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Statistical Analysis of the Rainfall of Four Major Districts of Gujarat State of India

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ABSTRACT
In this research, An Agroclimatic Zone – II of Gujarat state has been considered for the research work. The aim of research work is to carry out the rainfall anomaly index analysis. This zone contains 4 major districts namely Bharuch, Narmada, Surat & Tapi. Bharuch, Narmada, Surat & Tapi are having 8, 4, 9 & 4 numbers of rain gauge stations respectively. Total 25 number of rain gauge stations data have been used for the analysis purpose. The rainfall anomaly index analysis has been carried out using R-software Programming in which Kalman Smoothing & Arima Model and rainfall anomaly index method were used, for which Kalman Smoothing & Arima Model method and rainfall anomaly index methods 'imputeTS' and 'precintcon' packages used in R-software. Imputation of data carried out with the help of 'imputeTS' package. As per the rainfall anomaly index at 4 & -4, the extreme highest rainfall receiving years were 1976, 2005, 2006, 2013 and 2019 while the extreme reduction in rainfall years were 1986, 1987, 2000 and 2005 over last 47 years. Hansot, Jhagadia, Ukai, and Songadh had received the extreme highest rainfall while Bharuch, Jhagadia, Valod and Vyara had received the extreme reduction in rainfall over the last 47 years. Jhagadia is the common station having highest and lowest rainfall on both scales in same time period.
Keywords: *R- Software; Rainfall Anomaly Index; Agro-Climatic Zone; R-Studio; Precintcon package; Kalman Smoothing & Arima Model*

1. INTRODUCTION

In recent years heavy rain within a small span of the period has been observed in Gujarat, Maharashtra and in Kerala. (Saha et al., 2019). Because of uncertainty in the rainfall occurrence drought conditions recurrence has been increased in Gujarat state of India. (Koyel et al., 2020), and the average annual rainfall varies between 330 mm to 1,520mm (Dhorde et al., 2016). The aim of research work is to carry out the rainfall anomaly index analysis. This zone contains 4 major districts namely Bharuch, Narmada, Surat & Tapi. Bharuch, Narmada, Surat & Tapi are having 8, 4, 9 & 4 numbers of rain gauge stations respectively. Total 25 number of rain gauge stations data have been used for the analysis purpose. The rainfall anomaly index analysis has been carried out using R-software Programming in which Kalman Smoothing & Arima Model and rainfall anomaly index method were used, for which Kalman Smoothing & Arima Model method and rainfall anomaly index methods 'imputeTS' and 'precintcon' packages used in R-software. Imputation of data carried out with the help of 'imputeTS' package. The monsoon aberrations have become more frequent over India on which rainfed Agriculture is dependent. The moderate climate is observed in the southern districts. As per rainfall distribution, the year of Gujarat can be divided into four seasons, from December to February into winter, from March to May into summer, June to September into the southwest monsoon and October to November into the northeast monsoon. The Indian Council of Agricultural Research (ICAR) launched the National Initiative on Climate Resilient Agriculture (NICRA) as a comprehensive project covering strategic research, technology demonstration and capacity building. Patel et. al (2021) found that the spatio-temporal changes of the rainfall in the Bhogavo River watersheds. The analysis has been done using rainfall data of 11 stations, The M-k test, slope estimation using Sen's test, and the ITA method are used for carrying out trend analysis. Spatial distribution maps have been generated using mean monthly rainfall and slope values based on Sen's test to spot the spatial distribution of rainfall. Chandole et al. (2019) evaluated precipitation and temperature trends using the linear regression method, the M-k test, slope estimation using Sen's test, and ITA method. From the outcomes, it is observed that the results show close agreement. The spatial variability of rainfall in India's Sabarmati River basin is achieved using inverse distance weighting. Joshi

et al. (2019) focused the effect of climate change on the Sabarmati River basin. Monthly and Annual analysis of rainfall and temperatures is carried out using an ITA method, linear regression, the M-k test with slope estimation and Sen's test. It is evaluated that the MMk test is the best performing technique among the M-k test family. The conventionally used ordinary Mk-test for the trend analysis assumes the data to be free from auto-correlation, but a positive correlation may lead to a false significant trend (Yue et al., 2002).

2. Study Area

The Gujarat state is having eight Agro-Climatic Zones, they are Semi-arid climate, Arid to Semi-arid climate, Arid to Semi-arid climate, Semi-arid to Dry sub-humid climate and Arid to Semi-arid climate, and North Saurashtra as Dry sub-humid climate.

