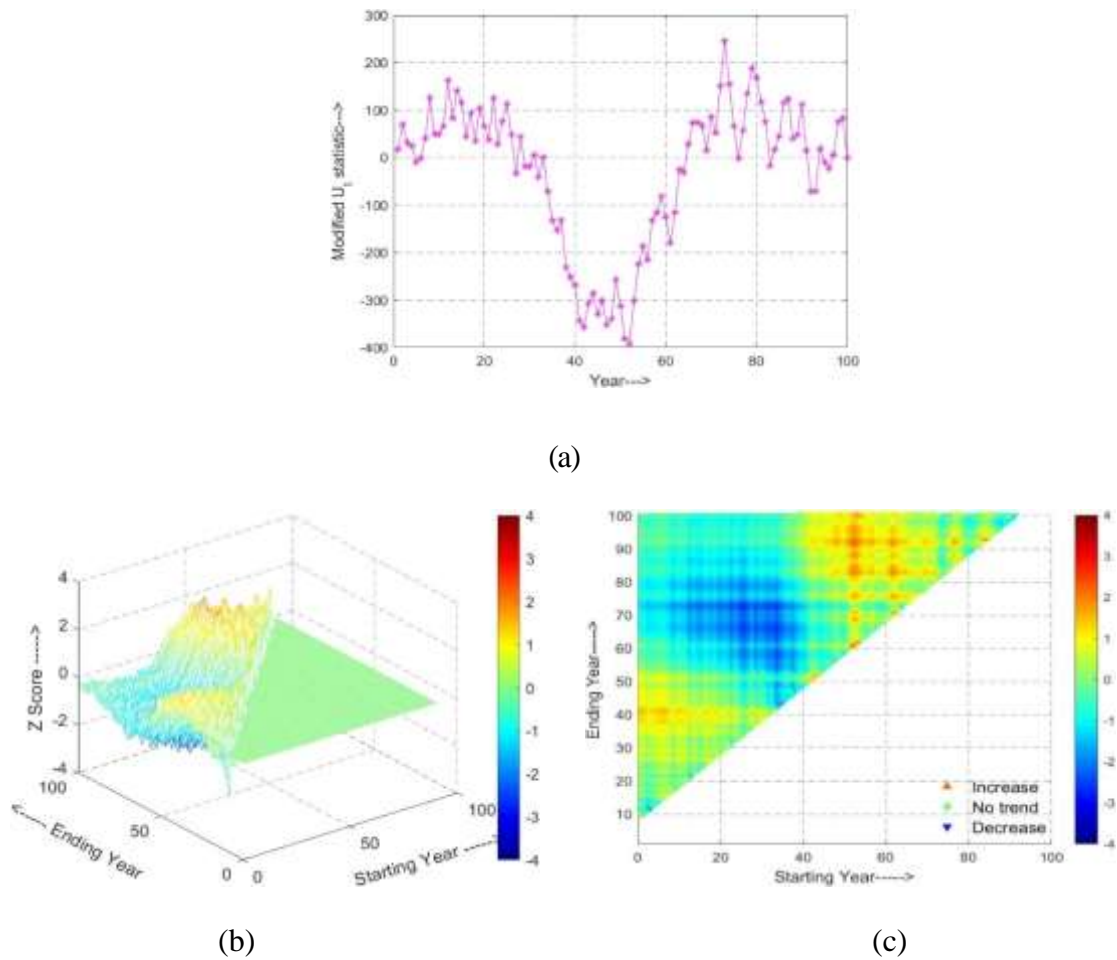
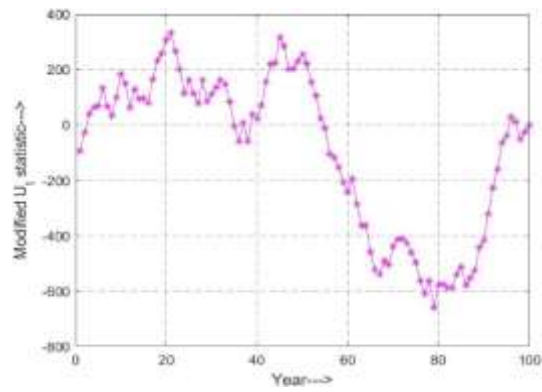
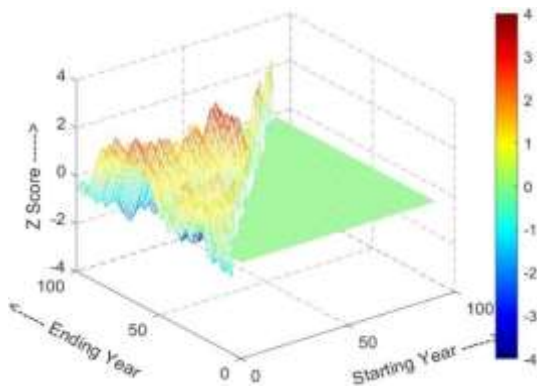


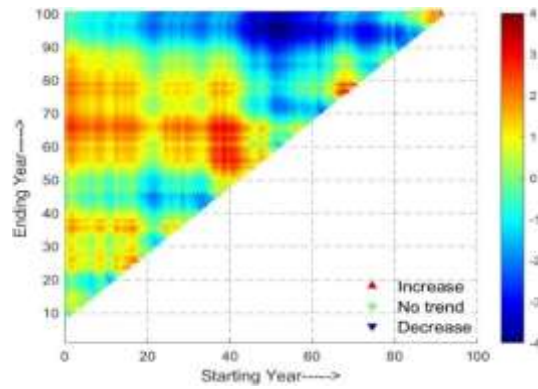
Figure 6.166 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the CDD trend in Purulia is at level of 0.05. (c) The 2-D pattern of the CDD trend in Purulia was at level of 0.05.



(a)



(b)



(c)

Figure 6.167 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the CWD trend in Purulia is at level of 0.05. (c) The 2-D pattern of the CWD trend in Purulia was at level of 0.05.

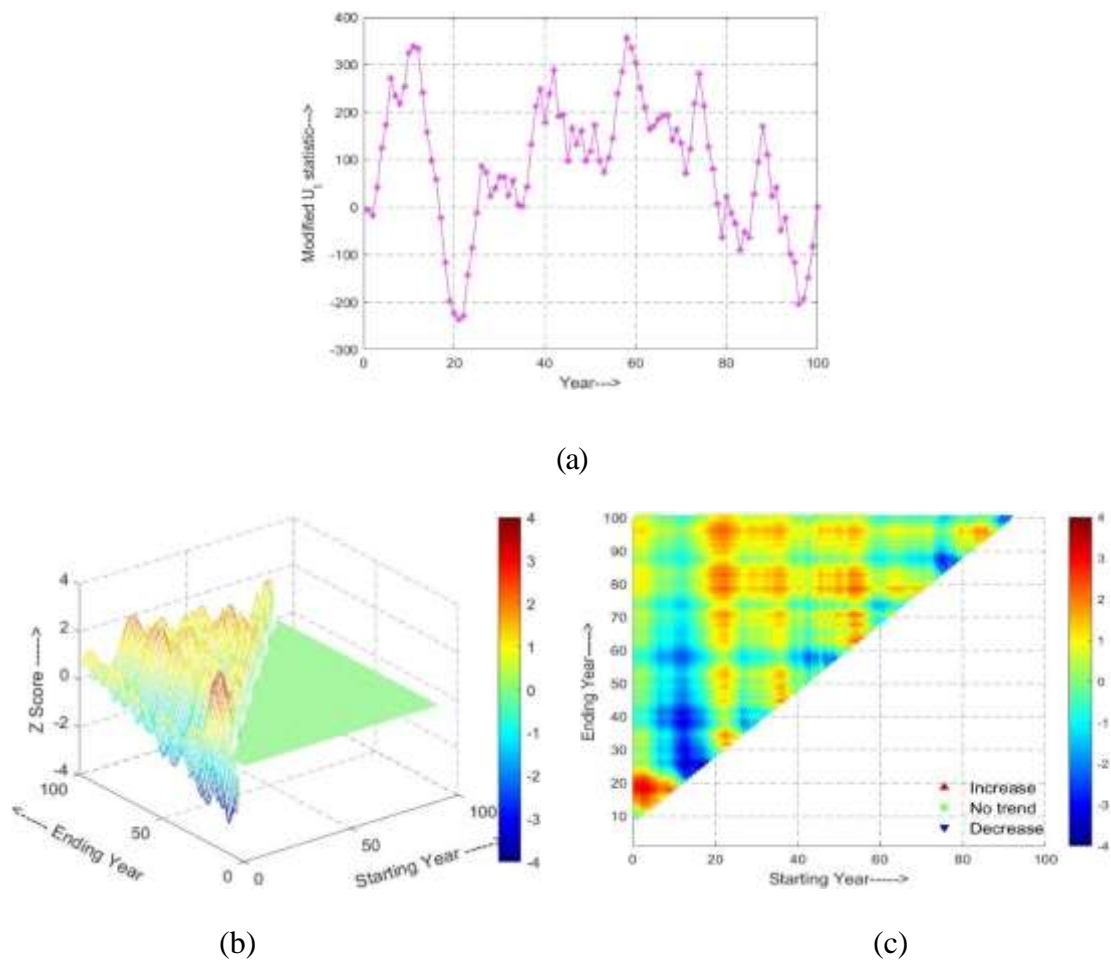


Figure 6.168 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the DTR trend in Purulia is at level of 0.05. (c) The 2-D pattern of the DTR trend in Purulia was at level of 0.05.

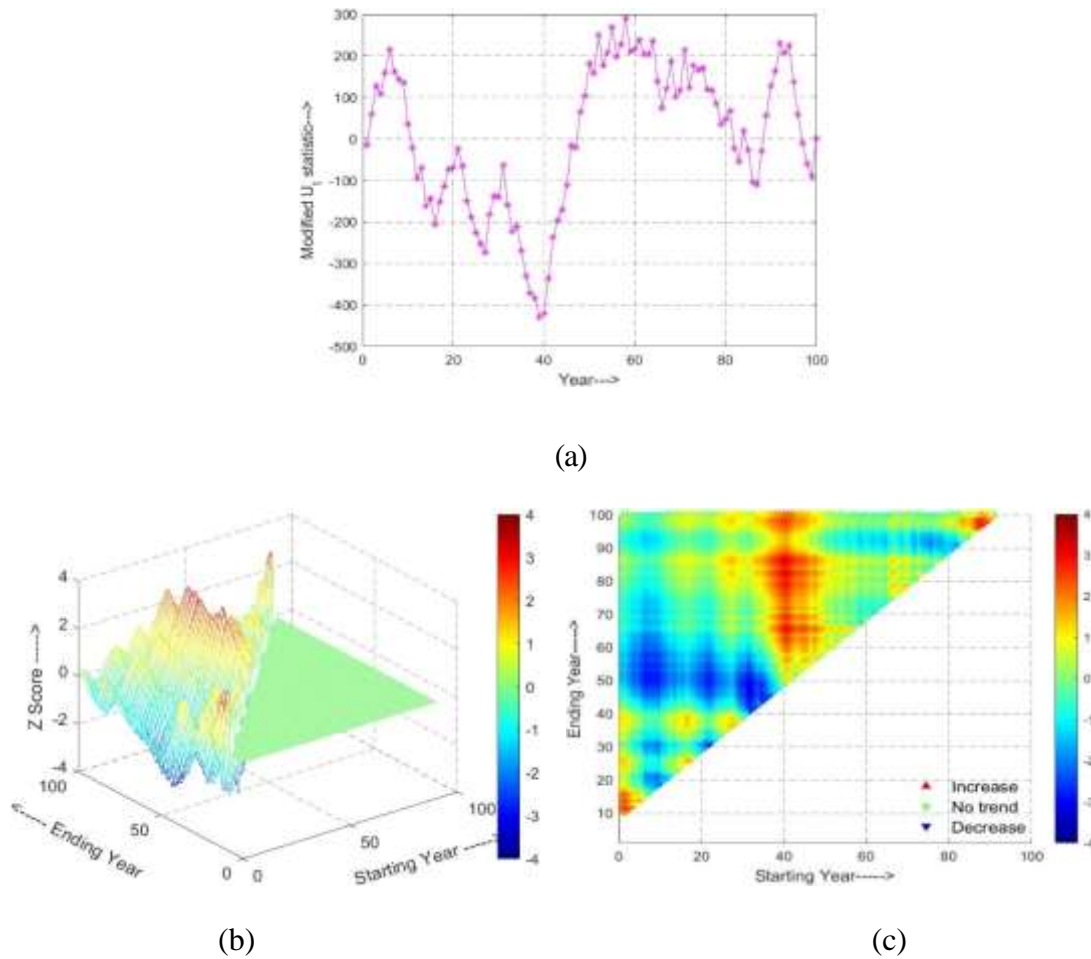


Figure 6.169 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the PRCPTOT trend in Purulia is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Purulia was at level of 0.05.

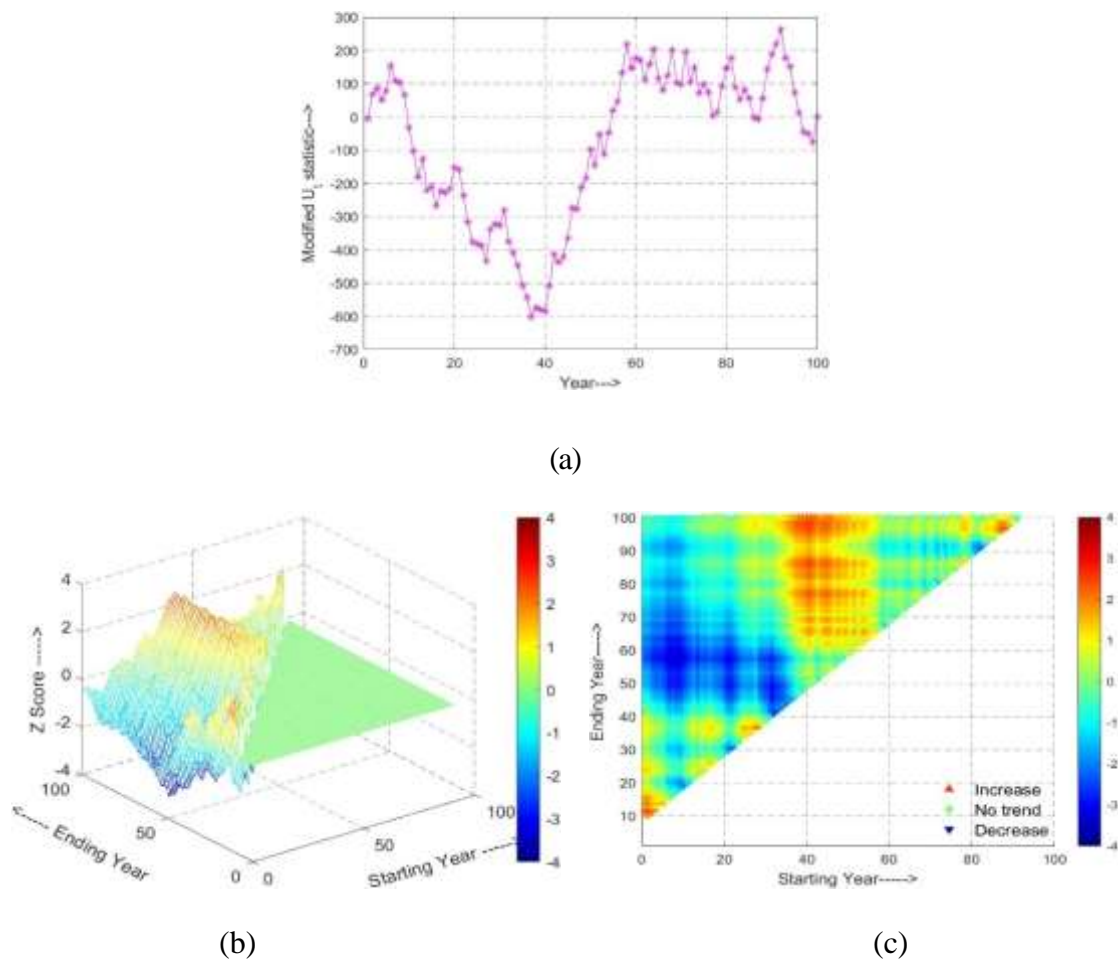
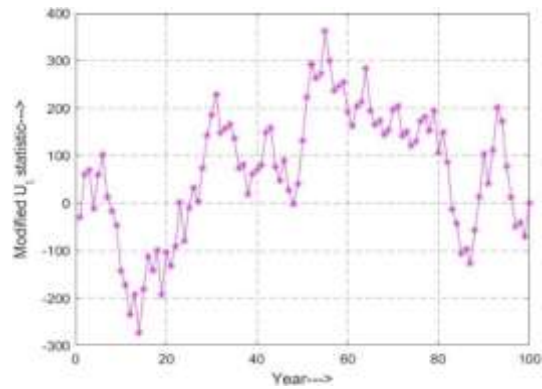
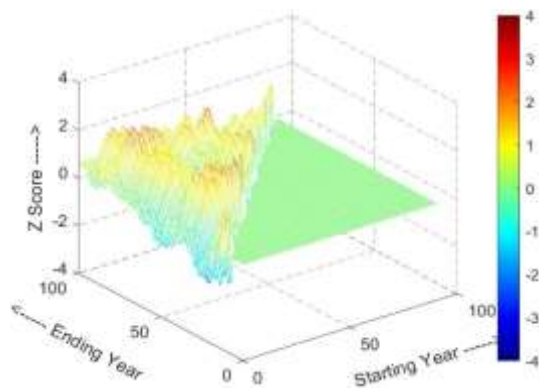


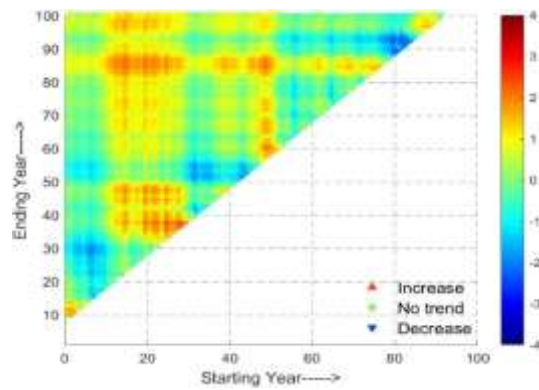
Figure 6.170 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the R10mm trend in Purulia is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Purulia was at level of 0.05.



(a)

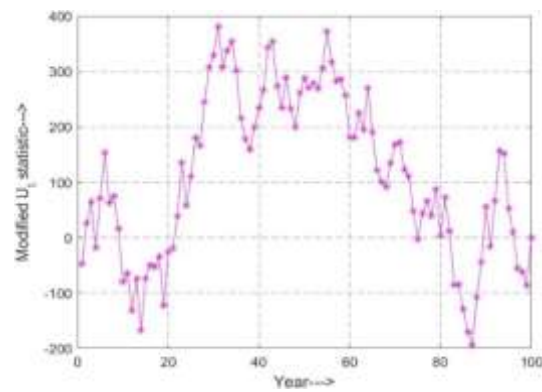


(b)

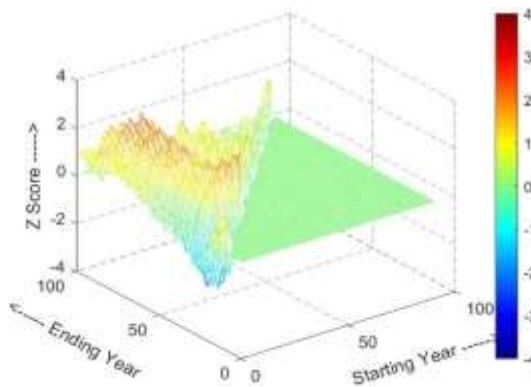


(c)

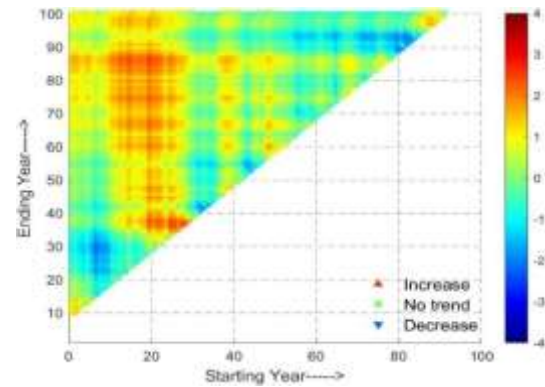
Figure 6.171 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the R20mm trend in Purulia is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Purulia was at level of 0.05.



(a)



(b)



(c)

Figure 6.172 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the R_{95p} trend in Purulia is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in Purulia was at level of 0.05.

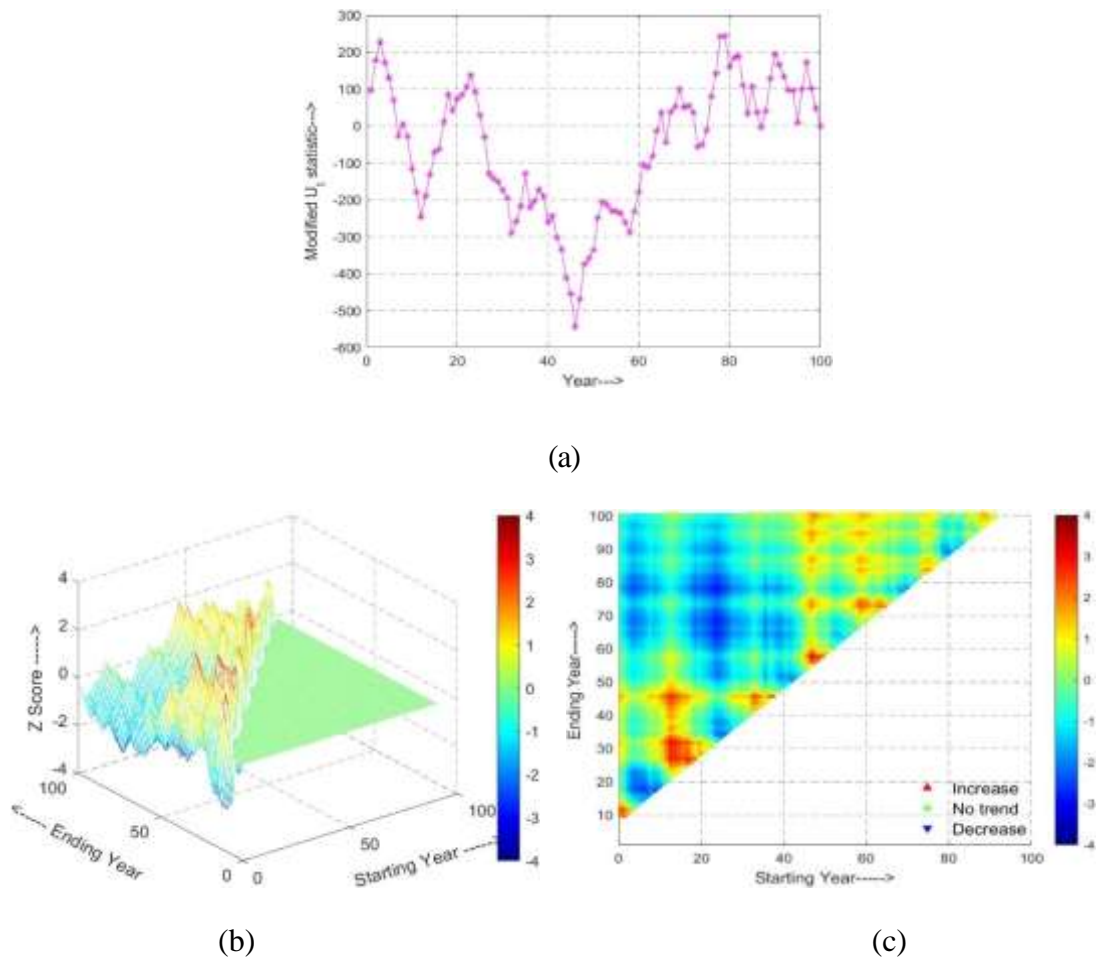


Figure 6.173 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the R_{99p} trend in Purulia is at level of 0.05. (c) The 2-D pattern of the R_{99p} trend in Purulia was at level of 0.05.

