

## Understanding Climate Change in Indore District: An Empirical Investigation of Trends and Shifts

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### Abstract

The study tries to analyse the phenomenon of climate-change with respect to Indore district. It attempts to empirically investigate whether the district has actually experienced climate change over the time period of a century (1901-2002) A.D. Eight climate variables namely temperature, precipitation, vapour-pressure, wet day frequency, diurnal temperature range, cloud-cover, reference crop evapotranspiration and potential evapotranspiration have been identified in the paper to study climate change. Linear and Quadratic regression models have been used to study the variation of chosen climate indicators with respect to passage of time. Seven year moving average method has been used to smoothen the trend of time-series fluctuations. The results have also been supported with graphical analysis. Use of dummy variable has been made to study whether there is a change in the trend of variation of various climate indicators with reference to a point in time; the year 1940. The findings clearly reveal a significant change in Indore district in terms of chosen indicators over the time-period of a century. As Indore is the representative district of the Chambal basin, the climatic variability and the study of its resultant effects on biodiversity, health, crop-distribution and associated yield is bound to have significant policy implications for the whole region. Study thus serves as a base for understanding the climate profile of the region as a whole. It can further be extended to establish linkages with respect to changes in agricultural trends and practices.

**Key-Words:** Climate-Change, Regional, Empirical, Indicators, Century

**JEL Classification:** Q54, R11

**Paper Classification:** Research Paper

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### Introduction

A consistent shift in the weather scenario of any specific region over a long period of time is termed as climate-change. It includes many variables like temperature, rainfall, rates of evaporation, wet day frequency etc. Agriculture as a managed ecosystem gets affected most significantly by climate-change. Productivity, crop-duration and even selection of crops to be grown in a region depends upon temperature coupled with duration and spatial distribution of rainfall. Hence, changes in average climatic conditions along with occurrence of extreme climatic events will have significant impacts on the agricultural sector which in its turn may have critical implications on the issue of food security. However, climate sensitivity of agriculture in varied regions differs significantly as there is regional variation of rainfall, temperature, crops, cropping

system, soils and agricultural management practices. Hence, it is important to systematically study the nature and scale climate change in a region-based manner. A set of climate-variables thus need to be identified and studied over a period of time to determine whether a region is undergoing the phenomenon of climate-change or not. Suitable adaptation and mitigation practices in the regions' agricultural sector can then be accordingly adopted after knowing the exact nature of climate-change in that area.

## Review of Literature

'District' as defined on a political basis acts as the unit for the collection of data pertaining to various spheres like socio-economic, environmental, geographical etc. Hence, in majority of the studies related to climate-change analysis; focus has been laid on a single district. The analysis of trends of climate-change is performed with reference to movement of economic variables as per the need of the study. The same approach was followed in a study while checking for the impacts of climate-change on regional water resources and agriculture in India Strzepek & McCluskey, (2006). Authors collected time-series district level data and tried to establish regression equations to study behaviour of climate-indicators with various economic indicators. Following the same line of approach in another study authors have tried to explore the impacts of climate-change on the yields of major crops in the mountainous parts of Nepal. They performed district-level analysis of meteorological variables of last thirty years of a representative district of the region namely Lamjung district. They then used Mann-Kendall and Sen's slop methods for the trend analysis. Poudel & Shaw, (2016). Taking a different path one more study focussed on tracing local and community awareness towards the harmful impacts of climate-change. The study aimed to analyse on-ground adaptation strategies by having a clear understanding about how climate is actually changing in a given area. The representative area for conduction of this study was downscaled up to the level of individual districts; namely the Laikipia and Narok districts of dry land Kenya Ojwang, Agatsiva, & Situma, (2010). Some researchers have also practiced a downscaled study up to the level of individual representative cities using regional climate-models for correct estimation of climate-change trends and their impacts on varied sectors in Thailand Wang, He, Herath, Basnayake, & Huang, (2014).

A few studies relate themselves to vulnerability assessment of regional agriculture with respect to phenomenon of climate change. For example in a study about vulnerability of agriculture to climate-change in the state of Manipur; researchers chose representative districts for analysis. Vulnerability indices were constructed based on several set of indicators and the chosen districts were then ranked with respect to their respective degrees of vulnerability Feroze, et al., (2014). Thus this study has focussed on inter district comparison and ranking while checking for specific climate-change related impacts on agriculture. Following the same line of approach a vulnerability profile of a total of 572 rural districts of India was prepared in a study by choosing 38 indicators related to sensitivity, adaptive capacity and exposure. Rao, et al., (2016). This study also took into account of the fact that a chunk of the development planning as well as programme implementation is being carried out in India at the district level; hence understanding about districts' vulnerability is of prime importance while developing understanding about interlinkages of climate-change and agriculture. The study concludes that districts situated in the peninsular and Western India possess a high degree of vulnerability towards climate-change.