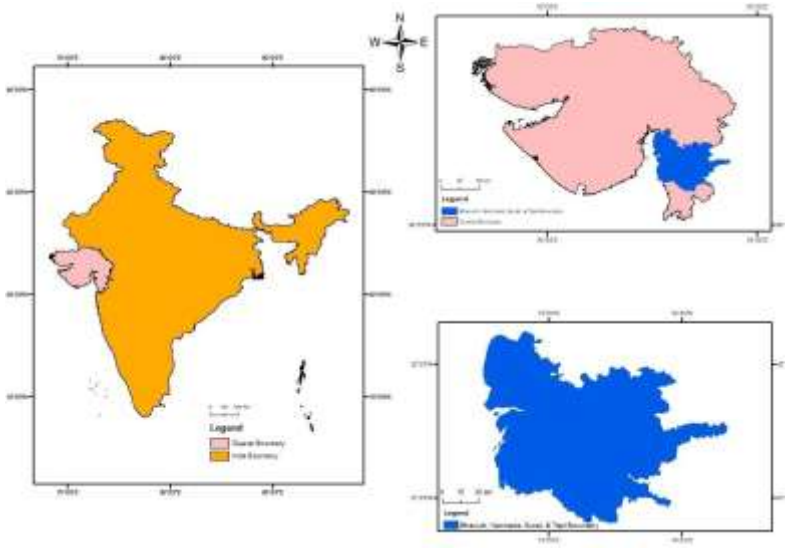

Figure 1. Index Map of Agro-climatic Zone - II

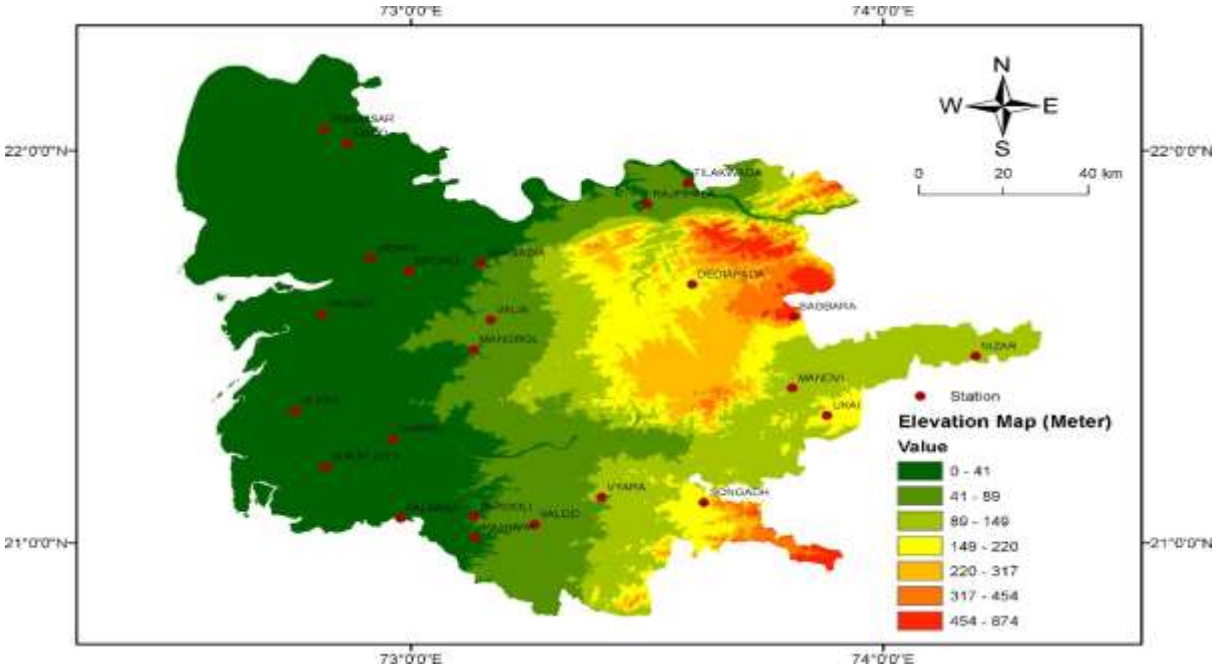

Figure 1. DEM map with location of rain gauge stations

Agroclimatic Zone – II of Gujarat state has been considered for the research work. This zone contains 4 major districts namely Bharuch, Narmada, Surat & Tapi. This semi-arid to dry sub-humid region of Gujarat covers area of 16,940 km^2 and is geographically located between latitudes 20.813 to 22.248 and longitudes 72.502 to 74.336 on the western coast of India. The location map of the Agro-Climatic Zones -II is shown in Figure. 1. and the rain gauge stations location is shown in Fig. 2.

3. METHODS

3.1 Data Collection

The rainfall data has been collected through State Water Data Centre (SWDC) of Gujarat and Indian Meteorological Department (IMD) Pune. The latitude, longitude, mean rainfall, time span and elevation of each station are shown in Table 1. Daily rainfall data has been collected for a total 29 number of rain gauge stations. Data from 20 rain gauge stations is collected through State Water data Centre (SWDC) and 9 station data has been collected through Indian Meteorological Department (IMD). The details of the rain gauge stations are shown in Table 1.

Table 1. Details of the rain gauge stations

Sr. No	Station	Latitude	Longitude	Data From	Data To
1	AMOD	22.019	72.865	1975	2021
2	ANKLESHWAR	21.610	73.015	1975	2021
3	BROACH	21.695	72.997	1975	2021
4	HANSOT	21.584	72.811	1975	2021
5	JAMBUSAR	22.057	72.817	1975	2021
6	JHAGADIA	21.714	73.148	1975	2021
7	VAGRA	21.726	72.915	1975	2021
8	VALIA	21.569	73.169	1975	2021
9	DEDIAPADA	21.661	73.595	1975	2021
10	RAJPIPALA	21.865	73.500	1975	2021
11	SAGBARA	21.578	73.811	1975	2021
12	TILAKWADA	21.919	73.586	1975	2021
13	BARDOLI	21.067	73.134	1975	2021
14	KAMREJ	21.267	72.960	1975	2021
15	MAHUWA	21.016	73.137	1975	2021
16	MANDVI	21.396	73.808	1975	2021
17	MANGROL	21.493	73.133	1975	2021
18	OLPAD	21.338	72.754	1975	2021
19	PALSANA	21.064	72.977	1975	2021
20	SURAT CITY	21.195	72.819	1975	2021
21	UKAI	21.326	73.881	1975	2021
22	NIZAR	21.105	73.620	1984	2021
23	SONGADH	21.048	73.262	1975	2021
24	VALOD	21.117	73.404	1975	2021
25	VYARA	21.117	73.404	1975	2021

3.2 Methodology

3.2.1 *Data Processing*

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Conversion of monthly (June, July, August, September, October & November) and SW- Monsoon rainfall from the daily rainfall data for 25 rain gauge stations. Imputation of the missing values is been done by Kalman Smoothing & Arima models in R-Software.

3.2.2 Rainfall *Anomaly Index (RAI)*

RAI is a ranking procedure to assign degree to negative and positive precipitation anomalies, which iscalculated using the below equation:

$$RAI = \frac{+3\,(P-\bar{P})}{(\bar{E}-\bar{P})} \qquad (1)$$

Where, P bar is the measured precipitation, E bar is mean precipitation and is average of 10 extrema. According to the magnitude, RAI is classified into nine classes which varies from extreme wet to extreme dry ranges.

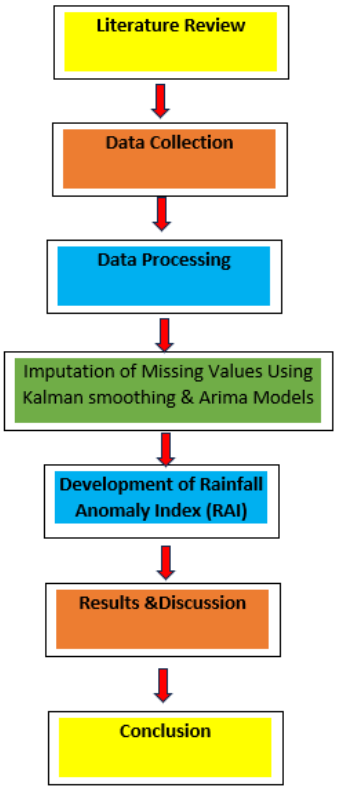


Figure 2. Methodology Flow Chart

Table 2. RAI Classes

RAI	Classification
≥ 4.00	Extremely rainy
3.00 to 3.99	Highly rainy
2.00 to 2.99	Moderately rainy
0.5 to 1.99	Low rainfall
-0.49 to 0.49	Normal
-1.99 to -0.5	Slight reduction in rainfall
-2.00 to -2.99	Moderate reduction in rainfall

-3.00 to -3.99	Large reduction in rainfall
≤-4.00	Extreme reduction in rainfall

3.2.3 *R -Software*

R is an open-source programming language that facilitates Statistical Computing & Graphical Libraries. R was created by statisticians Ross lhaka and Robert Gentlemen in June 1995. R is an interpreted language whose code could be directly run without a compiler. R provides a favorable environment for statistical computing and design. The main advantages of R-software are that it is an effective data handling and storage facility also suite of operators for calculations of large Arrays.