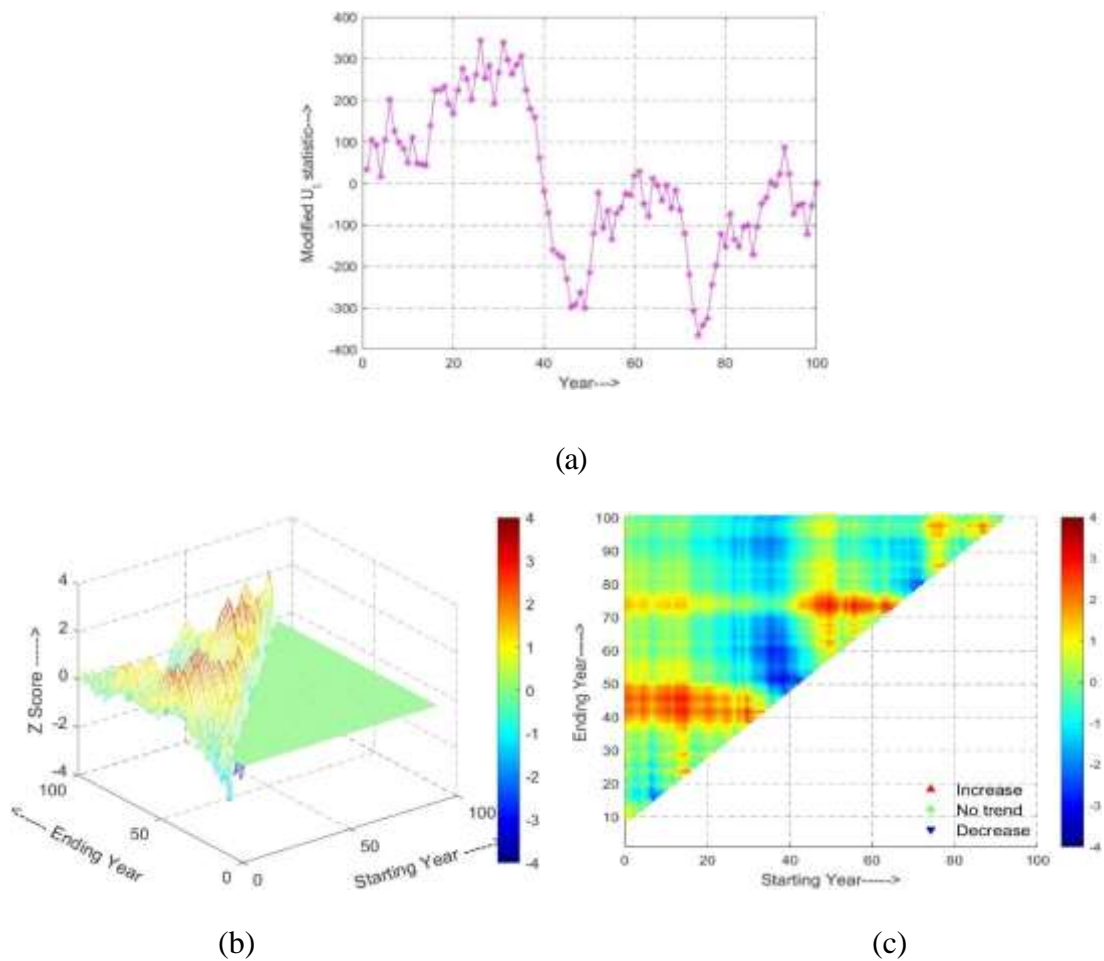
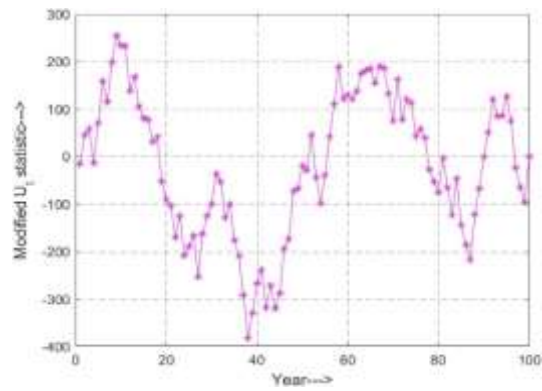
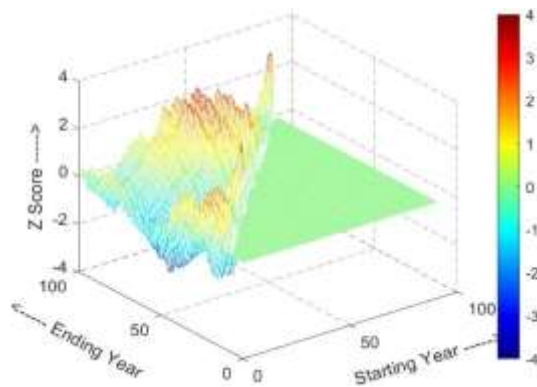


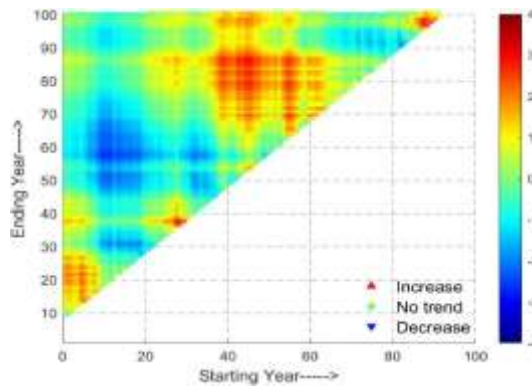
Figure 6.174 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the RX1day trend in Purulia is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Purulia was at level of 0.05.



(a)



(b)



(c)

Figure 6.175 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the RX5day trend in Purulia is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Purulia was at level of 0.05.

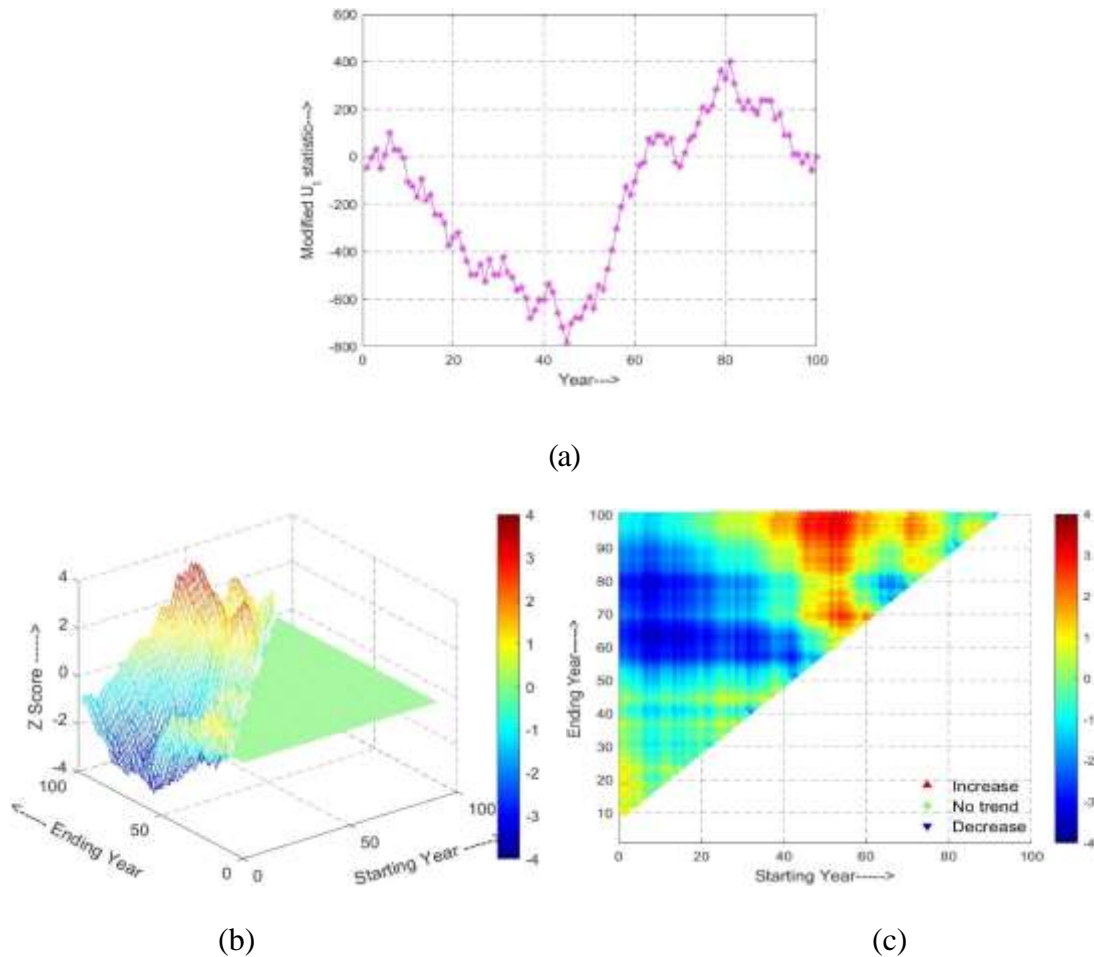
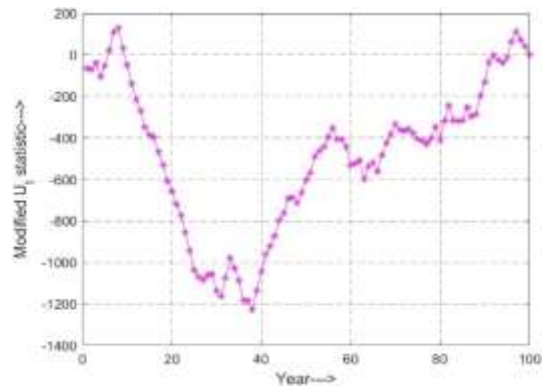
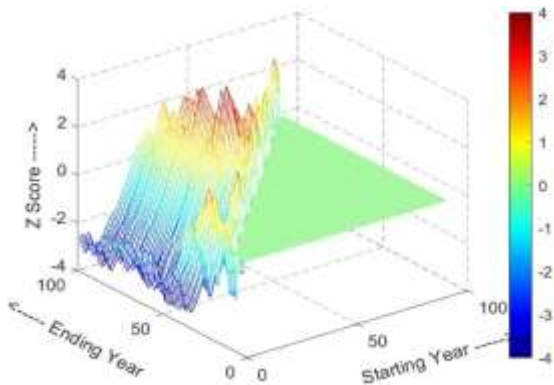


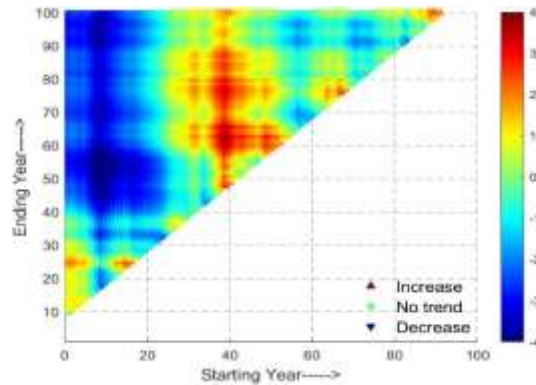
Figure 6.176 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the SDII trend in Purulia is at level of 0.05. (c) The 2-D pattern of the SDII trend in Purulia was at level of 0.05.



(a)



(b)



(c)

Figure 6.177 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the TNN trend in Purulia is at level of 0.05. (c) The 2-D pattern of the TNN trend in Purulia was at level of 0.05.

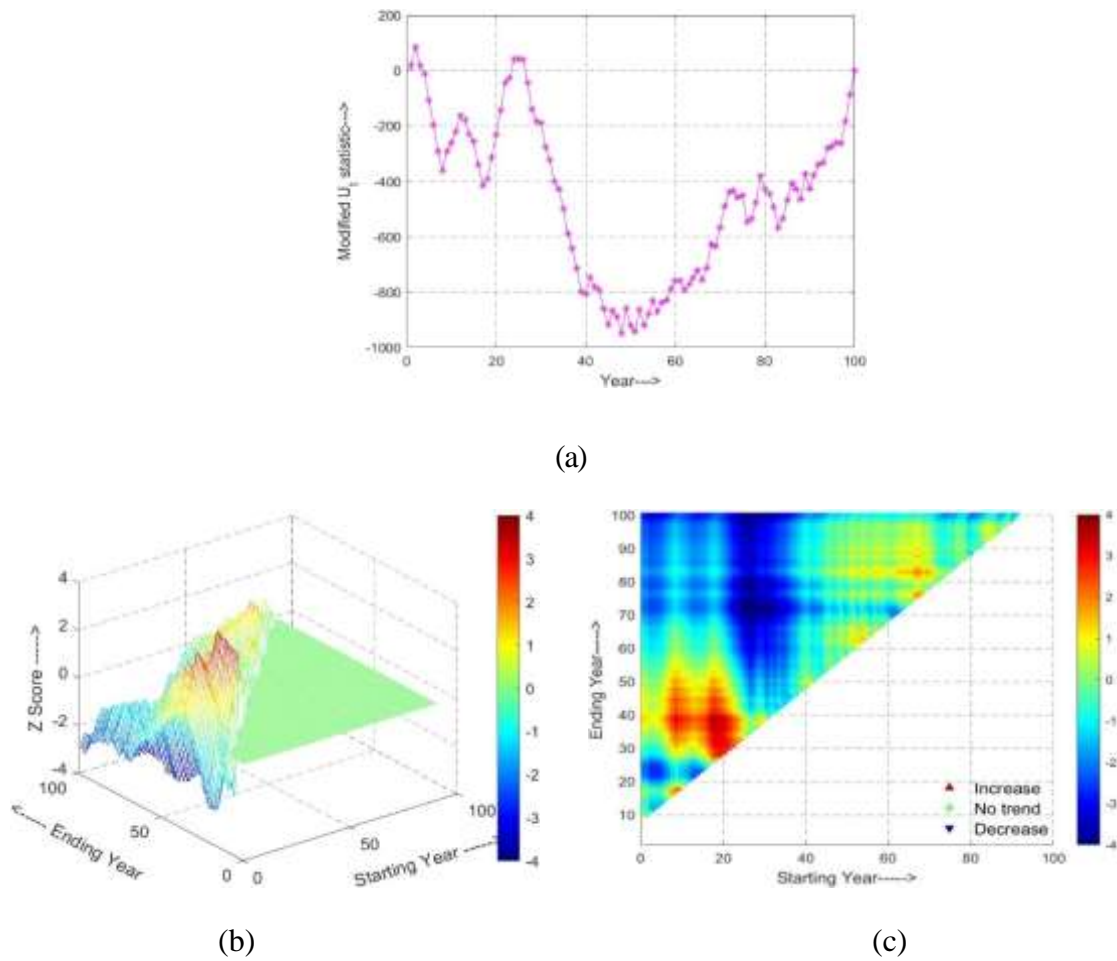
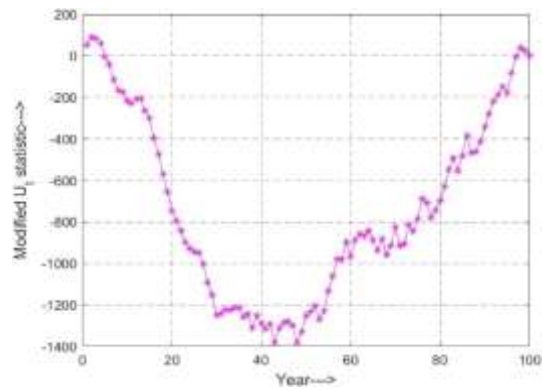
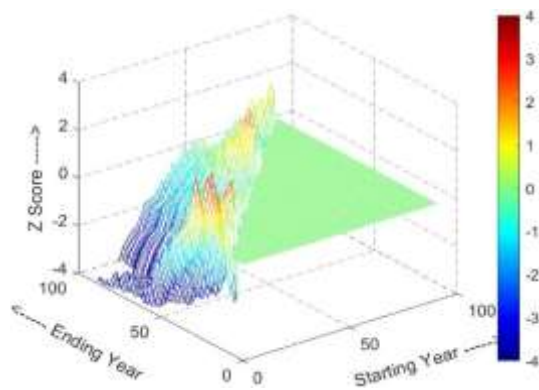


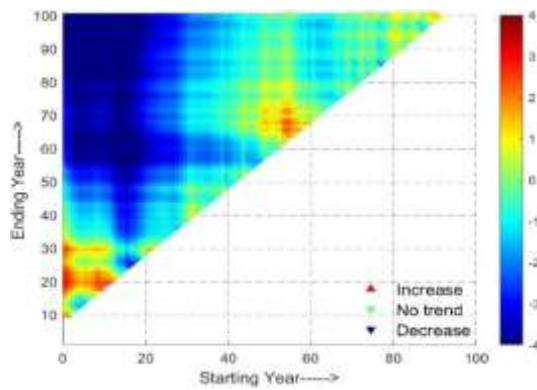
Figure 6.178 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the TNX trend in Purulia is at level of 0.05. (c) The 2-D pattern of the TNX trend in Purulia was at level of 0.05.



(a)



(b)



(c)

Figure 6.179 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the TXN trend in Purulia is at level of 0.05. (c) The 2-D pattern of the TXN trend in Purulia was at level of 0.05.

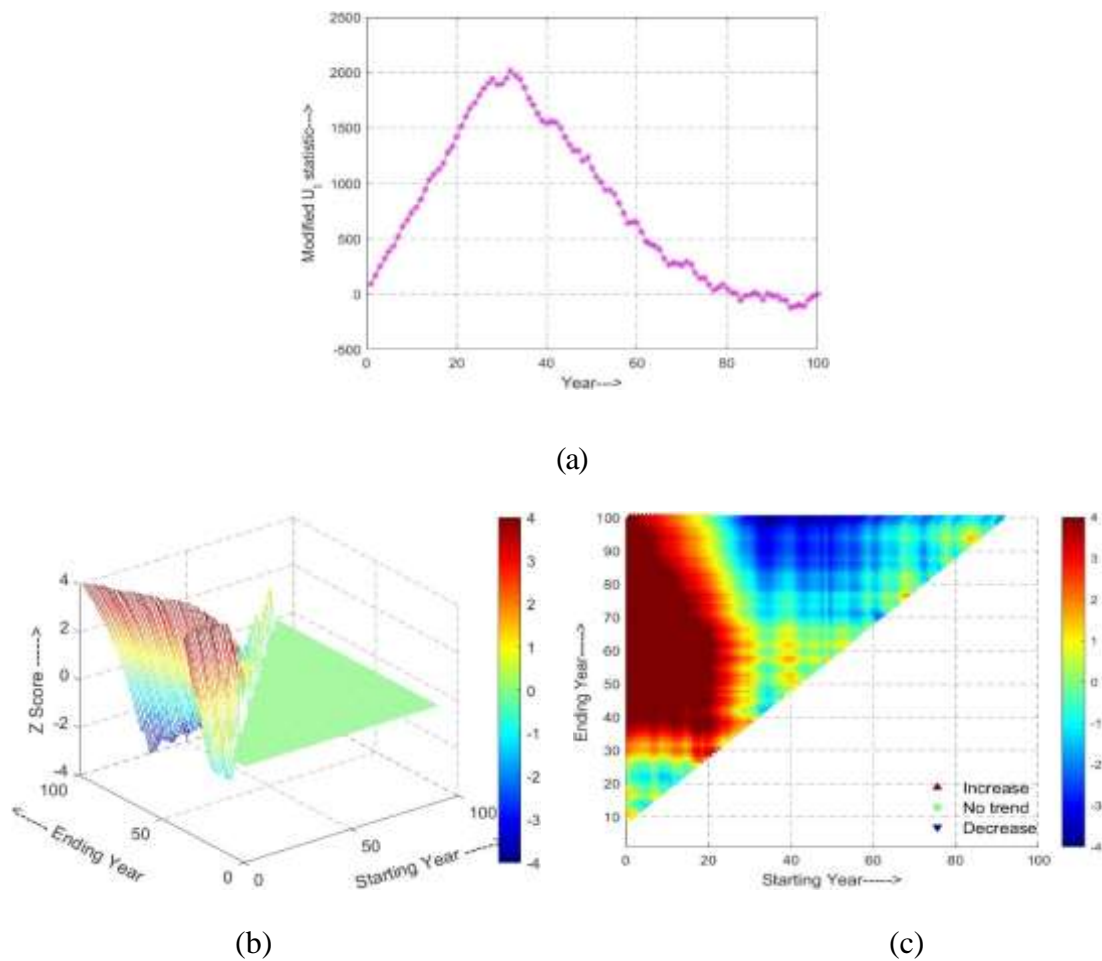


Figure 6.180 (a) Variation of modified U_t over the years to identify change points in Purulia. (b) The three-dimensional pattern of the TXX trend in Purulia is at level of 0.05. (c) The 2-D pattern of the TXX trend in Purulia was at level of 0.05.

