iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 10 **Issue:** VIII **Month of publication:** August 2022

**DOI:** https://doi.org/10.22214/ijraset.2022.46304

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 10 Issue VIII Aug 2022- Available at www.ijraset.com*

# Temporal Variations and Futuristic Projections of Temperature and Precipitation: A study of Vijayawada city

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***Abstract: Examining the temporal dynamics of meteorological variables in the context of changing climate, particularly in Vijayawada, where agriculture is predominant. Therefore, the study uses trend analysis of rainfall and temperature change in Vijayawada using precipitation data obtained from Precipitation and temperature data. Data have been analysed using the coefficient of variation and standard deviation. Furthermore, the Mann-Kendall test was used to detect the time series trend. The result revealed variability of rainfall and temperature. The month-wise analysis of the temperature and precipitation trends established different unique patterns. This is due to the fact that the sensitivity of the world to climate change varies temporally and spatially.***

***The scope of the study lies in developing the analysis to study different extreme events such as cloudbursts, heat waves, cold waves, etc. Furthermore, the spatial variations of the study can be used to establish the climate sensitivity with temporal factors.***

***Keywords: Temporal dynamics, climate sensitivity, Mann-Kendall Test, Sen-Slope Test***

## I. INTRODUCTION

The energy source for our Earth is solar radiation. The emissions of greenhouse gases allow solar energy to pass through. But the Earth's outgoing energy is redirected to the surface, causing more warming on the Earth's surface and the atmosphere alike (**Ayuyo, 2020**). The emission of Greenhouse gases is increasing with time. Meanwhile, changes in the atmosphere are also rising due to Human-induced activities such as deforestation, urbanisation, transportation, etc. The greenhouse influence upsurges the Earth's temperatures trapping heat in our atmosphere (Kweku, 2017). This is causing climate change, altering the balance and trends of several parameters such as temperature, precipitation, etc.,

Changes in the temperature can alter the water cycle and will change the average rainfall. Climate change also affects the intensity and frequency of precipitation. As the Earth's surface average temperatures increase due to climate change, it increases the overall evapotranspiration, increasing precipitation. However, this increase in rainfall, snowfall, and other rain forms will not necessarily fulfil the need for water requirements. High intense rainfall causes flooding and reduces the water storage potential, threatening water security. Due to deforestation, rise in average rainfall intensity, low infiltration, and more runoff. The lack of trees lowers the chances for more infiltration, which causes more runoff. The changes in temperature and rainfall can adversely affect the livelihood of people. The variation of temperature and rainfall are the two significant indicators to identify the variation in climatic variables and conditions in our ecological cycle (IPCC, 2010). The changes in air temperature and rainfall can occur due to atmospheric oscillations and also affects the atmosphere due to its changes. The local study describes the physical characteristics of each site or place on Earth, parameters like climate change, Topography, Vegetation, Latitudes, Elevation, etc. For our study, we took the parameters like climate change in Vijayawada city. Climate change includes temperature and rainfall variations. These two climatic variables can describe the changes in the climate conditions. To further understand the impacts of climate change, it is also possible to establish rainfall and temperature projections for the years such as 2050 and 2100. Using the following data, the temporal variation of temperature and rainfall, we can estimate the changes and variations for 2022-2100 in the graphical method. These estimations can aid us in establishing the effects of climate change and its impacts on various aspects of humankind. Also, these estimations may guide us through the necessary interventions to mitigate and adapt to climate change.

This city has witnessed significant trends of temperature increase and average rainfall rates. Toward this end, the study strives to (1) encounter the variation in temperature and average rainfall for 2001-2021; (2) estimate the future changes in climatic variables based above trend analysis.

## II. STUDY AREA AND DATA COLLECTION

### A. *Study Area*

Vijayawada is a historical place. It is situated in Andhra Pradesh in India, on the banks of river Krishna. Both southwest and northeast monsoons cause rainfall in Vijayawada. The region experiences hot summers and moderate winters. This city is also the capital of the newly formed Andhra Pradesh. Due to this region, the city has been growing rapidly since 2014. It is a flat region having few small to medium-sized hills (**Kusuma, 2015**). Vijayawada is dry with little or no precipitation during January, February, March, April, and May. Vijayawada is set to experience increased growth in population, causing stress on the available resources and adding to the severe vulnerability of the region. For the present study, Vijayawada city has been selected to understand the variations in climatic variables in the context of climate change.

### B. *Data Collection*

The data of maximum, minimum, and mean temperatures and total rainfall are collected for Vijayawada city from 2001 to 2021. The data has an hourly resolution on several climatic variables. The climatic variables that are measured from this city are maximum air temperature (**T** $_{max,}$ $^{0}$ **C),** minimum air temperature (**T** $_{max,}$ $^{0}$ **C),** mean temperature, and daily rainfall. The NASA/POWER CERES/MERRA2 Native Resolution Daily Data provides and controls this meteorological data. The data for the city of Vijayawada is obtained at Latitude 16.5025 North, Latitude 80.6396 East. Elevation of MERRA2 is average for 0.5×0.625 degree latitude/longitude region = 45.43 meters. The value for missing source data that cannot be computed or is outside the source available range is 999. The minimum temperature is from MERRA-2 temperature at 2 meters Minimum©, and the Maximum temperature is from MERRA-2 temperature at 2 meters Maximum©.'

## III. METHODOLOGY

The procedure for estimating minimum and maximum temperatures using NASA Native Resolution Daily Data is presented in this section. Maximum temperatures, minimum temperatures and daily rainfall data are taken as inputs, from which the monthly average values are computed, and the trends are established. And these monthly average values of climatic variables are plotted from 2001 to 2021 in graphs to obtain the slope values. This slope is further plotted and projected until 2100 to compute and estimate the trend of the climate variables. The non-parametric Mann-Kendell test and Sen's slope estimation were applied to determine monotonic trends in Vijayawada. Sen's slope estimation was used to determine monotonic trends in climatic variables. The Mann-Kendell test was proposed by (Mann, 1945) and improved by **(kendell, 1975)**. This method is applied to identify temporal trends and magnitude in annual climatic variables **(Junliang, 2016).** MK trend test is a non-parametric test commonly employed to detect monotonic trends in a series of data **(Asfaw Amogne, 2018)**. Since there are chances of outliers being present in the dataset, the non-parametric MK test is helpful because its statistic is based on the (+or -) signs rather than the values of the random variable, and therefore, the trends determined are less affected by the outliers (**Birsan, 2005)**. The MK test statistic 'S' is calculated based on (Mann, 1945) (kendell, 1975) and (Yue, 2002)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+!}^{n} sgn(xj - xi)$$

