

**AGROCLIMATIC ANALYSIS OF CHHATTISGARH STATE
WITH RESPECT TO SUSTAINABLE CROP PRODUCTION**

M.Sc. (Ag.) THESIS

by

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**DEPARTMENT OF AGROMETEOROLOGY
COLLEGE Of AGRICULTURE
FACULTY OF AGRICULTURE
INDIRA GANDHI KRISHI VISHWAVIDYALAYA
RAIPUR (Chhattisgarh)
2015**

**AGROCLIMATIC ANALYSIS OF CHHATTISGARH STATE
WITH RESPECT TO SUSTAINABLE CROP PRODUCTION**

Thesis
Submitted to the
Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.)

by

Shiv Kumar Bhuarya

**IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF**

Master of Science

In

Agriculture
(Agrometeorology)

Roll No. 20131418491

ID No. 120113131

JULY, 2015

CERTIFICATE – I

This is to certify that the thesis entitled “**Agroclimatic analysis of Chhattisgarh state with respect to sustainable crop production**” submitted in partial fulfillment of the requirements for the degree of “**Master of Science in Agriculture**” of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Shiv Kumar Bhuarya** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate, awarded etc.) or has been published/ published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

Date: 1.7.2015


(SHRI J.L. CHAUDHARY)
Chairman Advisory Committee

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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Member : Er. Dhiraj Khalkho



Member : Dr. (Smt.) G. Chandrakar



CERTIFICATE – II

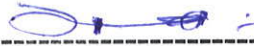
This is to certify that the thesis entitled “**Agroclimatic analysis of Chhattisgarh state with respect to sustainable crop production**” submitted by **Shiv Kumar Bhuarya** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) in partial fulfillment of the requirements for the degree of **M.Sc. (Ag.)** in the **Department of Agrometeorology** has been approved by the external examiner and Student's Advisory Committee after oral examination.


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Approved/Not approved

Director of Instructions

ACKNOWLEDGEMENT

At the outset, I submit that it is by the blessing of the omnipotent god lord Shri Ganesh I have been able to bring to light this humble piece of work for which I am externally indebted.

*With respectful respects and immense pleasure, I express my profound sense of gratitude to the chairman of my Advisory Committee, **Shri J.L. Chaudhary** Senior Scientist, Department Of Agrometeorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur for his guidance, timely emend and constructive criticism at every stage in the presentation and editing of this thesis.*

*I express my sincere and profound gratitude to **Dr. S.S. Rao** Dean and Head, Department of Agrometeorology and **Dr. A.S.R.A.S. Sastri** professor Department of Agrometeorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur for providing me all the necessary facilities, during my study at this college.*

*I humbly offer my heartily thanks to member of my advisory committee **Er. Dhiraj Khalkho** (Department of soil and water engineering, faculty of Agril. Eng., IGKV, Raipur (C.G.)) and **Dr. G. Chandrakar** (Department of Agricultural Statistics and social science I.) for their unstinted help, support, suggestions and whole hearted co-operation during the execution of my research work.*

*With deep respect and esteem regards I owe my indebtedness to **Shri R. Singh** Senior Scientist, Department of Agrometeorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, for his timely help, learned counsel, cordial treatment, meticulous guidance during the period of my study.*

*I have infinite pleasure in expressing my thanks to **Shri N. Manikandan** (Asst. Prof. Department of Agrometeorology), **Dr. Harsh Vardhan Puranik** (Asst. Prof. Department of Agrometeorology) and Research Associate **Shri Sanjay Bhelawe** and **Mr. Rajesh Khavse** for their help and guidance during period of my research work. With profound respect, I extend my gratitude to **Dr. S.K. Patil**, Hon'ble vice chancellor, **Dr. J.S. Urkurkar** Director of Research Services, **Dr. M.P. Thakur**, Director Extension Services, **Dr. S.S. Sengar** Dean Student Welfare, **Dr. S.S. Shaw** Director of Instructions IGKV, Raipur for providing necessary facilities, technical and administrative support for conductance of my research work.*

*Diction is not enough to express my thanks to my beloved parent **Shri Sukhit Ram Bhuarya** and **Smt. Kumari Bai Bhuarya** and my sister **Seema** they are ineffable and to their benevolent feet I am dedicating this thesis with great pleasure.*

*I have infinite pleasure to express whole hearted thanks to my loving friends **Kapil Soni**, **Pooja Thakur**, **Suresh Patle**, **Sanjay Dhruw** and **Bhaskar Sahu** their boundless love, constant help and moral support.*

*I owe my sincere thanks to my seniors **Yamlesh**, **Usha**, **Deepika**, **Uttam Diwan** for their constant encouragement and support during my study period.*

*I further extend my thanks to my colleagues **Deepanshu**, **Hemant Sinha**, **Surbhi**, **Rakesh Pandey**, **Vivek**, **Yugal** for their timely help and moral support during the period of my study.*

I owe my sincere thanks to my juniors Ansul, Anil, Manoj, Gurpreet, Ancy and Deepak for their generous help during my study.

I extend my thanks to Mahesh Yadav, Naveen, Sinha, Sunil Bijwe, Bhojraj Patle and Mangalsen Banjare, non-teaching staff of our department who were always ready to provide help during study.

I have pleasure to thanking Deelip Bhaiya, Mahesh Bhaiya, Khirdhar Bhaiya, Rajesh Bhaiya, Madhav, Himanshi and Vimla Didi for their precious help during my field experiment under research work.

Space does not allow to my desired extent but I wish to thanks all the people who directly or indirectly helped me during this investigation. I extend my sincere thanks for their co-operation.

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LIST OF SYMBOLS AND ABBREVIATIONS

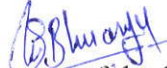
e_a	Actual vapour pressure
@	At the rate
&	and
e_s	Saturated vapour pressure
ACZ	Agro-climatic zone
CV	Coefficient of variation
Dec	Decreasing
°C	Degree Celsius
Fig.	Figure
ha	Hectare
Inc	Increasing
kg	kilogram
Lat.	Latitude
<	Less than
Long.	Longitude
MaxT	Maximum temperature
MinT	Minimum temperature
>	More than
NS	Non significant
/	Per
%	Percent
PET	Potential evapotranspiration
PM	Post-monsoon
RH-1	Morning relative humidity
RH-2	Afternoon relative humidity

SD	Standard deviation
SWM	Southwest monsoon
<i>Viz.</i>	Namely
Yr	Year


THESIS ABSTRACT

- a) Title of the Thesis: "Agroclimatic analysis of Chhattisgarh state with respect to sustainable crop production"
- b) Full Name of the Student: **Shiv Kumar Bhuarya**
- c) Major Subject: Agrometeorology
- d) Name and Address of the:
Major Advisor: **Shri J.L. Chaudhary**
Department of Agrometeorology,
IGKV, Raipur, (CG), 492012
- e) Degree to be Awarded: M.Sc. (Ag.) Agrometeorology


Signature of Major Advisor


Signature of the Student

Date: 01/07/15


Signature of Head of the Department

ABSTRACT

Among the climatic elements the rainfall is the first index, ever thought of by farmers and climatic analyzers as it is the most important single factor which determines the cropping pattern of an area in general and the type of crop to be cultivated and its success or failure in particular. Therefore, the present study deals with the rainfall characteristics of the Chhattisgarh state, which includes the spatial distribution and variability through different seasons and annual basis. The study is based on 84 rain gauge stations rainfall data. While analyzing the long term average of seasonal and annual rainfall, the annual rainfall of the state is 1167 ± 147 mm with 56 numbers of rainy days, of which the winter, summer, southwest and post-monsoon average is 19, 30, 1050 and 67 mm respectively. The district Surajpur in northern hills agro-climatic zone (ACZ) receives the highest annual rainfall of 1411 mm whereas Kawardha district in Chhattisgarh plain ACZ records the lowest of 885 mm. The annual variability ranges from 16 % to 32 %. The Bastar plateau ACZ receives highest rainfall whereas the least rainfall areas are the districts of the Chhattisgarh plain ACZ.

In this study, trend in temperature on annual and seasonal basis were examined for Ambikapur, Jagdalpur, Raipur, Bilaspur and Pendra stations of Chhattisgarh state. Linear regression techniques were used to determine temperature trend and its level of significance was assessed by the Mann-Kendall test. Out of these stations, Raipur and Bilaspur annual and seasonal maximum temperature showing significantly increasing trend, annual maximum temperature increasing at 1 % level of significance increasing of 0.006°C and 0.067°C/yr on annual basis. On the other hand the minimum temperature showing slightly decreasing trend for both stations but annual and seasonal maximum and minimum temperature of Pendra showing increasing trend at 1 % level of statistically significance and rate of change is 0.014°C and 0.004°C/yr on annual basis.

Chhattisgarh state average area under rice cultivation during *kharif* season found to be approximately 37.63 lakh ha and average rice production is found 4973 thousand tonnes. Raipur district has the highest area and production of 508 thousand ha and 651 thousand tonnes respectively. Janjgir-champa and Dhamtari districts are having highest productivity of 1815 kg/ha and 1769 kg/ha respectively but Kawardha district is found to be having lowest productivity district (1093 kg/ha). Around 99 thousand ha area of Chhattisgarh state covered by maize during *kharif* season with average production of 142 thousand tonnes. Surguja district covers large area 37 thousand ha for the maize cultivation with 50 thousand tonnes production. Approximately 51 thousand ha area covered by pigeonpea cultivation during *Kharif* season with 28 thousand tonnes production. Surguja district found highest area 14.5 thousand ha and average production found 8.1 thousand tonnes but Dhamtari district found with lowest area of 0.26 thousand ha and production is found 0.09 thousand tonnes. Bastar district is found to be high productivity district with 675 kg/ha but Dhamtari district is found as low productivity district with 363 kg/ha. In this study 16 parent districts of Chhattisgarh state are categorized under the different productivity zones based on their area and yield for the different crops. Around 51.8 thousand ha area is occupied by soybean during *kharif* season with an average production of 51.8 thousand tonnes. Highest area 19.41 thousand ha with 21.21 thousand tonnes production found at Kawardha district for soybean and categorized under high area and high productivity zone.

शोधग्रंथ सारांश

(अ) शोधग्रंथ का शीर्षक:-- टिकाऊ फसल उत्पादन के सम्बन्ध में छत्तीसगढ़ राज्य की कृषि जलवायु का विश्लेषण ।

(ब) छात्र का नाम - शिव कुमार भुआर्य

(स) मुख्य विषय - कृषि मौसम विज्ञान

(द) मुख्य सलाहकार का नाम पता - श्री जे. एल. चौधरी (वरिष्ठ वैज्ञानिक)

कृषि मौसम विज्ञान विभाग

इं.गां.कृ.वि.वि. रायपुर (छ.ग.)