6.2.13 Characteristics of Multiple Climatic Indices in Raghunathpur

Raghunathpur station, located in the West Bengal portion of the Damodar River Basin (DRB), has emerged as a significant site for research focused on long-term trends in extreme climate indices. This station was specifically selected for an in-depth analysis covering the years 1923 to 2022. Figures 6.181(b-c) to 6.195(b-c) provide both two-dimensional and three-dimensional visualizations of the extreme climate variables recorded at Raghunathpur. The initial sections of these figures illustrate patterns characterized by peaks and troughs, where peaks denote the intensity and direction of climate trends, while troughs represent fluctuations over time. These visual representations highlight Notable changes in extreme climate indices throughout the study period. The figures use various shaded zones to depict these variations, showing

troughs in the lower sections and crests in the upper portions of the triangular shapes, effectively capturing the dynamic nature of climate trends. The accompanying color bar in Figures 6.181(c) to 6.195(c) indicates that red represents an increasing rainfall trend, blue signifies a decreasing trend, and green reflects periods with no significant change.

From 1923 to 1950, Raghunathpur exhibited a declining trend in rainfall, as indicated by the blue shading in the figures. Conversely, an increasing trend was observed from 1950 to 1990, marked by red hues, while green areas denote periods of stability in the rainfall patterns. By analyzing the clustering of these trends, researchers were able to pinpoint key moments of significant shifts in climate patterns. The statistical data presented in Figures 6.181(c) to 6.195(c) affirm the accuracy and reliability of these visualized trends, enhancing the overall credibility of the analysis.

This research builds upon those findings by visualizing both increasing and decreasing rainfall trends from 1923 to 2022, utilizing advanced 2D and 3D models to effectively capture the evolving patterns. Additionally, the study introduced a modified version of the PMW test to identify multiple change points in the trends, offering a more detailed analysis compared to earlier studies that primarily focused on general trend detection.

The insights gained from this research are particularly relevant for planners and policymakers in the Raghunathpur region, as understanding the changing nature of rainfall patterns is crucial for effective agricultural management and water resource planning. Since a significant portion of Raghunathpur's population relies on agriculture, recognizing rainfall variability is essential for sustainable farming practices. By incorporating three-dimensional visualizations and identifying key change points in rainfall trends, this study contributes valuable knowledge regarding climate dynamics in Raghunathpur and their potential implications for agricultural and resource management strategies.

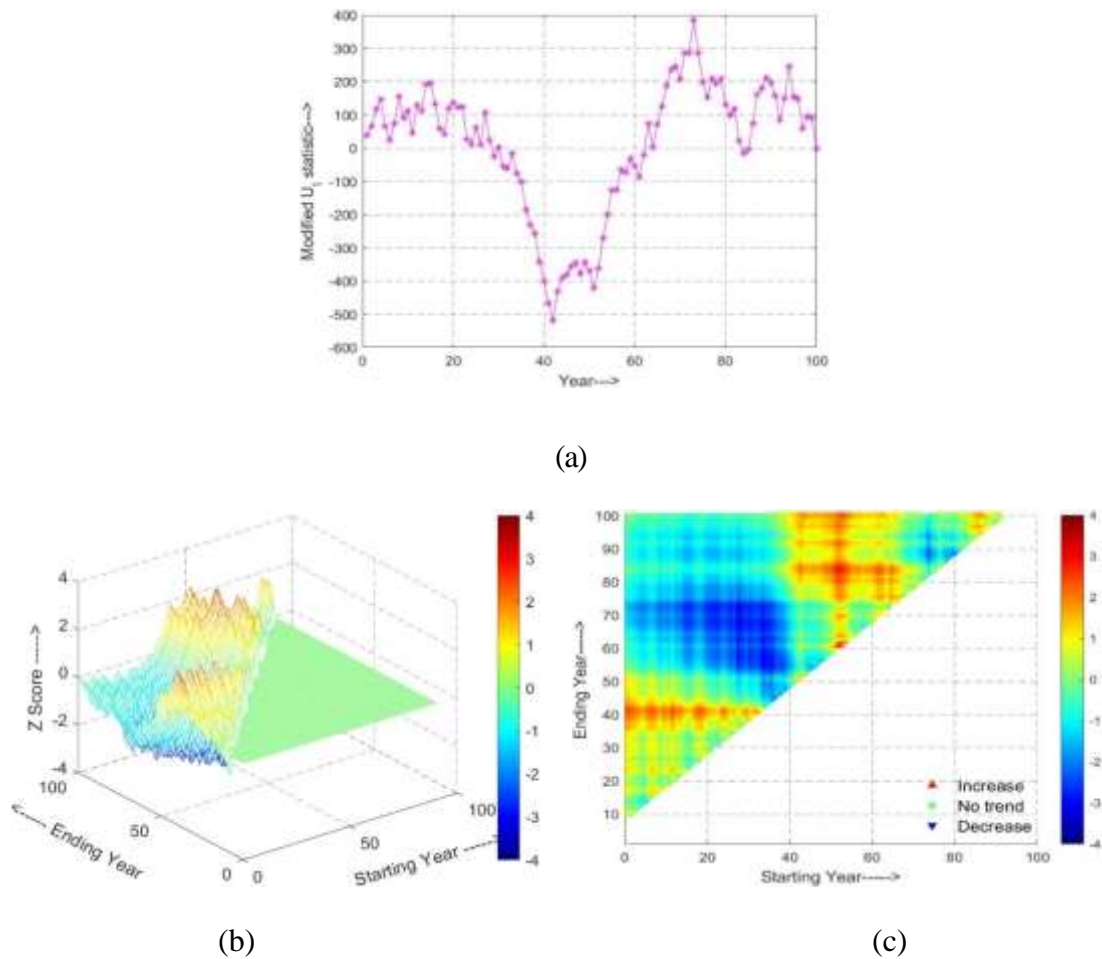


Figure 6.181 (a) Variation of modified U over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the CDD trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the CDD trend in Raghunathpur was at level of 0.05.

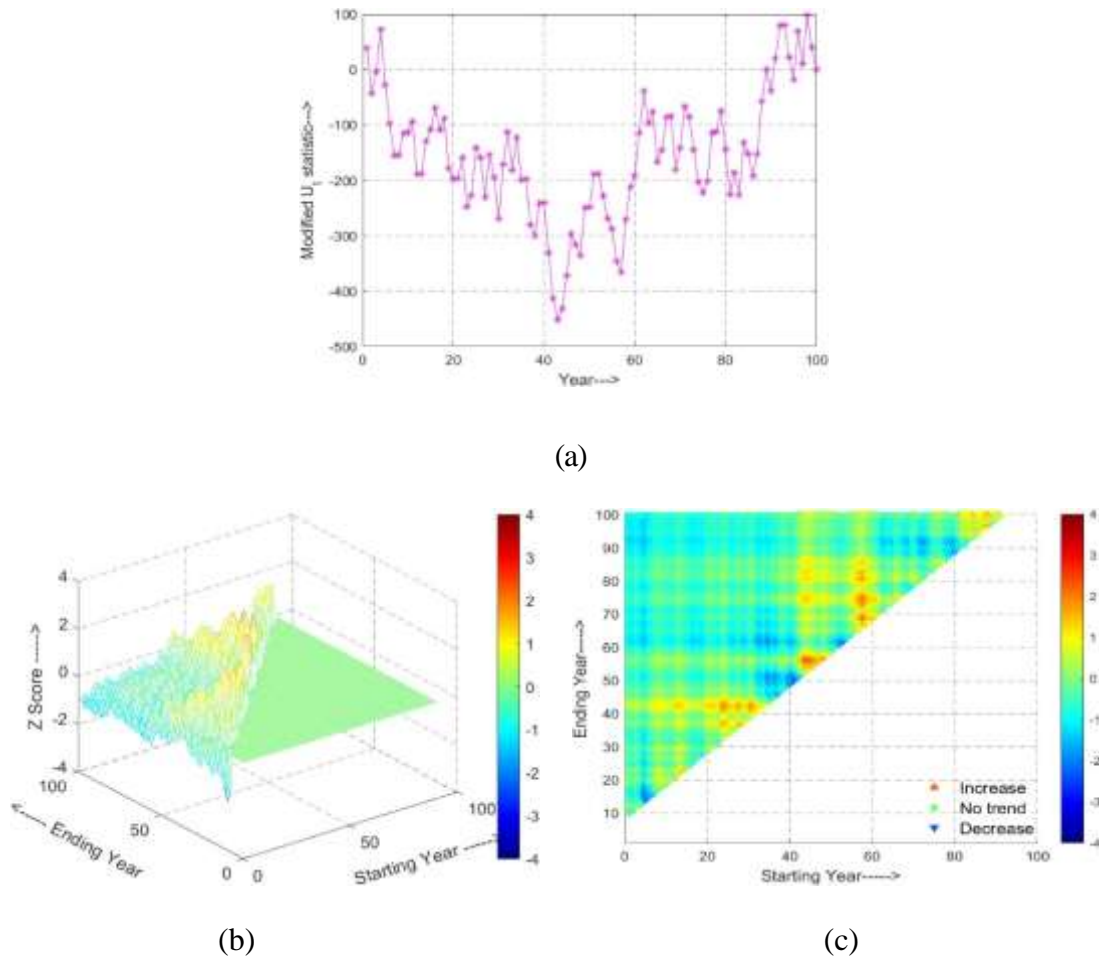


Figure 6.182 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the CWD trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the CWD trend in Raghunathpur was at level of 0.05.

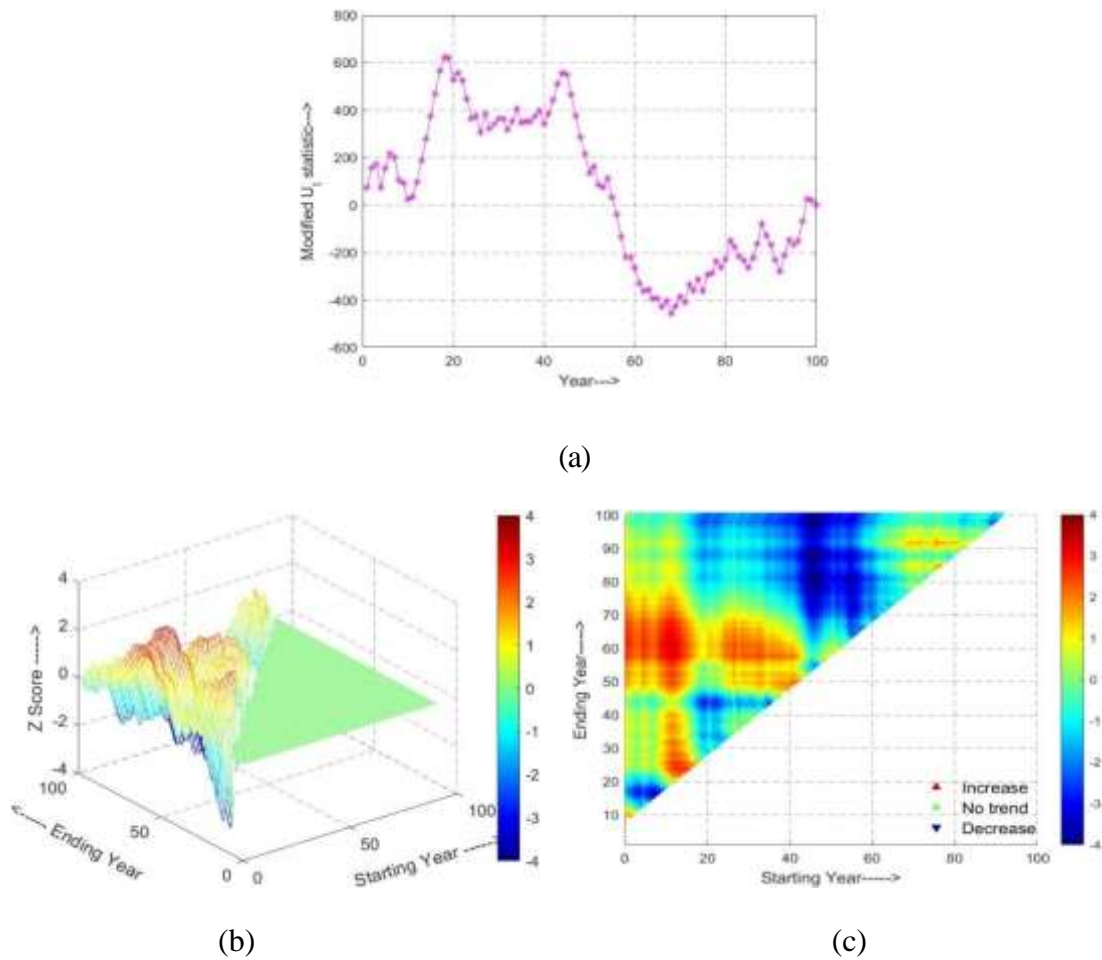
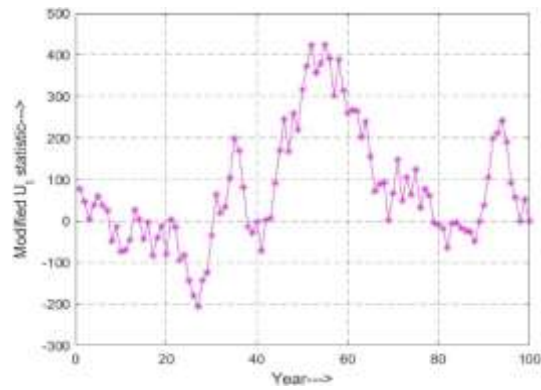
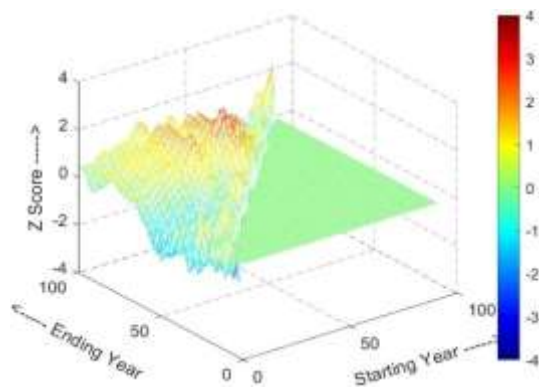


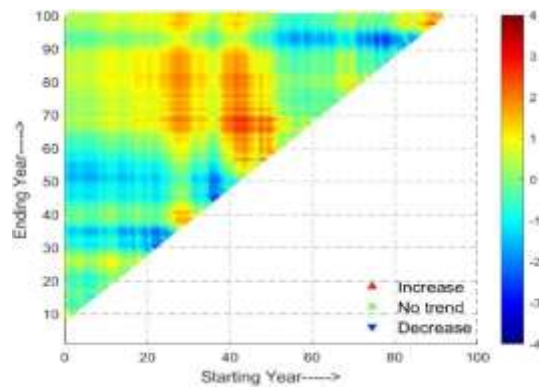
Figure 6.183 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the DTR trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the DTR trend in Raghunathpur was at level of 0.05.



(a)



(b)



(c)

Figure 6.184 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the PRCPTOT trend (c) The 2-D pattern of the PRCPTOT trend in Raghunathpur was at level of 0.05.

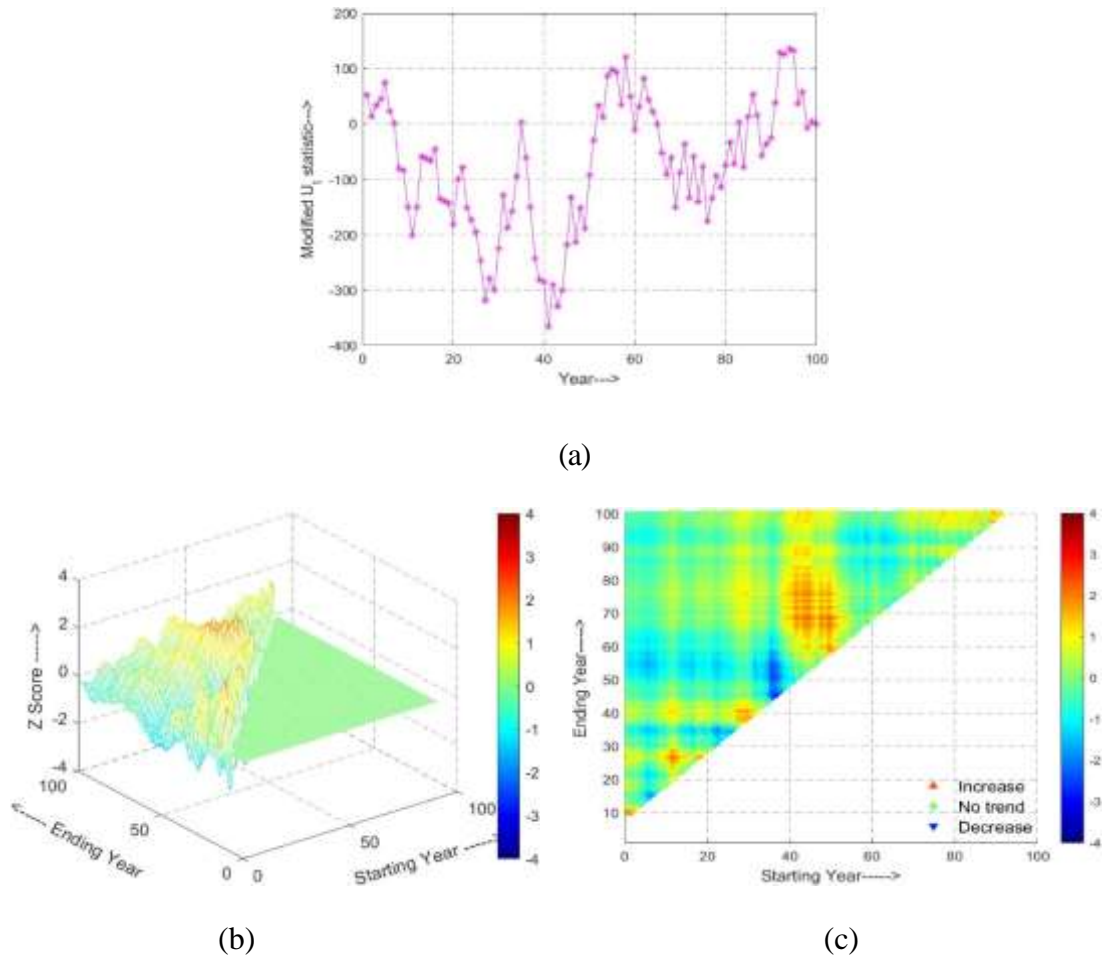
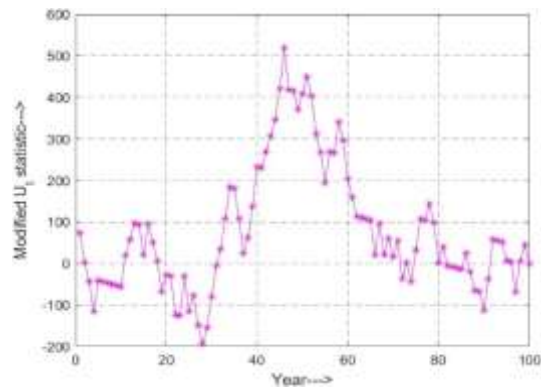
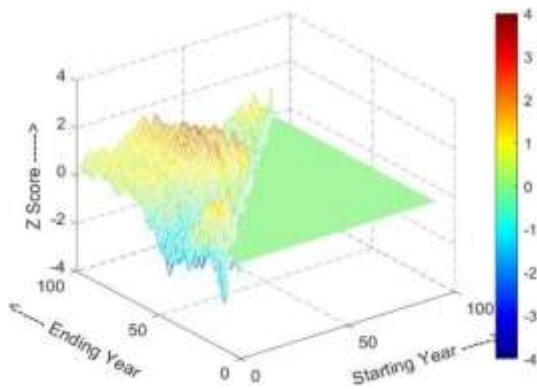


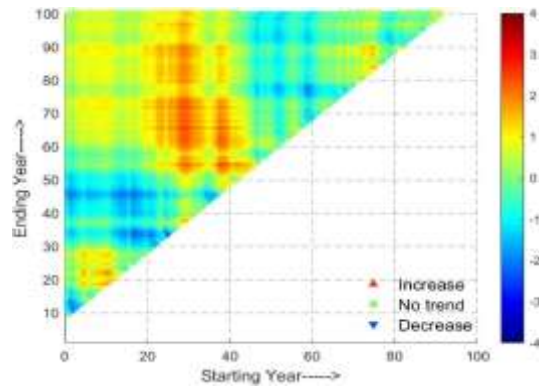
Figure 6.185 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the R10mm trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Raghunathpur was at level of 0.05



(a)



(b)



(c)

Figure 6.186 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the R20mm trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Raghunathpur was at level of 0.05