Different window and their functions in R software are shown below

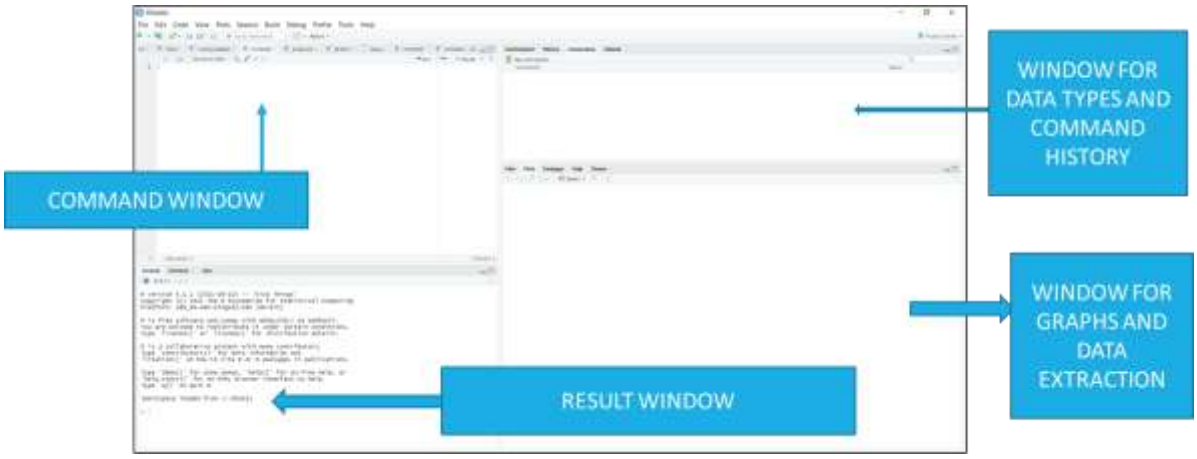


Figure 4. Different windows in R software

➢ Command Window: In the command window part, the programming part is to be carried out.

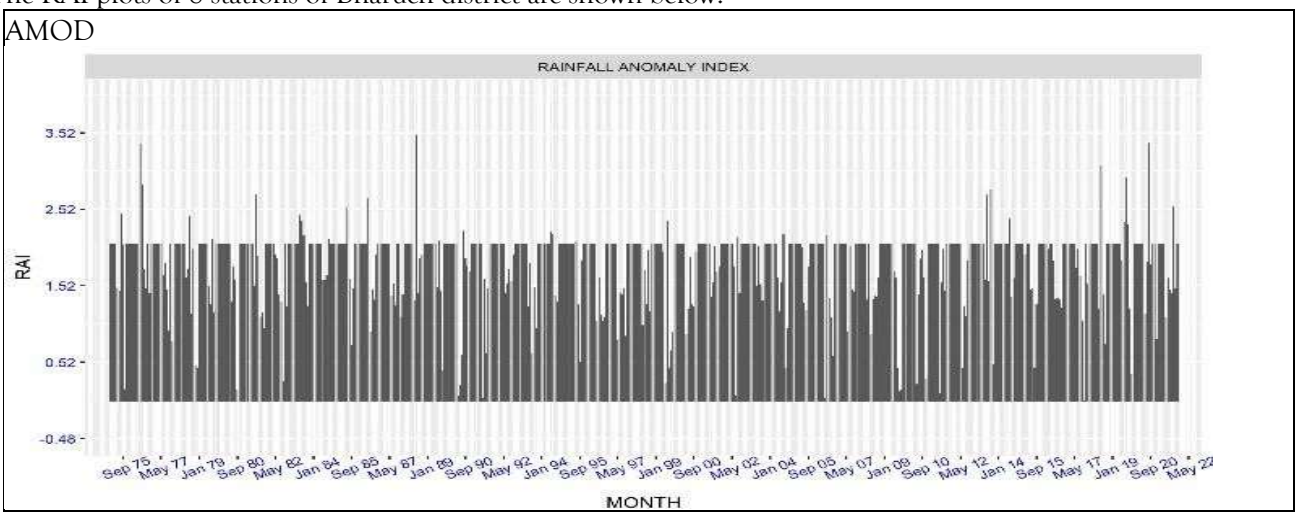
➢ Result Window: - When we run the analysis and the processing is done the results in terms of various statistical parameters will be shown in this window.

➢ History Window: This part of the screen shows the history of the commands performed.

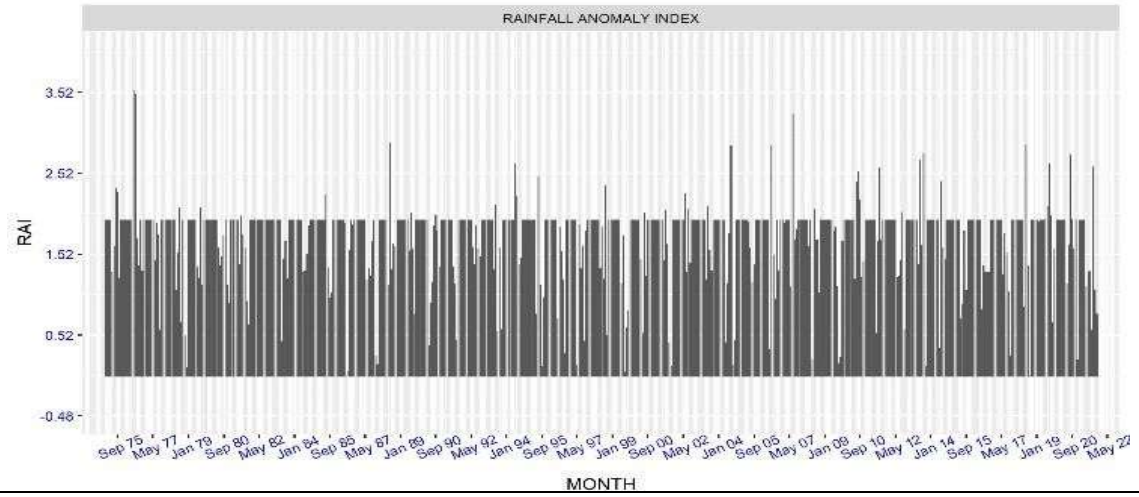
4. RESULT AND DISCUSSION

The RAI plots of 8 stations of Bharuch district are shown below:

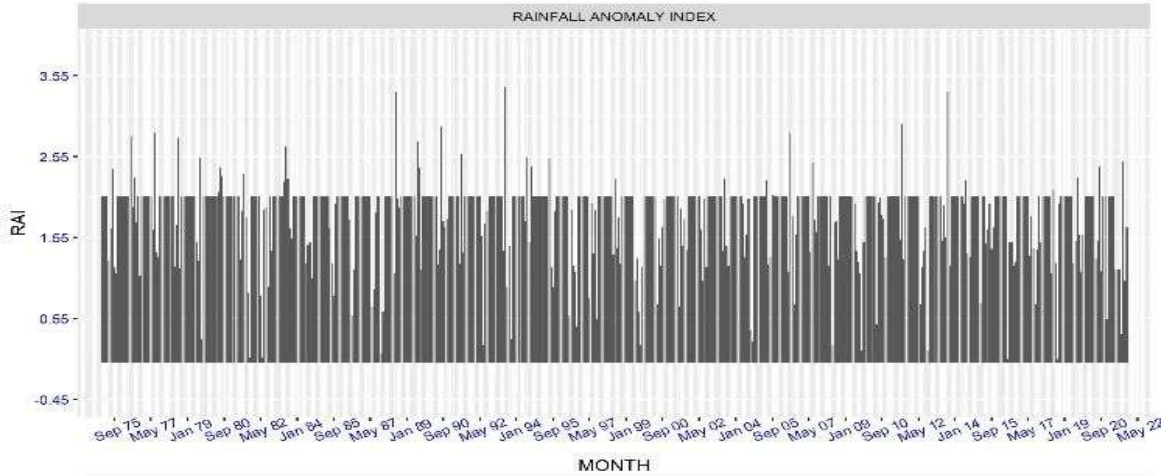
AMOD

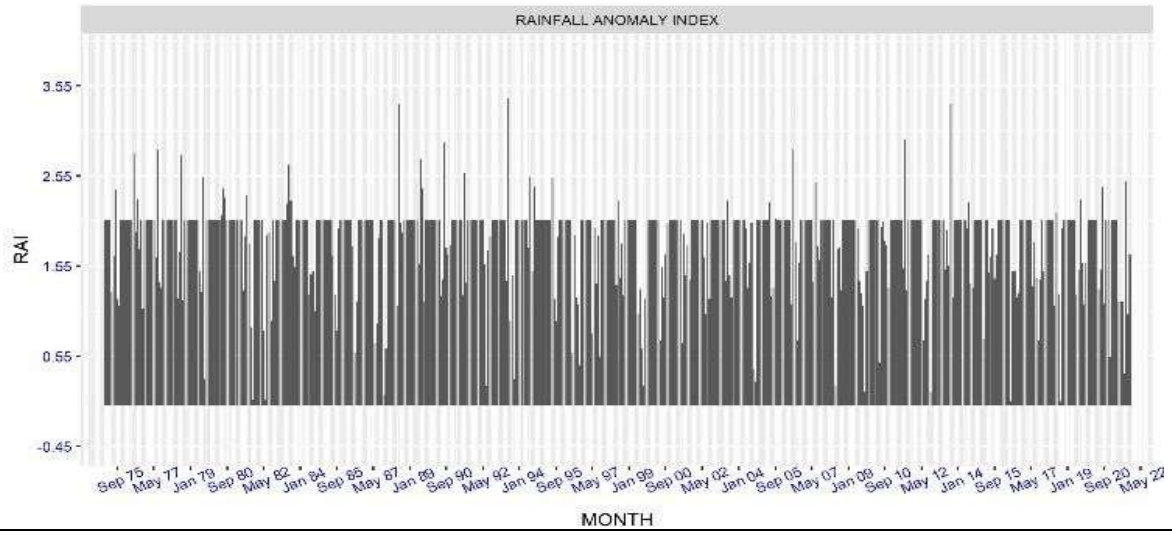


BHARUCH



JAMBUSAR





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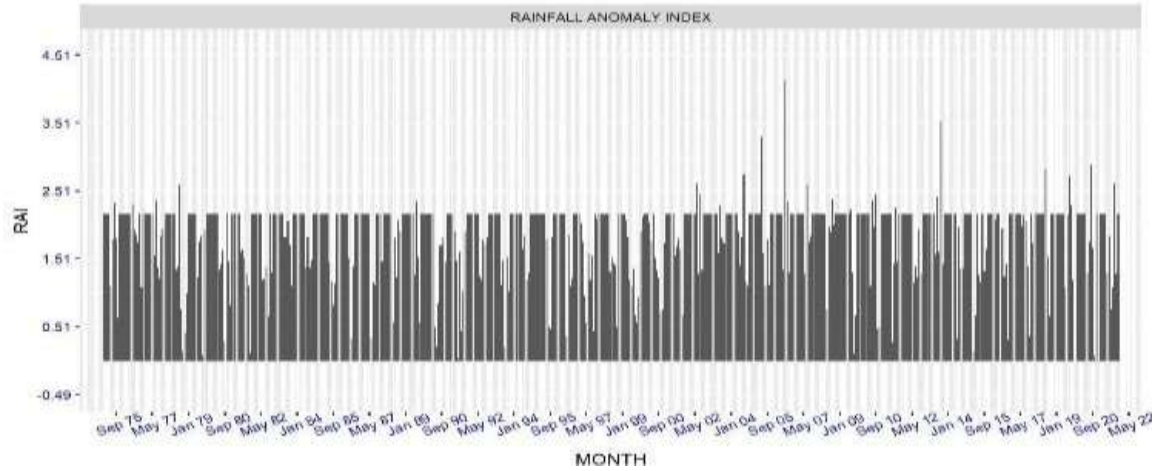
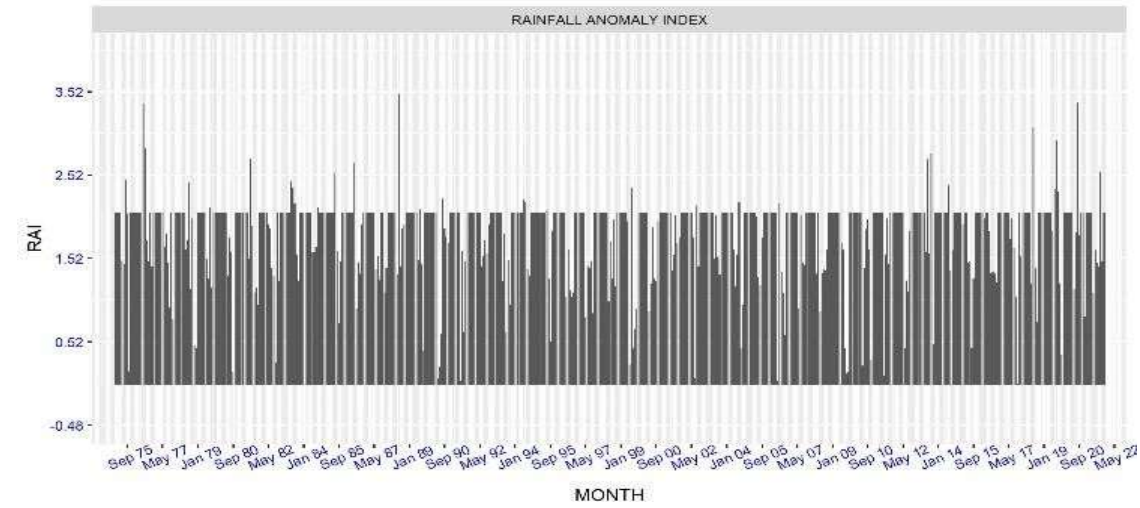
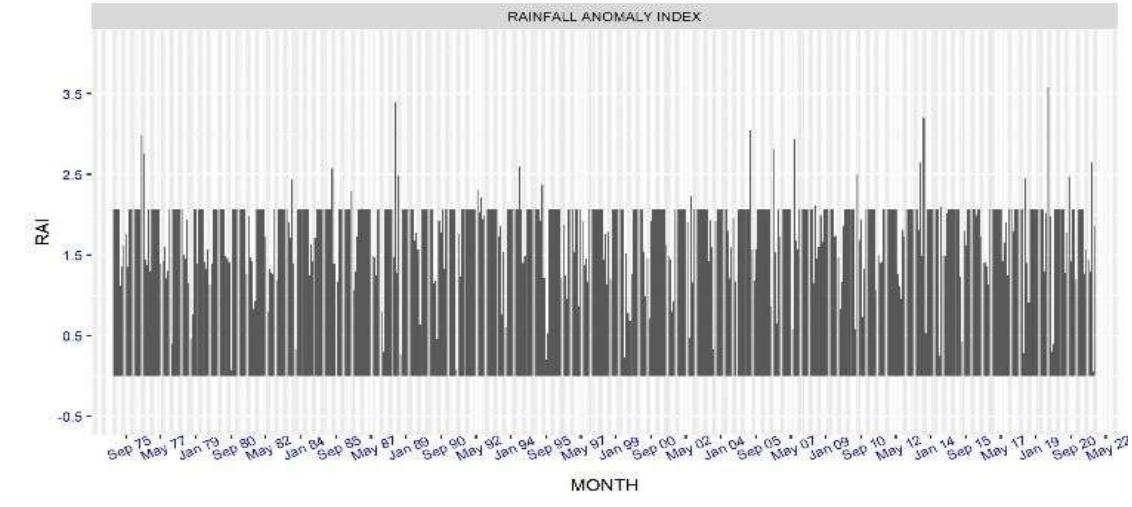
VAGRA