(इ) उपाधि से सम्मानित किया जाना ह - एम.एस.सी. (कृषि) कृषि मौसम विज्ञान


छात्र का हस्ताक्षर


मुख्य सलाहकार का हस्ताक्षर

दिनांक:- 01/07/15


विभागाध्यक्ष के हस्ताक्षर ।

सारांश

सभी जलवायवीय तत्वों की सूची में वर्षा का स्थान प्रथम है, यह प्रायः किसानों एवं जलवायु विश्लेषकों के लिए महत्वपूर्ण कारक रहा है जो किसी भी क्षेत्र की शंस्य पद्धति का निर्धारण और उगाई जाने वाली फसलों की सफलता और असफलताओं का भी निर्धारण करती है । वर्तमान शोध में छत्तीसगढ़ राज्य में होने वाली वर्षा का विभिन्न ऋतुओं और वार्षिक वितरण एवं विचरण गुणांक के सम्बन्ध में अध्ययन किया गया है जो 84 वर्षा मापी स्टेशनों के दैनिक वर्षा के आंकड़ों पर आधारित है । इस अध्ययन में दीर्घकालिन आंकड़ों के विश्लेषण से राज्य की वार्षिक वर्षा 56 बरसात के दिनों के साथ 1167 ± 147 मि.मी. तथा विचरण गुणांक 13 % पाई गई जिसमें से शरदऋतु, ग्रीष्मऋतु, दक्षिण-पश्चिम मानसून तथा पोस्ट मानसून में क्रमशः 19, 30, 1050 एवं 67 मि.मी. वर्षा पाई गई । अधिकतम वर्षा (1411 मि.मी.) उत्तरी पहाड़ी कृषि जलवायु क्षेत्र के अन्तर्गत आने वाली जिला सरगुजा में पाई गई है जबकि छत्तीसगढ़ की मैदानी क्षेत्र के अन्तर्गत आने वाली कवर्धा जिले में न्यूनतम वर्षा (885 मि.मी.) की स्थिति पाई गई है । वार्षिक वर्षा का विचरण गुणांक 16 %

से 32 % तक पाई गई है । बस्तर के पठारी कृषि जलवायु वाले क्षेत्र में अधिकतम वार्षिक वर्षा एवं छत्तीसगढ़ की मैदानी क्षेत्रों में न्यूनतम वार्षिक वर्षा की स्थिति पाई गई है ।

इस अध्ययन में छत्तीसगढ़ राज्य के अंबिकापुर, जगदलपुर, रायपुर, बिलासपुर और पेन्द्रा स्टेशनों के लिए वार्षिक और मौसम के आधार पर तापमान की प्रवृत्ति की जांच की गई है जिसके लिए रेखिय प्रतिगमन तकनीक तापमान की प्रवृत्ति का निर्धारण करने के लिए उपयोग किया गया है और इसकी सार्थकता की जांच मेन-केंडल परीक्षण द्वारा किया गया है । उपरोक्त स्टेशनों में से, रायपुर और बिलासपुर की वार्षिक एवं मौसमी अधिकतम तापमान में काफी वृद्धि की प्रवृत्ति पाई गयी है, अधिकतम तापमान वार्षिक आधार पर 1 % सार्थकता स्तर के साथ 0.006°C और $0.067^{\circ}\text{C}/\text{वर्ष}$ की दर से वृद्धि पाई गयी है और दूसरी ओर दोनों स्टेशनों की न्यूनतम तापमान में हल्की कमी पाई गई है किन्तु पेन्द्रा की वार्षिक और मौसमी अधिकतम तथा न्यूनतम तापमान में 1 % सार्थकता स्तर पर वृद्धि पाई गई है तथा वार्षिक आधार पर तापमान में वृद्धि 0.014°C तथा $0.004^{\circ}\text{C}/\text{वर्ष}$ पाई गई है ।

छत्तीसगढ़ राज्य में औसत 37.63 लाख हे. क्षेत्र में खरीफ सीजन में धान की खेती कि जाती है जिसकी औसत उत्पादन 4973 हजार टन पाया गया है । धान की खेती रायपुर जिले में अन्य जिलों की अपेक्षा अधिकतम 508 हजार हे. में की जाती है जिसकी उत्पादन लगभग 651 हजार टन होता है । जांजगीर चांपा और धमतरी जिलों में अधिकतम उत्पादकता क्रमशः 1815 कि.ग्रा./हे. और 1769 कि.ग्रा./हे. पाई गई है लेकिन सबसे कम उत्पादकता वाला जिला कवर्धा है सिक्की उत्पादकता 1093 कि.ग्रा./हे. पाई गई है । खरीफ सीजन में छत्तीसगढ़ राज्य की लगभग 99 हजार हे. क्षेत्र में मक्के की फसल लगाई जाती है जिसकी उत्पादन लगभग 142 हजार टन होती है । सरगुजा जिले में मक्के की खेती सर्वाधिक क्षेत्र (37 हजार हे.) में की जाती है जिससे लगभग 50 हजार टन उत्पादन होती है । खरीफ सीजन में छत्तीसगढ़ राज्य की लगभग 51 हजार हे. क्षेत्र में अरहर की खेती की जाती है जिसकी औसत उत्पादन 28 हजार टन पाई गई है इसकी खेती अधिकतम क्षेत्र (14.5 हजार हे.) में सरगुजा जिले में होती है जिससे औसत 8.1 हजार टन उत्पादन होती है तथा धमतरी जिले में इसकी सबसे कम क्षेत्र 0.26 हजार हे. पाई गई जिससे लगभग 0.09 हजार टन उत्पादन प्राप्त होती है । इसकी उत्पादकता सभी जिलो की अपेक्षा बस्तर में अधिक (775 कि.ग्रा./हे.) तथा धमतरी में सबसे कम (363 कि. ग्रा./हे.) पाई गई है । इस अध्ययन में छत्तीसगढ़ राज्य की प्रथम 16 जिलों को उसकी क्षेत्राच्छादन एवं उपज के आधार पर अलग-अलग उत्पादकता समूह में वर्गीकृत किया गया है तथा इस राज्य की लगभग 51.8 हजार हे. क्षेत्र में खरीफ सीजन में सोयाबीन की खेती की जाती है जिसकी औसत उत्पादन 51.8 हजार टन है कवर्धा जिले में इसकी खेती सबसे अधिक क्षेत्र 19.14 हजार हे. में की जाती है जिसका औसत उत्पादन 21.21 हजार टन पाया गया है अतः यह जिला अधिक क्षेत्र व अधिक उत्पादकता वाली वर्ग में रखा गया है ।

CHAPTER - I INTRODUCTION

Climate is the primary important factor for agricultural production. The climate is among the most important factors that determine the agricultural potentialities of a region and the suitability of a region for a specific crop whereas the yield is determined by weather conditions (Pereira, 1982). Concerning the potential effects of climatic change on agriculture has motivated important change in research. Agro-climatological analysis is used to study about climatic characteristics, crop performance of a particular region and also to know the climatic variability/climate change and its impact on agriculture. Agriculture is highly dependent on environmental conditions, a quantitative understanding of the climate of a region is essential for developing improved farming systems (Reddy, 1983).

In order to achieve maximum and sustainable crop production from available farm resources, it is essential to have proper knowledge of the agro-climatic resources of the location/region. Therefore, a thorough understanding of the climatic conditions would help in determining the suitable agricultural management practices for taking advantage of the favorable weather conditions and avoiding or minimizing risks due to adverse weather conditions. The climate is the least manageable part of environmental resources, yet a better understanding of the climatic resources and their interactions with agricultural parameters can help to increase the crop productivity. Weather and climate greatly influence the agricultural productivity in any region. Agricultural production and productivity of any region is being regulated by the prevailing climate of that area through temperature, rainfall, light intensity, radiation, sunshine duration etc. (Goswami *et al.* 2006).

The impacts of environmental changes are higher when examined at regional level than at global level. Even a temporary change of climate can have profound impact on agricultural production and on the use of energy and water resources (Gates 1988). Such variations, if occur frequently, then there is a need to

modify the existing cropping patterns and to develop suitable strategies for improving the agricultural production (Subramaniam and Raju, 1988).

Sustainable agriculture is one that produces abundant food without depleting the earth's resources or polluting its environment. The agriculture sector faces increasing challenges from climate and weather risks will become increasingly important in the mix of factors to consider and those already following sustainable agricultural practices. Rapidly raising greenhouse gases, enhanced land and sea temperatures and increased frequency and magnitude of extreme events pose enormous risks to various economic activities and fresh water availability and affect the sustainability of agriculture and food security of billions of people around the world, especially in the developing countries. In recent decades, sustainable farmers and researchers around the world have responded to the extractive industrial model with ecology-based approaches, variously called natural, organic, low-input, alternative, regenerative, holistic, Biodynamic, and biological farming systems. All of them, representing thousands of farms, have contributed to our understanding of what sustainable systems are and each of them shares a vision of "farming with nature," an agro-ecology that promotes biodiversity, recycles plant nutrients, protects soil from erosion, conserves and protects water, uses minimum tillage and integrates crop and livestock enterprises on the farm.

The general climate of Chhattisgarh state is dry sub-humid type where the annual potential evapotranspiration is slightly higher than the annual rainfall. The average annual rainfall of the region is around 1400 mm and about 90 to 95 percent of this amount is received during south-west monsoon season (June-October). The monsoon sets in around 10th June in the tip of the Bastar area and covers the entire area by 25th June. The monsoon withdraws from different areas of the state between 15th and 25th September. Months of July and August are the wettest months. Rainfall in October month occurs due to cyclonic activity in the Bay of Bengal and October rainfall is most crucial for the productivity of rice in the state. Winter conditions set in from mid-November when the average minimum temperature starts falling below 15⁰C. The northern districts especially Bilaspur division have more severe and longer winter period as compared to southern parts

especially Bastar division. The atmospheric humidity is very high (>90%) during monsoon months and starts decreasing from October onwards and reaches as low as 15-20 percent during peak summer months.

The soils of Chhattisgarh vary considerably in the three agro-climatic zones. Though the nomenclature is different, the types of the soils especially the physical properties are the same. The different soils that exist in the three agro-climatic zones are as follows Chhattisgarh plains bhata (lateritic), matasi (sandy loam), dorsa (clay loam), kanhar (clay), bastar plateau marhan (coarse sandy), tikra (sandy), mal (sandy loam), gabhar (clay & clay loam) and northern hills hilly soils, tikra, goda chawar and bahara soils.

The first two categories of the soils in the three agroclimatic zones are very light type of soils with very low water retentive capacity. As a result water stress or drought conditions occur either during the crop growing season when there is a break of monsoon for more than 5-7 days or immediately after the withdrawal of monsoon. In Bastar plateau and northern hill zone rice is grown in upland conditions without bunds and they are called uplands. In Chhattisgarh plains rice is mostly grown under bunded condition. About 45.7 per cent of the population belongs to scheduled castes and scheduled tribes. Agriculture is the main occupation of more than 80 per cent of the population with cropping intensity of 117 per cent. Mono cropping of rice is predominant while other crops grown are lathyrus, linseed and chickpea as relay crops (*Utera*). Chhattisgarh comes under sub-humid climate and receives 1200 to 1600 mm of rainfall. Though this amount is quite sufficient for growing rice crop but due to erratic distribution of rainfall frequent dry spells and heavy rainfall at times causes failure and adversely affect the economic conditions of the farmers.

Chhattisgarh state popularly known as “Rice Bowl of India” occupies an area around 3610.47 thousand hectare of rice crop with the production of 5.48 Mt and productivity of 1517 kg per hectare (Anonymous, 2010). In Chhattisgarh rice is the main crop-grown in about 37 lakh ha covering 77 percent of the net sown area. Only about 20 percent area is under irrigation and rest under rainfed conditions. Of the three agro-climatic zones, about 73 percent area in Chhattisgarh plains, 97 percent in Bastar plateau and 95 percent area in Northern hills are

rained. The cropping intensity is 121 for the state, out of this a major area in *rabi* season is under *utera* (relay cropping) and mostly lathyrus is grown under *utera*, thus assured irrigated double cropped area is very less. After rice, *kodo-kutki* is an important crop covering major areas in Chhattisgarh plains and Bastar plateau. There is substantial area under maize during *kharif* season (45000 ha.) in Northern hills and about 25000 ha in Bastar plateau. Soybean and sunflower crop have been introduced and presently covers more than 1.0 lakh ha in Chhattisgarh plains and needs further boost. During *rabi* season lathyrus, gram, wheat and linseed are grown. Lathyrus is the main crop during *rabi* season covering an area of about 5.8 lakh ha and is grown mainly as a relay (*utera*) crop.