The trend test is applied to a time series Xi that is ranked from i=1, 2 … n-1 and Xj, which is ranked from j=i+1, 2, .. n. Each of the data points $X_i$ is taken as a reference point, which is compared with the rest of the data point $X_j$ **(Asfaw Amogne, 2018)** so that:

$$sgn(xj - xi) = \{\langle +1\, if\ (xj - xi) > 0 | 0\, if\ (xj - xi) = 0 | -1\, if\ (xj = xi) < 0 \rangle$$

In this variance, the statistic is as given below

$$var(s) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t1(t1-1)(2t1+5)}{18}$$

n is the number of observations, and $t_i$ is the ties of the sample time series **(Asfaw Amogne, 2018)**. The test statistics $Z_c$ is as follows:

$$Z = \{\langle (s-1) \div var(s) if\ s > 0 \,|\, 0\ if\ s = 0 \,|\, (s+1) \div var(s) if\ s < 0 \rangle$$

Z follows a normal distribution. A positive Z and a negative Z depict an upward and downwards trend for the period, respectively. Sen's Slope estimation test computes both the slope (i.e. the linear rate of change) and intercepts according to Sen's method **(Asfaw Amogne, 2018).** The magnitude of the trend is predicted by and **(Sen, 1968)** slope estimator methods. A positive value indicates an 'upward trend' (increasing values with time), while a negative value indicates a 'downward trend. In general, the slope Ti between any two values of a time series x can be estimated from:

$$T = \frac{(\text{Xj-Xi})}{(j-i)}$$

In this, Xj and Xi are considered values at times j and i.

In this study, rainfall and temperature variability have been computed using CV. Furthermore, MK was used to detect the trend of precipitation and temperature with Sen's slope estimator. Data analysis was undertaken using an Excel spreadsheet. CV is calculated to evaluate the variability of the rainfall **(Asfaw Amogne, 2018).** A higher value of CV is the indicator of more significant variability, and vice versa, which is computed as:

$$\text{CV}=\frac{\sigma}{\mu}\times 100$$

CV is the coefficient of variation, σ is the standard deviation, and μ is the mean precipitation **(Asfaw Amogne, 2018)**. CV is used to classify the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), and high (CV > 30) **(Hare, 2003)**

## IV. RESULTS AND DISCUSSIONS

### *A. Temporal variation of rainfall*

Analysis of the monthly and seasonal trend of temperature (2001-2021) and seasonal and monthly rainfall (2001-2021) was done in the Vijayawada region. In the MK test, parameters like Kendall's test, S statistic, and the Z statistic were considered to identify the increasing or decreasing trend in the time series of climatic parameters (**Asfaw Amogne, 2018)**. Sen's slope is used to get the magnitude of the trend. It showed the decreasing/increasing trend with the significance levelling with the trend of 20 years of rainfall and temperature. The monthly rainfall for that trend shows significant or non-significant, positive or negative, and no trend analysis. For now, we plot the tables and graphs monthly-wise average data for 20 years.

If we observe, it is about the monthly average rainfall data for 20 years trend. Temporally averaged rainfall generally decreased from 2001 to 2021 across Vijayawada for January. Trend analysis confirmed that rainfall in Vijayawada has reduced with a negative slope of -0.08679. The year 2012 collected more rainfall in January month. In 2006, 2007, 2009, 2011, 2013, 2014, and 2017, 2018, it showed 0 rainfall defining no rainfall in January for those years. The climatic zone exhibited large fluctuations in January month.

February month shows monthly changes in 20 years. It indicated many significant variations in rainfall trends. The trend and change rate varies widely in different years. It was observed to have a positive trend and increasing rate of change in most years, with particular significance in 2008, 2011, and 2013. 2013 has the highest rate of significant increasing rainfall, followed by 2008 and 2011. The month of February shows large fluctuations, either more rainfall or no rainfall. The Vijayawada shows a significant increasing trend with a 0.206883 mm/year slope. Notably, most of the years in March observed no such substantial changes in precipitation. Thus, overall dominance of negative trend was noticed despite some mixed trends observed in different years. 2008 only showed the highest peak of rainfall, almost 80% greater. This highest peak causes a negative slope of -0.55966 mm/year. However, a significantly high positive rate was observed in the year 2008. Except that there are only minor fluctuations over that trend. A significant trend was noticed in April, with a decreasing change rate of -0.84549.

From the graph, the highest peak was observed in 2001 only, then it gradually fluctuated with small a range. But for May, it showed a positive trend with an increasing rate of 1.038325 mm/year. In the summer month, there is an increasing rate. The rainfall trend and rate of change in June months show a significant positive trend of 3.883039 mm/year. In July, there is also a positive rate of 7.21265mm/year. On considering seasonal variation, there is a positive trend: an annual increase in average rainfall. The trend magnitude of monthly annual rainfall gives a significant increase in August (2.982831 mm/year), September (1.200896 mm/year), and November (1.893377 mm/year). An increase in rainfall is observed in most of the summer season, with a high rate decrease in annual rainfall observed in October (-7.11896 mm/year) and December (-0.90394 mm/year). Summer (May, June, July, and August) is the primary rainy season in the study area. The total rainfall was also estimated from 2021 to 2100 from collected data for the 2001-2021 trend shown below in graphs. Trend detection and analysis are performed only through parametric and non-parametric tests for consistent data.

From Table 2, the maximum and minimum mean rainfalls were 187.078 mm (in July, the wettest month) and 6.57mm (in January, the driest month) over trend, respectively. CV defines its degree of variability. The degree of variability over the trend in August is medium, while in the remaining months, it was high based on CV %. And the increasing and decreasing trends were determined by the slope. The increasing trend was observed in February, May, June, July, August, September, and November. And a decreasing trend was observed in January, March, April, October, and December. There was a more increasing rate in July month over the trend. And the mean rainfall in 2030,2050,2075,2100 was more in July, with 325mm, 466.4mm, 650mm, and 829mm, respectively. And the least rainfall was observed in February, March, and December.