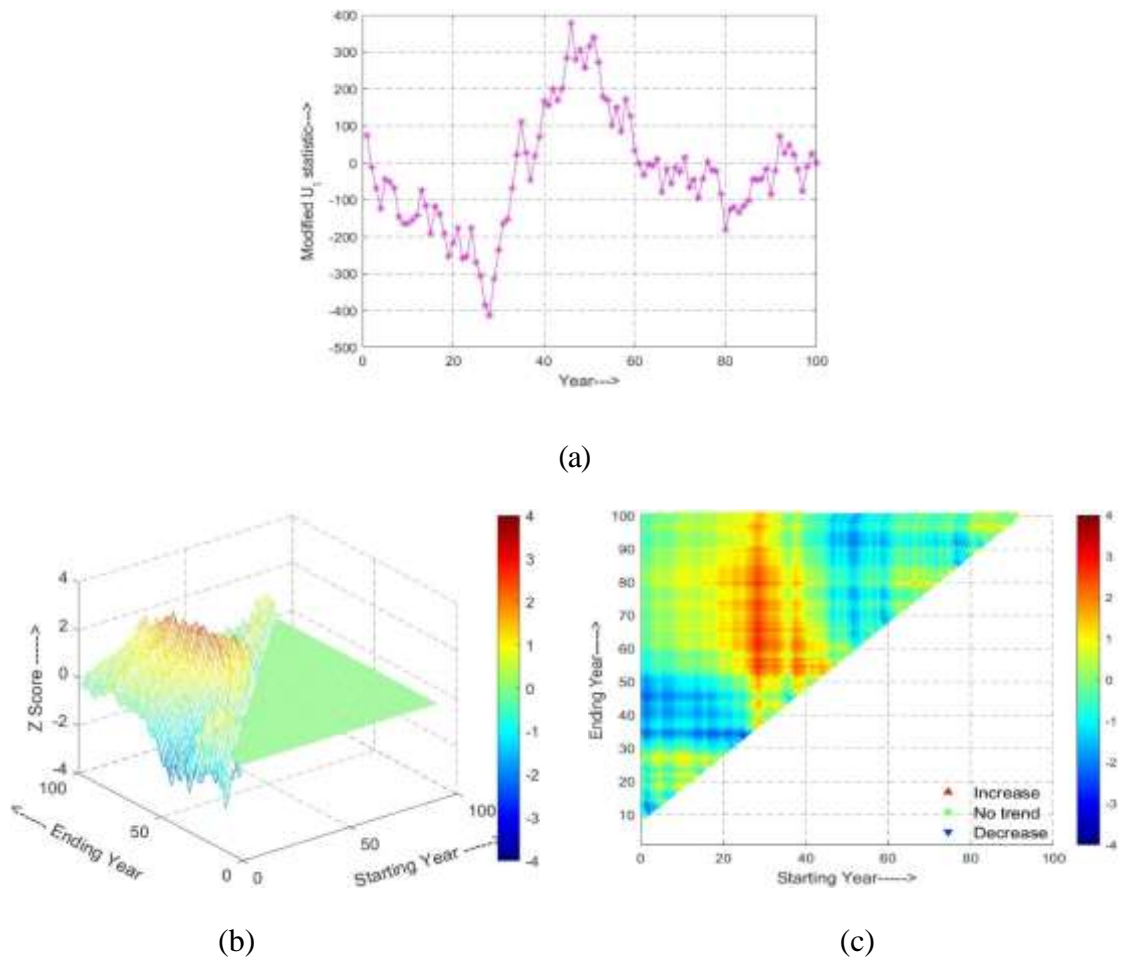
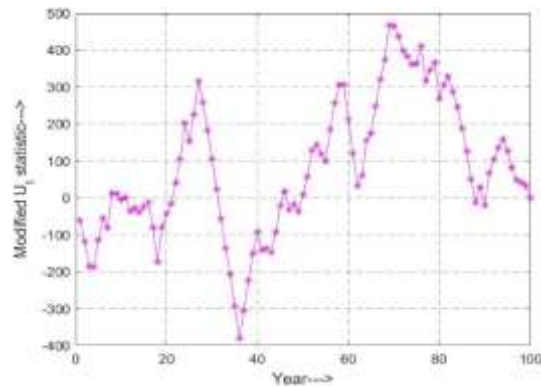
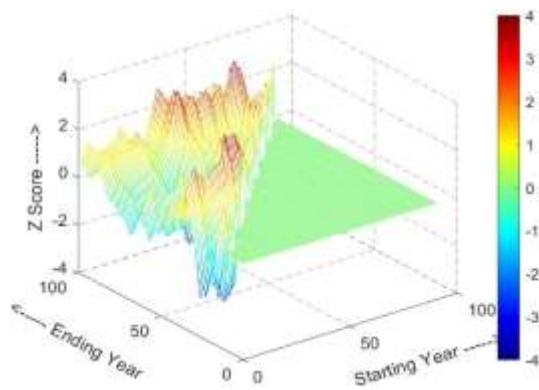


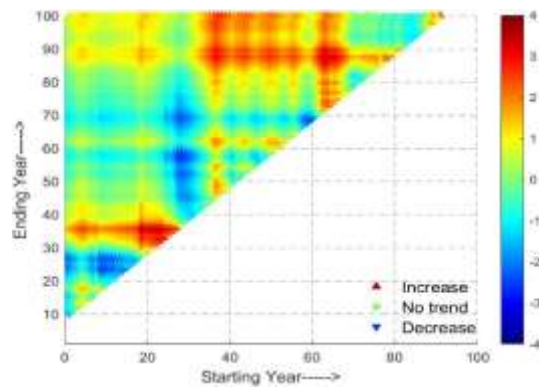
Figure 6.187 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the R_{95p} trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in Raghunathpur was at level of 0.05.



(a)



(b)



(c)

Figure 6.188 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the $R99p$ trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the $R99p$ trend in Raghunathpur was at level of 0.05.

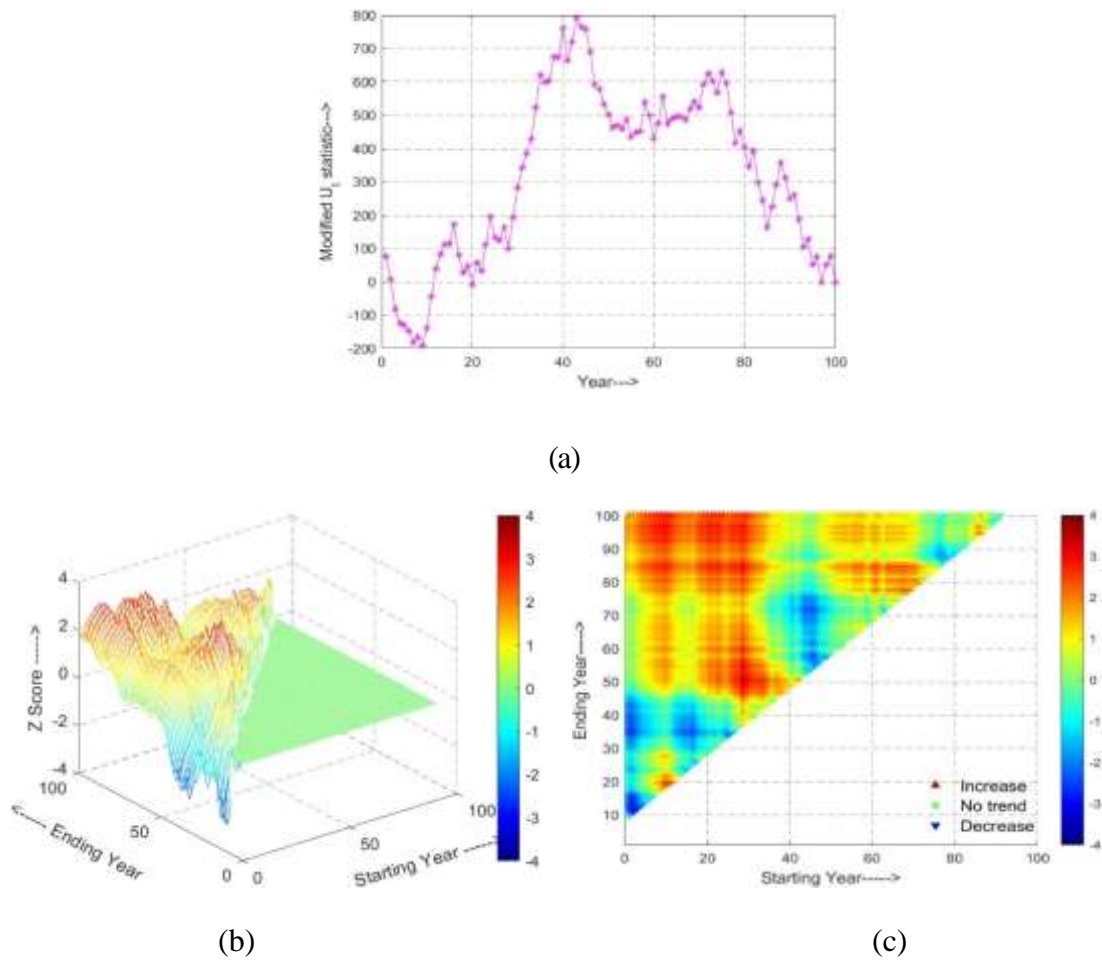
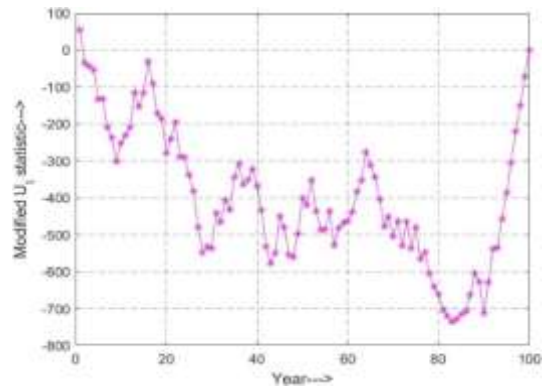
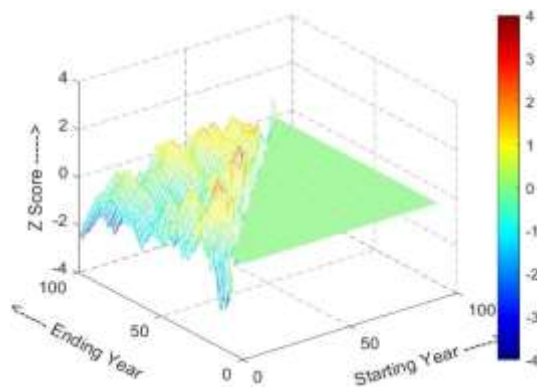


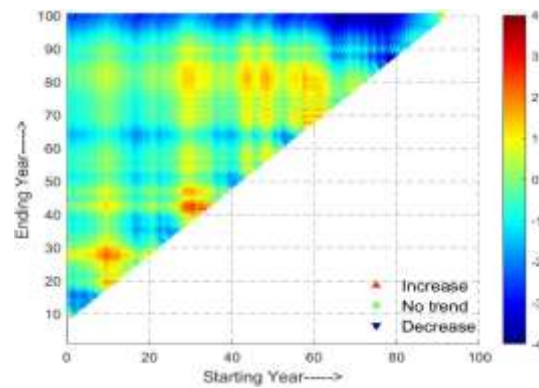
Figure 6.189 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the RX1day trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Raghunathpur was at level of 0.05.



(a)



(b)



(c)

Figure 6.190 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the RX5day trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Raghunathpur was at level of 0.05

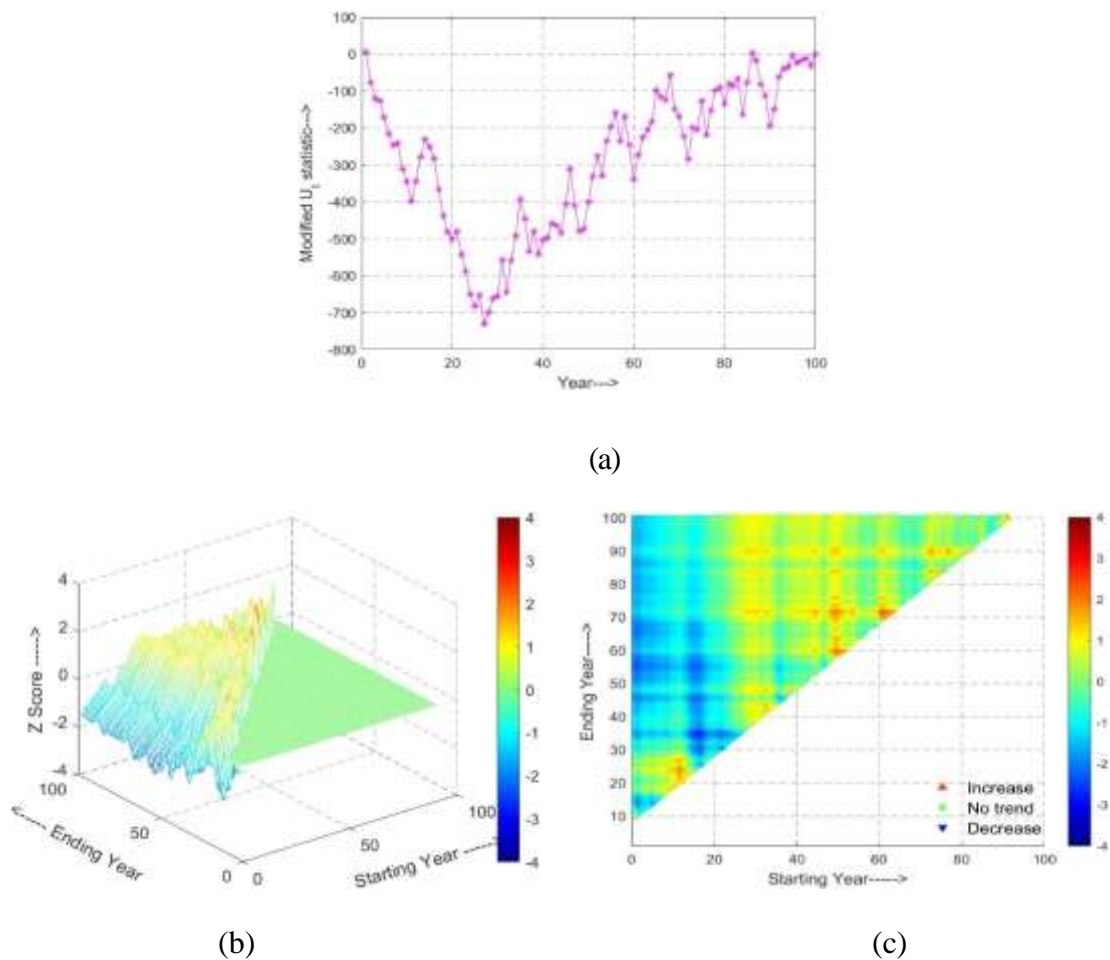
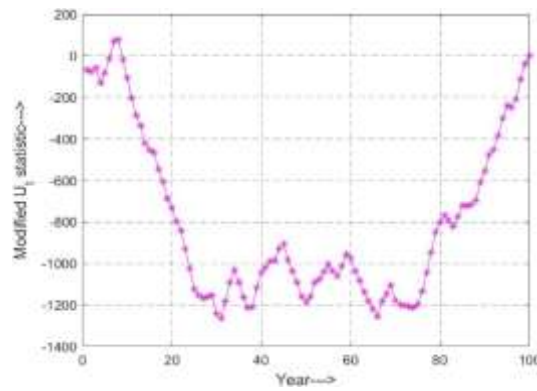
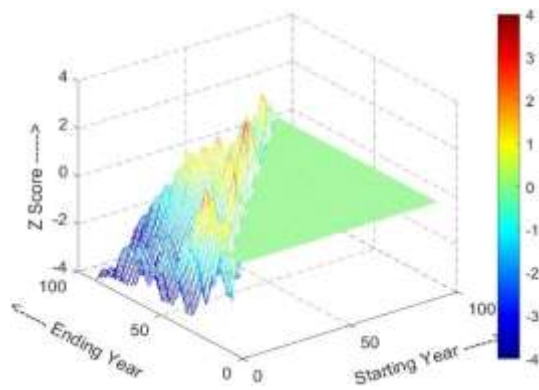


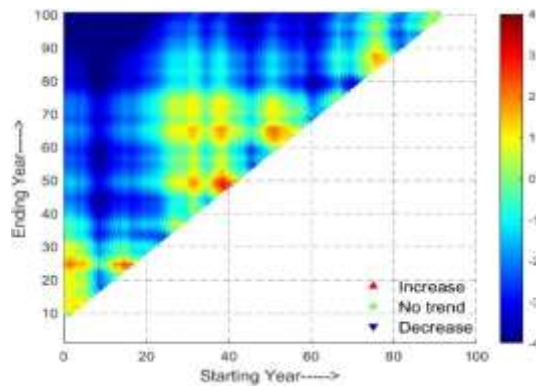
Figure 6.191 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the SDII trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the SDII trend in Raghunathpur was at level of 0.05.



(a)



(b)



(c)

Figure 6.192 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the TNN trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the TNN trend in Raghunathpur was at level of 0.05.

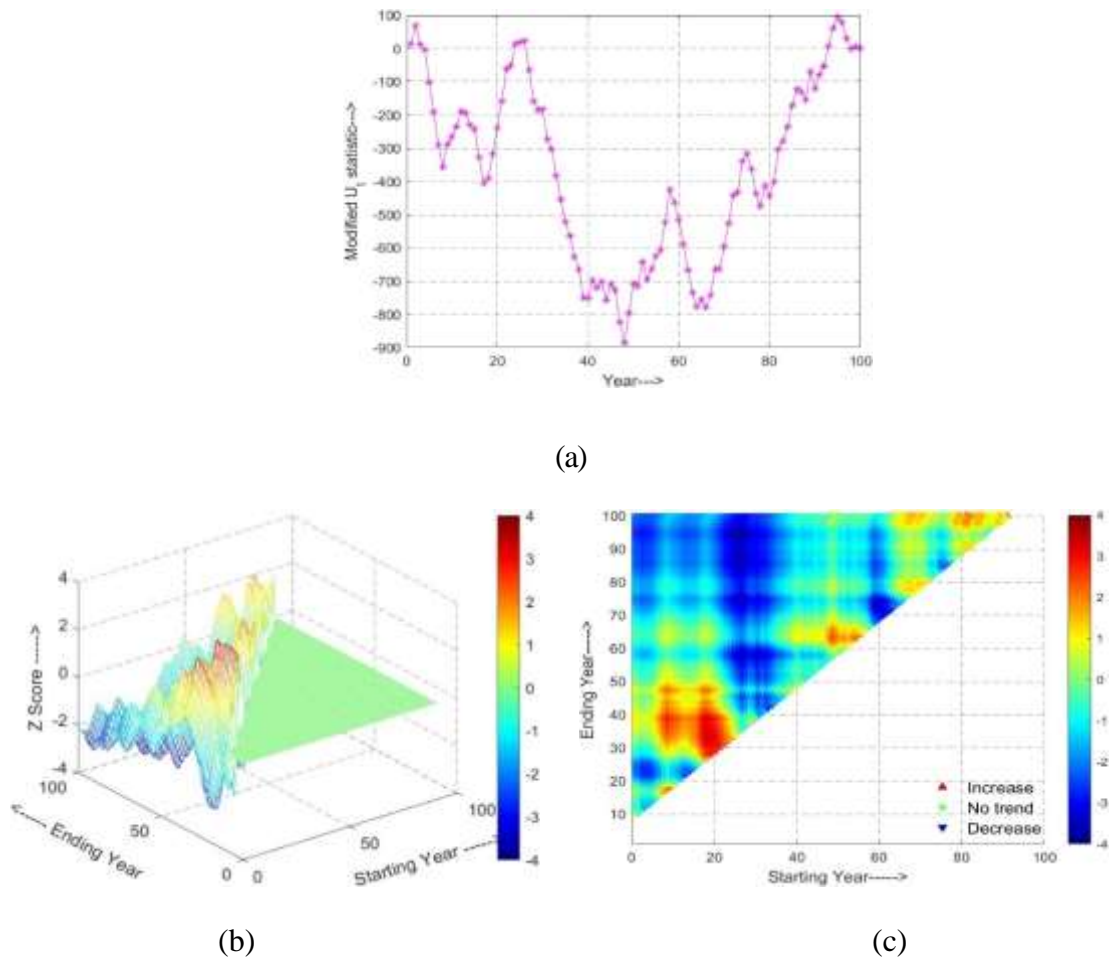


Figure 6.193 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the TNX trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the TNX trend in Raghunathpur was at level of 0.05.

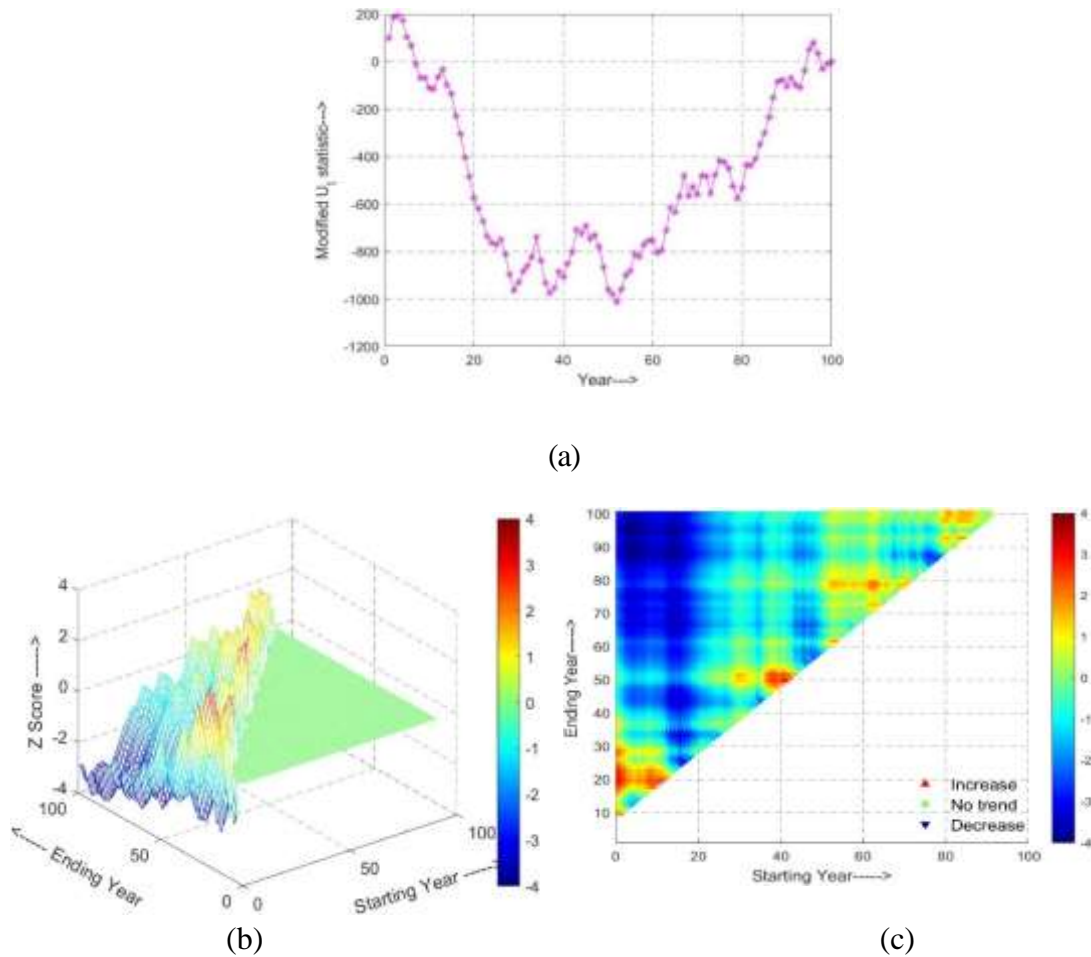
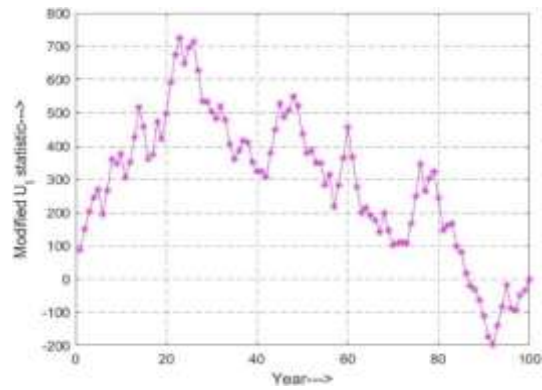
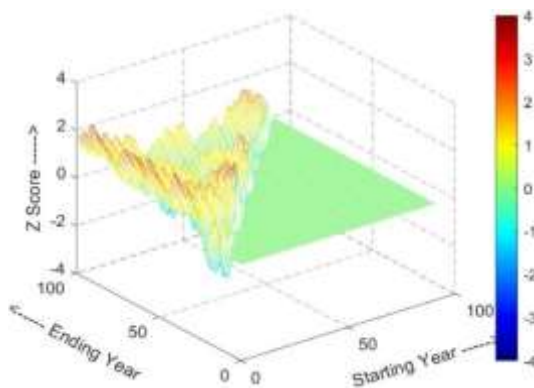


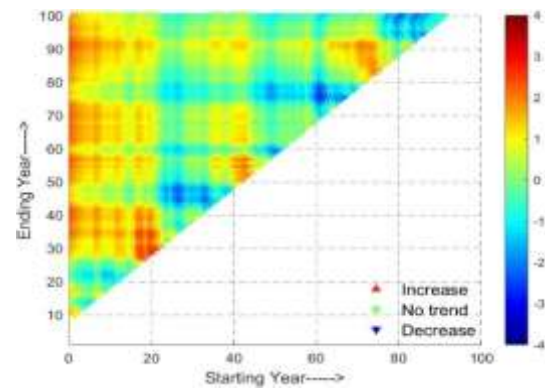
Figure 6.194 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the TXN trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the TXN trend in Raghunathpur was at level of 0.05.