The present experiment on “**Agroclimatic analysis of Chhattisgarh state with respect to sustainable crop production**” has been conducted with the following objectives.

- 1. To delineate distribution of annual and seasonal rainfall (mm) over Chhattisgarh state**
- 2. To compute annual and seasonal rainy days**
- 3. To find out trends of annual and seasonal maximum and minimum temperature**
- 4. To compute annual and seasonal relative humidity and potential evapotranspiration (PET)**
- 5. Delineation of productivity zones of major *Kharif* crops of Chhattisgarh state**

CHAPTER – II REVIEW OF LITERATURE

Agricultural production and productivity of any region is being regulated by the prevailing climate of that area through temperature, rainfall, light intensity, radiation, sunshine duration etc. To achieve the maximum and sustainable crop production from available farm resources, it is essential to have proper knowledge of the agro-climatic resources of the location/region. Therefore, a thorough understanding of the climatic conditions would help in determining the suitable agricultural management practices for taking advantage of the favourable weather conditions and avoiding or minimizing risks due to adverse weather conditions.

This chapter deals with the brief review of work done by past researchers on the agro-climatic analysis. This is discussed under following sections-

2.1 Brief review of agro-climatic characterization

2.2 Relative humidity, potential evapotranspiration analysis and temperature trend analysis

2.3 Rainfall and rainy days analysis

2.4 Delineation of production and productivity zones

2.1 Brief review of agro-climatic characterization

Skidmore *et al.* (1997) studied the use of remote sensing and GIS for sustainable land management, remote sensing provides the basic data to undertake inventory of land as well as the temporal information required to monitor sustainable land management practices. In this paper, the current use of remote sensing for sustainable land management is reviewed and the potential of future (new) satellite systems to contribute to sustainable development is explored. Other elements for successful sustainable development (good policy and participatory approaches) are then compared and contrasted with information requirements.

Chaudhary and Tomar (1999) determined the rainfall pattern over 12 stations of Bastar district in Chhattisgarh region of Madhya Pradesh by analysing

40 years of rainfall data (1957-86) and relationship between rainfall and rice yield were worked out. Weekly mean rainfall of 50 mm for lowland and 75 mm for upland with coefficient of variation of <100 per cent were considered as stable rainfall period for a particular week.

Pandey *et al* (2001) revealed agroclimatic features of LASPEX sites. Paper deals with the physiography, soil and climate of Gujrat in general and Sabarmati and Mahi river basin area where in LASPEX 97 was conducted in particular. The LASPEX region was relatively homogeneous uniform terrain with altitude ranging between 25 to 85 m. although stations fall under semi-arid climate region, the western part of LASPEX is more prone to experience arid environment as the rainfall was less and evaporation rate are high.

Fischer *et al.* (2002) made global agro-ecological assessment for agriculture in the 21st Century: methodology and results, over the past 20 years, the term "agro-ecological zones methodology," or AEZ, has become widely used. However, it has been associated with a wide range of different activities that are often related yet quite different in scope and objectives. First, AEZ provides a standardized framework for the characterization of climate, soil and terrain conditions relevant to agricultural production. In this context, the concepts of "length of growing period" and of latitudinal thermal climates have been applied in mapping activities focusing on zoning at various scales, from the sub national to the global level. Second, AEZ matching procedures are used to identify crop-specific limitations of prevailing climate, soil and terrain resources under assumed levels of inputs and management conditions. Third, AEZ provides the frame for various applications.

Roohi *et al.* (2002) made the characterization and classification of agro-climates of Pakistan. The seasonal aridity and crop growth indices were used to characterize and classify the agro-environments. The aridity index refers to the ratio of 50% probability of rainfall and actual crop evapotranspiration. The aridity classes ranged from humid to hyper-arid. Based on the seasonal aridity classes, 18 zones were delineated. The crop growth index reflects the temperature availability for crop growth and estimated as a ratio of growing degree-days available to those

required by a particular crop. The crop growth classes defined ranged from deficit to excess. A total of 9 zones were defined by superimposing the seasonal crop growth maps. These two indices contributed to the classification of 57 agro-climates in Pakistan.

Tsiros *et al.* (2008) made sustainable production zoning for agro-climatic classification using GIS and remote sensing. Aridity index (AI) and vegetation health index (VHI) are used in order to define zones adequate for sustainable farming according to water limitations. As crop growth is affected by water supply, these zones are named water limited growth environment (WLGE) zones. AI and VHI are computed on monthly time step for twenty hydrological years, from October 1981 to September 2001. Then, WLGE zones are combined with soil maps and a digital elevation model (DEM) of the area under investigation is framed in order to define zones appropriate for sustainable production. The current application has resulted in the definition of sustainable production using the two indices, soil maps and DEM.

Rao *et al.* (2008) revealed agro-climatic planning and information bank (APIB) for Uttarakhand state, India. Agriculture reform is the need of the hour to bring better productivity through utilization of new technology. APIB has designed a database structure to contain information on both spatial and non-spatial elements namely mapping, GPS survey, soil survey, GIS and Image Processing analysis, fertilizers use, plant protection, seeds/seedlings, package of practices, agricultural implements, Climatological data, credit/insurance schemes available, infrastructure for processing and marketing, demographic details, etc. The strength of APIB is a powerful state-of-the-art image analysis and GIS facilities to assess the natural resources endowments to any agro-climatic and would present them in the spatial and temporal domain.

Wart *et al.* (2013) studied the use of agro-climatic zones to upscale simulated crop yield potential. Climate heterogeneity was very large in CZ schemes with less than 100 zones. Of the other four schemes, the Global Yield Gap Atlas Extrapolation Domain (GYGA-ED) approach, based on a matrix of three

categorical variables (growing degree days, aridity index, temperature seasonality) to delineate CZs for harvested area of all major food crops, achieved reasonable balance between number of CZs to cover 80% of global crop area and climate homogeneity within zones. While CZ schemes derived from two climate-related categorical variables require a similar number of zones to cover 80% of crop area, within-zone heterogeneity is substantially greater than for the GYGA-ED for most weather variables that are sensitive drivers of crop production.

Bhelawe *et al.* (2013) made delineation of agro-climatic zones of Chhattisgarh. Agro-climatic zone can be defined as a land unit having a greater degree of commonality with respect to various resources. The agro-climatic zone was based on moisture, thermal regimes and length of growing period. Results revealed that delineation of the state may be divided into three regions based on rainfall, temperature and length of growing period if they are considered separately. By super-imposing the layers of temperature, rainfall and length of growing period, the state has been divided into 10 agro-climatic zones.

Rao *et al.* (2013) generated the agro-climatic atlas of Andhra Pradesh state. This study attempts to present an agro-climatic Atlas for the state of Andhra Pradesh with covering all aspects of agro-meteorology. The state predominantly is semi-arid tropical region with 63% area falling under semi-arid climate, about 18% of the state's area is sub-humid and about 15% area is arid. The mean daily PET on annual basis ranged from 4.9 to 5.9 mm/day in the state. Spatial differences are noticed. Highest PET (5.7 to 5.8 mm/day) is observed in majority area of SPSR Nellore and eastern part of Chittoor district. Large geographical area of the state experienced PET values in the range of 5.3 to 5.7 mm/day. Lowest PET (4.9 to 5.1 mm/day) values are recorded in Visakhapatnam.

Hiremath and Shiyani (2013) made the analysis of vulnerability indices in various agro-climatic zones of Gujarat. Component-wise and overall vulnerability indices as well as component-wise contributions to the overall vulnerability to climate change for the years 1991 and 2008 are presented. It is noticed that the ranks and relative magnitude of the indices varied during the years 1991 and 2008.

In general, the variables pertaining to agricultural and occupation vulnerability were major contributors to the overall vulnerability to climate change in these two years. The prime variables in the agricultural sector included the productivity of major crops, total food grains, cropping intensity, irrigation intensity and percentage forest area.

2.2 Relative humidity, potential evapotranspiration analysis and temperature trend analysis

Soman and Kumar (1990) revealed the rainfall data related to the southwest monsoon season June to September (122 days), which accounts for the major part of the annual rainfall over most part of the country, for each of the station the rainy days are arranged in ascending order of rain amount, and the association between the cumulated percentage rain amount (x) and the cumulated percentage number of rain days (y), designed as the normalized rainfall curve (NRC) is calculated. The coefficient of variation of the daily rainfall series varies between 100 per cent and 230 per cent at individual station, with nearly half the number of stations having CV value in the range 130-150 per cent, the number of days of significant rainfall (days with rainfall greater than the mean intensity per rainy day) constitute about 30 per cent of the total number of rainy days and account for about 75 per cent of the seasonal rainfall at almost all the stations.

Chaudhary (1994) performed the probability of rainfall occurrence in Bastar district of Madhya Pradesh and consequences for crop production are suited with particular reference to rice.

Taher and Alshaikh (1998) made spatial analysis of rainfall in southwest of Saudi Arabia using GIS. A Geographic Information System was used to study the characteristics and distribution of precipitation in southwest of Saudi Arabia based on a number of influencing factors including elevation, mountain slope and orientation, distance from moisture source and equator, wind direction and geographic location. Results indicate that elevation explains about 25% of variability in precipitation in most of the seasons. Other factors such as aspect, slope, distance from moisture source have different effects but less than the effect of elevation. Finally a polynomial trend surface has been generated to correlate

geographic location with precipitation and has shown a coefficient of determination of 70%.

Stafford *et al.* (2000) studied the temperature and precipitation of Alaska: 50 year trend analysis. Temperature and precipitation records from 1949 to 1998 were examined for 25 stations throughout the State of Alaska. Mean, maxima and minima temperatures, diurnal temperature range and total precipitation were analyzed for linear trends using least squares regressions. Annual and seasonal mean temperature increases were found for the entire state and the majority was found to be statistically significant at the 95% level or better. The highest increase was found in winter in the Interior region (2.2 °C) for the 50 year period of record. Decreases in annual and seasonal mean diurnal temperature range were also found of which only about half were statistically significant.

Hobbins and Ramirez (2004) studied trends in pan evaporation and actual evapotranspiration across the conterminous U.S. Paradoxical or complementary. Pan evaporation (ET_{pan}) has decreased at 64% of pans in the conterminous U.S. over the past half-century. Comparing trends in ET_{pan} and water budget-derived actual evapotranspiration (ET^*_a), we observe the so-called “Pan Evaporation Paradox,” which we confirm is no more than a manifestation of the complementarities between actual evapotranspiration (ET_a) and potential evapotranspiration (ET_p). Examining trends in the components of ET_a —the radiative energy and regional advective budgets—we show that both components must be considered together to explain the relationship between ET_{pan} and ET^*_a .

Bhowmik and Das (2007) studied rainfall analysis for Indian monsoon region using the merged rain gauge observations and satellite estimates: Evaluation of monsoon rainfall features. The inter-comparison with the observations suggests that the new analysis could distinctly capture characteristic features of the summer monsoon such as north–south oriented belt of heavy rainfall along the Western Ghats with sharp gradient of rainfall between the west coast heavy rain region and the rain shadow region to the east, pockets of heavy rainfall along the location of

monsoon trough/low, over the east central parts of the country, over north-east India, along the foot hills of Himalayas and over the north Bay of Bengal.