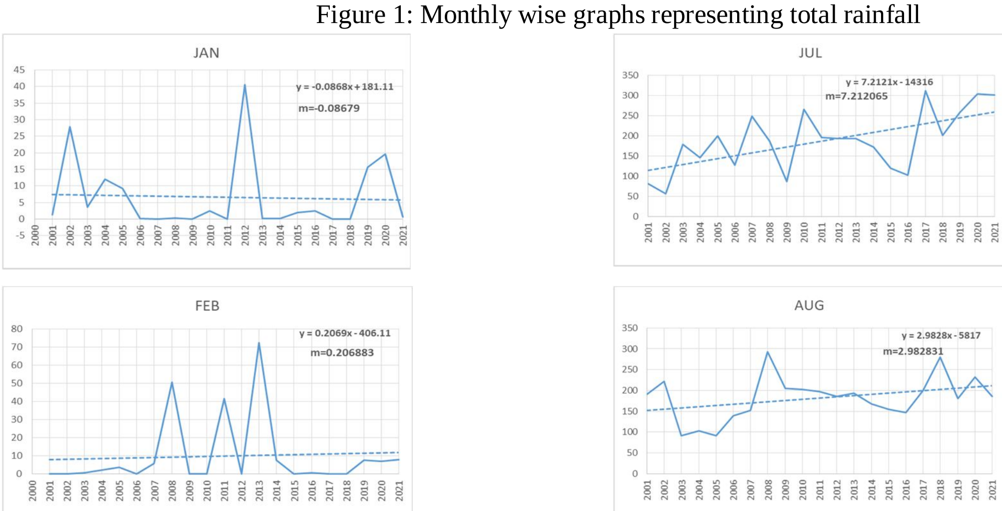
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VIII Aug 2022- Available at www.ijraset.com

MK test values determine the increasing and decreasing trends. As per MK test values, there was an increasing trend in February, April, May, June, July, August, September, and November. The in remaining months it was showing the decreasing and over the trend. Mostly CV and MK test values show similar trend variations. Monthly rainfall showed an increasing trend in February, May, June, July, August, September, and November from 2001 to 2100. The results of the above graphs display a decreasing trend in January, March, April, October, and December.

Table 1 Monthly temporal variation of rainfall between 2001 and 2021

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 1.33 | 0 | 4.49 | 138.31 | 14.77 | 87.09 | 82.04 | 190.42 | 150.33 | 158.75 | 68.93 | 13.67 |
| 2002 | 27.8 | 0.11 | 3.55 | 3.27 | 13.33 | 72.19 | 55.8 | 221.64 | 31.3 | 254.37 | 57.69 | 27.13 |
| 2003 | 3.66 | 0.64 | 11.87 | 1.59 | 2.8 | 82.3 | 179.11 | 90.74 | 149.09 | 203.76 | 4.15 | 127.56 |
| 2004 | 12 | 2.21 | 2.11 | 7.77 | 62.33 | 88.31 | 145.29 | 102.68 | 153.93 | 162.39 | 19.94 | 0.17 |
| 2005 | 9.29 | 3.78 | 3.33 | 7.29 | 49.35 | 50.09 | 200.35 | 91.61 | 358 | 367.15 | 45.85 | 6.19 |
| 2006 | 0.07 | 0 | 16.25 | 35.1 | 34.96 | 130.5 | 127.79 | 139.16 | 167.77 | 564.85 | 125.66 | 1.49 |
| 2007 | 0.01 | 5.89 | 0.79 | 4.38 | 11.06 | 235.93 | 248.94 | 152.13 | 210.57 | 181.86 | 11 | 5.17 |
| 2008 | 0.26 | 50.55 | 113.29 | 0.97 | 13.49 | 106.77 | 186.75 | 292.75 | 164.04 | 71.32 | 156.07 | 1.41 |
| 2009 | 0.02 | 0 | 0.95 | 1.71 | 108.27 | 88.57 | 86.68 | 204.35 | 151.92 | 31.39 | 136.16 | 9.61 |
| 2010 | 2.37 | 0.08 | 0.51 | 25.82 | 166.14 | 102.33 | 265.51 | 201.98 | 312.77 | 284.02 | 118 | 77.75 |
| 2011 | 0.01 | 41.43 | 0.03 | 32.52 | 50.6 | 96.08 | 195.89 | 197.2 | 29.13 | 63.91 | 9.71 | 13.63 |
| 2012 | 40.57 | 0 | 5.33 | 14.61 | 89.36 | 106.61 | 192.9 | 186.02 | 255.13 | 151.42 | 150.21 | 0.43 |
| 2013 | 0.16 | 72.47 | 0 | 41.81 | 33.36 | 140.98 | 192.71 | 193.33 | 109.08 | 412.16 | 82.33 | 1.12 |
| 2014 | 0.22 | 7.66 | 2.89 | 0.17 | 73.06 | 18.52 | 172.49 | 166.86 | 118.03 | 134.44 | 42.83 | 11.98 |
| 2015 | 1.88 | 0.03 | 0.29 | 15.04 | 4.65 | 218.86 | 119.73 | 154.28 | 139.99 | 65.02 | 98.52 | 5.73 |
| 2016 | 2.53 | 0.64 | 0 | 0 | 142.13 | 275.37 | 102.09 | 147.35 | 199.45 | 51.03 | 1.79 | 13.32 |
| 2017 | 0.01 | 0 | 4.13 | 1.49 | 31.54 | 189.18 | 311.47 | 199.82 | 121.42 | 103.2 | 28.91 | 0.01 |
| 2018 | 0 | 0 | 1.3 | 18.34 | 32.12 | 154.15 | 201.57 | 280.19 | 80.53 | 36.78 | 22.95 | 99.11 |
| 2019 | 15.61 | 7.81 | 12.43 | 19.04 | 17.48 | 94.32 | 257.64 | 180.55 | 206.23 | 207.1 | 4.37 | 5.22 |
| 2020 | 19.59 | 7.17 | 5.87 | 33.82 | 10.65 | 141.35 | 303.26 | 232.25 | 266.88 | 223.36 | 204.94 | 0.94 |
| 2021 | 0.63 | 8.06 | 0.1 | 30.61 | 70.99 | 134.64 | 300.63 | 186.13 | 218.92 | 103.94 | 158.52 | 0.08 |

Figure 1: Monthly wise graphs representing total rainfall



International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 10 Issue VIII Aug 2022- Available at www.ijraset.com*