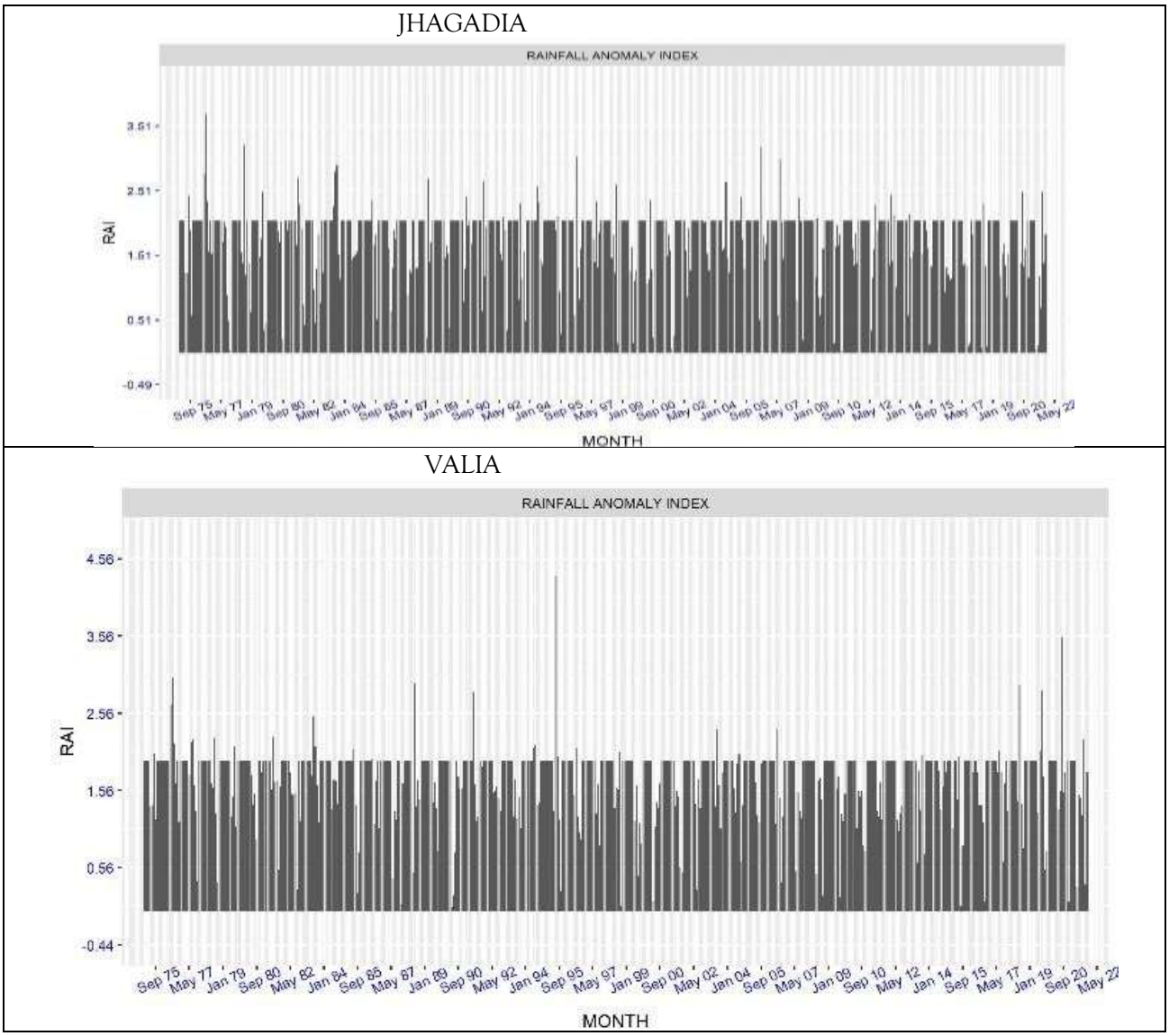


ANKLESHWAR



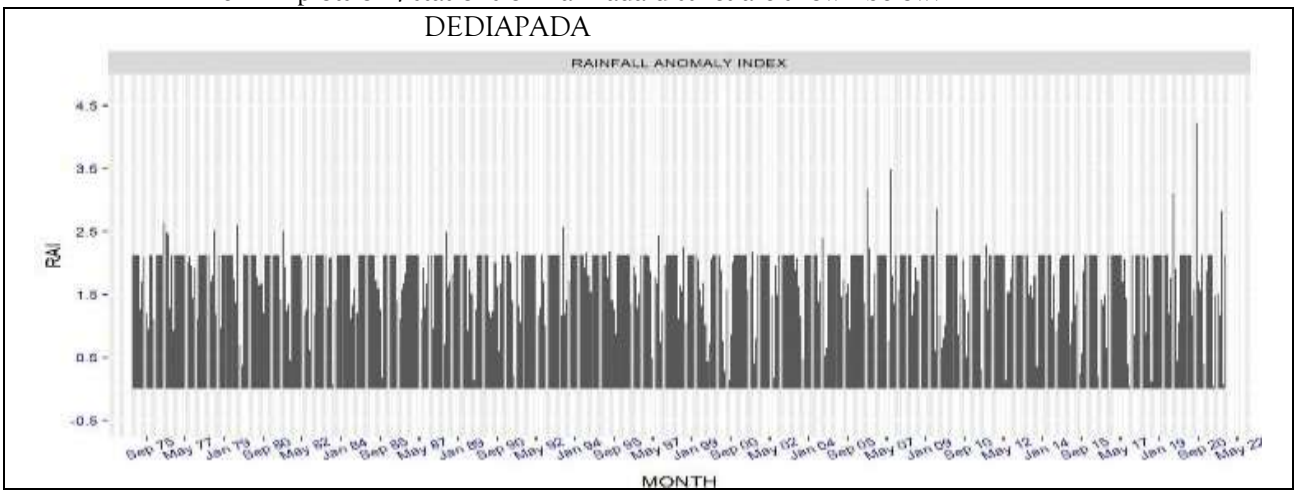
HANSOT





Faigure 5. RAI Plots of Amod, Ankleshwar, Bharuch, Hansot, Jambusar, Jhagadia, Vagra & Valia