(a)



(b)



(c)

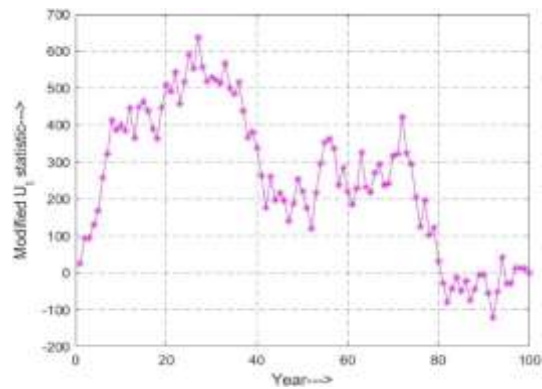
Figure 6.195 (a) Variation of modified U_t over the years to identify change points in Raghunathpur. (b) The three-dimensional pattern of the TXX trend in Raghunathpur is at level of 0.05. (c) The 2-D pattern of the TXX trend in Raghunathpur was at level of 0.05.

6.2.14 Characteristics of Multiple Climatic Indices in Ramgarh

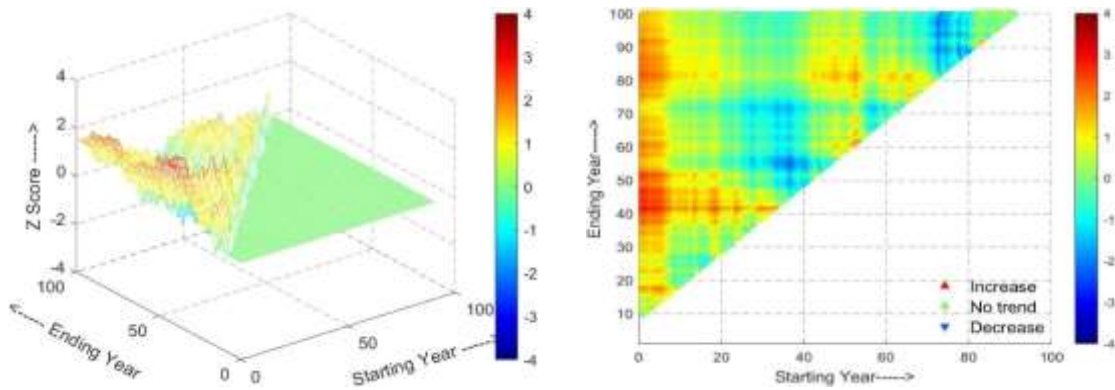
Ramgarh station, located in the Jharkhand portion of the Damodar River Basin (DRB), has become an important center for research aimed at examining long-term trends in extreme climate indices. This station was specifically selected for a thorough analysis covering the period from 1923 to 2022. Figures 6.196(b-c) to 6.210(b-c) present both two-dimensional and three-dimensional visualizations of the extreme climate variables observed at Ramgarh. The initial segments of these figures reveal patterns characterized by peaks and troughs, where peaks indicate the intensity and direction of climate trends, while troughs reflect fluctuations over time. These visual representations underscore significant changes in extreme climate indices throughout the study period. The figures utilize various shaded zones to depict these variations, displaying troughs in the lower sections and crests in the upper portions of the triangular shapes, effectively illustrating the dynamic nature of climate trends. The accompanying color bar in Figures 6.196(c) to 6.210(c) indicates that red corresponds to an increasing rainfall trend, blue signifies a decreasing trend, and green reflects periods of no substantial change.

From 1923 to 1950, Ramgarh displayed a downward trend in rainfall, as indicated by the blue shading in the figures. In contrast, an upward trend was observed from 1950 to 1990, marked by red hues, while green areas denote periods of stability in the rainfall patterns. By analyzing the clustering of these trends, researchers were able to identify key moments of significant shifts in climate patterns. The statistical data presented in Figures 6.196(c) to 6.210(c) support the accuracy and reliability of these visualized trends, thereby enhancing the overall credibility of the analysis.

The insights gained from this research are particularly relevant for planners and policymakers in the Ramgarh region, as understanding the evolving nature of rainfall patterns is crucial for effective agricultural management and water resource planning. Given that a significant portion of the population in Ramgarh relies on agriculture, recognizing rainfall variability is essential for sustainable farming practices. By incorporating three-dimensional visualizations and pinpointing key change points in rainfall trends, this study contributes valuable knowledge regarding climate dynamics in Ramgarh and their potential implications for agricultural and resource management strategies.



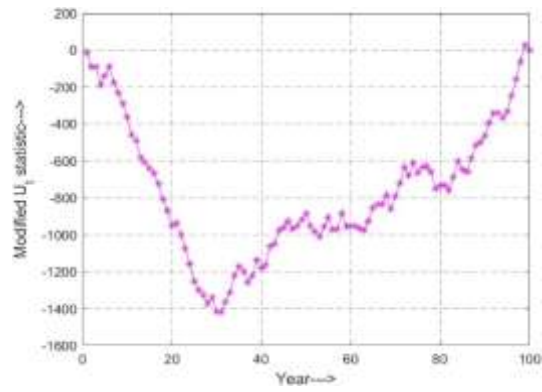
(a)



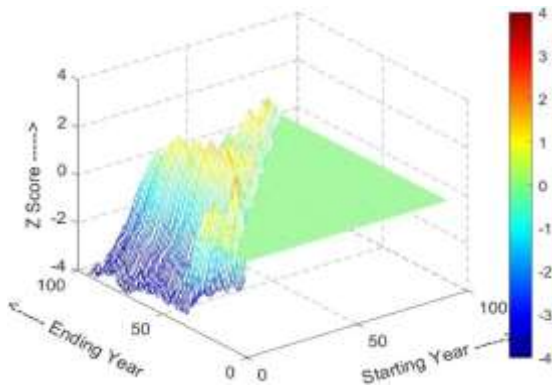
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(c)

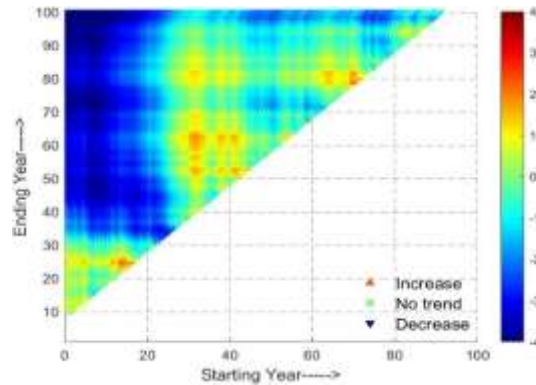
Figure 6.196 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the CDD trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the CDD trend in Ramgarh was at level of 0.05.



(a)

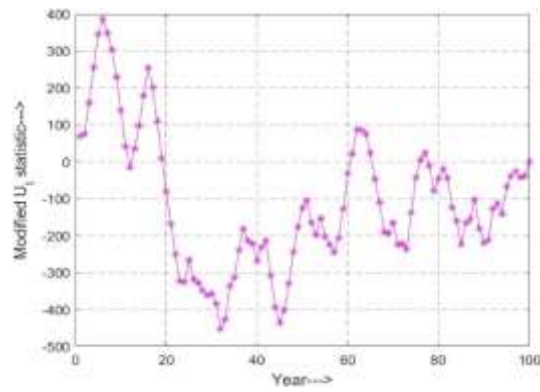


(b)

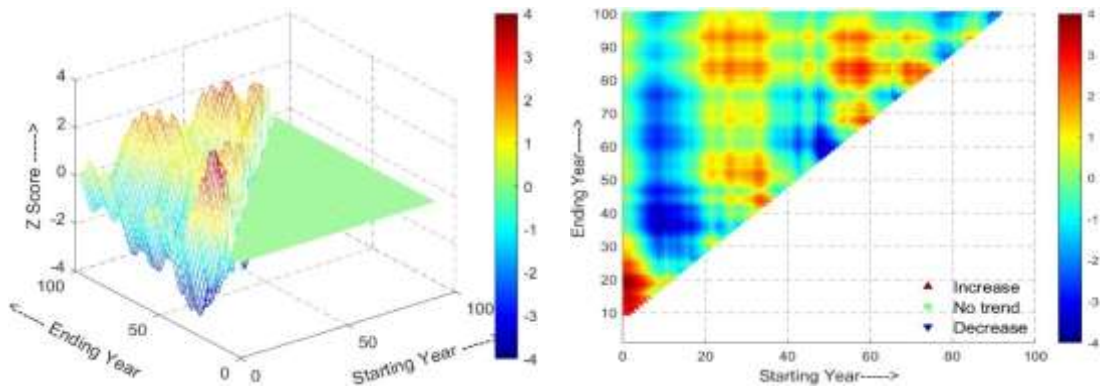


(c)

Figure 6.197 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the CWD trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the CWD trend in Ramgarh was at level of 0.05.



(a)



(b)

(c)

Figure 6.198 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the DTR trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the DTR trend in Ramgarh was at level of 0.05.

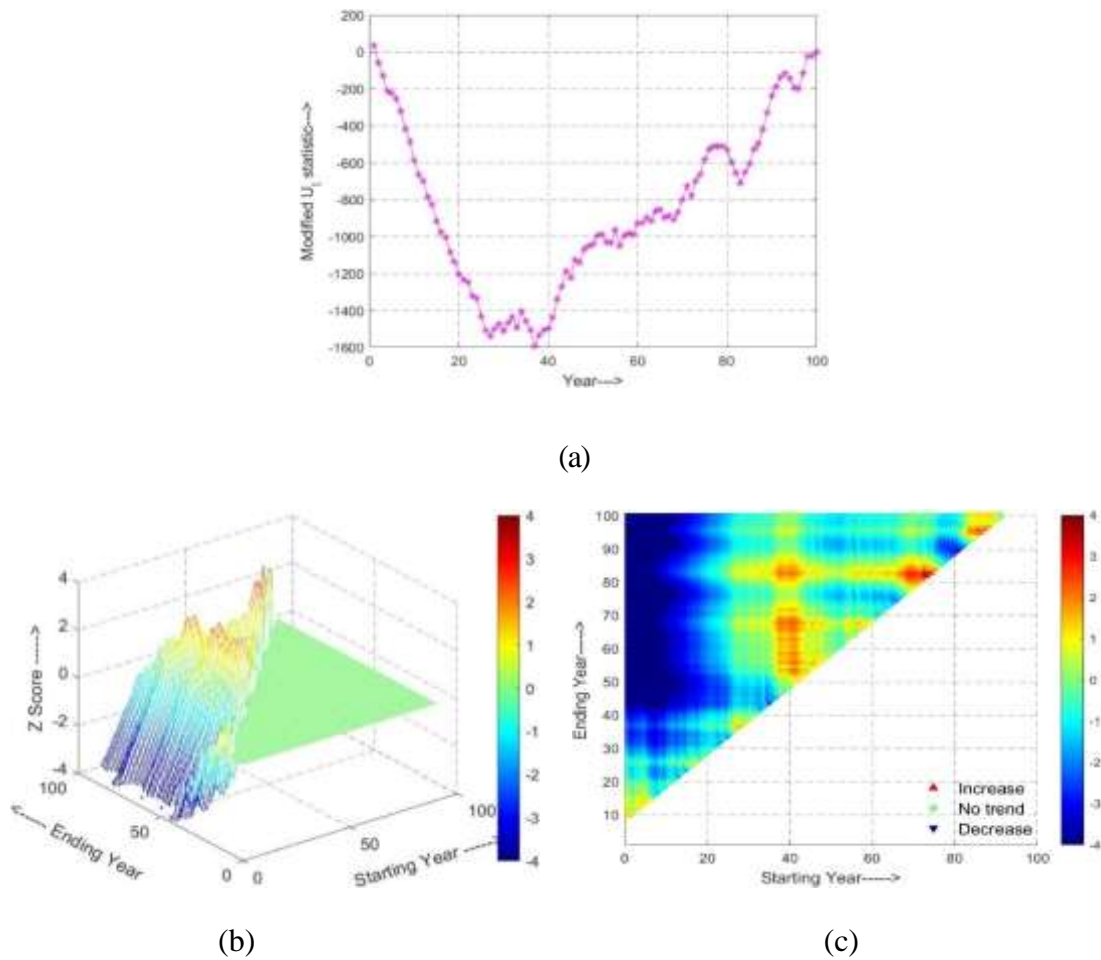


Figure 6.199 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the PRCPTOT trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in Ramgarh was at level of 0.05.

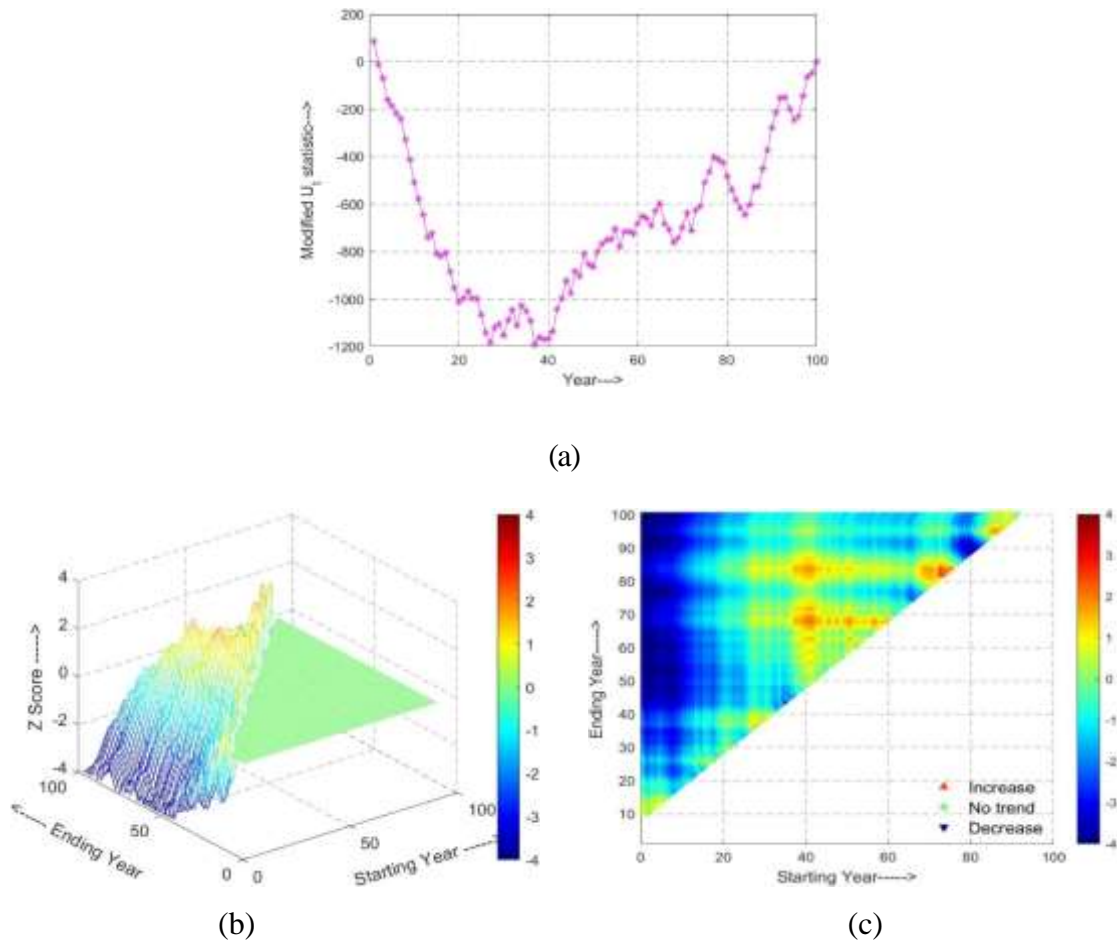
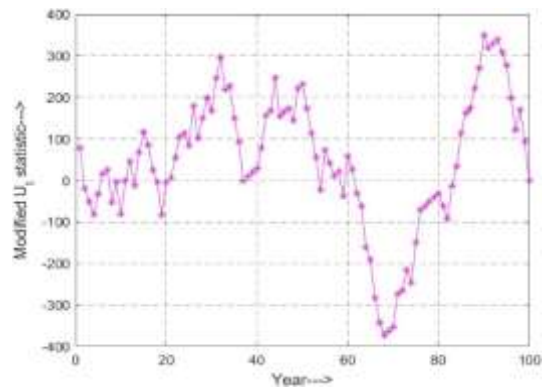
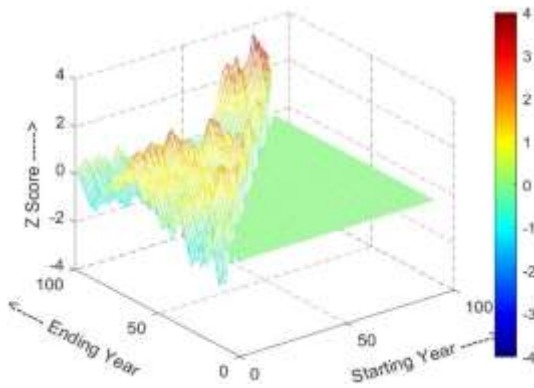


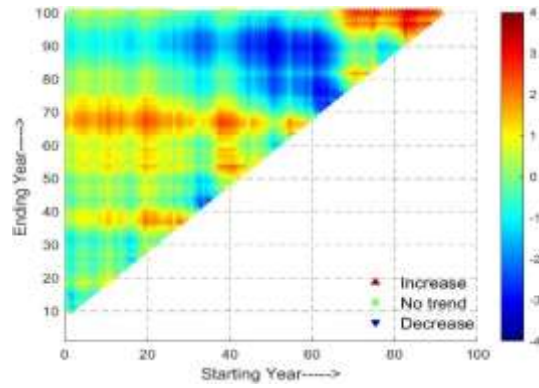
Figure 6.200 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the R10mm trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the R10mm trend in Ramgarh was at level of 0.05.



(a)

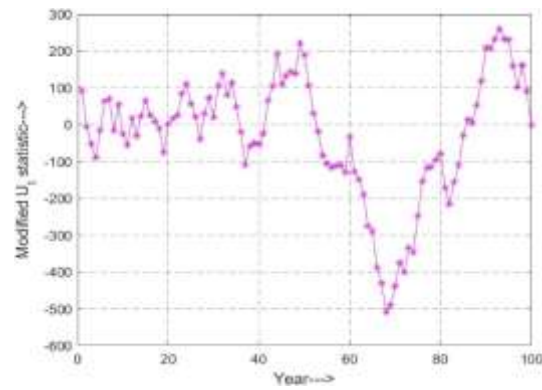


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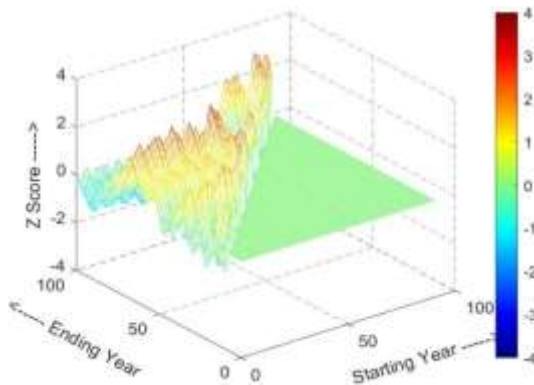


(c)

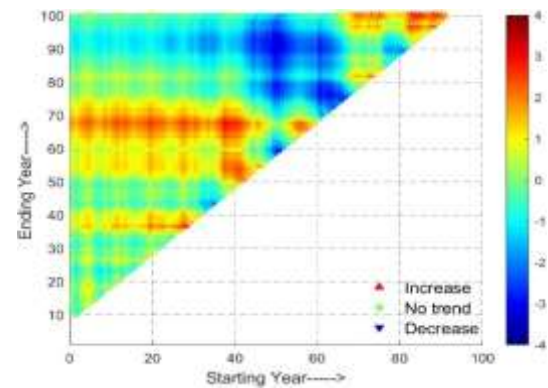
Figure 6.201 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the R20mm trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the R20mm trend in Ramgarh was at level of 0.05.