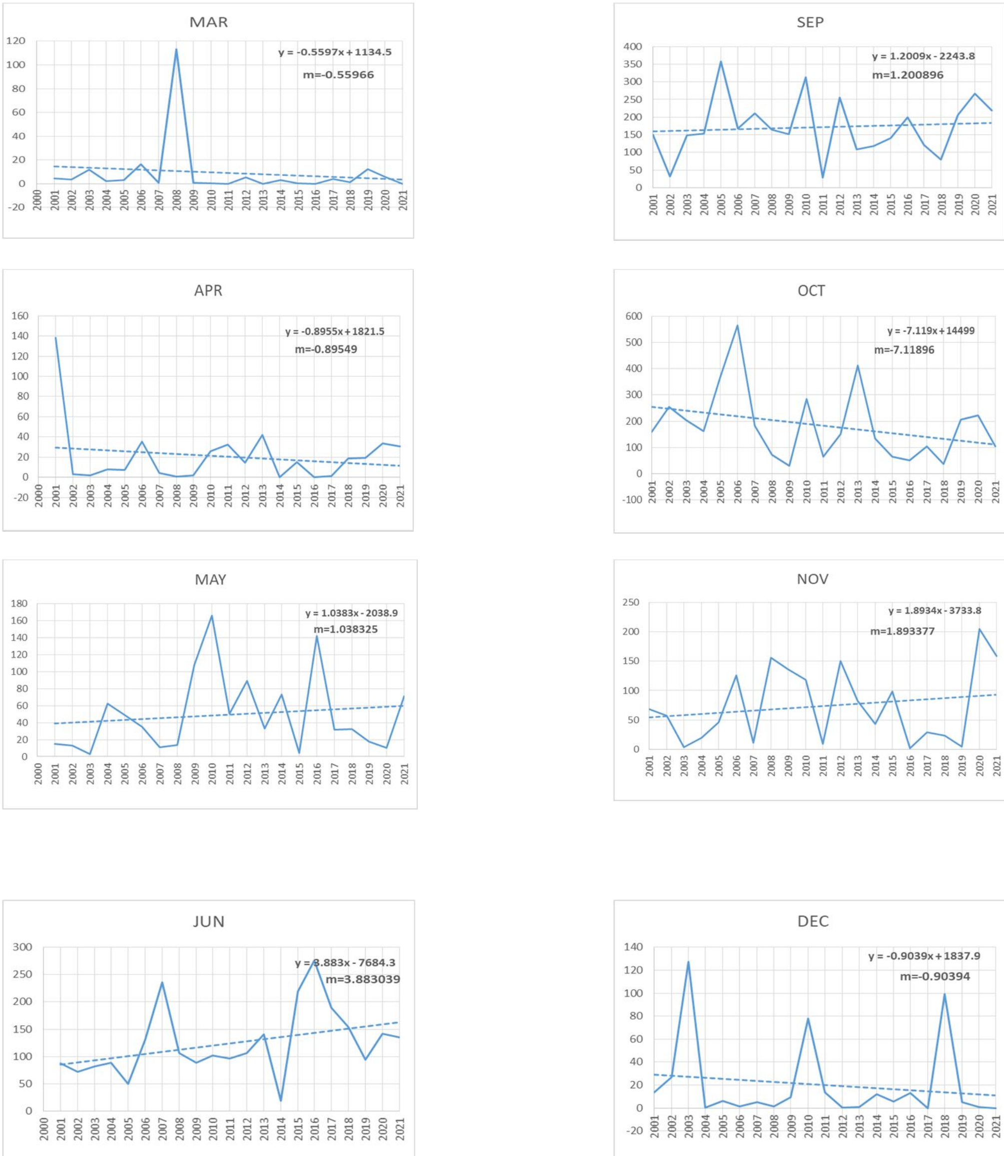
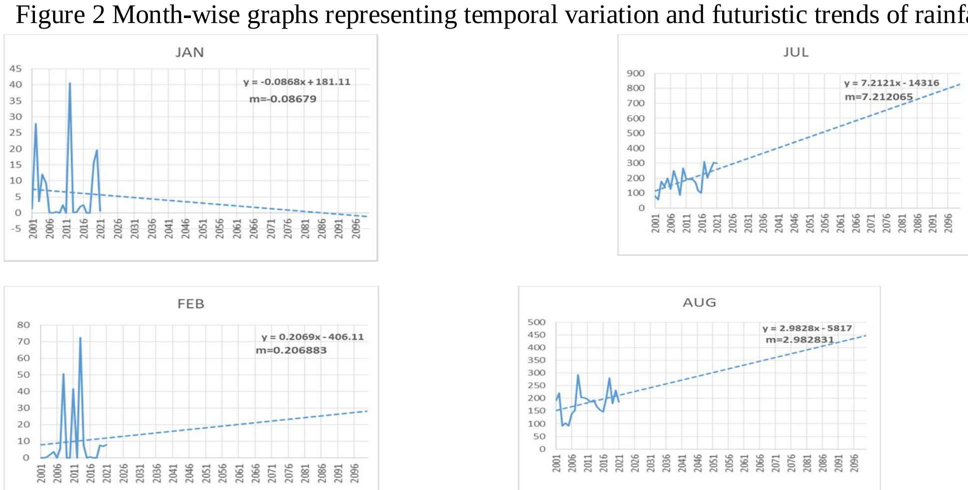



Figure 2 Month-wise graphs representing temporal variation and futuristic trends of rainfall



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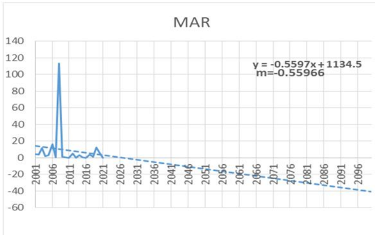