The State of Madhya-Pradesh lies in this zone and has been indicated to be a 'severely affected region in the event of climate-change' Gossain, Ravindranath, Garg, & Rao,(2014). The report also points out that Indore district has high vulnerability with respect to water resource index and a moderate environmental vulnerability. The district of Indore is particularly important

for individual climate-change analysis as it is identified as a 'hotspot under forest ecosystem classification' (Irfaan, Jo, & Mondal, 2016). The authors clearly state that there has been a decline in water-flow regulating service in the district and is thus an issue of concern with respect to the region's future sustainability. Finally; it has also been pointed out that the event of climate-change can pose unique threats to the Indore district. The uncertainty regarding future climate-change projections may complicate resilience planning efforts. Water will be the most critical resource getting affected by climate-change in the Indore district Palaniappan, Srinivasan, & Cohen, (2011).

### **Research Gap and Contributions of the Study**

These studies have specifically underlined the importance of 'district' as the unit of climate-change analysis and are using non-parametric tests and their application for such an analysis. Some studies have investigated the extent of vulnerability of Madhya-Pradesh state and Indore district in this regard with the help of vulnerability indices. However, there is a lack of analysis with respect to trend and shift analysis in climate-variables over longer period time-series data of a bunch of climate-indicators in Indore district. This study fulfils this gap by conducting such an analysis on Indore district with the help of rigorous regression equations.

### **Objectives of the Study**

1. To analyse the trend and direction of change in climate-variables in Indore district.
2. To identify the year of shift, if any; in the trends of the change of climate-variables in Indore district.

### **Research Methodology**

#### **A. Type of Study**

This is an empirical investigation trying to estimate trends and shifts in the meteorological variables in the Indore district.

#### **B. Sample**

The time-period of the study is a span of hundred and two years from 1901-2002 A.D. Continuous data on all eight climate variables was available only up to 2002. The study has emphasised on knowing the trend (i.e. direction) of movement of climatic variables. Continuous data of 100 years thus gives sufficient indication of trend in this regard. As the study acts as a base study for linkage with other economic sectors; it is sufficient and appropriate to know the direction of trend based on 100 year data up to 2002.

#### **C. Method of Data Collection**

This is a secondary data-based study.

- a. Main source of data for our study with respect to the district of Indore for our chosen climate variables as a monthly mean for all the years ranging from 1901-2002 is the site of India Water-portal (India Water Portal, 2009) Then we have calculated yearly averages of these monthly means for different years for our study.
- b. Some more information has been extracted from the web-site of Indian Meteorological Department.

#### D. Variables Studied and their Detailed Definition

The climatic condition of the region depends on the various indicators which constitutes weather conditions in the region. The following indicators have been considered for this study.

- i. Average Temperature(Unit: integer / degree Celsius)  
The numerical measurement of heat in the atmosphere is known as temperature. Here we have daily records of minimum and maximum temperatures. The average of these two is taken as daily temperature. The average of these daily temperatures is then finally converted into yearly temperature.
- ii. Precipitation(Unit: Integer / mm)  
Rainfall in any form (liquid as well as solid – e.g. Drizzle, downpour, hail, sleet, snow etc.) is being considered as precipitation. The study takes into account average monthly means of precipitation; from which their yearly averages have been calculated.
- iii. Vapour Pressure(Unit: Integer / hPa) i.e. hectopascal(1 hPa  $\approx$  100 Pa)  
Partial pressure exerted by amount of water vapor present in atmosphere out of total atmospheric pressure is known as vapour-pressure.
- iv. Wet Day Frequency (Unit: Integer / Days)  
The proportion of total number of wet days from all days in a calendar year is called as wet day frequency. It may also be interpreted as probability of rain on a day.
- v. Diurnal Temperature Range(Unit: Integer / degree Celsius)  
It is the difference between the daily maximum and the daily minimum recorded temperature of a particular station.
- vi. Cloud Cover (Unit: Integer / %)  
Cloud cover is the state of the sky when it is covered by clouds.
- vii. Reference Crop Evapotranspiration (Unit: mm / day)denoted as ETo.  
The rate of evapotranspiration from a reference surface is known as Reference Crop Evapotranspiration, which is usually denoted as ETo. The reference surface in consideration possesses some specific characteristics. ETo is expected to increase with temperature of the region.
- viii. Potential Evapotranspiration (Unit: mm / day) denoted as PET  
With the availability of abundant amount of water resources, the maximum amount of evapotranspiration which can take place is known as potential evapotranspiration. Varied factors affect it like solar insolation, atmospheric as well as terrestrial temperatures, wind speed etc.