(a)

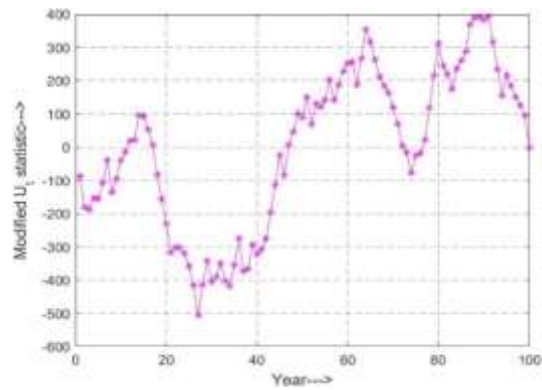


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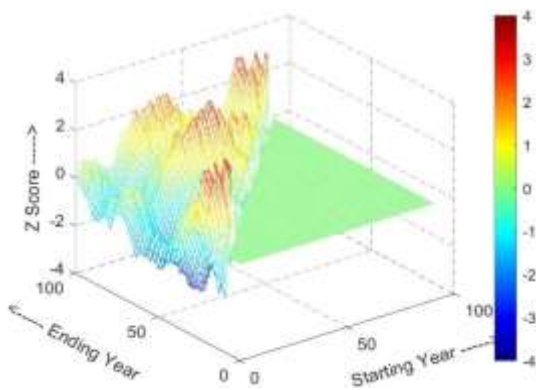


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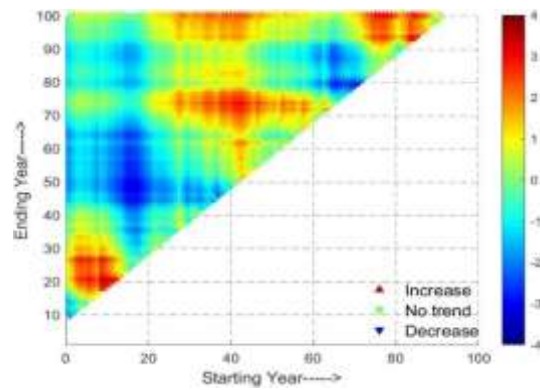
Figure 6.202 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the R95p trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the R95p trend in Ramgarh was at level of 0.05.



(a)

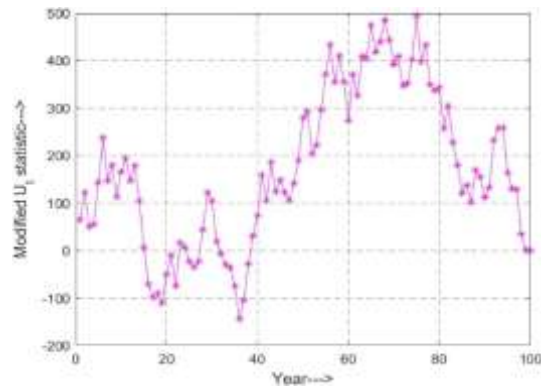


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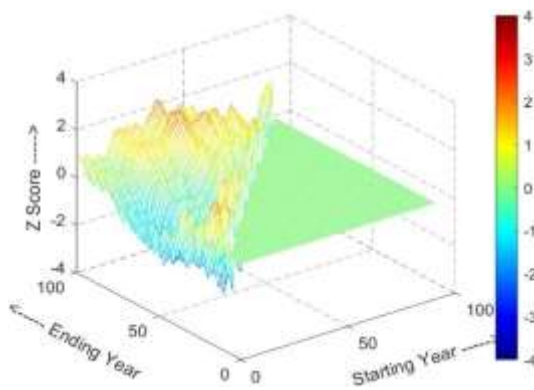


(c)

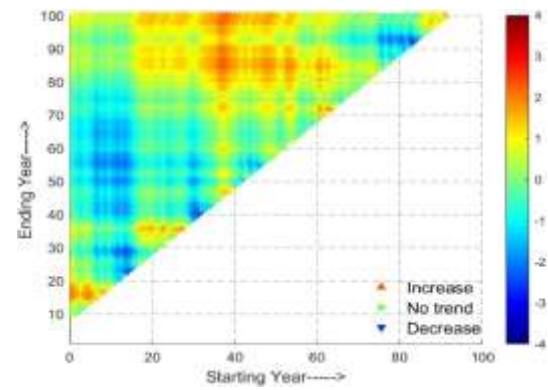
Figure 6.203 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the R99p trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the R99p trend in Ramgarh was at level of 0.05.



(a)

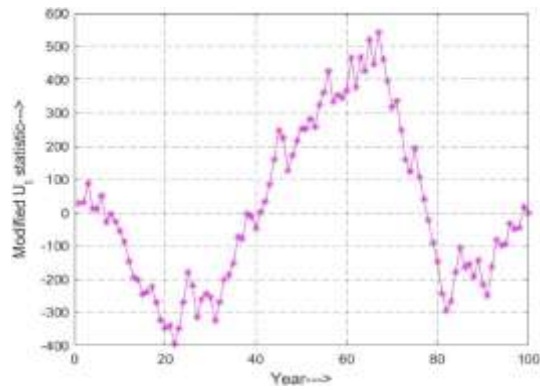


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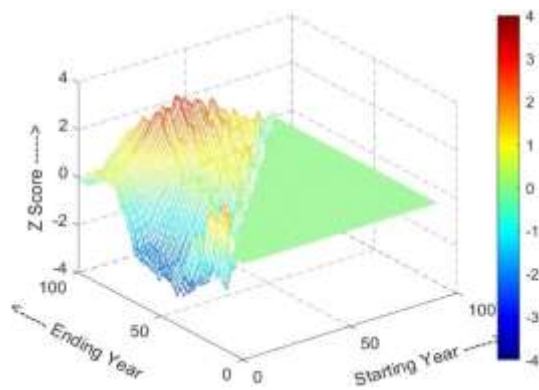


(c)

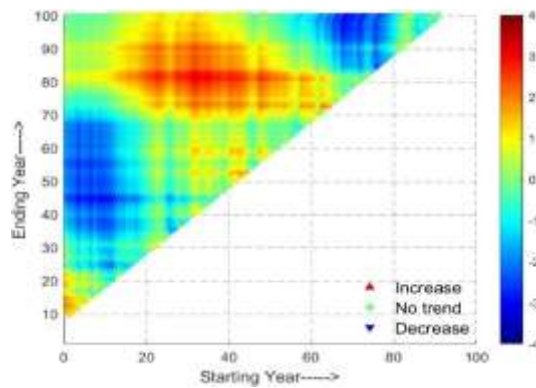
Figure 6.204 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the RX1day trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the RX1day trend in Ramgarh was at level of 0.05.



(a)



(b)



(c)

Figure 6.205 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the RX5day trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the RX5day trend in Ramgarh was at level of 0.05.

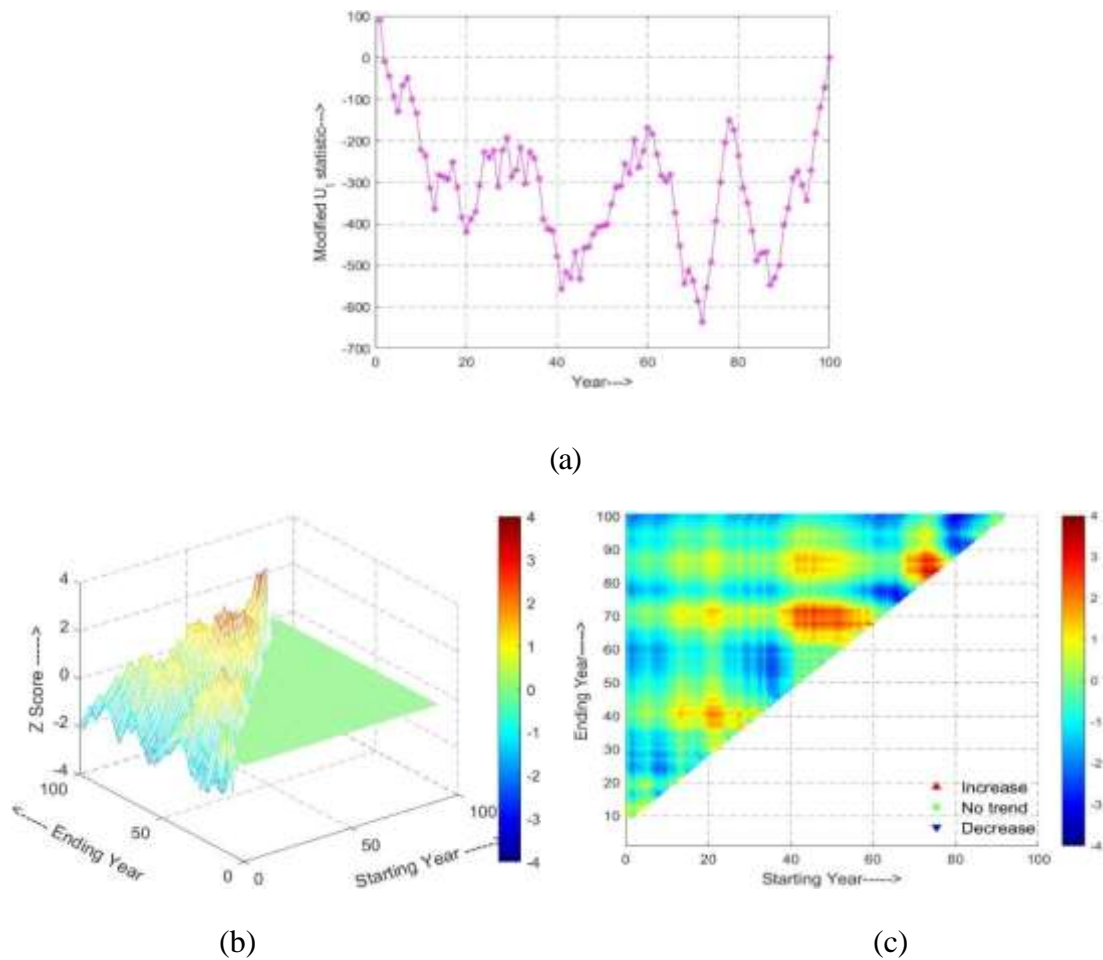


Figure 6.206 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the SDII trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the SDII trend in Ramgarh was at level of 0.05.

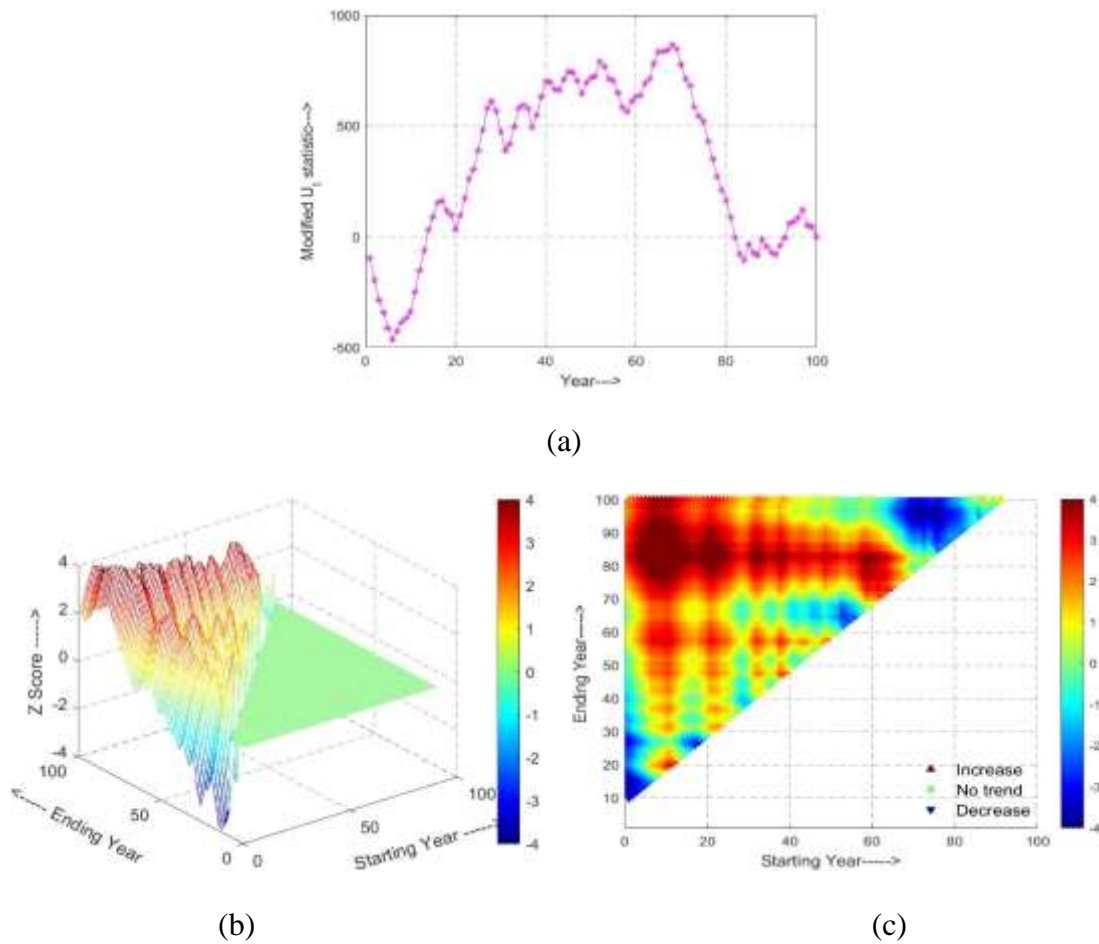
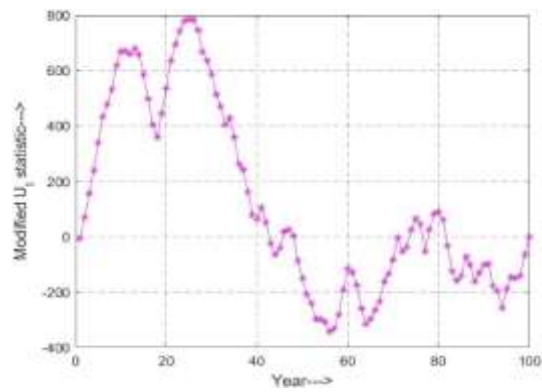
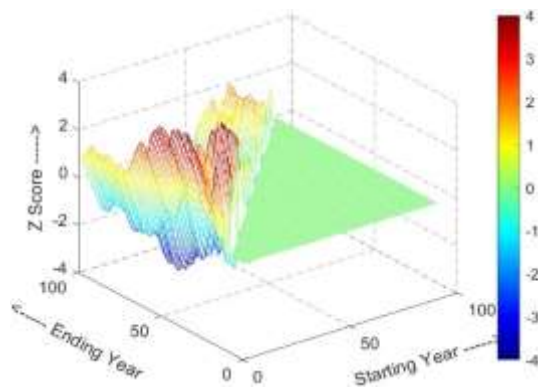


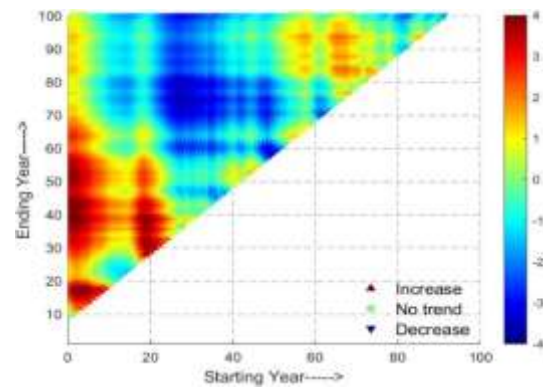
Figure 6.207 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the TNN trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the TNN trend in Ramgarh was at level of 0.05.



(a)

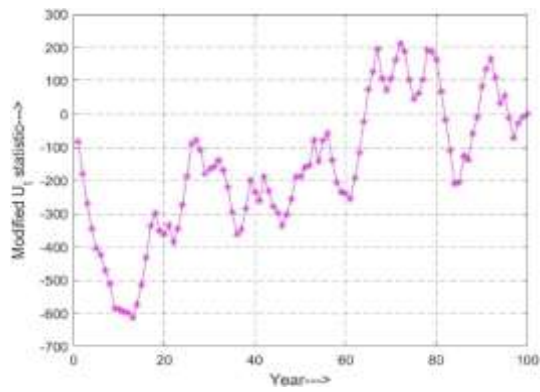


(b)

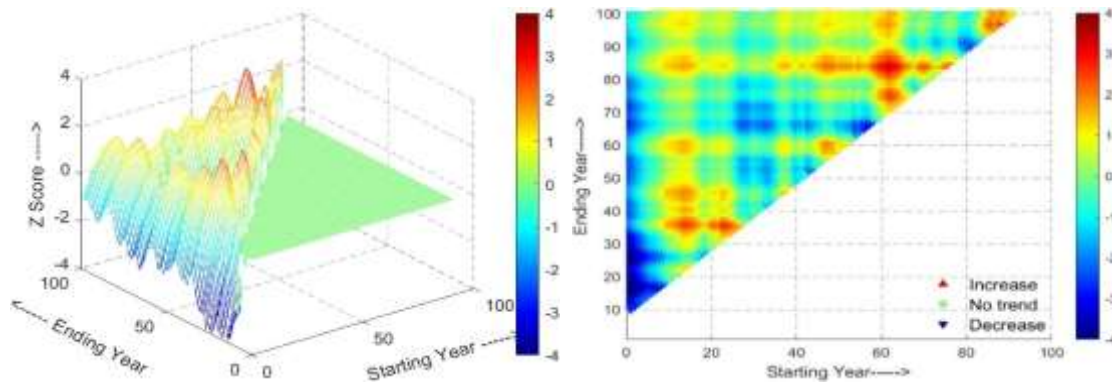


(c)

Figure 6.208 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the TNX trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the TNX trend in Ramgarh was at level of 0.05.



(a)



(b)

(c)

Figure 6.209 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the TXn trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the TXn trend in Ramgarh was at level of 0.05.

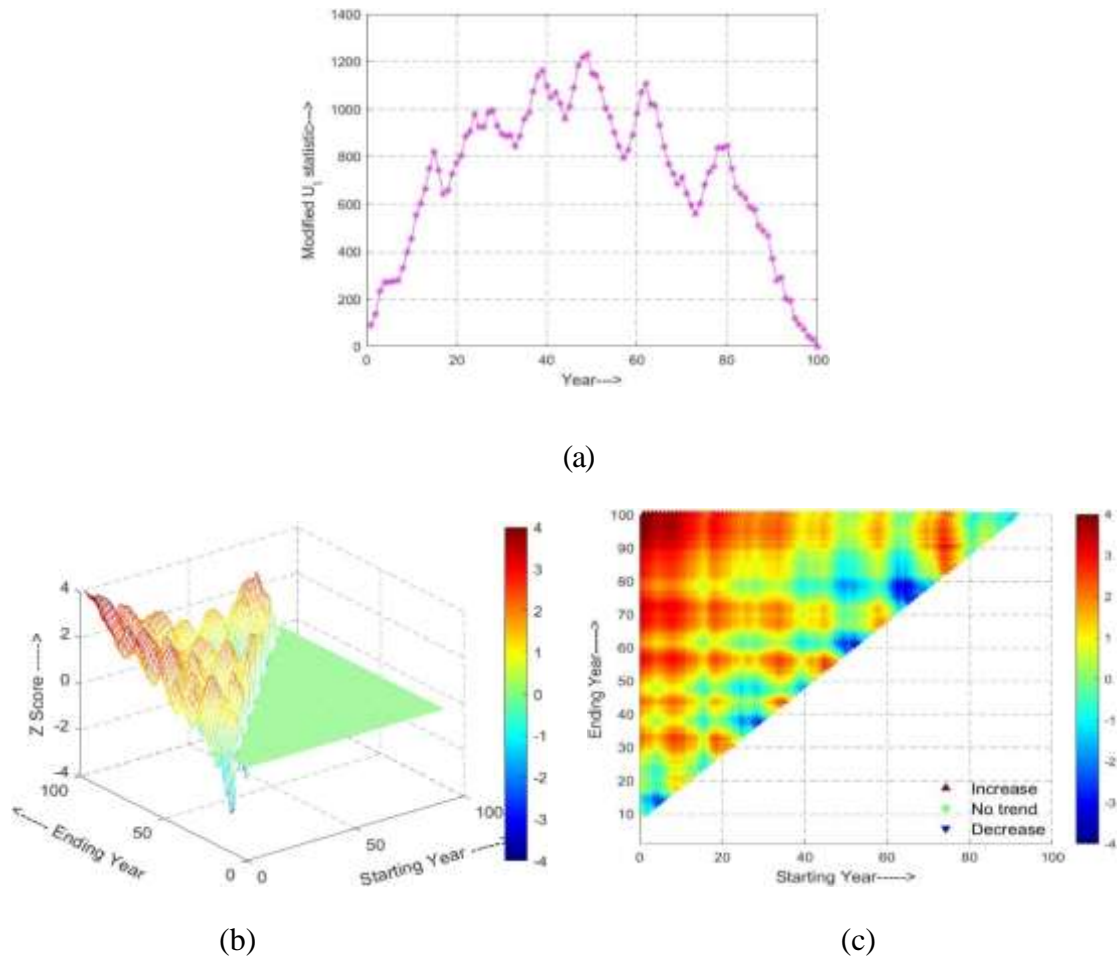


Figure 6.210 (a) Variation of modified U_t over the years to identify change points in Ramgarh. (b) The three-dimensional pattern of the TX_x trend in Ramgarh is at level of 0.05. (c) The 2-D pattern of the TX_x trend in Ramgarh was at level of 0.05.

6.2.15 Characteristics of Multiple Climatic Indices in West-Medinipur

West Medinipur station, located in the West Bengal portion of the Damodar River Basin (DRB), has emerged as a significant research hub focused on long-term trends in extreme climate indices. This station was specifically selected for an extensive analysis spanning from 1923 to 2022. Figures 6.211(b-c) to 6.225(b-c) provide both two-dimensional and three-dimensional visual representations of the extreme climate variables observed at West Medinipur. The initial segments of these figures illustrate patterns characterized by peaks and troughs, where peaks signify the intensity and direction of climate trends, while troughs reflect fluctuations over time. These visualizations highlight Notable changes in extreme climate indices throughout the study period. The figures utilize various shaded zones to depict these variations, showcasing troughs in the lower sections and crests in the upper portions of the triangular shapes, effectively capturing the dynamic nature of climate trends. The accompanying color bar in Figures 6.211(c) to 6.225(c) indicates that red represents an increasing rainfall trend, blue signifies a decreasing trend, and green reflects periods with no significant change.