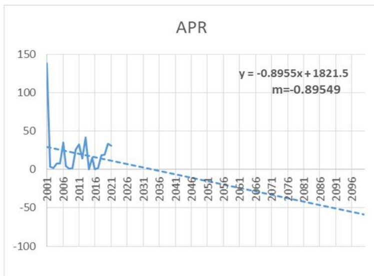


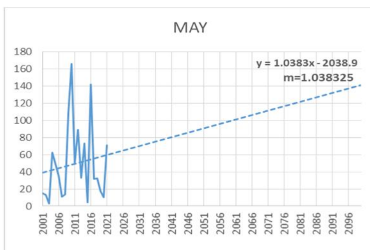


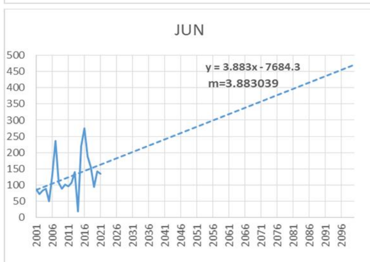


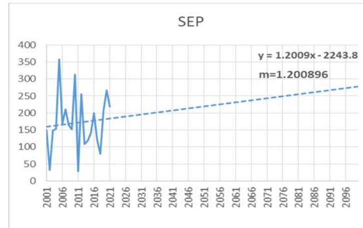


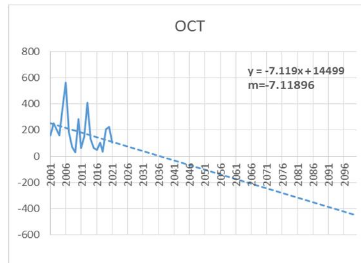


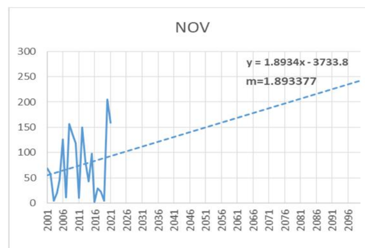


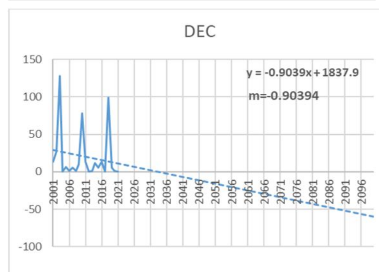


Table 2 Basic statistics and MK trend analysis of rainfall

| MONTH | MEAN | SD | CV (%) | MK test | Sen's Slope | 2030 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| January | 6.572380952 | 10.95593442 | 166.6965823 | -0.101 | -0.086792208 | 4.9 | 3.2 | 1 | -1.1 |
| February | 9.93 | 19.6770079 | 198.1571793 | 0.103 | 0.206883117 | 13.9 | 17.9 | 23.1 | 28.3 |
| March | 9.024285714 | 24.31465208 | 269.435752 | -0.174 | -0.559662338 | -1.6 | -12.7 | -26.7 | -40.3 |
| April | 20.65047619 | 30.20762428 | 146.2805216 | 0.189 | -0.895493506 | 3.8 | -14.2 | -36.6 | -59 |
| May | 49.16380952 | 45.56349893 | 92.67690883 | 0.032 | 1.038324675 | 69 | 89.2 | 115.4 | 141.6 |
| June | 124.4828571 | 62.43780066 | 50.15775031 | 0.347 | 3.883038961 | 198 | 274.5 | 371 | 470 |
| July | 187.0780952 | 75.16504245 | 40.17843048 | 0.337 | 7.212064935 | 325 | 466.4 | 650 | 829 |
| August | 181.4971429 | 52.62886377 | 28.99707562 | 0.24 | 2.982831169 | 238.5 | 297 | 372 | 447 |
| September | 171.1671429 | 82.69218785 | 48.31078352 | 0.074 | 1.200896104 | 194 | 218 | 248 | 278 |
| October | 182.4866667 | 135.925158 | 74.48498045 | -0.242 | -7.118961039 | 47.5 | -94 | -274 | -451 |
| November | 73.73952381 | 62.70224593 | 85.03207329 | 0.063 | 1.893376623 | 110 | 147 | 195 | 242 |
| December | 20.08190476 | 35.5838009 | 177.1933555 | -0.189 | -0.903935065 | 2.9 | 15.8 | -38 | -60 |

Table 3 Temporal variation in Minimum, Maximum, and Mean Temperatures for Nov, Dec, Jan, and Feb

| YEAR | NOV | | | DEC | | | JAN | | | FEB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | max | mean | min | max | mean | min | max | mean | min | max | mean | min |
| 2001 | 29.12 | 24.57 | 20.79 | 29.86 | 22.72 | 17.33 | 33.10 | 24.74 | 18.41 | 37.55 | 27.48 | 19.64 |
| 2002 | 29.32 | 23.84 | 19.34 | 30.37 | 23.29 | 18.09 | 31.37 | 23.95 | 18.59 | 35.49 | 26.71 | 19.98 |
| 2003 | 29.85 | 24.10 | 19.28 | 29.17 | 22.53 | 17.36 | 31.70 | 24.04 | 18.41 | 35.79 | 27.61 | 21.27 |
| 2004 | 30.21 | 23.92 | 18.90 | 31.52 | 23.45 | 17.42 | 30.20 | 22.97 | 17.53 | 34.53 | 26.07 | 19.44 |
| 2005 | 27.32 | 22.08 | 17.40 | 27.13 | 21.52 | 16.77 | 33.14 | 25.60 | 19.82 | 36.86 | 27.84 | 20.73 |
| 2006 | 28.16 | 24.07 | 20.70 | 27.81 | 22.20 | 17.40 | 29.79 | 22.55 | 16.49 | 35.33 | 26.08 | 19.00 |
| 2007 | 28.45 | 23.00 | 18.04 | 29.08 | 22.90 | 17.99 | 30.16 | 22.95 | 17.61 | 33.74 | 25.73 | 19.54 |
| 2008 | 29.49 | 24.32 | 20.09 | 29.31 | 23.38 | 18.79 | 31.77 | 23.60 | 17.60 | 33.38 | 26.27 | 20.91 |
| 2009 | 30.06 | 25.39 | 21.78 | 30.41 | 23.73 | 18.69 | 31.91 | 24.03 | 18.33 | 36.72 | 27.81 | 20.69 |
| 2010 | 28.88 | 25.14 | 22.23 | 26.49 | 21.40 | 16.99 | 31.98 | 24.77 | 19.26 | 36.17 | 27.37 | 20.67 |
| 2011 | 33.35 | 25.95 | 20.21 | 33.38 | 25.64 | 19.85 | 28.03 | 21.26 | 15.67 | 32.21 | 24.79 | 19.24 |
| 2012 | 28.25 | 23.44 | 19.52 | 29.03 | 22.66 | 17.67 | 31.98 | 24.39 | 18.71 | 36.43 | 27.07 | 19.68 |
| 2013 | 28.55 | 23.89 | 19.87 | 27.45 | 21.65 | 16.86 | 31.56 | 24.31 | 18.77 | 33.77 | 25.77 | 19.51 |
| 2014 | 30.34 | 24.30 | 19.53 | 30.61 | 23.48 | 17.86 | 29.72 | 23.22 | 17.96 | 33.25 | 25.31 | 18.97 |
| 2015 | 30.70 | 25.18 | 21.09 | 31.70 | 24.42 | 19.06 | 32.17 | 23.97 | 17.40 | 34.92 | 26.24 | 19.25 |
| 2016 | 32.24 | 24.76 | 18.84 | 32.23 | 24.17 | 17.87 | 32.66 | 25.03 | 19.10 | 36.43 | 27.94 | 21.39 |
| 2017 | 29.66 | 24.43 | 20.15 | 30.46 | 22.91 | 17.03 | 33.33 | 25.16 | 18.61 | 36.45 | 27.23 | 19.92 |
| 2018 | 33.58 | 26.64 | 21.42 | 30.70 | 24.27 | 19.19 | 32.36 | 24.26 | 17.96 | 35.65 | 26.64 | 19.54 |
| 2019 | 29.52 | 24.56 | 20.31 | 29.37 | 23.57 | 19.12 | 30.85 | 23.07 | 17.00 | 35.24 | 26.88 | 20.34 |
| 2020 | 28.89 | 24.65 | 21.11 | 27.33 | 21.81 | 17.02 | 31.66 | 24.85 | 19.73 | 34.42 | 26.77 | 20.81 |
| 2021 | 28.47 | 25.07 | 22.58 | 27.50 | 22.17 | 17.70 | 29.75 | 23.74 | 19.08 | 33.32 | 25.24 | 19.06 |