#### E. Null Hypotheses

H1 = Chosen Climate Variables do not change significantly with increasing period of time.

H2= The trend in variation of climate variables does not experience any change around a specific point in time (Here 1940).

These objectives and hypothesis thus penetrate into the issue that the nature of climate-change in a region can be logically analysed.

## F. Research Models Used

Regression analysis has been used to study the pattern, direction and nature of changes in these indicators of climatic conditions. Final equation used in the study is:-

$$Y = a + bT + cT^2 + dD + U$$

Here Y is the climate variable whose variation over time is being analysed.

T is the time-period of the study in terms of number of years.

T<sup>2</sup> is the Square of the time period in terms of number of years.

D is the dummy variable used in the study. The value of D is "Zero" till the 1940 and "One" thereafter. If the coefficient of Dummy Variable comes significant it will indicate that the year 1940 is the point from where a change in the trend of variation of the climate-indicator with respect to time occurs. Seven year moving average has been used to smoothen the trend of time-series fluctuations

Significance of the year 1940. How temperatures are changing globally has always been a cause of concern for researchers. Trends of temperature changes have been minutely studied and have been linked with changes in other variables of interest. In one such important study temperature change assessment of the world was done for the past 157 years Solomon, Qin, & Manning, (2007). Year 1940 was considered as the point of shift in segregating two main phases of climate change in the study.

## G. About the Study Area

The area of study for observing the phenomenon of climate change is the Indore district lying in the catchment area of River Chambal. Its geographical location is 22.2-23.05 Degrees North latitude and 75.25-76.16 Degrees East Longitude with an average altitude of 550 m above sea-level. It is thus located in a semi-arid zone towards the southern edge of Malwa plateau. The region lies in rain-shadow area of Western Ghats and receives majority of its rains through south-west monsoon. Predominantly covered by black soil the region supports wheat and gram as major food crops; 'moomg-moth', 'urhar' (tur), pea among pulses and finally Soyabean as the major cash-crop. Earlier this region also known as Malwa region was known for its pleasant summers and water-abundance but it is now facing droughts, excessive heavy rainfalls, heat-waves, frost and cold waves. The diverse cropping system of the region has been replaced by wheat-soybean annual crop cycle with excessive reliance on ground water exploitation (Vijayshankar, 2014). Instances of severe ground water exploitation have been reported in the region at an alarming level Gupta, Kawadia, & Attari, (2007). Various climate-indicators like those of temperature, precipitation, vapour pressure, cloud-cover, and reference as well potential evapotranspiration etc. are showing changes in their patterns. The study of Indore is thus important to see the long term pattern in the various indicators of climatic conditions.

The study area under consideration is one of the most developed areas of central India. There has been a significant degree of industrialisation and the district presents itself as the unique blend of tradition and modernity. In terms of socio-economic parameters; literacy rates and standard of living of the people are usually high; both in urban as well as in rural areas of Indore district. Of late, the agriculture of the region has displayed a remarkable resilience. The region is now internationally being recognised for its Soyabean production and wheat-production of superior quality. However, it is important to check its long-term sustainability. Hence, an understanding of

the major features and conclusions drawn in terms of climate-change in the Indore district would prove useful for establishing further links with agricultural production practices of the region and its economic prosperity as a whole.

## Overview of Climatic Conditions in Indore based on Major Indicators

**Temperature** – It is the most important variable of climate. Most of the time the region enjoys moderate temperature. April to June comprises summer season when temperature peaks as up to 45 degree Celsius in the region while average temperature ranges between 35 and 40 degree Celsius. The area is now sometimes witnessing sharp heat waves. The months from November to February constitute winter season. During this season day-temperature ranges usually between 18 and 20 degree Celsius while night- temperature falls to an average of 10 degree Celsius with lowest magnitudes occurring as low as 2-3 degree Celsius.

**Precipitation** –Indore district receives its major chunk of precipitation through south-west monsoon. The mean annual precipitation in the region is around 1050mm. Earlier the rainfall used to be evenly spread throughout the monsoon season, however in recent years the trend has shifted towards more number of dry days during rainy season with few instances of very heavy downpours. Instances of water-logging and flooding have become common in such a scenario.

**Vapour Pressure** –Maximum vapour pressure in Indore district is experienced mainly in the months of July, the average lying around 28-29 / hetro Pascal, while the minimum average vapour pressure is experienced somewhere in February with value lying at 9/hpa.

**Wet Day Frequency** – The highest wet day frequency is around 65% during the months of July-August in the Indore District. The lowest occurs around 2-3 % during the months of February-March.

**Diurnal Temperature Range**- Maximum diurnal temperature range in the district can be seen during winters in the month of January with its value around 17 Degree Celsius while the minimum range is usually observed during and after monsoons, in the month of August with value lying at 6-7 Degree Celsius.