From 1923 to 1950, West Medinipur exhibited a declining trend in rainfall, as indicated by the blue shading in the figures. Conversely, an increasing trend was observed from 1950 to 1990, marked by red hues, while green areas denote periods of stability in the rainfall patterns. By analyzing the clustering of these trends, researchers were able to pinpoint key moments of significant shifts in climate patterns. The statistical data presented in Figures 6.211(c) to 6.225(c) affirm the accuracy and reliability of these visualized trends, enhancing the overall credibility of the analysis.

The insights gained from this research are particularly significant for planners and policymakers in the West Medinipur region, as understanding the changing nature of rainfall patterns is crucial for effective agricultural management and water resource planning. Given that a significant portion of the population in West Medinipur relies on agriculture, recognizing rainfall variability is essential for sustainable farming practices. By incorporating three-dimensional visualizations and identifying key change points in rainfall trends, this study contributes valuable knowledge regarding climate dynamics in West Medinipur and their potential implications for agricultural and resource management strategies.

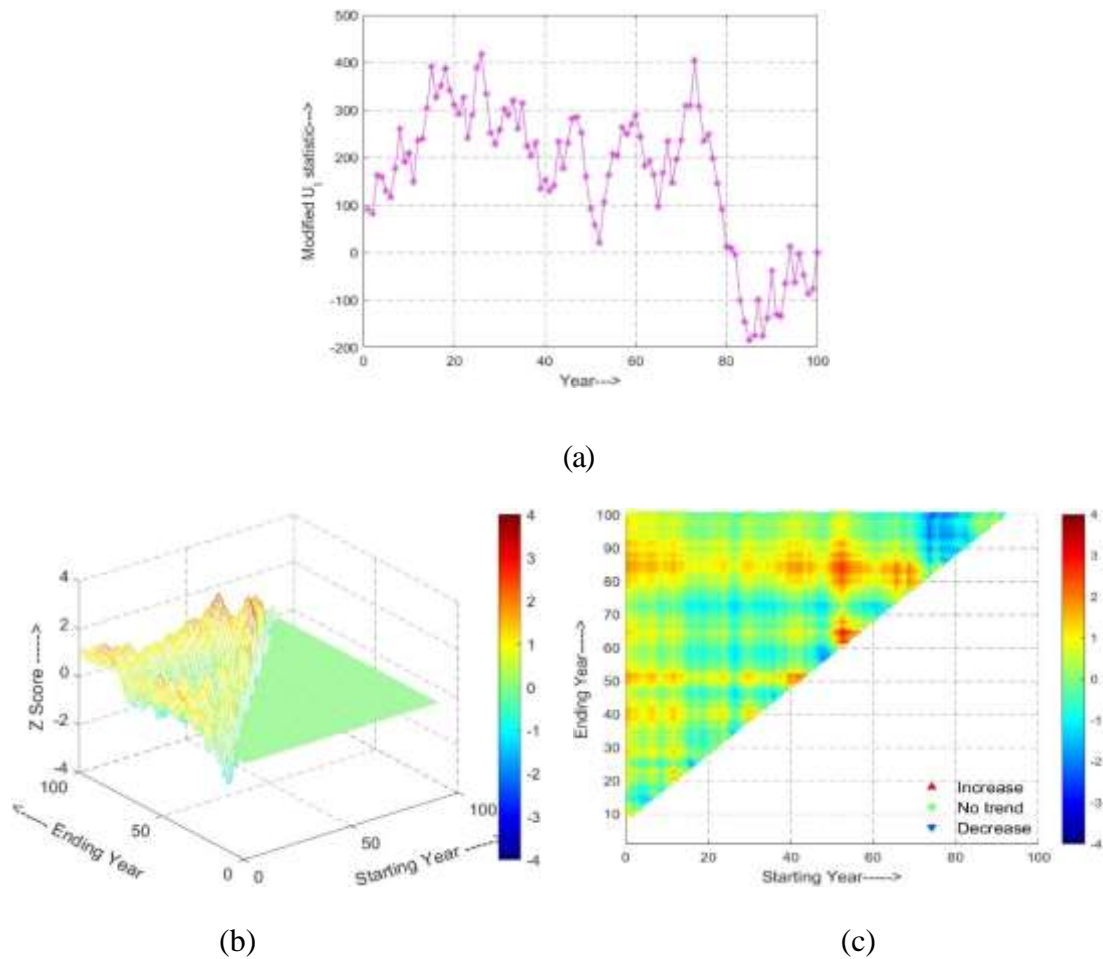
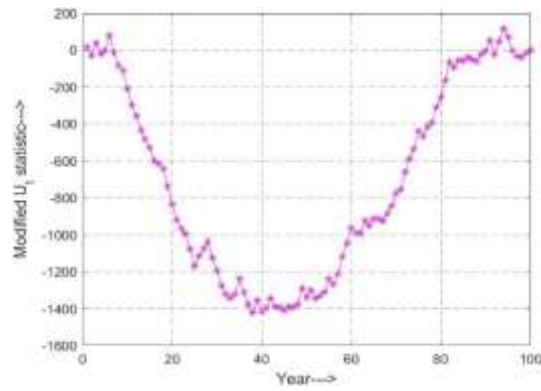
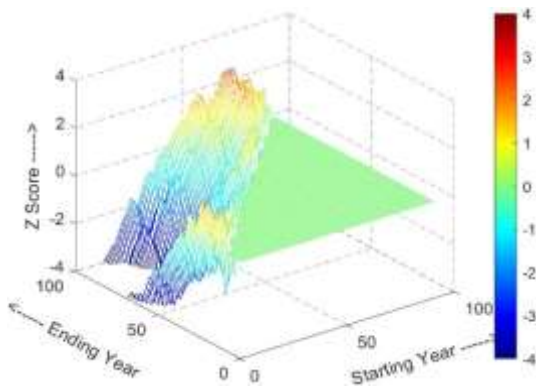


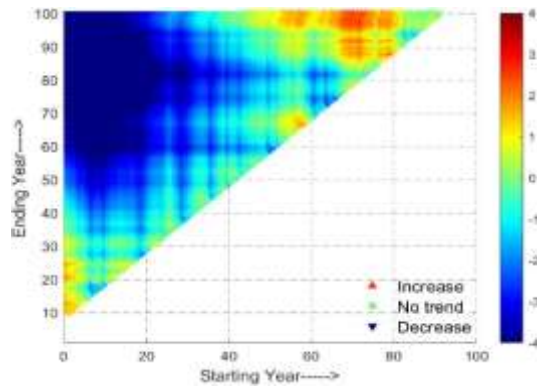
Figure 6.211 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the CDD trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the CDD trend in West-Medinipur was at level of 0.05.



(a)



(b)



(c)

Figure 6.212 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the CWD trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the CWD trend in West-Medinipur was at level of 0.05.

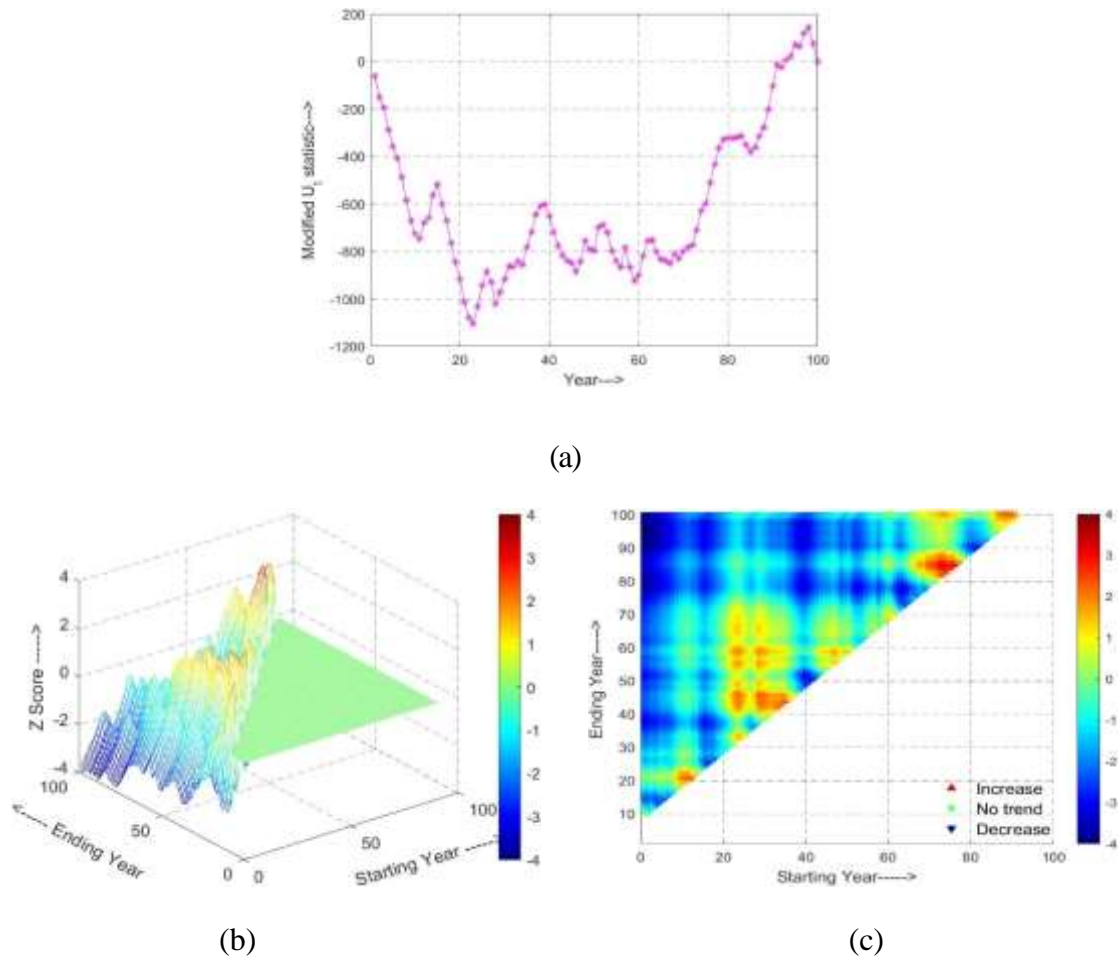
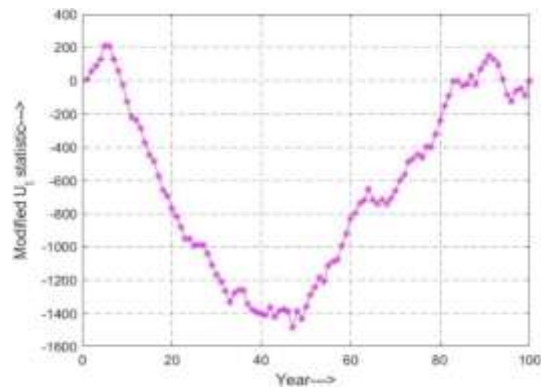
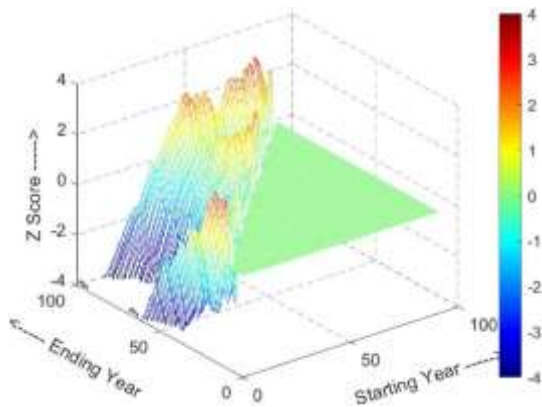


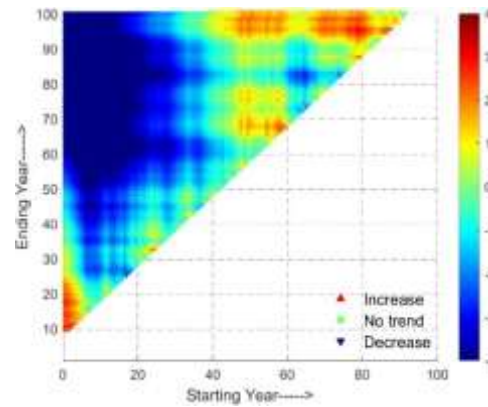
Figure 6.213 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the DTR trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the DTR trend in West-Medinipur was at level of 0.05.



(a)



(b)



(c)

Figure 6.214 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the PRCPTOT trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the PRCPTOT trend in West-Medinipur was at level 0.05

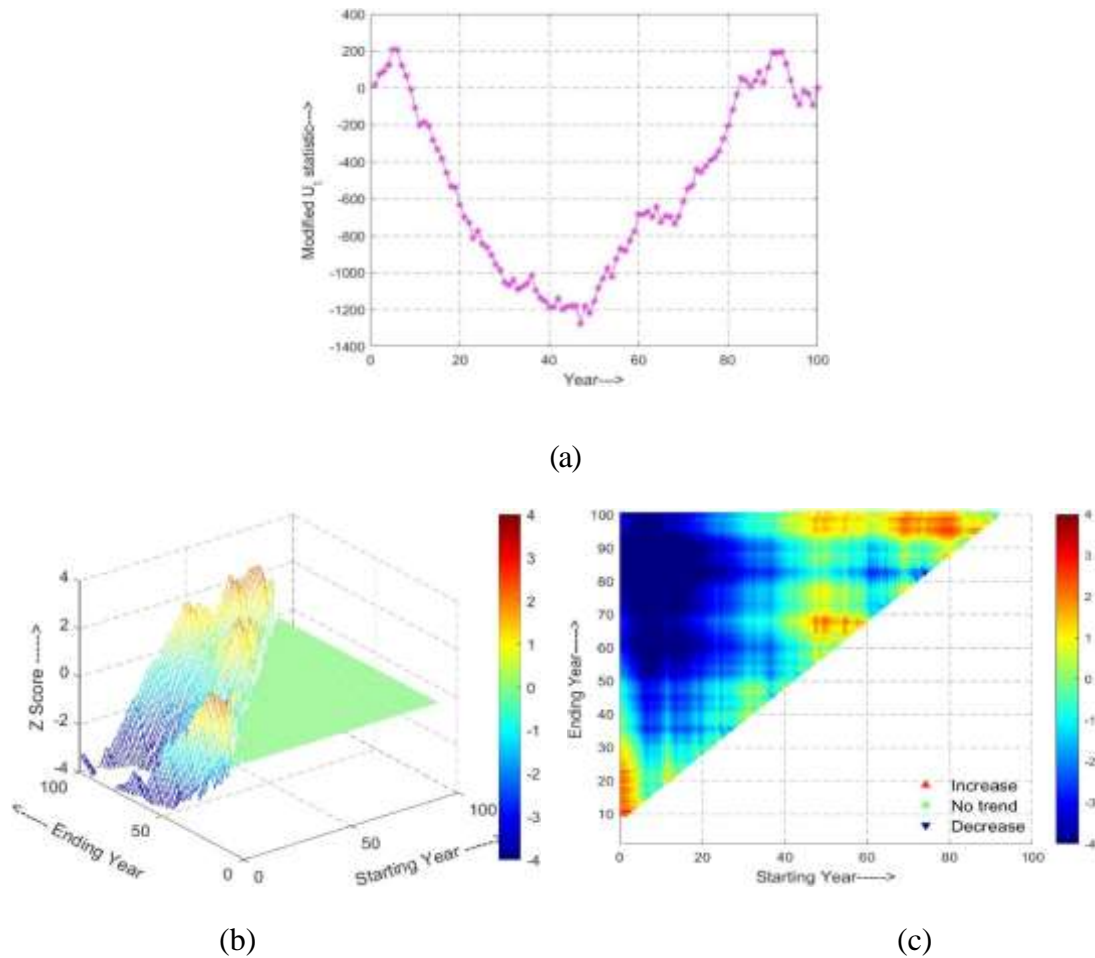
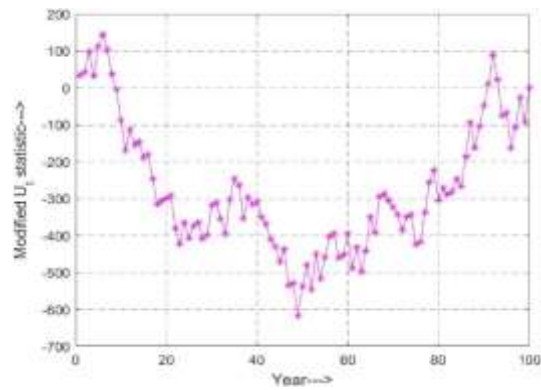
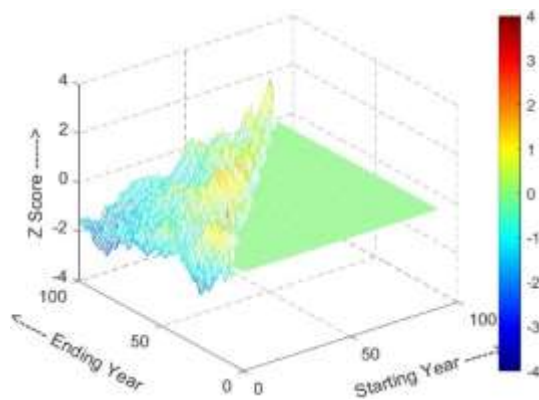


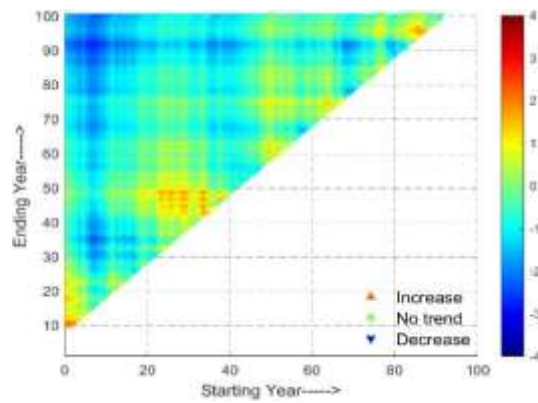
Figure 6.215 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the R10mm trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the R10mm trend in West-Medinipur was at level of 0.05.



(a)

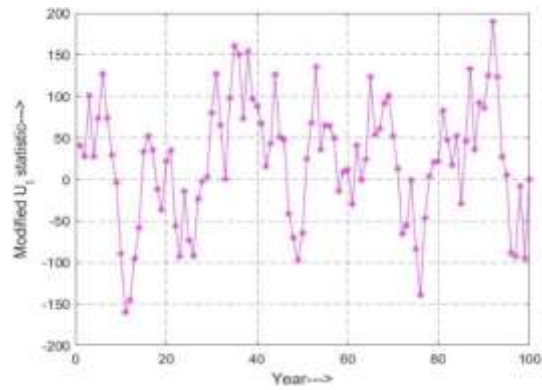


(b)

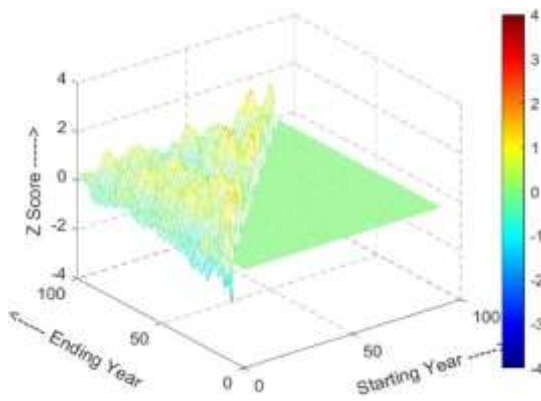


(c)

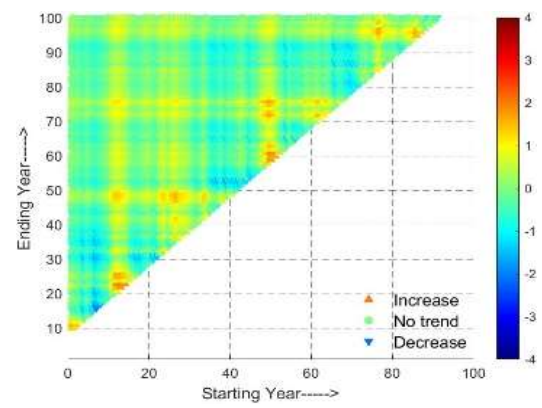
Figure 6.216 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the R20mm trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the R20mm trend in West-Medinipur was at level of 0.05.



(a)

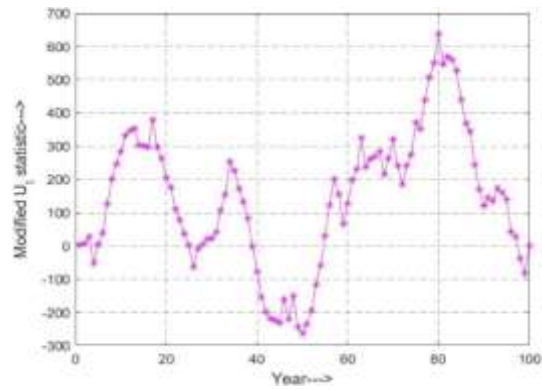


(b)

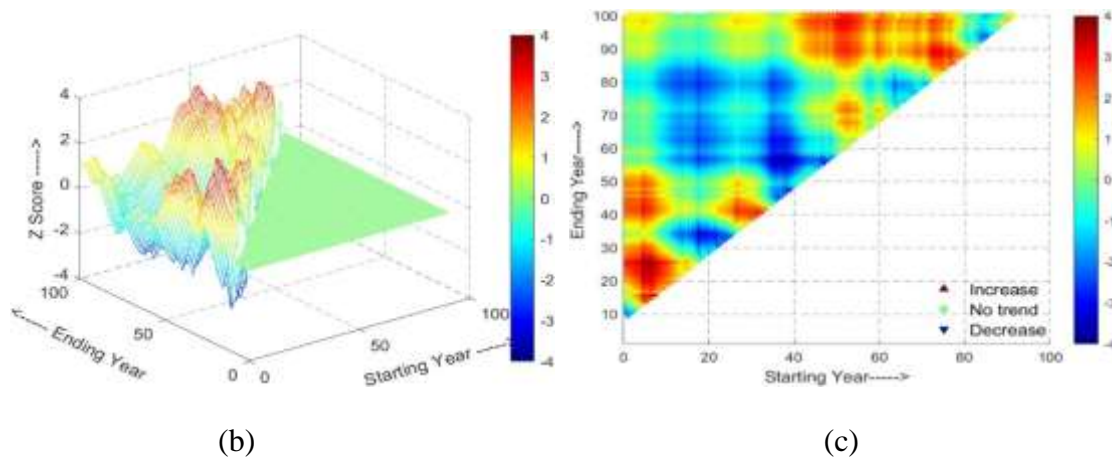


(c)

Figure 6.217 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the R_{95p} trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the R_{95p} trend in West-Medinipur was at level of 0.05



(a)



(b)

(c)

Figure 6.218 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the $R99p$ trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the $R99p$ trend in West-Medinipur was at level of 0.05.