The RAI plots of 4 stations of Narmada district are shown below:



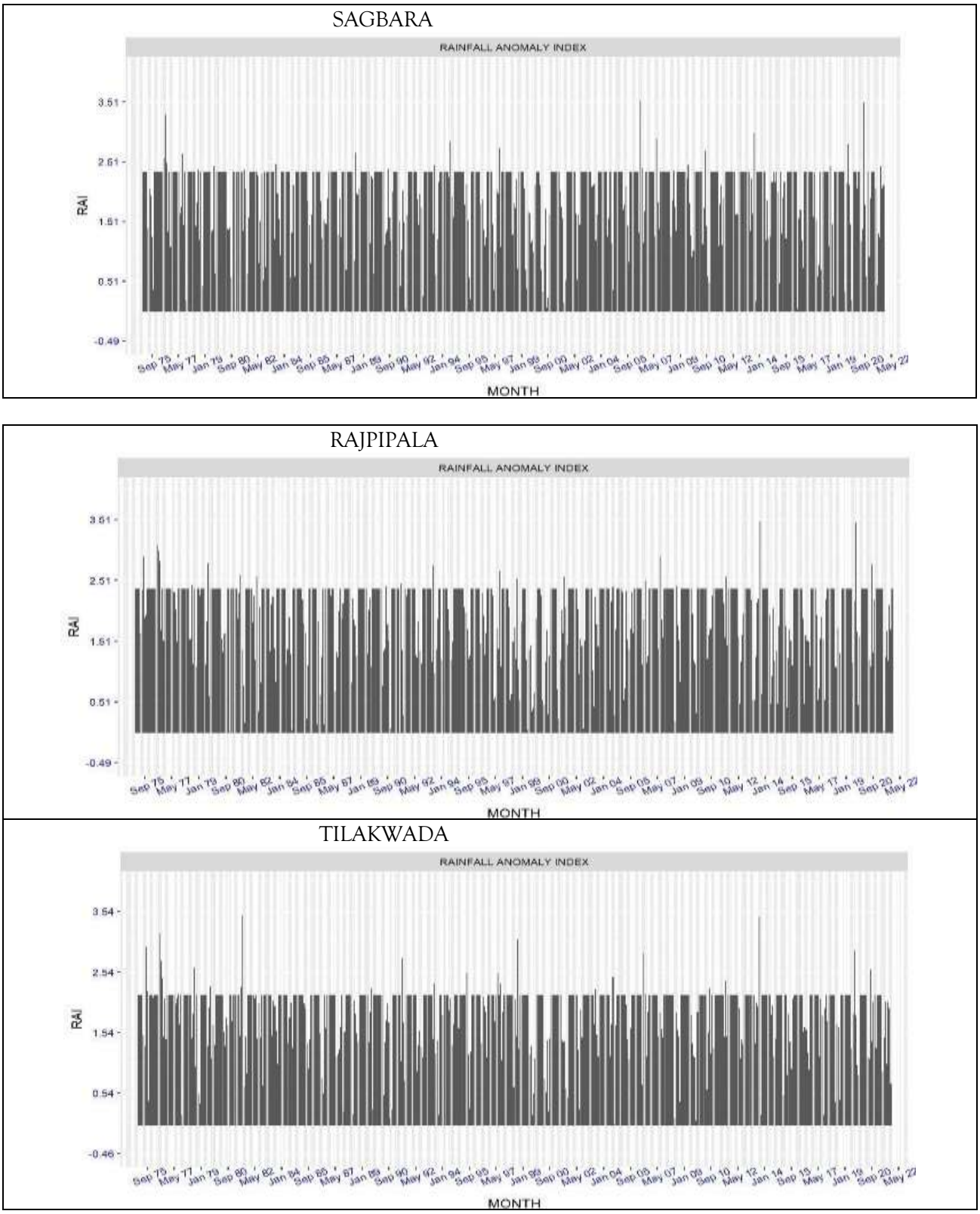
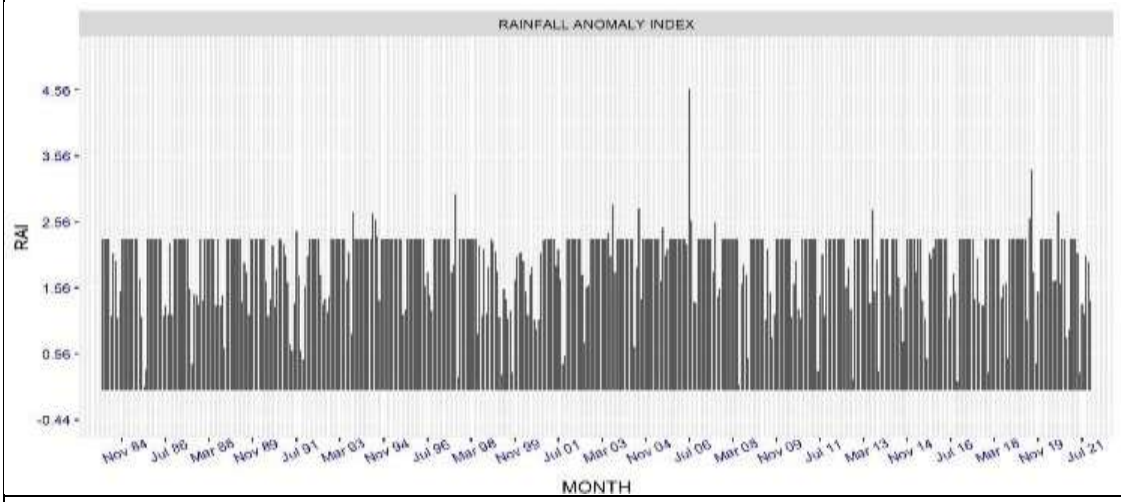