Table 4 Temporal variation in Minimum, Maximum, and Mean Temperatures for Mar, Apr, May and Jun

| YEAR | MAR | | | APR | | | MAY | | | JUN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | max | mean | min | max | mean | min | max | mean | min | max | mean | min |
| 2001 | 39.25 | 30.57 | 23.82 | 37.44 | 30.35 | 24.90 | 41.04 | 33.99 | 28.56 | 35.02 | 30.39 | 26.54 |
| 2002 | 39.44 | 30.36 | 23.08 | 41.82 | 32.82 | 25.90 | 43.61 | 35.86 | 29.45 | 35.40 | 30.92 | 27.22 |
| 2003 | 38.53 | 30.15 | 23.52 | 41.48 | 32.81 | 26.14 | 43.62 | 35.71 | 29.20 | 38.00 | 32.59 | 28.29 |
| 2004 | 39.82 | 30.30 | 22.64 | 41.19 | 33.02 | 26.75 | 36.76 | 31.40 | 27.14 | 35.40 | 30.57 | 26.49 |
| 2005 | 38.99 | 30.35 | 23.61 | 39.93 | 32.61 | 27.00 | 40.38 | 33.35 | 28.10 | 37.26 | 32.16 | 27.97 |
| 2006 | 38.07 | 29.98 | 23.34 | 40.61 | 32.41 | 25.79 | 37.71 | 32.20 | 27.77 | 34.64 | 30.33 | 26.75 |
| 2007 | 38.43 | 29.77 | 22.75 | 40.73 | 32.31 | 25.92 | 42.02 | 35.14 | 29.45 | 33.90 | 30.15 | 26.99 |
| 2008 | 35.65 | 28.21 | 22.35 | 39.46 | 31.36 | 24.91 | 42.86 | 35.42 | 29.21 | 35.79 | 30.83 | 26.84 |
| 2009 | 39.77 | 30.54 | 23.00 | 41.13 | 32.88 | 26.44 | 39.04 | 32.36 | 27.46 | 35.84 | 30.71 | 26.52 |
| 2010 | 40.20 | 31.10 | 23.46 | 41.41 | 33.04 | 27.12 | 40.23 | 33.19 | 27.88 | 35.16 | 30.25 | 26.44 |
| 2011 | 37.98 | 28.93 | 23.46 | 38.86 | 30.96 | 25.01 | 40.44 | 33.73 | 28.45 | 36.46 | 31.06 | 26.79 |
| 2012 | 39.69 | 30.63 | 23.46 | 40.22 | 32.23 | 26.16 | 40.21 | 33.14 | 28.07 | 36.96 | 31.84 | 27.74 |
| 2013 | 38.05 | 29.06 | 21.93 | 40.15 | 31.80 | 25.42 | 40.67 | 33.77 | 28.56 | 34.36 | 29.83 | 26.13 |
| 2014 | 38.14 | 29.61 | 22.50 | 41.71 | 32.96 | 25.96 | 38.87 | 32.32 | 27.42 | 39.04 | 33.99 | 29.81 |
| 2015 | 38.08 | 29.78 | 23.13 | 39.47 | 31.63 | 25.64 | 41.47 | 34.30 | 28.83 | 33.50 | 29.22 | 25.78 |
| 2016 | 38.89 | 30.31 | 23.71 | 42.56 | 33.05 | 25.88 | 40.38 | 33.25 | 27.63 | 32.71 | 28.78 | 25.71 |
| 2017 | 39.13 | 30.53 | 23.72 | 42.61 | 33.55 | 26.61 | 40.76 | 33.86 | 28.43 | 34.66 | 30.14 | 26.61 |
| 2018 | 39.43 | 30.28 | 22.90 | 40.79 | 32.39 | 25.97 | 39.14 | 32.35 | 27.42 | 35.62 | 30.59 | 26.64 |
| 2019 | 39.05 | 30.40 | 23.62 | 41.61 | 32.71 | 25.78 | 41.38 | 34.10 | 28.77 | 36.87 | 31.96 | 28.11 |
| 2020 | 38.40 | 30.00 | 23.24 | 40.55 | 32.39 | 26.00 | 42.19 | 34.34 | 28.32 | 35.08 | 30.50 | 26.84 |
| 2021 | 39.42 | 29.95 | 22.19 | 40.30 | 32.28 | 26.00 | 38.29 | 32.19 | 27.41 | 35.20 | 30.34 | 26.27 |

Table 5 Temporal variation in Minimum, Maximum, and Mean Temperatures for Jul, Aug, Sep and O

| YEAR | JUL | | | AUG | | | SEP | | | OCT | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | max | mean | min | max | mean | min | max | mean | min | max | mean | min |
| 2001 | 35.10 | 30.24 | 26.32 | 31.35 | 27.48 | 24.59 | 31.50 | 27.84 | 24.72 | 30.24 | 26.54 | 23.27 |
| 2002 | 35.71 | 31.09 | 27.39 | 32.78 | 28.38 | 24.95 | 33.97 | 28.81 | 24.52 | 30.43 | 26.35 | 23.22 |
| 2003 | 32.22 | 28.29 | 25.27 | 31.69 | 27.92 | 24.92 | 31.25 | 27.53 | 24.63 | 30.30 | 26.47 | 23.16 |
| 2004 | 32.30 | 28.37 | 25.22 | 33.35 | 28.76 | 25.06 | 31.65 | 27.85 | 24.83 | 29.91 | 26.03 | 22.74 |
| 2005 | 32.88 | 28.88 | 25.67 | 31.38 | 27.71 | 24.81 | 30.13 | 27.07 | 24.72 | 29.33 | 26.34 | 23.81 |
| 2006 | 34.84 | 29.95 | 25.89 | 31.21 | 27.45 | 24.48 | 31.11 | 27.33 | 24.38 | 31.98 | 27.22 | 23.13 |
| 2007 | 31.90 | 28.12 | 25.09 | 30.67 | 27.25 | 24.52 | 29.95 | 26.90 | 24.47 | 28.92 | 25.02 | 21.43 |
| 2008 | 33.53 | 29.26 | 25.81 | 30.53 | 27.12 | 24.51 | 30.44 | 26.95 | 23.93 | 30.22 | 25.84 | 22.13 |
| 2009 | 35.27 | 30.12 | 25.91 | 32.79 | 28.78 | 25.64 | 31.44 | 27.82 | 24.77 | 32.15 | 26.94 | 22.55 |
| 2010 | 31.62 | 27.76 | 24.83 | 31.24 | 27.69 | 24.75 | 30.04 | 26.91 | 24.40 | 29.80 | 26.32 | 23.47 |
| 2011 | 33.48 | 29.10 | 25.52 | 31.77 | 27.96 | 24.97 | 32.07 | 27.97 | 24.62 | 33.35 | 27.95 | 23.63 |
| 2012 | 33.12 | 28.71 | 25.13 | 31.67 | 27.60 | 24.40 | 30.43 | 27.04 | 24.32 | 30.18 | 25.78 | 21.90 |
| 2013 | 32.52 | 28.14 | 24.74 | 31.54 | 27.59 | 24.43 | 30.80 | 27.12 | 24.18 | 29.72 | 26.45 | 23.78 |
| 2014 | 35.33 | 30.43 | 26.43 | 32.56 | 28.41 | 25.13 | 31.20 | 27.29 | 24.19 | 31.48 | 26.74 | 22.86 |
| 2015 | 34.68 | 29.91 | 26.08 | 32.56 | 28.47 | 25.05 | 31.34 | 27.57 | 24.56 | 32.98 | 27.70 | 23.45 |
| 2016 | 32.07 | 28.20 | 25.10 | 32.94 | 28.67 | 25.20 | 30.38 | 26.81 | 23.98 | 30.72 | 25.54 | 21.31 |
| 2017 | 32.95 | 28.60 | 25.05 | 30.84 | 27.40 | 24.59 | 30.40 | 27.32 | 24.65 | 30.44 | 26.59 | 23.31 |
| 2018 | 33.40 | 28.75 | 25.12 | 31.65 | 27.58 | 24.46 | 31.11 | 27.41 | 24.24 | 32.55 | 27.02 | 22.48 |
| 2019 | 34.01 | 29.55 | 25.99 | 31.42 | 27.77 | 24.91 | 30.86 | 27.32 | 24.63 | 29.52 | 26.49 | 24.05 |
| 2020 | 31.49 | 28.07 | 25.33 | 30.53 | 27.37 | 24.94 | 30.39 | 27.27 | 24.70 | 29.84 | 26.47 | 23.62 |
| 2021 | 31.83 | 28.10 | 25.14 | 31.70 | 28.03 | 25.00 | 30.62 | 27.39 | 24.57 | 30.26 | 26.69 | 23.65 |