Karabulut *et al.* (2008) made precipitation and temperature trend analysis in samsun. The results showed that there is no negative or positive statistically significant trend in the study area, despite of slight precipitation decrease in winter for the period of 1931-2006. In contrast, 1974-2006 seasons represent slight precipitation increase (which are not statistically significant) annually and seasonally. Temperature data showed slight increase annually even though results are not statistically significant during the period of 1931-2006. On the other hand, results of temperature trend analyses represent statistically significant trend for the period of 1974-2006. The temperature data for summer months represent statistically significant trends during the last 32 years.

Rathod and Aruchamy (2010) made spatial analysis of rainfall variation in Coimbatore district Tamilnadu using GIS. Analyzing the long term average of monthly and annual rainfall, the annual rainfall of the district is 1242 mm of which the winter, summer, southwest and northeast monsoon share 2.07, 14.97, 46.13 and 36.83 % respectively. The station upper Niradam receives the highest rainfall of 4655 mm whereas Krishnapuram records the lowest of 414 mm. The annual variability ranges from 21.16 percent to 52.28 percent. The south, southwest and northwestern parts of the district experience the heavy rainfall whereas the least rainfall areas are the east, northeast and southeastern parts of the district.

Sharma and Singh (2010) made use of probability distribution in rainfall analysis. The best fit probability distribution was identified based on the minimum deviation between actual and estimated values. The lognormal and gamma distribution were found as the best fit probability distribution for the annual and monsoon season period of study, respectively. Generalized extreme value distribution was observed in most of the weekly period as best fit probability distribution. The best fit probability distribution of monthly data was found to be different for each month. The scientific results clearly established that the

analytical procedure devised and tested in this study may be suitably applied for the identification of the best fit probability distribution of weather parameters.

Kirono and Kent (2010) revealed assessment of rainfall and potential evaporation from global climate models (GCMs) and its implications for Australian regional drought projection. This paper assesses how well a set of GCMs can reproduce observed characteristics of historical rainfall and PET on a regional basis and explores the implications for regional drought projections if the poorer performing GCMs are omitted. Fourteen of the GCMs used in the IPCC's 4th assessment report are considered and their results compared with 1951–2006 observed rainfall and PET over Australia. The results indicate that some GCMs can reproduce the observed spatial patterns of both the means and variability (represented as the coefficient of variation), but most GCMs fail to reproduce the linear long-term trends. There is less clear difference between the better and poorer GCMs at a national level, but there is a clearer distinction at the regional level.

Trenberth (2011) revealed changes in precipitation with climate change. Events are observed to be widely occurring, even where total precipitation is decreasing: *'it never rains but it pours!'* This increases the risk of flooding. The atmospheric and surface energy budget plays a critical role in the hydrological cycle, and also in the slower rate of change that occurs in total precipitation than total column water vapor. With modest changes in winds, patterns of precipitation do not change much, but result in dry areas becoming drier (generally throughout the subtropics) and wet areas becoming wetter, especially in the mid- to high latitudes: the *'rich get richer and the poor get poorer'*. This pattern is simulated by climate models and is projected to continue into the future. Because, with warming, more precipitation occurs as rain instead of snow and snow melts earlier, there is increased runoff and risk of flooding in early spring, but increased risk of drought in summer, especially over continental areas.

Jain and Kumar (2012) studied trend analysis of rainfall and temperature data for India. This article aims to review studies pertaining to trends in rainfall, rainy days and temperature over India. Spatial units for trend analysis vary from

station data to sub-division to sub-basin/river basins. There are differences in the results of the various studies and a clear and consistent picture of rainfall trend has not emerged. In a study on basin-wise trend analysis 15 basins had decreasing trend in annual rainfall; only one basin showed significant decreasing trend at 95% confidence level. The mean minimum temperature showed a rising as well as a falling trend. At most of the stations in the south, central and western parts of India a rising trend was found. Some stations located in the north and northeastern India showed a falling trend in annual mean temperature.

Tirkey *et al.* (2012) revealed groundwater level and rainfall variability trend analysis using GIS in parts of Jharkhand state (India) for sustainable management of water resources. The analysis revealed that this region during the post-monsoon season exhibit shallow depth of water level (2-3m) which declines up to 8-10m during pre-monsoon in the month of May. The declining trend of water level is more conspicuous at those places which are located relatively at lower elevation. Although the south-eastern region exhibits an increase in the rainfall over the years, yet the average water level is very deep indicating large water losses due to runoff. On the contrary, the southern region shows an increase in the amount of rainfall over the years with concomitant increase in the water level indicating a positive relationship between rainfall and depth of water level.

Owiti and Zhu (2012) studied spatial distribution of rainfall seasonality over East Africa. Harmonic analysis was used to model the annual and semi-annual modes of rainfall seasonality at each station. The ratio of the modeled semi-annual range (R_2) to annual range (R_1) was used as an objective index to measure the degree of bimodal behavior of rainfall at a given station. Areas of bimodal regime were qualitatively delineated based on the difference of the fractional variance ($V_1 - V_2$) explained by each of the modes. Results show that negative values of $V_1 - V_2$, signifying bimodal regime, compares well to R_2/R_1 exceeding 0.3. Stations in areas of transition between annual and semi-annual regimes have value of $V_1 - V_2$ near zero indicating that neither of the two modes dominates.

Sahin (2012) studied an aridity index defined by precipitation and specific humidity. In this work, specific humidity was used instead of PET and a new aridity index (Iq) has been defined using the ratio of annual precipitation totals and annual mean specific humidity (SH). As shown in this study, SH can be easily computed with very high accuracy (3.569% error rate) with mean temperature, relative humidity and local pressure which are most commonly and widely measured meteorological data. According to the common and different aspects of arid zones found with AI, Iq and Erinc aridity index (Im), Iq found to be applicable for monitoring climate change and distribution of arid zones.

Pali *et al* (2013) revealed rainfall analysis for effective crop and water resources planning for Raipur region of Chhattisgarh. The study revealed that Raipur region receives an average annual rainfall of 1134.6 mm, out of which, 88 per cent pours down in monsoon season itself with a standard deviation of 287.2 mm and coefficient of variation as 28.7 percent. Only 15 per cent of total years of record (1969-2009) were excess rainfall year, and 60 per cent of years were found to be deficit rainfall years, whereas normal rainfall years were found to be only 25 per cent. This indicates the necessity of supplemental irrigation for rice crop. The mean date of onset and withdrawal of effective monsoon are 16th June and 21st September, respectively.

Khalkho *et al* (2013) studied cadastral level mapping for efficient natural resources management of Turenar cluster villages using remote sensing and GIS technologies. Five farming situations was identified, characterized and mapped as per the local names of the agro climatic zone viz. *badi*, *marhan*, *tikra*, *mal* and *gabhar*. The *badi* (12.6%) comprises of upland settlement, *marhan* (35.4%) is the upper upland, *tikra* (19.3%) is the lower upland, *mal* (9.1%) comprises the midland part and *gabhar* (23.7%) is the low lying situation. *Marhan* are un-bunded with gentle to moderately sloping situation, *tikra* is the un-bunded upland entisols with gentle to moderate slope, *mal* is the midland characterized as inceptisol, alfisol, bunded, flat lands and *gabhar* is the lowland comprising of bunded, Alfisol/Vertisol. The major crops during *Kharif* are paddy, maize, horse gram,

niger and millets. In *rabi*, winter maize and wheat are suitable for mid and low land farming situation with appropriate water resources.

Chaudhary *et al* (2013) analyzed weather parameters of Bastar plateau agro-climatic zone for strategic crop planning. It can be said that cooling trend is there creating favourable climatic conditions for *rabi* crops in this region. Mean monthly rainfall quantity is in between 6.7 mm to 353.0 mm. When considered on overall annual basis, maximum temperature is most consistent parameter as its CV value is least 1.85 per cent but minimum temperature CV is 4.57 per cent. Average rainfall for this region is 1399.1 mm with CV values of 20.63 per cent. Total annual rainfall has varied in between 795.3 mm (1992) to 2285.9 mm (1990) over the years and this happens to be the most inconsistent parameter. Relative humidity in morning hours is more consistent as compared to evening relative humidity. Average wind speed is 5.2 kmph, evaporation is 4.3 mm/day and bright sunshine hours mean is 6.6 hours/day on annual mean basis.

Hadgu *et al.* (2013) revealed trend and variability of rainfall in Tigray, northern Ethiopia. The results indicate that rainfall in the region is highly variable with a non-significant trend in both annual and seasonal totals for all stations. However, trends of rainfall events such as onset date, cessation date, LGP and dry spell length changed significantly in most stations. Moreover, most stations experienced drought conditions in the last decade. The results suggest the need for designing appropriate agronomic and water management strategies to offset the negative impacts of rainfall variability in the study area.

McMahon *et al* (2013) made estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. This guide to estimating daily and monthly actual, potential, reference crop and pan evaporation covers topics that are of interest to researchers, consulting hydrologists and practicing engineers. Topics include estimating actual evaporation from deep lakes and from farm dams and for catchment water balance studies, estimating potential evaporation as input to rainfall-runoff models and reference

crop evapotranspiration for small irrigation areas and for irrigation within large irrigation districts.

Bhargava *et al.* (2013) made rainfall spatial analysis using GIS. This research paper is made to understand the rainfall fluctuation with respect to spatial distribution in Bhilwara tehsil of Bhilwara district in Rajasthan. It illustrates the practical approach towards classification of rainfall data over the study area. To achieve the aim, it is divided into three sections. The first section describes pre-processing, data collection, geo-referencing, digitization, database creation and refinement of data has been accomplished. In the second section joining of spatial and non-spatial data with map creation is accomplished. In the last section post processing part and the final layout with various components is created.

Manickam *et al.* (2013) studied analysis of precipitation concentration index and rainfall prediction in various Agro-Climatic Zones of Andhra Pradesh, India. The results indicated that the values of prediction of rainfall for Karimnagar showed that for the years 2006, 07, 08 and 11 the prediction was fairly consistent showing an error within the range of $\pm 5\%$. Prakasam showed highly erratic values between the forecasted and predicted and actual data. This is attributed to the diverse agro-climatic regions in Prakasam when compared to Karimnagar which falls into a single agro-climatic zone.

Akpan and Okoro (2013) studied developing rainfall intensity–duration–frequency models for Calabar City, South-South, Nigeria. The first set of models represents an inverse relationship between rainfall intensities and duration for specified frequencies which are called “INTENSITY – DURATION MODELS” and frequencies of 1, 1.1, 1.2, 1.4, 1.6, 1.8, 2.2, 2.8, 3.7, 5.5, and 11 years are used; and very high and positive regression coefficient ranging from 0.9372 to 0.9930 and goodness of fit 0.8788 to 0.9851 were recorded. The second set of models represents rainfall intensities and frequencies for specified duration which are called “INTENSITY – FREQUENCY MODELS”, and durations of 15, 30, 45, 60, 90, 120, 180, 300 and 420 minutes were used, and very high and positive

regression coefficients ranging from 0.7908 to 0.9890 and goodness of fit 0.6263 to 0.9863 were obtained.