**Cloud Cover** –During monsoons in the month of July cloud cover is maximum at about 75- 76 % while it is at a minimum of 10-11% during winters in January; in the Indore district.

**Reference Crop Evapotranspiration**–Maximum reference crop evapotranspiration can be seen during summer season in the months of April-May with value around 7-8 mm/day while the minimum is noticed usually in winters in the months of December-January with value lying around 3-4 mm/day.

**Potential Evapotranspiration** –The maximum potential evapotranspiration for Indore District lies between 8-9 mm/day during the months of April-May while the minimum value occurs around 5-6 mm/day. This value stands for the winter season in the district during months of December-January as well as during the months of July-August-September.

## Discussion of Climate Variables as per Regression Results and Graphical Analysis

**Temperature**–The regression estimate of Quadratic equation is showing U pattern in temperature with 1940 as the point of turning. The model explains about 82 percent of the

variation in the temperature and thus the results are quite consistent. It can thus be concluded that the region is thus showing an increasing trend in the yearly average temperature of the area.

**Precipitation** -The regression estimate of Quadratic equation is showing Inverted-U pattern in precipitation with 1940 as the point of turning. It can thus be concluded that the region is showing a decreasing trend in the yearly average precipitation in the area.

**Vapour Pressure**– Vapour Pressure is expected to increase with more temperature. With increase in temperature an increase in vapour-pressure over the studied time-period is expected. Regression estimate of Quadratic equation supports the view. It clearly shows an emerging U pattern in temperature with 1940 as the point of turning. The model explains around 79 percent of the variation in the vapour-pressure. It can thus be concluded that Indore district is showing an increasing trend in the yearly vapour-pressure.

**Wet Day Frequency**–Wet day frequency is closely related to variation in precipitation. So its variation is expected to show the same trend as that of precipitation. Regression estimate of Quadratic equation is showing Inverted-U pattern in wet day frequency variation with 1940 as the point of turning. It can thus be concluded that the district is showing a decreasing trend in the yearly average wet day frequency.

**Diurnal Temperature Range**-Regression results do not lead to emergence of any clear trend in diurnal temperature range of the region.

**Cloud Cover** –With the increase in time-period, an increase in pollution, dust-particles, particulate matter and green-house gases is clearly seen. Thus cloud cover is expected to increase. Regression estimate of Quadratic equation is showing U pattern in temperature with 1940 as the point of turning. It can thus be concluded that the district is showing an increasing trend in the yearly cloud cover.

**Reference Crop Evapotranspiration**– Regression estimate of Quadratic equation shows a very clear emerging U pattern in reference crop evapotranspiration with 1940 as the point of turning. It can thus be concluded that the district is showing an increasing trend in the yearly reference crop evapotranspiration.

**Potential Evapotranspiration**– Regression results show the change in potential evapotranspiration is poorly significant with no clear pattern emerging from the dataset. The results are in conformity with evidences as supported by other studies of Indore in Madhya-Pradesh.

So, Indore district is experiencing a situation of climate-change with respect to ‘six’ out of ‘eight’ chosen climatic indicators in the study. Table 1 (below) presents a summary of regression results and graphical analysis with respect to the considered eight climate-variables of the study.

**Table 1: Summary of Regression Results and Graphical Analysis**

Climate Indicator	Coefficient of Time	Coefficient of Time Square	Coefficient of Dummy Variable	Overall Remarks based on Graphical analysis
Temperature	Negative and Significant	Positive and Significant	Insignificant	It increases significantly at an Increasing Rate and the shape of the curve emerges like that of alphabet U
Precipitation	Positive and Significant	Negative and Significant	Negative and Significant	It is significantly declining with a diminishing rate over time. Trend in Precipitation acquires a clear-cut Inverted U shape with the year 1940 as the turning point.

Vapour Pressure	Negative and Significant	Positive and Significant	Positive and Significant	It increases significantly at an Increasing rate and the shape of the curve emerges like that of alphabet U with the year 1940 showing a turning point.
Wet-Day Frequency	Positive and Significant	Negative and Significant	Negative and Significant	It is significantly declining with a diminishing rate over time. Its trend acquires a clear-cut Inverted U shape with the year 1940 showing a change in the trend towards significant decrease.
Diurnal Temperature Range	Insignificant	Insignificant	Insignificant	No clear pattern is emerging.
Cloud Cover	Negative and Significant	Positive and Significant	Insignificant	It Increases significantly at an Increasing rate and the shape of the curve emerges like that of alphabet U
Reference Crop Evapotranspiration	Negative and Significant	Positive and Significant	Insignificant	It Increases significantly at an Increasing rate and the shape of the curve emerges like that of alphabet U
Potential Evapotranspiration	Positive and Significant	Negative but poorly significant	Insignificant	No clear pattern is emerging
Note – i. Exact regression equations can be referred in the Appendix 1 in the form $Y = a + bT + cT^2 + dD + U$ ii. Graphs of the climate-indicators with a significant change in their variation trend with respect to time. (linear fit and quadratic fit) can be referred in Appendix 2				