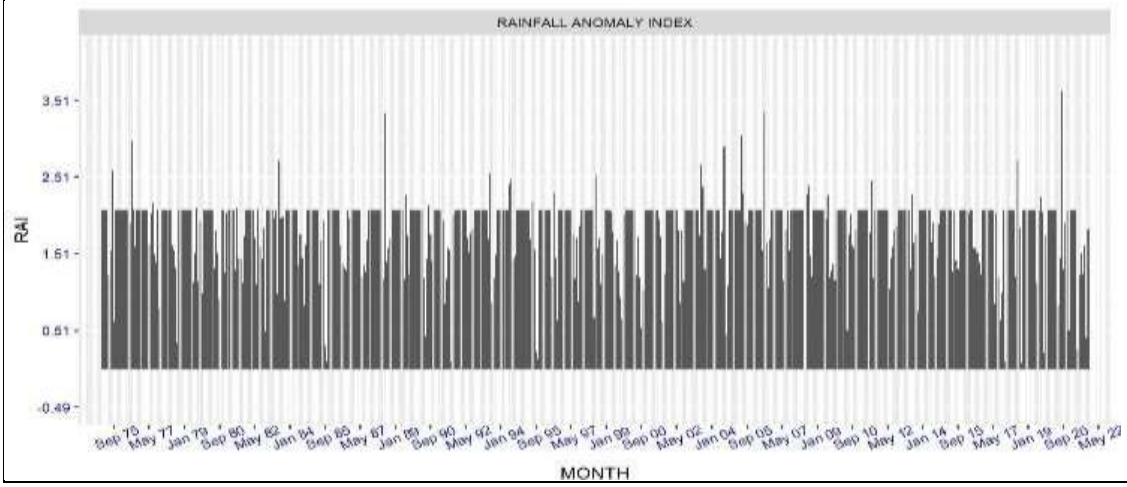
Figure 6. RAI Plots of Dediapada, Rajpipala, Sagbara & Tilakwada

The RAI of 4 stations of Tapi district is shown below:

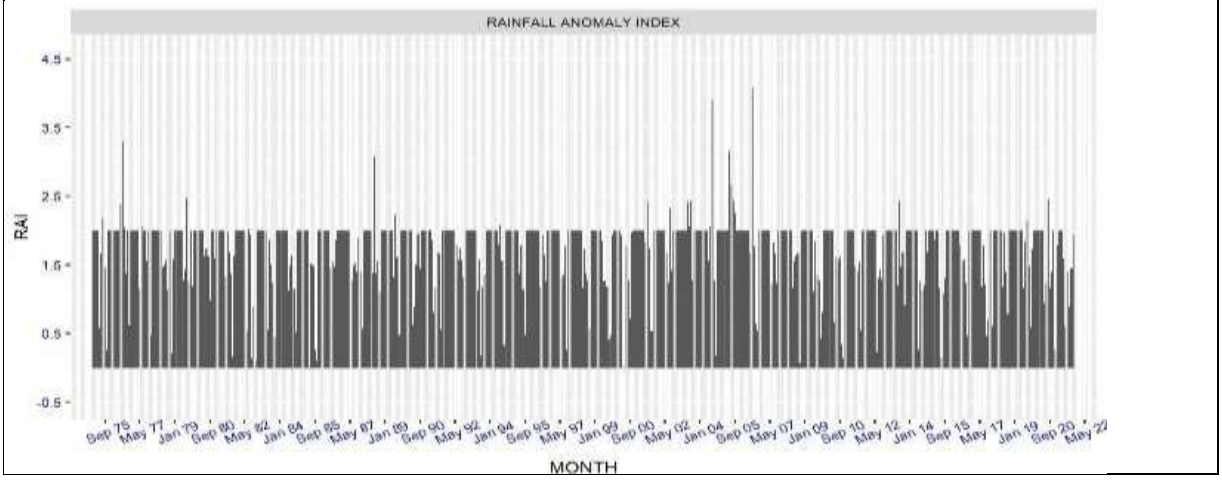
NIZAR



VALOD



SONGADH



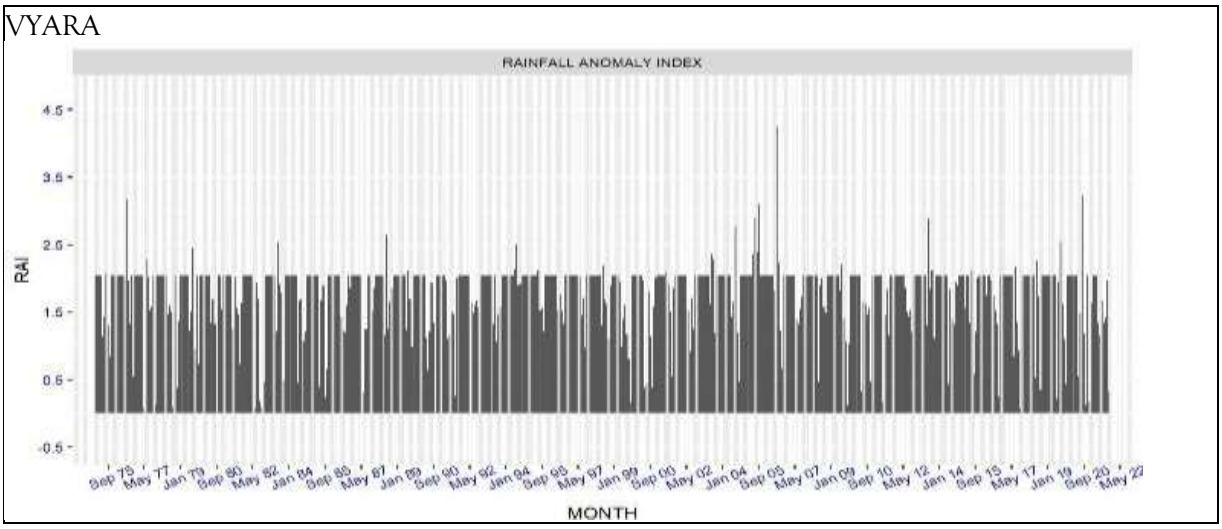


Figure 7. RAI Plots of Nizar, Songadh, Valod & Vyara

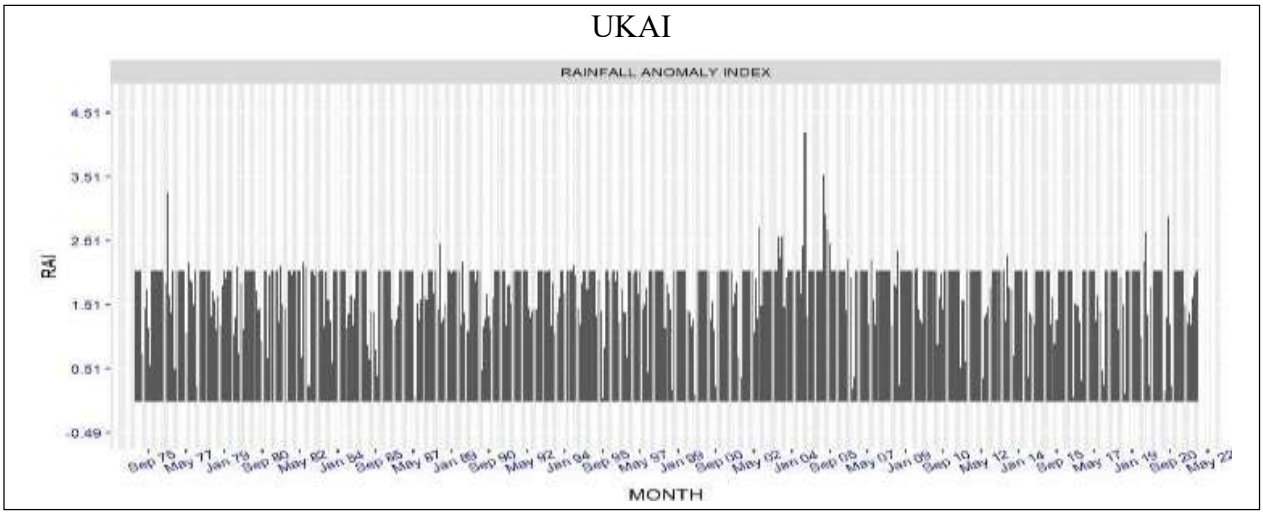


Figure 8. RAI Plot of Ukai

Jhagadia is the common station having highest and lowest rainfall on both scales in same time period According to rainfall anomaly index at 3 & -3, the highly rainfall receiving years were 1976, 1983, 1989, 1994, 2003, 2005, 2006, 2013, 2018 and 2019 while the large reduction in rainfall receiving years were 1982, 1985, 1986, 1987, 1991, 1998, 2000, 2012, 2014 and 2015 over the last 47 years.

As per the rainfall anomaly index at 4 & -4, the extreme highest rainfall receiving years were 1976, 2005, 2006, 2013 and2019 while the extreme reduction in rainfall years were 1986, 1987, 2000 and 2005 over last 47 years.

Amod, Hansot, Jambusar, Valia, Sagbara, Bardoli, Kamrej, Palsana and Songadh had received highly rainfall while Hansot,Jambusar, Vagra, Valia, Rajpilala, Sagbara, Tilakwada, Kamrej, Mangrol, Olpad, Ukai, Nizar, and Songadh have large reduction in rainfall in the last 47 years.

Common stations on the both increasing and decreasing scales during the same span are Hansot, Jambusar, Valia, Sagbara,Kamrej and Songadh.

Years with negative RAI values less than 0 indicate below-average rainfall. These years can lead to drought conditions,affecting crops, water reserves, and overall ecosystem health. Some of the years with significant below-average rainfallinclude 1985, 1986, 1987, 2000, 2014 and 2015.

CONCLUSIONS

Agroclimatic Zone – II of Gujarat state has been considered for the research work. This zone contains 4 major districts namely Bharuch, Narmada, Surat & Tapi. There are total 25 number of rain gauge stations, out of which 24 stations are having timeseries of 47 years (1975-2021) and 1 station is having 38 years (1984-2021) of rainfall data respectively. The daily rainfall data of these 25 numbers of rain gauge stations has been collected from the Indian Meteorological Department (IMD, Pune) and State Water Data Centre (SWDC, Gandhinagar).

If there is a consistent increase or decrease in RAI values over time, it could indicate shifts in the local climate. Years with positive RAI values greater than 0 indicate above-average rainfall. These years are generally favorable for agricultural activities and water availability. Some of the years with notable above-average rainfall include 1976, 1983,1994, 2003, 2004, 2005, 2006, and 2013. Hansot, Jhagadia, Ukai, and Songadh had received the extreme highest rainfall while Bharuch, Jhagadia, Valod and Vyarahad received the extreme reduction in rainfall over the last 47 years.

The years with extreme RAI values (very positive or very negative) can have significant impacts on agriculture, waterresources, and the environment. Adequate preparation, such as water conservation measures in dry years or flood management strategies in wet years, can help mitigate these impacts.

Monthly and SW-Monsoon rainfall trend analysis is done using data of 29 rain gauge stations for the Semi-Arid region of Gujarat state. Independency in the rainfall data is checked using the Wallis and Moore Phase-Frequency test.

Monthly and SW-Monsoon rainfall trend analysis is done using data of 29 rain gauge stations for the Semi-Arid region of Gujarat state. Independency in the rainfall data is checked using the Wallis and Moore Phase-Frequency test.

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