Eludoyin (2014) studied a perspective of the diurnal aspect of thermal comfort in Nigeria. Results indicated thermal stress in Nigeria and showed that both heat and cold stress varied temporally and spatially (1200 - 1500 Local Standard Time, LST as the most thermally uncomfortable period of the day, while before 0900 and around 2100 LST were more comfortable). The study showed that judgment on climate issues were often beclouded by religious or ignorant sentiments. Efficient coping strategies for thermal stress are generally lacking, being limited by poor education, financial capacity and inadequate government commitment to cater for the health effects of extreme climate conditions.

Sharma and Chaudhary (2014) studied time trends in temperature of Bastar plateau agro-climatic zone of Chhattisgarh state. The analysis showed that number of days recorded under different ranges of maximum temperature is not in increasing pattern in this region. Number of days with minimum temperature $\leq 10^{\circ}\text{C}$ is found increasing in the months of December and January and found statistically significant at 1 per cent level. Number of days with $\leq 7^{\circ}\text{C}$ showed increasing trend in the months of December, January and February. Analysis of maximum temperature crossing certain threshold values $\geq 40^{\circ}\text{C}$, $\geq 41^{\circ}\text{C}$, $\geq 42^{\circ}\text{C}$, $\geq 43^{\circ}\text{C}$ leads to conclusion that trends shown by linear equations are all non-significant, indicating that number of such days are not on the increase.

2.3 Rainfall and rainy days analysis

Chaudhary (1999) studied the variation of rainfall, rainy days etc. for understanding and adopting the suitable cropping system and scope for application of modern techniques for increased cropping intensity and crop productivity. The coefficient of variation of monsoon rainfall was least in the Sukma, Bijapur and Jagdalpur regions indicating that rice production will be more sustainable in this region. The high value of coefficient of variation around Dantewara during both monsoonal and post monsoonal season indicated that this is highly unstable region for rice production.

Gupta *et al* (2000) analyzed rainfall data recorded in Jabalpur, Madhya Pradesh, India, for 26 years (from 1971 to 1996). Average rice productivity was 589 kg/ha. Rice yields were significantly correlated with quantum of rainfall, length of rainy season and number of rainy days. Over-all productivity of rainfed rice was unstable due to frequent fluctuations in the amount of rainfall, number of rainy days and duration of the rainy season.

Kumar and Jain (2011) reported among 22 basins studied, 15 showed a decreasing trend in annual rainfall; only one basin showed a significant decreasing trend at 95% confidence level. Of the 6 basins showing an increasing trend, 1 basin showed a significant positive trend. The monsoon rainfall increased over 6 basins, decreased over 16 basins and a decreasing trend for 2 basins was found statistical significant. With the exception of Ganga, Brahmaputra and EFR4, all river basins experienced the same direction of trend in monsoon and annual rainfall. Four river basins experienced increasing (non-significant) trend in annual rainy days; three basins did not show any change in annual rainy days whereas 15 basins have shown a decreasing trend in annual rainy days.

Nandargi and Mulye (2011) revealed in the present study, daily rainfall data of the stations inside the Koyna catchment has been analysed for the period of 1961-2005 to understand the relationship between the rain and rainy days, mean daily intensity (MDI) and seasonal rainfall over the catchment on monthly as well as seasonal scale. Considering the topographical location of the catchment, analysis of seasonal rainfall data of 8 stations suggests that a linear relationship fits better than the logarithmic relationship in the case of seasonal rainfall versus mean daily intensity. So far as seasonal rainfall versus number of rainy days is considered, the logarithmic relationship is found to be better.

Jhajharia *et al* (2012) assessed the average monsoon rainfall (rainy days) during the monsoon months of June to September is about 1606 mm (70), which accounts for about 70% (64%) of the annual rainfall (rainy days). On monthly time scales, sixteen and seventeen sites (twenty-one sites each) witnessed decreasing trends in the total rainfall (rainy days), out of which one and three trends (seven

trends each) were found to be statistically significant in June and July respectively. For the rainy days during the months of November to January, twenty-two or more sites witnessed decreasing trends in Assam, but for nine (November), twelve (January) and eighteen (December) sites, these trends were statistically significant.

Mummigatti *et al* (2013) found the annual rainfall variability during the last 27 years (1985 to 2011) indicate that 17 years normal rainfall (-4.8 to 58.2%) and 5 years slightly drought (-13.2 to -24.4%) and 2 years moderate drought (-26.9 to -39.6%) and 3 years severe drought (-49.7 to -75.7%). There was no significant trend in the mean annual rainfall. The mean annual 54 rainy days of 27 years (1985-2011) was recorded with maximum contribution of 68.72 per cent with 37 rainy days from south west monsoon (June to September).

Ahonsi and Kazeem (2014) analysed the relationship between dew point temperature, relative humidity of the air and sunshine hours in Jos, Nigeria and derived the predictive model. The 10 years (2001-2010) of measurements were obtained from the weather observatory at the University of Jos, for analysis. Regression analysis techniques were then used to analyse and examine the relationship between the weather elements. The coefficient of regression analysis R^2 and R_a^2 (R^2 adjusted) were calculated. An empirical equation which was derived was used to compare the measured dew point temperature values and the predicted. Value of R^2 gave 98.5 % while that of R_a^2 registered 88.0%. It was discovered that the developed model can be used for the prediction of dew point temperature on a short and long-term basis.

Nazaripour and Daneshvar (2014) results revealed that the contribution of the one-day precipitation to general rainfall has reductive trends in almost 17.5% of the whole Iran. The most integrated and significant reductive trend of one-day precipitation contribution to rainfall spreads north-eastern and eastern parts of Iran. However, in the western parts of Iran, decreasing one-day precipitation contribution to rainy days affects to increase in the diurnal rainfall. The mentioned variability can be considered as the climate change signals in respect of one-day precipitation.

Das *et al* (2014) reported a statistically significant increasing trend of both rainfall and rainy days during the monsoon season found over the east coast and Deccan Plateau region of India. Meteorological subdivisions over the west coast, western arid region and north-eastern humid region showed significantly decreasing trends in both rainfall and rainy days. The northern hilly parts of the Himalaya were found to have a significantly increasing trend of rainfall but decreasing trend of rainy days. The north and central plains of India showed a decreasing trend of rainy days and the eastern plain was found to have a decreasing trend of rainfall during the summer monsoon period.

2.4 Delineation of production and productivity zones

Waghmare *et al* (2002) explained the pattern of changes in area production and productivity of maize in Satpura Plateau Zone (Chhindwara and Betul districts) Madhya Pradesh, India, during 1969/70-1997/98.

Dhakre and Sharma (2010) explained that maximum decrease in area under maize crop was (-) 16.02% found in the year 1999-2000 and maximum increase in area under maize crop was 30.23% in the year 2000-01, whereas maximum increase in production and productivity of maize crop in Nagaland was 103.05% in the year 1988-89 and 101.26% in the 1988-89 respectively. Among area, production and productivity of maize the instability was highest for the production. Growth rates were significant at 1% level of significance.

Haris *et al* (2011) made a study and examined the area, production and productivity of rice over Bihar from 1974 to 1999, and analysed the influence of the monsoon and rainfall distribution on production. It is revealed that *kharif* season rainfall accounts for 29% and annual rainfall accounts for 34% variability in rice productivity. Productivity of rice has shown a decreasing trend from year 2000 to 2005. Kharif season rainfall and annual rainfall have also shown a decreasing trend during the same time period.

Kumar and Bourai (2012) studied the production of pulses in Uttarakhand has drastically come down in the period during 1990-91 to 2007-08. The pulses data of government of Uttarakhand, directorate of agriculture, 2008, shows that the

winter pulses (lentil and chickpea) area declined in this period 5 thousands hectare. The reasons for declining the pulses were most of the farmers are economically inefficient in producing pulses in the region.

Kokilavani and Geethalakshami (2013) studied the data on area, production and productivity of study crops for 2000–01 to 2009–10 and indices such as relative spread index (RSI) and relative yield index (RYI) were computed and the potential cropping districts for the study crops were identified. In Tamil Nadu, nine districts were found to be prospective regions for rice, seven districts for maize and three districts for groundnut as in these areas both the RYI and the RSI were high. In some of the districts, RSI is more for a particular crop while the RYI is low indicating non suitability of that crop.

Borgohain (2013) explained that the total rice production in the state stands at 1.141 million tonnes to 5.086 million tonnes with an average rice crop yield ranging from 855 kg/ha to 1983 kg/ha during 1950-51 to 2010-1 period. This increase in yield was primarily due to increase in area under modern variety since 1980s. Rice yield thus found positively associated with the adoption of modern technology. However, the adoption needs to be further accelerated because at the current rate of increase in area under HYV, the state would take at least two decades to achieve complete adoption level. Thus the task for development of this sector is very challenging. Besides, mere enhancing production and productivity of rice, overall development of this sector is need of the hour, not only for the state alone but also for other rice consuming states in the country.

Sen *et al* (2013) made a study and described the trends in area, production and productivity of soybean in Kota district of Rajasthan, India, from 2001-02 to 2010-11. The compound growth rates for area, production and productivity were 2.41, 5.75 and 3.95 %, respectively. Among the three variables, none showed significant growth rates.

Kaloo *et al* (2014) revealed apart from this estimated production of rice in the year 2012 was calculated through compound growth rate. The estimation of 261.33(000) qtls was for the year 2012. Data used in the study has shown

continuous fluctuation and declining trend in the production and productivity from the last decade due to conversion of paddy land for other commercial purposes which is a threat to the people of Jammu and Kashmir.

Dhekale *et al* (2014) studied relative growth rates of area, production and productivity based on the best fitted trend function. The nonparametric regression model emerged as the best fitted trend functions for the area, production of rice crop and for productivity. Gompertz model was best fitted trend function. The per cent growth rate values are obtained for the successive years during the period under study for the area, production and productivity, when average showed that the production had increased at a rate of 3.26% per annum, which was due to combined effect of increase in area and productivity at a rate of 0.81 and 1.98% per annum respectively.

Koshal (2014) made the analysis of *kharif* and *rabi* time series data; the overall analysis of total DN values are divided in three range classes viz. 128, 128-192 & 192 assigned in pink, yellow and green and re-classified in low, medium and high agriculture area. The overall digital numbers (DN values) of *kharif* and *rabi* season average temporal data analysis are observed medium class (128-192) have 46.6% and 57.1% values coverage area and high coverage area having only 13% and 17.6 % respectively.

CHAPTER-III MATERIALS AND METHODS

This chapter describes the various methods used to analyze the data and the materials which are used for analysis with their source of collected data and description of study area in order to fulfill the assigned objectives of this research work entitled “Agroclimatic analysis of Chhattisgarh state with respect to sustainable crop production”

3.1 Description of the study areas

Chhattisgarh is a comparatively new Indian state carved out of the state Madhya Pradesh in November 2000. The state is located in the central part of India, between the latitudes of 17° 46' N -24° 5' N and longitudes of 80° 15' E- 84° 20' E. It is landlocked by Madhya Pradesh, Uttar Pradesh, Maharashtra, Orissa, Jharkhand and Andhra Pradesh. The state has 27 districts and spreading over a geographical area of 137.90 lakh hectares. The state has three agro-climatic zones *viz.* Chhattisgarh plains (Raipur, Gariyaband, Baloda Bazar, Mahasamund, Dhamtari, Durg, Bemetara, Balod, Rajnandgaon, Kabirdham, Bilaspur, Mungeli, Korba, Janjgir and part of Kanker district (Narharpur & Kanker block) along with part of Raigarh district, Bastar plateau (Bastar, Kondagaon, Dantewara, Bijapur, Narayanpur and remaining part of Kanker district) and Northern hills zone (Surguja, Surajpur, Balrampur, Koriya, Jashpurnagar and Dharamjaigarh tehsils of Raigarh district).