### Concluding Remarks for Climate Change in Indore District

To conclude about the climate profile of the Indore district; it can well be observed that the variables namely temperature, vapour pressure, cloud cover and reference crop evapotranspiration show an increasing trend with an increasing rate with respect to time. The indicators of precipitation and wet day frequency however show a decreasing trend with a diminishing rate with time. The 'six' out of 'eight' major climate variables indicate a significant change in the climate of the region. Only with respect to the two indicators of Diurnal Temperature Range and Potential Evapotranspiration; no clear-cut pattern is emerging in the region.

The study thus clearly reveals a significant climate-change in Indore district in terms of chosen climatic indicators over the time-period of a century. As Indore is the representative district of the Chambal basin, the climatic variability and the study of its resultant effects on biodiversity, health, crop distribution and associated yield is bound to have significant policy implications for the whole region. The present information thus could act as the basic foundation for future study activities regarding development of understanding about linkages between climate change and agricultural activities of the region. Adaptation strategies can then be devised to assist development planning. Finally, it may be stated that this study provides a background framework for broader analysis related to livelihood opportunities of the people and overall human well-being in this region.

### Limitations of the Study and Direction for Future Research

This study focussed on mere investigation of trends and shifts in meteorological variables to explore the nature of climate-change in the Indore district. It thus serves only as a base for future studies dealing with inter-linkages of climate-change with related sectors like



agriculture, livestock, forestry, health and livelihood related issues. It is not an impact-assessment exercise. Hence it also does not deal with related perception, adaptation and mitigation options. Future studies could well be carried out in these domains especially with reference to the agricultural sector.

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**Appendix 1**

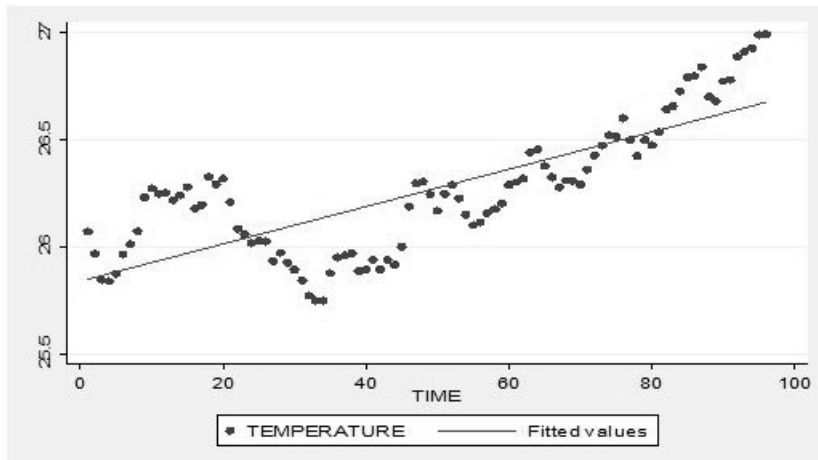
Regression Estimates:  $Y = a + bT + cT^2 + dD + U$  for Significant Variables

Variable	Intercept	Coefficient of T	Coefficient of T <sup>2</sup>	Coefficient of Dummy	r Square
Temperature	26.1892	-0.01326 (0.0025)	0.00021 (0.0000212)	0.0824 (0.149)	0.8208
Precipitation	55.0063	0.7152 (0.1079)	-0.0058 (0.0009)	-8.1818 (2.4071)	0.3279
Vapour Pressure	16.8630	-0.0082 (0.00125)	0.0001 (0.0000)	0.10123 (0.0279)	0.7956
Wet Day Frequency	3.1447	0.0167 (0.000)	-0.0001 (0.000)	-0.1483 (0.012)	0.3328
Cloud Cover	33.5273	-0.0749 (0.000)	0.0008 (0.000)	0.3604 (0.351)	0.2724
Reference Crop Evapo-Transpiration	5.1428	-0.00144 (0.000)	0.0000234 (0.000)	0.01022 (0.136)	0.7994