Table 6 Basic statistics and MK trend analysis of Temperature in Vijayawada (2001–2021)

| MONTH | MEAN | SD | CV (%) | MK test | Sen's Slope | 2030 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|---|---|---|
| January | 6.572380952 | 10.95593442 | 166.6965823 | -0.101 | -0.086792208 | 4.9 | 3.2 | 1 | -1.1 |
| February | 9.93 | 19.6770079 | 198.1571793 | 0.103 | 0.206883117 | 13.9 | 17.9 | 23.1 | 28.3 |
| March | 9.024285714 | 24.31465208 | 269.435752 | -0.174 | -0.559662338 | -1.6 | -12.7 | -26.7 | -40.3 |
| April | 20.65047619 | 30.20762428 | 146.2805216 | 0.189 | -0.895493506 | 3.8 | -14.2 | -36.6 | -59 |
| May | 49.16380952 | 45.56349893 | 92.67690883 | 0.032 | 1.038324675 | 69 | 89.2 | 115.4 | 141.6 |
| June | 124.4828571 | 62.43780066 | 50.15775031 | 0.347 | 3.883038961 | 198 | 274.5 | 371 | 470 |
| July | 187.0780952 | 75.16504245 | 40.17843048 | 0.337 | 7.212064935 | 325 | 466.4 | 650 | 829 |
| August | 181.4971429 | 52.62886377 | 28.99707562 | 0.24 | 2.982831169 | 238.5 | 297 | 372 | 447 |
| September | 171.1671429 | 82.69218785 | 48.31078352 | 0.074 | 1.200896104 | 194 | 218 | 248 | 278 |
| October | 182.4866667 | 135.925158 | 74.48498045 | -0.242 | -7.118961039 | 47.5 | -94 | -274 | -451 |
| November | 73.73952381 | 62.70224593 | 85.03207329 | 0.063 | 1.893376623 | 110 | 147 | 195 | 242 |
| December | 20.08190476 | 35.5838009 | 177.1933555 | -0.189 | -0.903935065 | 2.9 | 15.8 | -38 | -60 |

### *A. Temporal variation in Minimum, Maximum and Mean Temperatures*

An increase in temperature is among the manifestation of climate change. Monthly temperature data were analysed to detect the variability and trend of temperature change in the study area from 2001-2021. The trend values with significance are presented in monthly annual temperature analysis graphs. In all the months, January, April, August, October, November, and December showed an increase in the minimum temperature. In comparison, November has shown a high minimum temperature rate in all the months. As observed in the graphs, significant changes are observed in all the months in the minimum temperature. A considerable increase in the minimum temperature in November was observed (0.0922 $^{0}$c/year). There was a decreasing trend of minimum temperature in February, March, May, June, July, and September with slopes of -0.0109,-0.0129,-0.0355,-0.0197,-0.038,-0.0086, respectively.

The increasing rate of T $_{min}$ (0.0922 $^0$c/year) was the largest in November, while those for April and October were the most minor (0.001$^0$c/year, 0.00152$^0$c/year, respectively). And other months exhibited a similar variation. Although the overall trends of monthly annual minimum temperature during 2001-2021 were increasing or decreasing. Temporal variations of monthly annual Maximum Temperature averaged from all months from 2001 to 2021 exhibit fluctuations. Trend analysis showed that maximum temperature in Vijayawada increased in March (0.0012 $^0$c/year), April (0.0515 $^0$c/year), October (0.03$^0$c/year), November (0.0687$^0$c/year). In these months, Vijayawada shows an increasing trend; these trends are statically increased. Most of the months in this 20 years trend show decreasing rate. The decreasing rate was largest in July month -0.0644$^0$c/year. However, negative trends were for the
January (-0.0076$^0$c/year), February (-0.0608$^0$c/year), May (-0.048$^0$c/year), June (-0.0349$^0$c/year), July (-0.0644$^0$c/year), August (-0.018$^0$c/year), September (-0.056$^0$c/year), December (-0.0026$^0$c/year). If we observe the variation of mean temperature across Vijayawada on monthly data over the trend, it shows an increasing rate in January (0.0157), April (0.0236), October (0.019), and November (0.0734), December (0.022). While in February (-0.0304), March (-0.0054), May (-0.0514), June (-0.0305), July (-0.05), August (-0.0034), September (-0.0284) it shows decreasing rate. It shows a continuous increasing rate in October, November, and December.