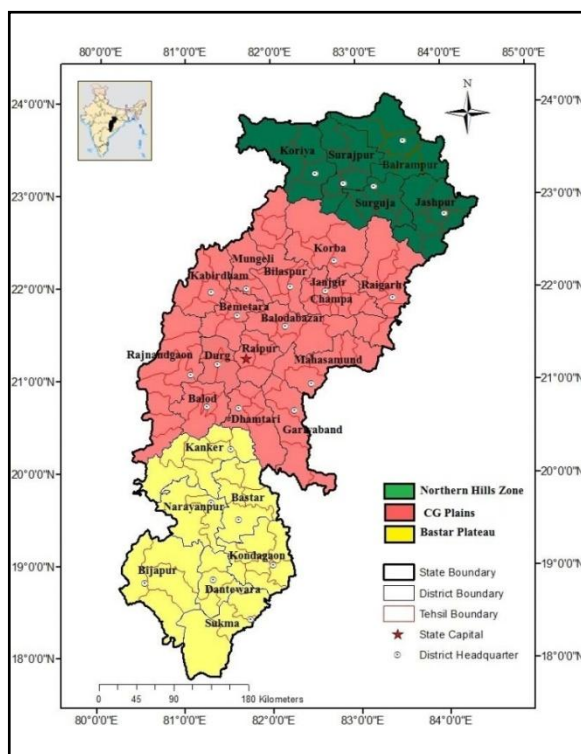


Fig. 3.1: Location map of Chhattisgarh state with agro-climatic zones

3.2 Data base used

To achieve the objectives of the present study following data were used. Daily rainfall data (mm) for 84 rain gauge stations of Chhattisgarh state listed in appendix-A along with period of rainfall availability, daily and monthly minimum and maximum temperature ($^{\circ}\text{C}$) for five stations and relative humidity (%) for four station were collected from the weather database of department of agrometeorology IGKV Raipur given Table 3.1 and district wise area, production and productivity of major *kharif* season crops Rice (*Oryza sativa*), Maize (*Zea mays*), Soybean (*Glycine max*) and Pigeonpea (*Cajanus cajan*) of Chhattisgarh state has been collected and compiled from the government approved websites viz. www.apy.dacnet.nic.in and www.agridept.cg.gov.in furnished in Table 3.2. The collected data has been processed and analyzed and maps have been prepared using software arcGIS 10.1.

Table 3.1: Weather database used for study

No.	Station Name	Lat.	Long.	Elevation	Database period	
					Temperature	Relative Humidity
1	Ambikapur	23 $^{\circ}$ 13'N	83 $^{\circ}$ 14'E	611	1951-2013	1994-2013
2	Jagdapur	19 $^{\circ}$ 08'N	82 $^{\circ}$ 02'E	553	1910-2013	1980-2013
3	Raipur	21 $^{\circ}$ 26'N	81 $^{\circ}$ 6'E	298	1901-2013	1971-2013
4	Bilaspur	22 $^{\circ}$ 08'N	82 $^{\circ}$ 13'E	271	1983-2013	1984-2013
5	Pendra	22 $^{\circ}$ 77'N	81 $^{\circ}$ 96'E	617	1904-2013	Nil

Table 3.2: Area, production and productivity data availability for major *kharif* crops in Chhattisgarh state

No.	Crop	Database period
1	Rice	1998-2013
2	Maize	1998-2012
3	Pigeonpea	1998-2012
4	Soybean	2000-2012

3.3 Rainfall analysis

The daily rainfall data has been converted into annual and seasonal rainfall and rainy days using weathercock software (Rao *et al* 2011). Further annual and seasonal average rainfall and rainy days were computed. Rainy days also have been worked out as per IMD criteria with their standard deviation and coefficient of variation by using the following equations-

Meteorological seasons over India are

Winter season: January – February

Pre-Monsoon season (summer): March – May

Southwest monsoon season (SWM): June – September

Post monsoon season (PM): October - December

Rainy day: A day with rainfall amount equal or more than 2.5 mm considered as a rainy day according to India Meteorological Department for Indian region.

3.3.1 Mean rainfall

The amount of rainfall collected by a given rain gauge in 24 hrs is known as daily rainfall (mm) and the amount collected in one year is known as annual rainfall. The mean of the annual rainfall over 30 years is known as normal annual rainfall of particular place or region.

$$\text{Mean Annual Rainfall} = \frac{\text{Total Rain fall}}{\text{Number of Years}}$$

3.3.2 Standard deviation (SD)

It is defined as the square root of the mean of the square of deviation of the rainfall value from the arithmetic mean of all such rainfall. It is a measure of variability or the scatter or the dispersion about the mean value.

$$\text{Standard deviation } (\sigma) = \sqrt{\frac{\sum(X - \bar{X})^2}{n - 1}}$$

Where:-

X = Rainfall

\bar{X} = Mean Rainfall

n = Number of years

3.3.3 Coefficient of variation (CV)

Assessment of rainfall variability was carried out through coefficient of variation (%). CV is defined as the standard deviation divided by the mean value of rainfall. It shows the variability of rainfall in percentage.

$$\text{Coefficient of Variation (CV)} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

3.4 Temperature trend analysis

Daily maximum and minimum temperature data has been converted into annual and seasonal data using weather cock software and temperature trend analysed. Several tests are available for the detection and estimation of trends. In this particular study, Mann-Kendall's test was employed. Mann-Kendall's test is a non-parametric method, this method tests whether there is a trend in the time series data. It is a non-parametric test. The n time series values ($X_1, X_2, X_3, \dots, X_n$) are replaced by their relative ranks ($R_1, R_2, R_3, \dots, R_n$) (starting at 1 for the lowest up to n).

The test statistic S is:

$$s = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(R_j - R_i)$$

Where:

$$\text{sgn}(X) = \begin{cases} +1 & \text{for } (X) > 0 \\ 0 & \text{for } (X) = 0 \\ -1 & \text{for } (X) < 0 \end{cases}$$

If the null hypothesis H_0 is true, then S is approximately normally distributed with:

$$\begin{aligned} \mu &= 0 \\ \sigma &= n(n-1)(2n+5)/18 \end{aligned}$$

The z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):

$$Z = |S|/\sigma^{0.5}$$

A positive value of S indicates that there is an increasing trend and vice versa.

3.5 Potential evapotranspiration (PET)

PET is defined as “the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water”. Potential evapotranspiration values in present study was computed using temperature data by Hargreaves method for all the five stations using “PET calculator v3” (Bapuji Rao, B. *et al.*, 2012).

Hargreaves equation

$$PET = 0.0023 \times Ra \times TD^{0.5} \times (Tm + 17.8)$$

Where:

PET= Potential evapotranspiration (mm/month)

Ra = Extraterrestrial radiation ($\text{MJ m}^{-2}\text{day}^{-1}$)

TD = Difference between maximum and minimum temperatures in $^{\circ}\text{C}$

Tm = Average monthly temperature ($(t_{\max} + t_{\min})/2$).

The coefficient generator generates PET coefficient as a function of geographical coordinates (Latitude, Longitude) of a place. Hargreaves PET value is converted into FAO Penman-Montieth method by using its coefficient values.

Simple regression equation is used to convert Hargreaves PET to FAO Penman-Montieth PET:

$$Y = a + bx$$

Where: Y = FAO Penman-Montieth PET

a= Interceptor

b= slope

x= Hargreaves PET

Table 3.3: Values of interceptor and slope used in regression equation to convert Hargreaves PET to FAO Penman-Montieth PET

Station	Hargreaves interceptor (a)	Hargreaves slope (b)
Ambikapur	-0.15	0.92
Raipur	-0.65	0.99
Bilaspur	-0.3	0.95
Pendra	-0.23	0.94
Jagdapur	-0.17	0.95

3.6 Relative humidity (RH)

Relative humidity is the most commonly used parameter to express moisture content of air. It is defined as the ratio of the amount of water vapour that is actually present in air (actual vapour pressure) to the amount of water vapour that air can hold at maximum capacity (saturated vapour pressure) at a given temperature and expressed as percentage. Daily relative humidity values have been converted into annual and seasonal values. RH is expressed as-

$$Relative\ humidity\ (RH) = \frac{actual\ vapour\ pressure\ (e_a)}{saturated\ vapour\ pressure\ (e_s)} \times 100$$

3.7 Delineation of productivity zones

Criteria adopted for categorization of productivity zones of major *kharif* crops (Rice, Maize, Soybean and Pigeonpea) of Chhattisgarh state is furnished in Table no. 3.4. Districts are placed in different categories depending upon the area and productivity levels and nine categories are considered *viz.*, High area-High yield (HH), High area-Medium yield (HM), High area-Low yield (HL), Medium area- High yield (MH), Medium area- Medium yield (MM), Medium area- Low yield (ML), Low area- High yield (LH), Low area- Medium yield (LM), Low area- Low yield (LL).

Table 3.4: Criteria adopted for categorization of productivity zones

Crops	Area (ha)			Productivity (kg/ha)		
	High	Medium	Low	High	Medium	Low
Rice	>3 lakh	1.5-3 lakh	<1.5 lakh	>1500	1200-1500	<1200
Maize	>5000	2000-5000	<2000	>1500	1200-1500	<1200
Pigeonpea	>5000	2000-5000	<2000	>600	500-600	<500
Soybean	>10000	1000-10000	<1000	>1000	800-1000	<800

CHAPTER - IV RESULTS AND DISCUSSION

The major predicament in today's scenario is to effectively feed the population from the infertile soil in a fragile world. This will necessitate development of technologies to increase crop productivity. This in turn will be initiated through improved resource use efficiently. An attempt was made to create a digital data base of rainfall and productivity zones of major *kharif* crops. In addition to it, temperature humidity and PET is also analyzed in annual and seasonal basis of some stations. Various outputs were generated in both tabular and map forms. The following section deals with the major results and the outcomes of the study.

- 4.1 Annual and seasonal rainfall and rainy days
- 4.2 Annual and seasonal average temperature and their trends
- 4.3 Annual and seasonal relative humidity (RH) and PET
- 4.4 Area, production and productivity of major *kharif* crops

4.1 Annual and seasonal rainfall and rainy days

Annual mean rainfall of Chhattisgarh state has been found to be 1167 mm with standard deviation value of ± 147 and coefficient of variation is found to be 13 % based on the available database in which lowest annual rainfall found at Kawardha district (885 mm) and highest annual rainfall found at Surajpur district (1411 mm). The state is characterized with unique aerial topography according to the annual rainfall of 84 rain gauge stations with its CV percentage shown in Fig. 4.1 and 4.2. Around 90 % (1050 ± 123 mm with 12 % CV) of annual rainfall received during SWM season during this season Kawardha district receives lowest 778 mm and Surajpur district receives highest 1311 mm amount of rainfall respectively. Remaining 10 % of annual rainfall received during winter, summer and post-monsoon season. A few part of southern Chhattisgarh receives good quantity of rainfall during post-monsoon season. Approximately 19 mm average rainfall received during winter season and its standard deviation is found ± 10 mm

and CV is 53 % but during summer season mean rainfall 30 mm is observed with its standard deviation ± 26 mm and CV 86 %. During post-monsoon season Chhattisgarh state receives 67 mm mean rainfall that is approximately 6 % of annual mean rainfall and its standard deviation is approximately ± 18 mm and CV is found 26 % the results shown in Fig. 4.4, 4.7 to 4.9 and CV of SWM shown in Fig. 5 during this analysis. Inferring findings are that Jashpur receives highest annual rainfall of 1605 mm based on the database. The southern district of Chhattisgarh state which comes under Bastar plateau agroclimatic zone and some district of northern hilly zone (Jashpur and Surajpur) receives high rainfall ranging from 1318-1411 mm but in plain zone's districts annual rainfall ranges found between 885 mm at Kawardha to 1228 mm at Janjgir-Champa furnished in Table 4.1.