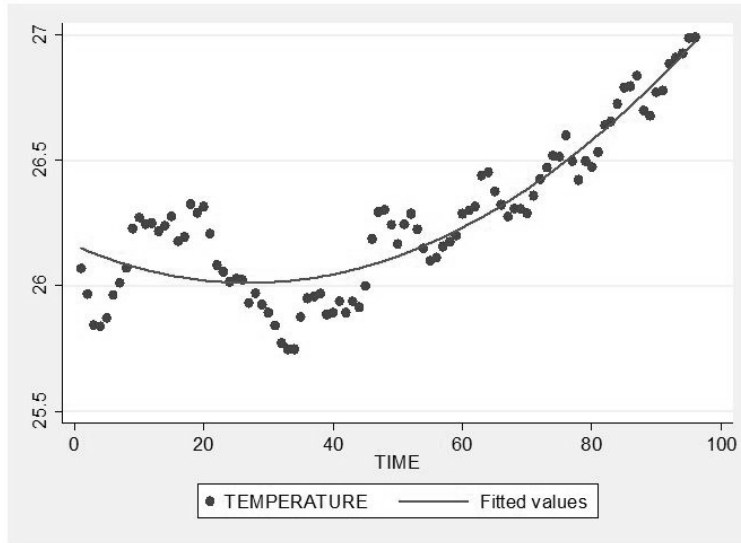
Note – Values in the parentheses indicate p-values of the corresponding coefficients.

**Appendix 2**

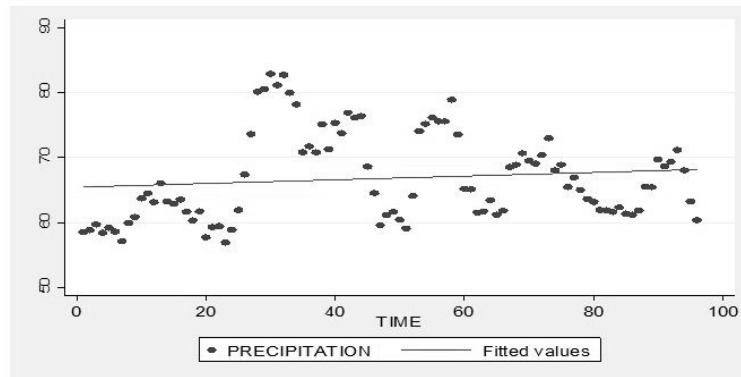
**Linear and Quadratic Trend Graphs of Climate-Indicators  
 Depicting Significant Change in their Variation Trend  
 Temperature – Linear fit**