### B. *Basic statistics and MK trend analysis of Temperature in Vijayawada (2001–2021)*

An increase in temperature is among the manifestations of global climate change (Asfaw Amogne, 2018). Monthly temperature data were analysed to detect the variability and trend of temperature change in the study area from 2001-2021. The above table portrays the monthly temperature (minimum, maximum and mean) and its trend in the examination period. The mean temperature ranged from 23.042$^0$ C (minimum) to 33.358 $^0$c (maximum). The lowest minimum temperature occurred in December (0.070c), and the highest maximum temperature occurred in April (40.66$^0$c). And the second highest maximum temperature in determined

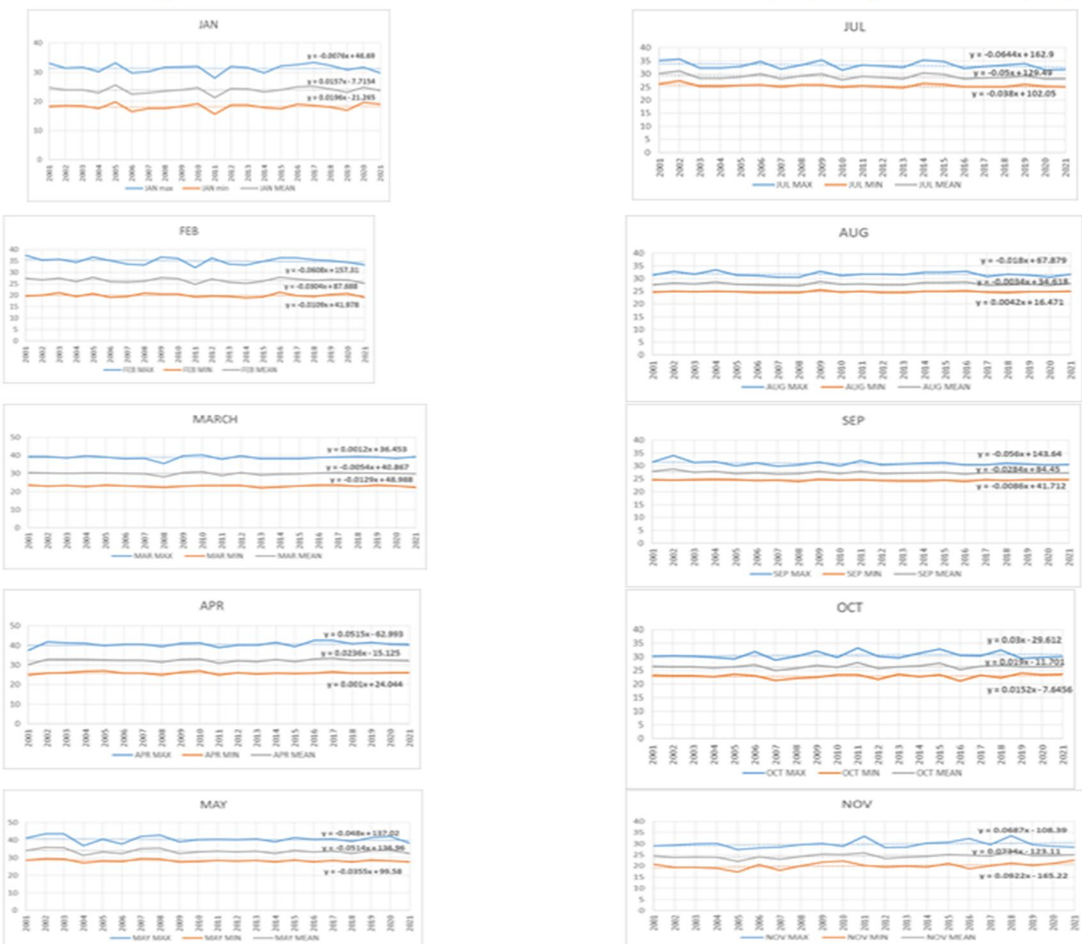


Figure 3 Graphs representing minimum, maximum and mean temperatures (2001-2021)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 10 Issue VIII Aug 2022- Available at www.ijraset.com*


Figure 4 The temporal variations of mean temperature and futuristic projections (2001-2021)

in May (40.52$^0$c). As demonstrated in the above table, the MK trend test result revealed that mean temperatures have decreased over time. According to MK test values, an increasing trend was observed in January, October, November, and December. While in the remaining months it was showing a decreasing trend. The monthly mean temperatures based on CV %, there was a low degree of variability in all months except March and July. In these two months, there was a moderate degree of variability. Based on the slope, there was an increasing rate in January (0.015), March (0.1), April (0.023), July (0.136), October (0.018), November (0.07), and December (0.0219). The decreasing rate is shown in the remaining months with almost equal slopes.

The maximum mean temperature will be observed in April from 2030-2100. The minimum mean temperature will appear in December month over the period from 2030-2100. The increasing rate will be observed in January (0.019), April (0.0009), August (0.004), October (0.015), November (0.0921), and December (0.0298). The increasing rate will be observed in November 2001-2100. And in the remaining months, there will be decreasing rate based on slope values. There will be a more decreasing rate in July (-0.038), next to May (-0.035) from 2001 to 2100.

The above graphs represent the temporal variation of maximum temperatures from 2001-2100. The increasing rate will be observed in March (0.0012), April (0.05), October (0.03), and November (0.068) based on slope values. There will be a more increasing rate in November over the trend. The months January (-0.007), February (-0.06), May (-0.04), June (-0.03), July (-0.064), August (-0.017), September (-0.05), December (-0.0025) show decreasing rate. The more decreasing trend occurred in January month over the trend.

The above graphs describe the temporal variation of mean temperatures throughout 2001-2100. We can observe the increasing or decreasing trend over the trend for Vijayawada city in the aspect of mean temperature. There was an increasing rate in January (0.0157), April (0.0236), October (0.029), November (0.0734), and December (0.022) over the trend. While in the remaining months it was showing decreasing rate, it was demonstrated in above graphs. By that, we can estimate whether the trend analysis of temperatures in Vijayawada will increase or decrease in future years up to 2100.

## V. CONCLUSIONS

In this study, the variations of extreme temperatures and rainfall were selected. The temporal changes from 2001 to 2100 were analysed based on trend analysis. This work leads to the following conclusions:

Both kinds of extreme temperatures have sharp changing points. The temperature has insignificant changes. The extreme precipitation did not show significant changes during 2001–2100. Correlation between extreme temperature and precipitation.

Variations of rainfall in Vijayawada have been observed from 2001 to 2021. Vijayawada city receives an increasing rainfall rate in February, May, June, July, August, September, and November. While in the other months it shows the decreasing rate.

The minimum, maximum, and mean temperatures were considered to examine the temperature variations in Vijayawada city by taking data from NASA/POWER CERES/MERRA2 Native resolution daily data.

From extreme temperature graphs, we can conclude that there was a negative trend for minimum, maximum, and mean temperatures in the month's March, May, June, July, and September. There was an increasing rate of minimum, maximum, and mean temperatures for December, November, October, and April.

More months have shown decreasing rate of extreme temperatures. And also, there was a low degree of variability.

But rainfall has a high degree of variability in all months over the trend. So total rainfall trends show more variations than extreme temperatures.

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