In this study of annual and seasonal average rainy days analysis results found for the district level of Chhattisgarh state. Average annual rainfall are found to be with approximately 56 ± 8 numbers of rainy days (rainy days is more than or equal to 2.5 mm rainfall/day) shown in Fig. 4.3. During SWM season average rainfall occurs with 48 ± 5 numbers of rainy days shown in Fig. 4.6 and remaining three seasons winter, summer and post-monsoon season mean rainfall occurs with 1, 2 and 4 number of rainy days. On annual basis maximum numbers of rainy days recorded at Bastar district 76 and minimum found at Bemetara and Durg districts (43 rainy days each). During SWM season highest number of rainy days found at Jashpur district 58 and minimum numbers of rainy days recorded at Durg district 39 given in Table 4.2. In this study maximum numbers of rainy days found at Bastar plateau and northern hills ACZ but minimum numbers of rainy days observed at Chhattisgarh plain ACZ.

Table 4.1: Annual and seasonal average rainfall of different district of Chhattisgarh state with its SD and CV

No	Districts	Winter			Summer			SWM			Post-monsoon			Annual		
		Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1	Balod	11	28	274	13	24	194	938	288	31	55	64	116	1017	309	31
2	Balodabazar	13	21	158	16	30	194	929	235	26	50	57	114	1008	257	26
3	Bemetara	8	21	315	9	19	262	890	241	27	41	48	117	948	251	26
4	Durg	6	16	279	12	27	253	891	260	31	46	59	128	954	282	31
5	Dhamtari	22	25	123	39	42	110	1012	255	25	60	65	109	1133	289	26
6	Mahasamund	16	42	258	20	34	246	1033	313	31	48	57	123	1117	326	29
7	Kanker	17	24	146	30	62	215	1032	268	26	74	82	111	1152	324	28
8	Gariaband	11	24	258	18	37	244	1065	306	29	46	61	132	1140	323	28
9	Raipur	11	22	245	18	29	252	954	298	31	52	63	124	1035	321	31
10	Mungeli	26	34	135	29	32	111	928	219	24	71	61	86	1055	252	24
11	Kawardha	29	43	150	25	34	175	778	197	26	53	55	104	885	221	26
12	Rajnandgaon	17	36	199	21	36	188	1004	327	33	63	70	112	1105	336	30
13	Bilaspur	47	55	117	56	59	111	935	207	22	58	58	96	1096	232	21
14	Korba	17	33	196	30	41	135	1018	261	26	46	56	122	1111	274	25
15	Janjgir-Champa	29	38	132	27	36	134	1095	334	31	77	87	114	1228	383	32
16	Raigarh	21	30	148	43	79	158	1061	287	27	68	73	105	1192	310	26
17	Jashpur	24	35	157	42	52	136	1174	310	27	78	75	99	1318	342	27
18	Koriya	25	40	162	20	44	218	1113	261	23	67	71	107	1225	311	25
19	Surajpur	12	22	193	10	21	208	1311	382	29	78	71	92	1411	368	26
20	Surguja	47	41	88	48	47	96	1170	321	27	83	61	73	1348	342	25
21	Sukma	6	16	271	49	53	108	1199	261	22	88	74	85	1342	268	20
22	Bastar	22	22	98	143	71	49	1129	232	21	113	93	82	1408	289	21
23	Bijapur	27	54	185	31	38	151	1167	297	25	64	60	97	1288	321	25
24	Kondagaon	18	23	126	27	26	93	1121	173	15	85	79	93	1252	196	16
25	Narayanpur	15	28	188	29	55	190	1235	245	20	88	69	79	1366	289	21
26	Dantewara	14	37	260	6	13	208	1170	355	30	91	75	83	1282	334	26
27	Balrampur	13	22	176	9	19	215	1009	304	30	63	53	84	1094	351	32
	State	19	10	53	30	26	86	1050	123	12	67	18	26	1167	147	13

Table 4.2: Annual and seasonal average number of rainy days of different district of Chhattisgarh state with its SD and CV

No	Districts	Winter			Summer			SWM			Post-monsoon			Annual		
		Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1	Balod	1	1	255	1	2	199	41	10	24	3	3	99	45	11	24
2	Balodabazar	1	2	162	1	2	191	44	9	20	3	2	83	49	10	20
3	Bemetara	1	1	310	1	1	269	40	8	21	2	2	98	43	9	21
4	Durg	0	1	245	1	2	252	39	10	27	3	3	108	43	11	27
5	Dhamtari	2	2	110	3	3	96	46	9	20	4	3	92	55	12	22
6	Mahasamund	1	2	212	2	2	222	47	9	20	3	3	96	53	10	19
7	Kanker	1	1	135	2	4	221	46	8	19	4	4	90	53	13	25
8	Gariaband	1	1	226	1	2	245	45	9	21	3	3	94	50	11	21
9	Raipur	1	1	224	1	2	220	42	9	21	3	3	101	47	10	22
10	Mungeli	2	3	125	3	3	99	46	9	19	4	3	82	55	11	20
11	Kawardha	2	3	139	2	2	135	44	9	20	4	3	84	51	11	21
12	Rajnandgaon	1	2	167	1	2	171	43	10	23	3	3	97	49	11	22
13	Bilaspur	4	4	103	5	4	81	48	9	18	4	3	79	60	11	19
14	Korba	1	2	160	2	3	125	46	10	21	3	3	103	52	11	22
15	Janjgir-Champa	2	2	120	2	2	121	47	10	23	4	4	90	55	13	24
16	Raigarh	1	2	132	3	5	135	52	10	19	4	3	87	60	11	19
17	Jashpur	2	2	135	3	3	118	58	11	19	4	4	85	67	14	21
18	Koriya	2	3	156	1	2	151	46	9	19	4	4	97	53	11	21
19	Surajpur	1	1	155	1	2	198	52	6	12	5	4	87	58	11	18
20	Surguja	4	3	70	5	3	70	54	9	17	6	4	69	68	11	16
21	Sukma	0	1	292	3	4	120	56	10	18	5	4	83	65	11	18
22	Bastar	2	2	106	11	3	30	57	8	15	7	4	59	76	11	15
23	Bijapur	2	3	177	2	2	139	51	9	18	4	3	81	59	11	19
24	Balrampur	1	1	198	1	1	198	48	10	21	4	3	72	53	13	24
25	Dantewara	1	1	191	0	1	206	54	10	19	5	4	79	60	11	19
26	Narayanpur	1	1	180	2	3	152	57	8	14	5	4	67	65	10	15
27	Kondagaon	1	1	142	3	2	75	54	7	12	5	4	75	63	7	11
	State	1	1	65	2	2	85	48	5	11	4	1	27	56	8	14