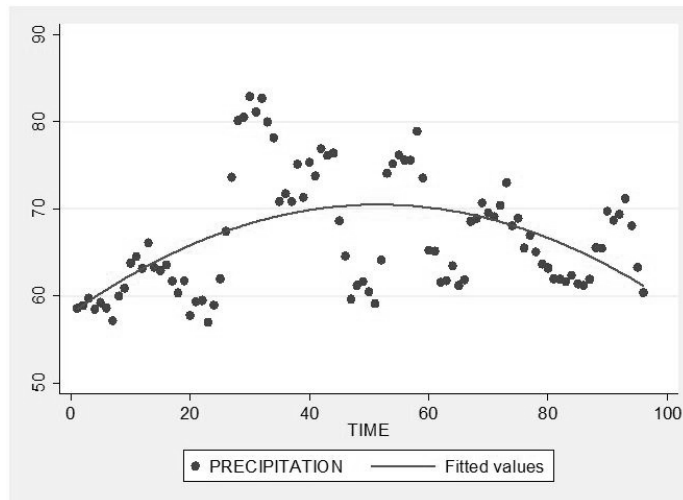
Temperature – Quadratic Fit



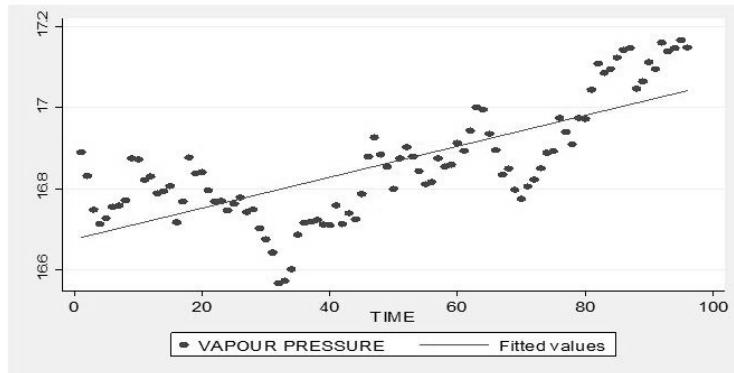
Precipitation – Linear Fit



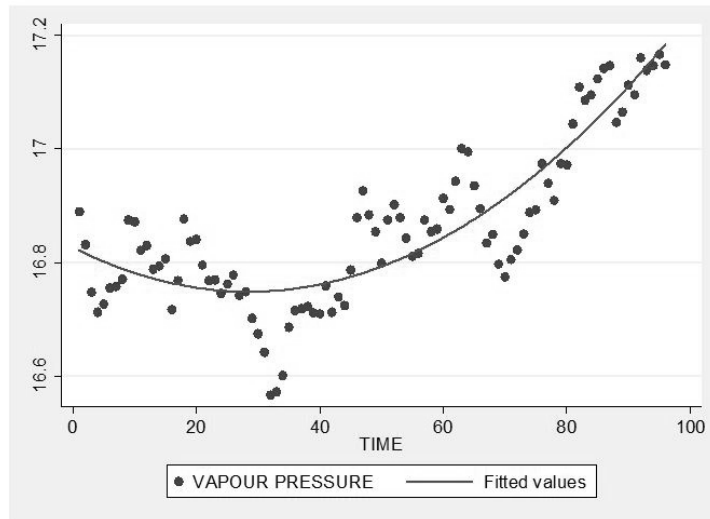
Precipitation – Quadratic Fit



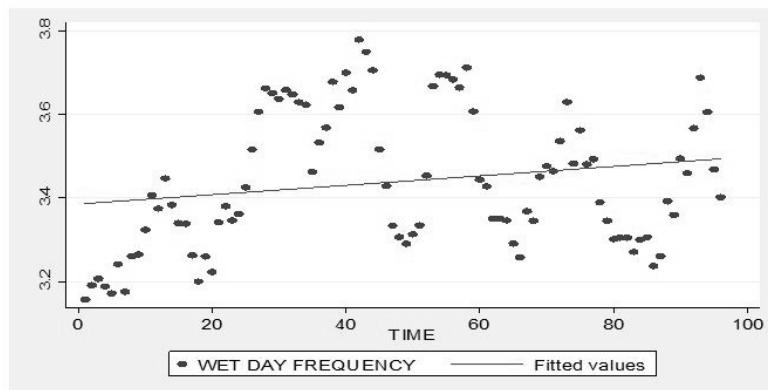
Vapour Pressure – Linear Fit



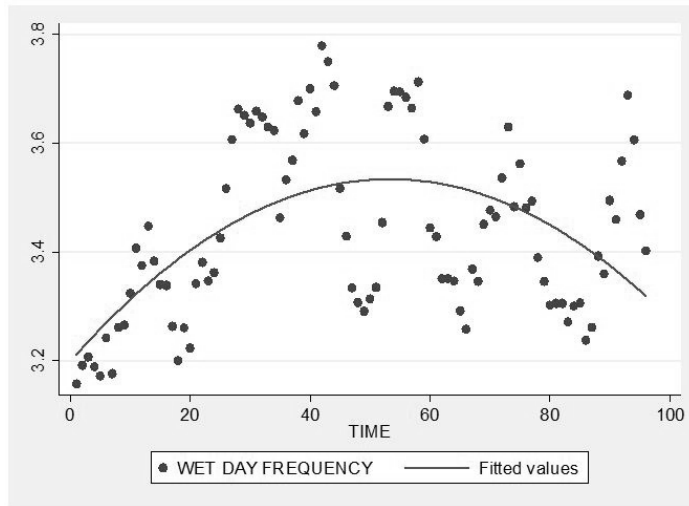
Vapour Pressure – Quadratic Fit



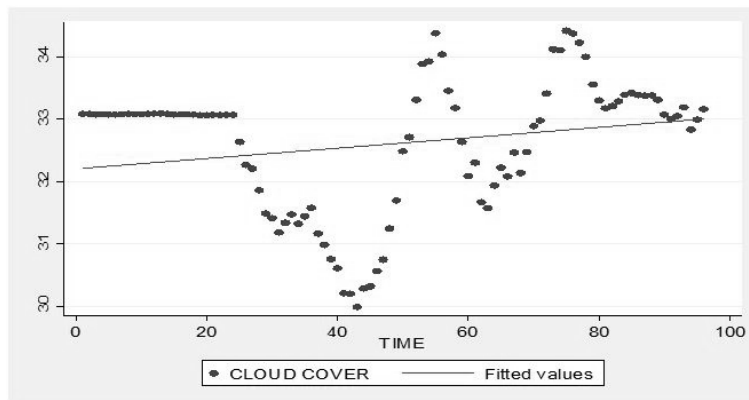
Wet Day Frequency – Linear Fit



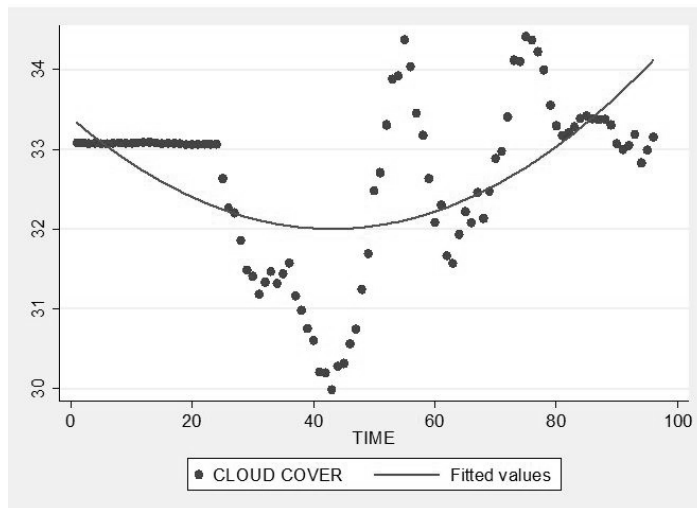
Wet Day Frequency – Quadratic Fit



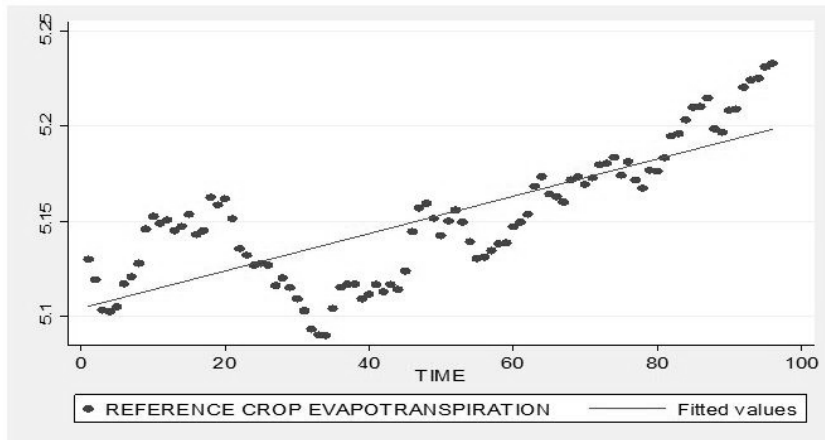
Cloud Cover – Linear Fit



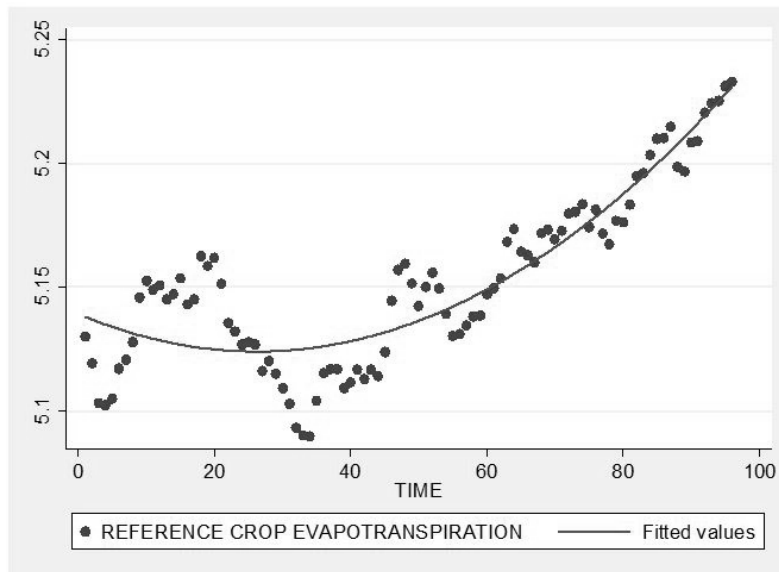
Cloud Cover – Quadratic Fit



Reference Crop Evapotranspiration – Linear Fit



Reference Crop Evapotranspiration – Quadratic Fit



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***Authors' Profile***

**Ganesh Kawadia** is presently Professor & Head, School of Economics, Devi Ahilya University, Indore, India and is involved with many other administrative responsibilities. He is Chairman, International Cooperation Cell, Devi Ahilya University, Indore (M.P.); Coordinator, UGC-Special Assistance Programme at DRS Phase-III; and Member, Executive Council, Devi Ahilya University, Indore(M.P.). He has successfully completed many Major Research Projects of ICSSR, as well as of UGC and has also guided successfully more than 30 students for their Doctorate degree. A teacher at heart, he has been awarded with the Best Professor Award in Economics by World Education Congress, Global Awards for Excellence in Education, Leadership and Teaching in Mumbai. He has also visited University of Connecticut in U.S.A. and has presented a paper in an International Conference on Knowledge Globalisation organised by Suffolk University, Boston for research guidance on Environment, Development and Poverty. His teaching and research interests include Econometrics, Environmental, Agricultural and Macro Economics.

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