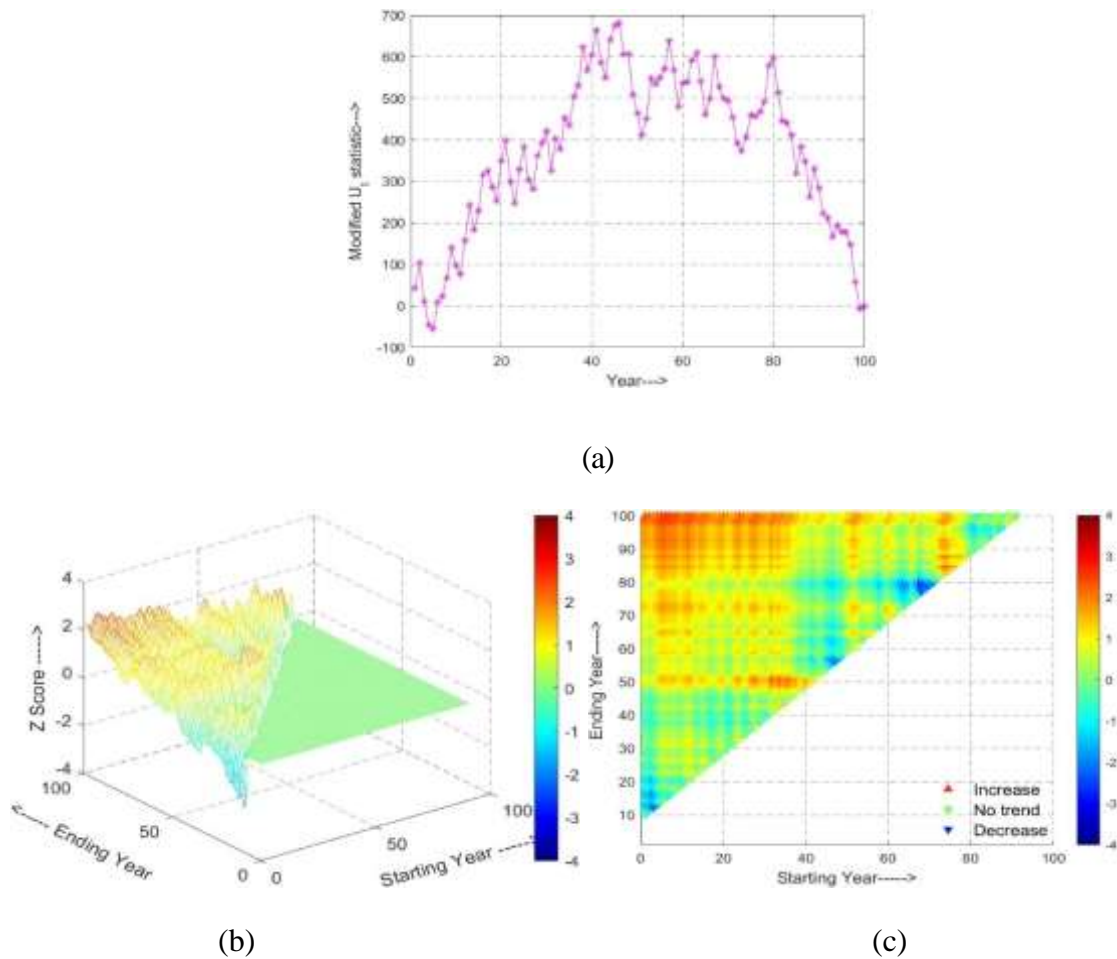
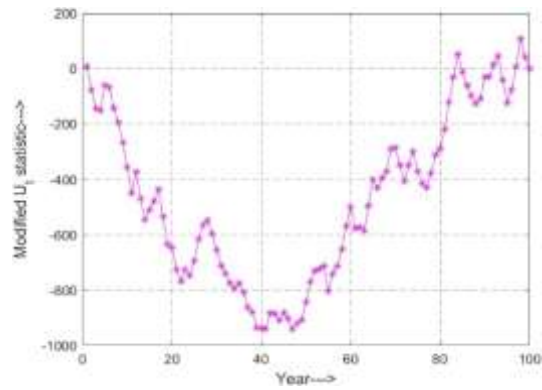
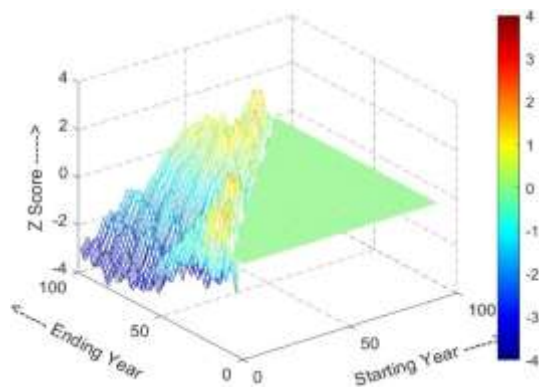


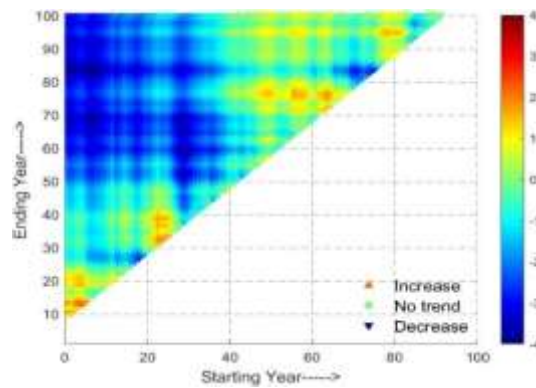
Figure 6.219 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the RX1day trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the RX1day trend in West-Medinipur was at level of 0.05.



(a)



(b)



(c)

Figure 6.220 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the RX5day trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the RX5day trend in West-Medinipur was at level of 0.05

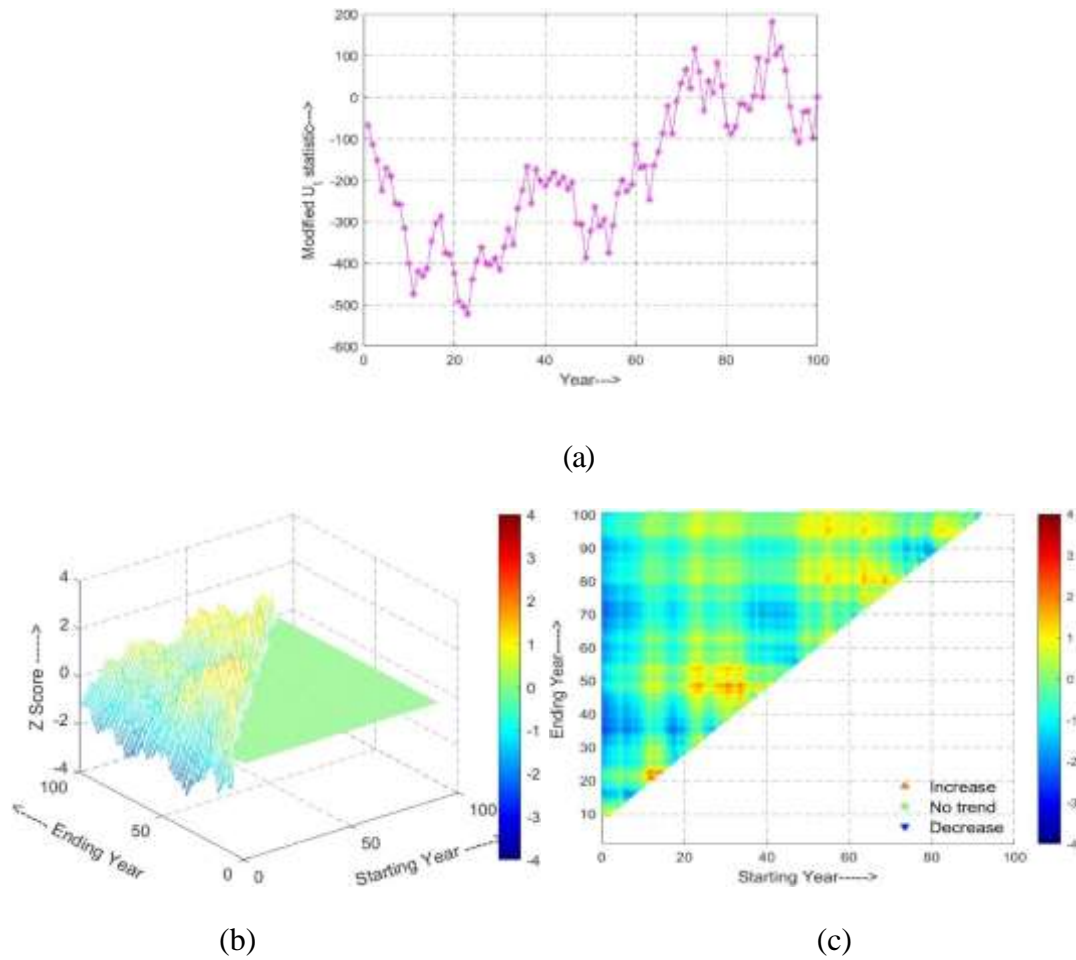
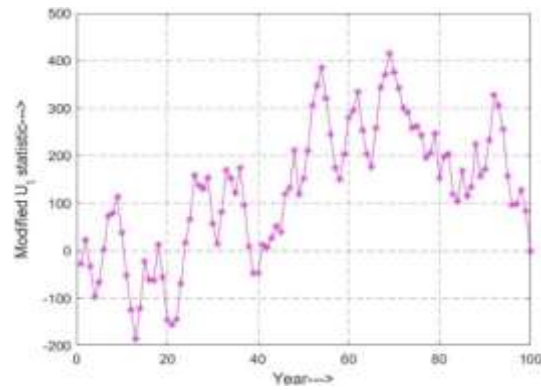
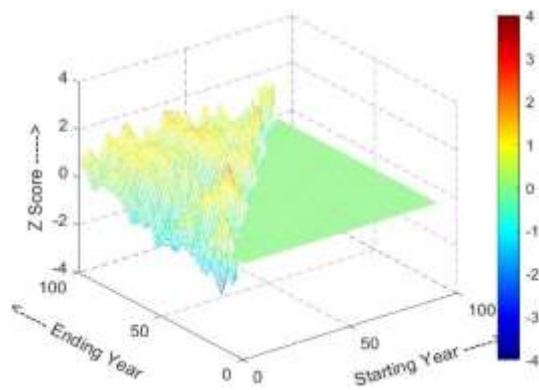


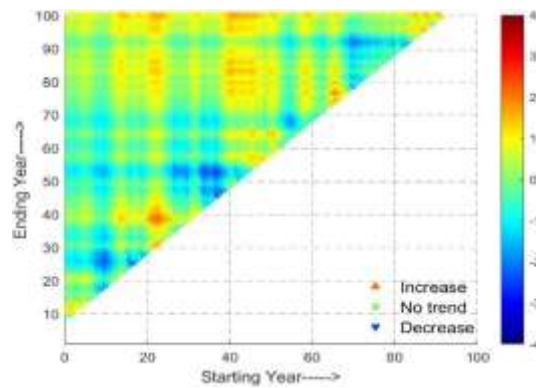
Figure 6.221 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the SDII trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the SDII trend in West-Medinipur was at level of 0.05



(a)



(b)



(c)

Figure 6.222 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the TN_n trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the TN_n trend in West-Medinipur was at level of 0.05

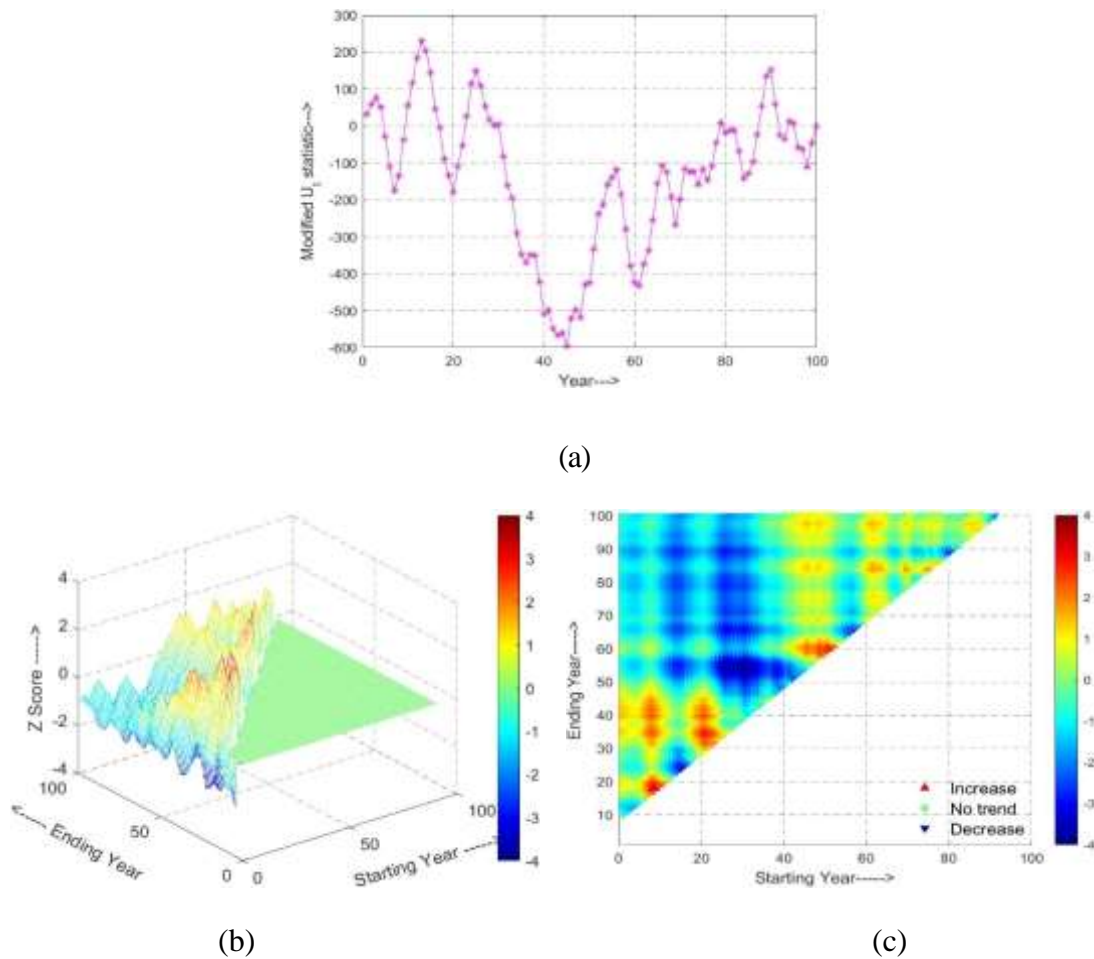
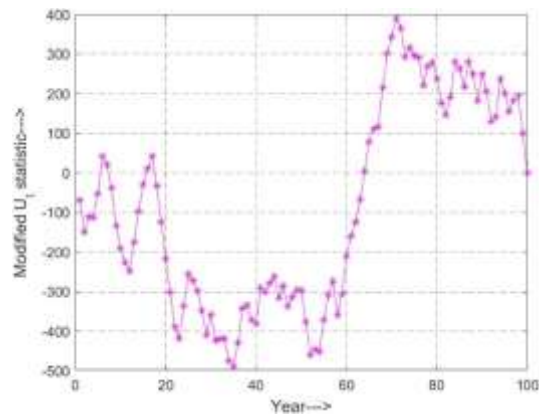
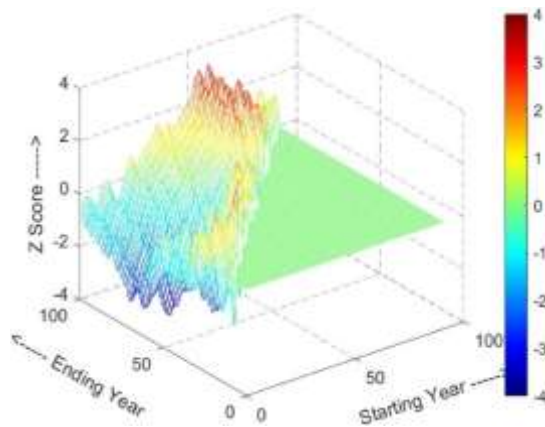


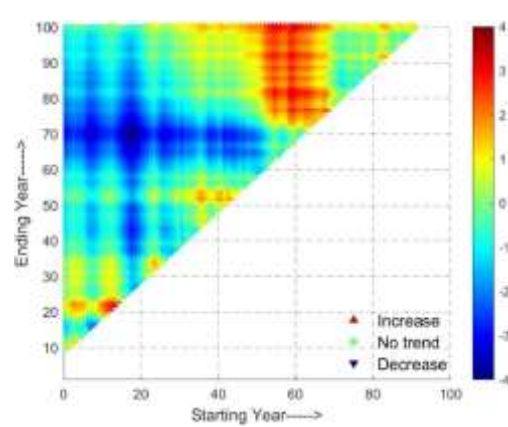
Figure 6.223 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the TNx trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the TNx trend in West-Medinipur was at level of 0.05



(a)



(b)



(c)

Figure 6.224 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the TXN trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the TXN trend in West-Medinipur was at level of 0.05

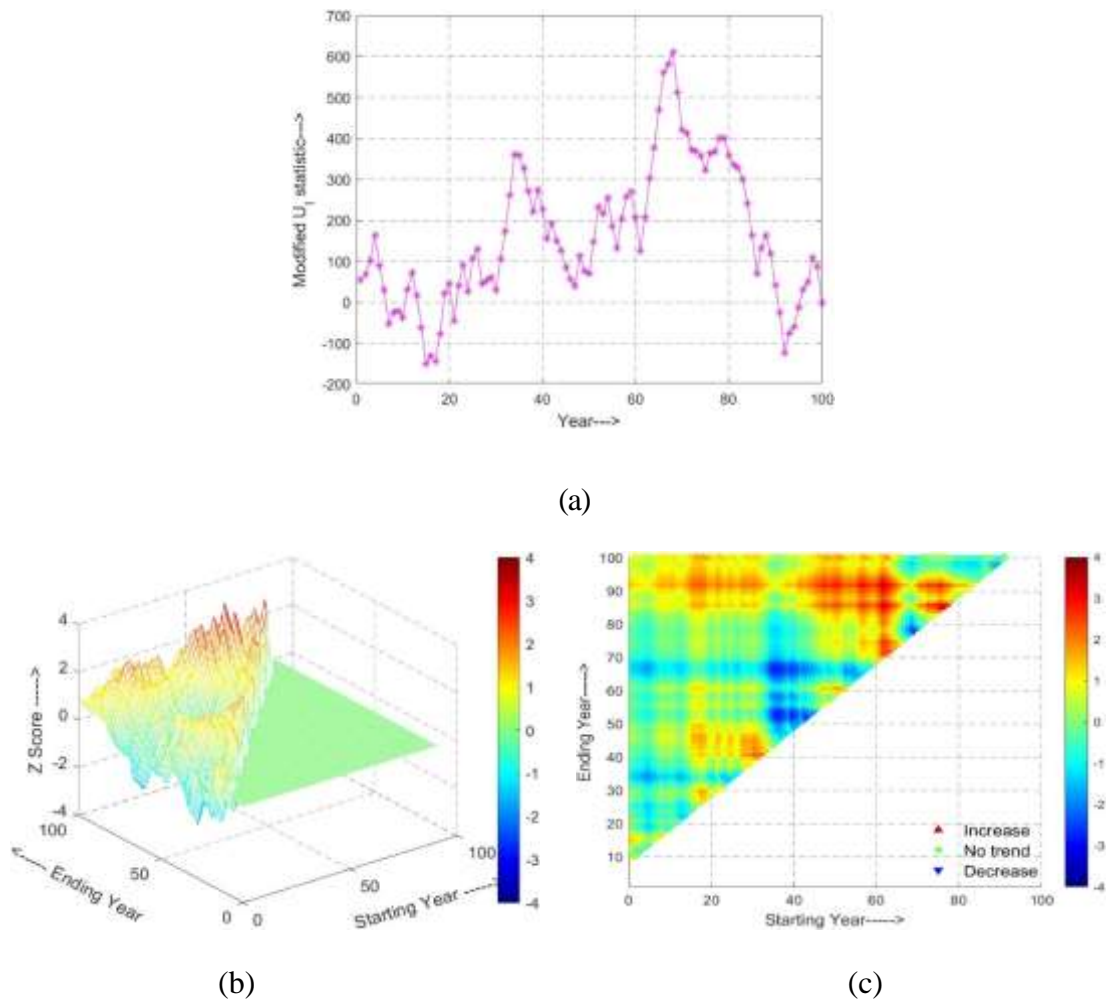


Figure 6. 225 (a) Variation of modified U_t over the years to identify change points in West-Medinipur. (b) The three-dimensional pattern of the TXX trend in West-Medinipur is at level of 0.05. (c) The 2-D pattern of the TXX trend in West-Medinipur was at level of 0.05.

6.3 Summary

The study focuses on long-term rainfall trend analysis in the Damodar River Basin (DRB) in India, assessing extreme climate events like floods and droughts through 2D and 3D visual representations. Utilizing Variable-Size Cluster Analysis (VSCA), Mann-Kendall (MK) tests, and a modified Pettitt-Mann-Whitney (PMW) test, the research examines rainfall data from 1922 to 2021 across eight localities, detecting trends and change points. Declining rainfall trends were identified in Bardhaman, Dhanbad, and Hazaribag, while rising trends were observed in Koderma and Purulia. The study's use of 3D graphical representations enhances trend visualization and provides insights for water resource management. The findings also highlight multiple rainfall change points, particularly useful for agricultural planning, given the basin's agricultural dependence. This study enhances understanding of shifting climate patterns and informs resource planning in the DRB region.