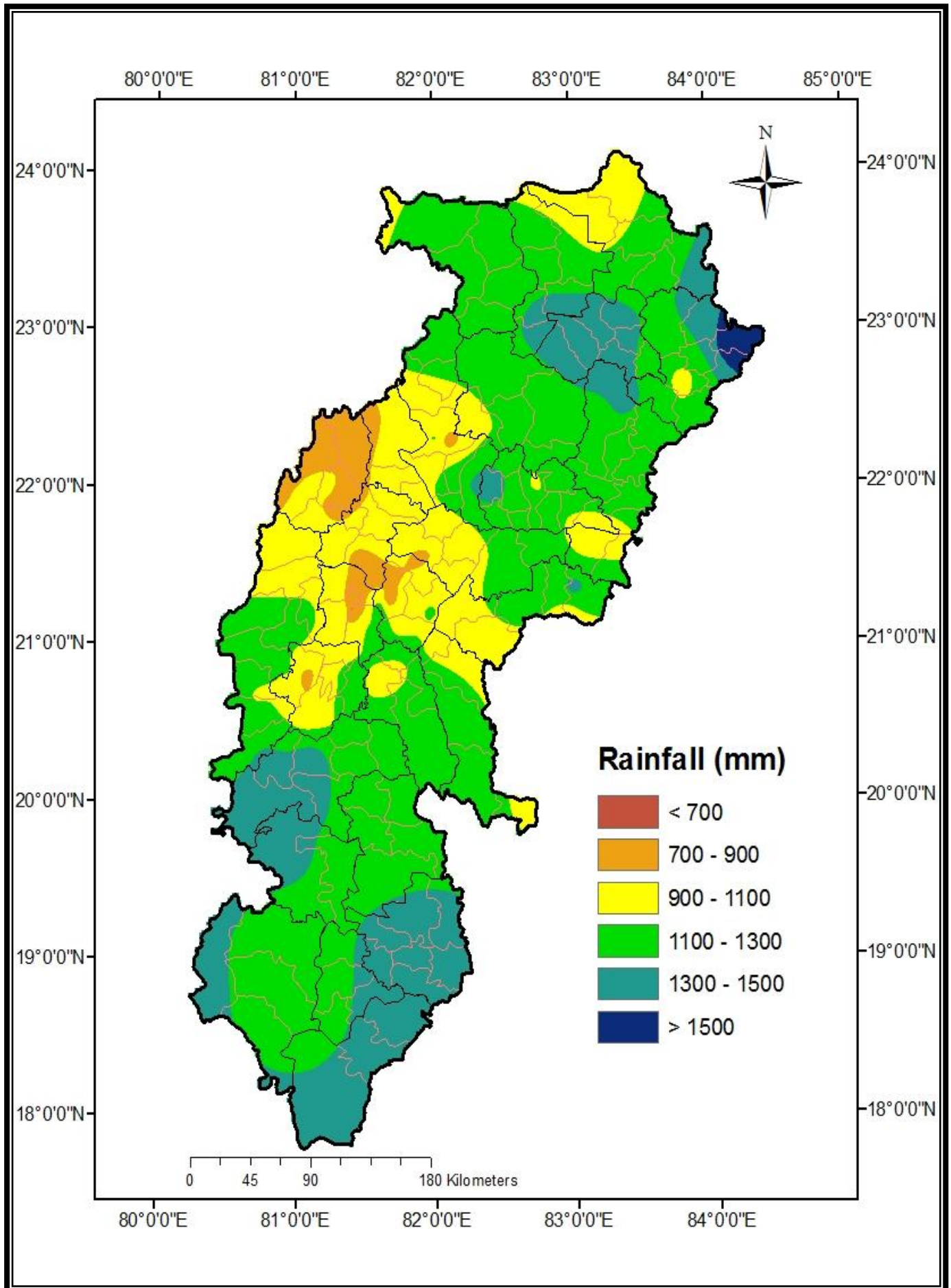


Fig. 4.1: Annual rain (mm) over Chhattisgarh state

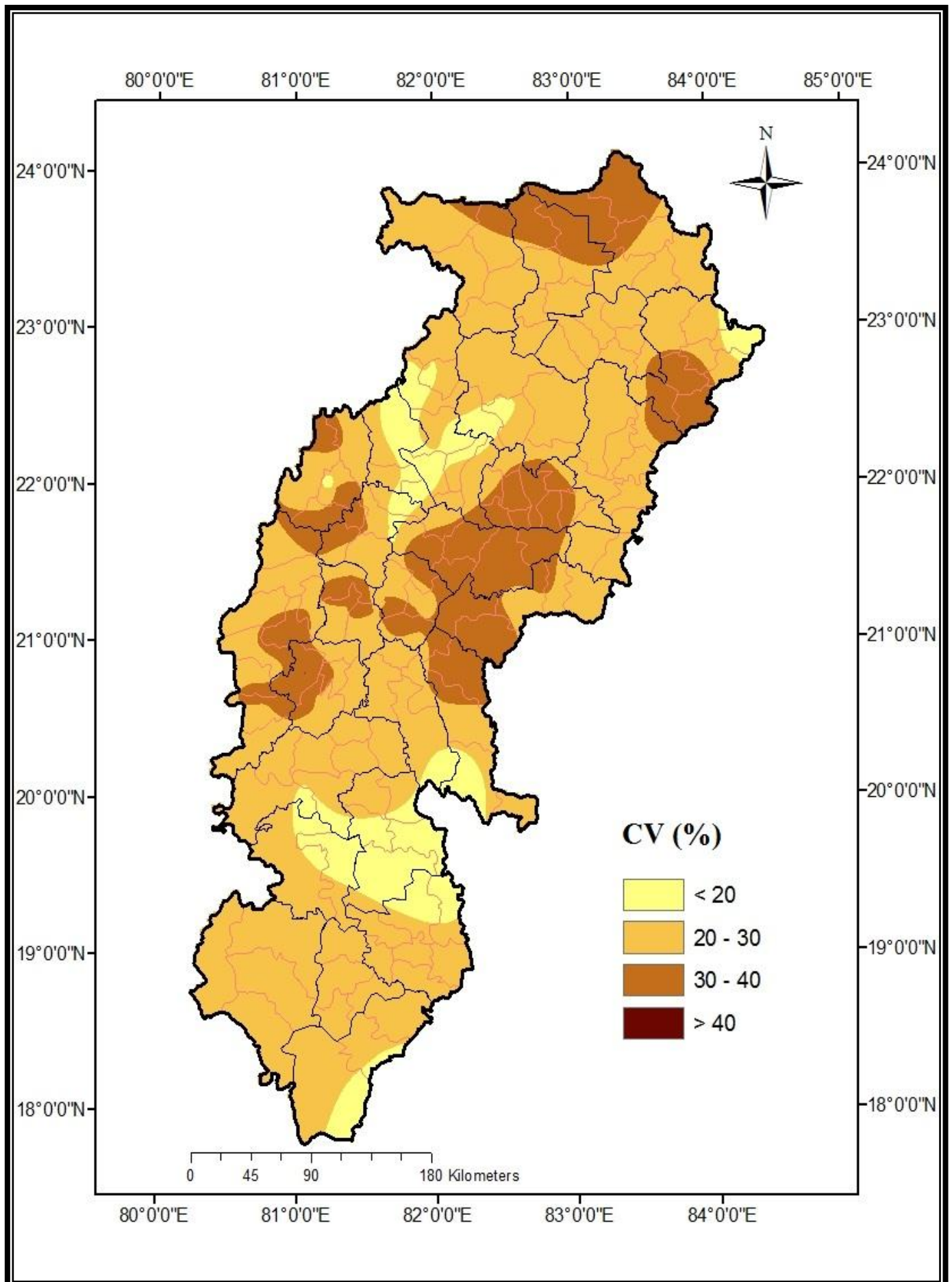


Fig. 4.2: Spatial variability (CV %) of annual rain in Chhattisgarh state

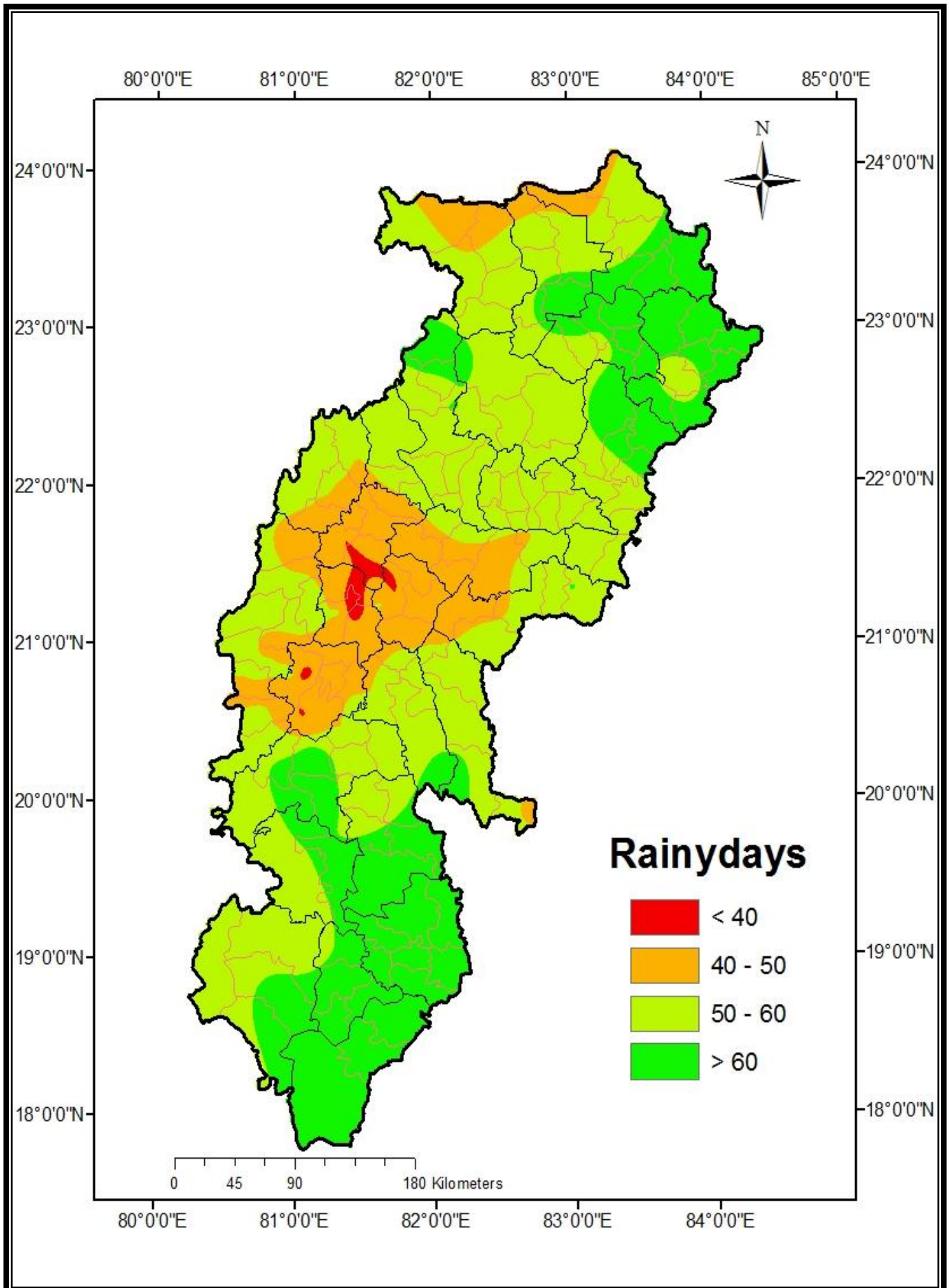


Fig. 4.3: Annual number of rainy days in Chhattisgarh state

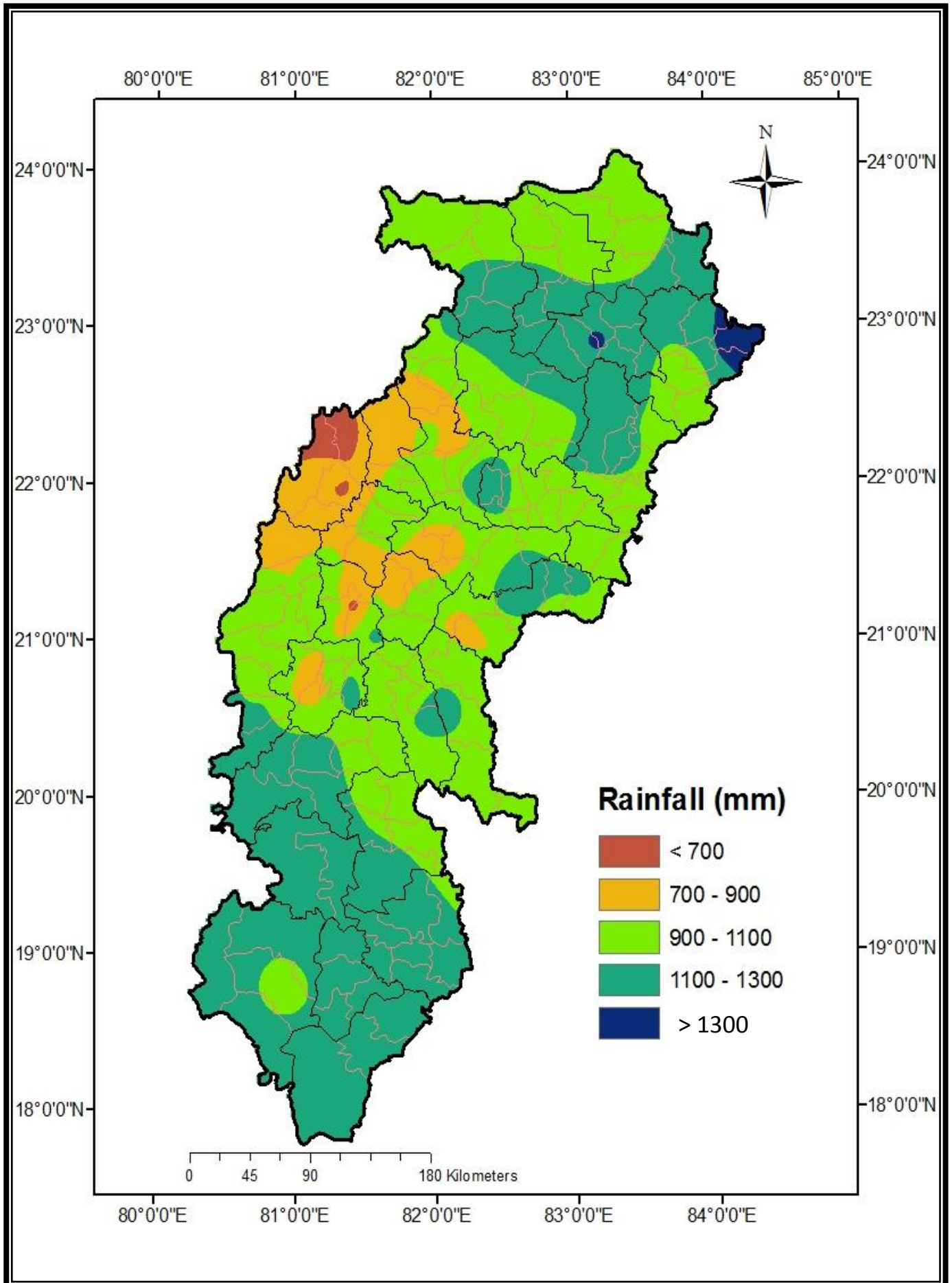


Fig. 4.4: Southwest monsoon rain (mm) over Chhattisgarh state

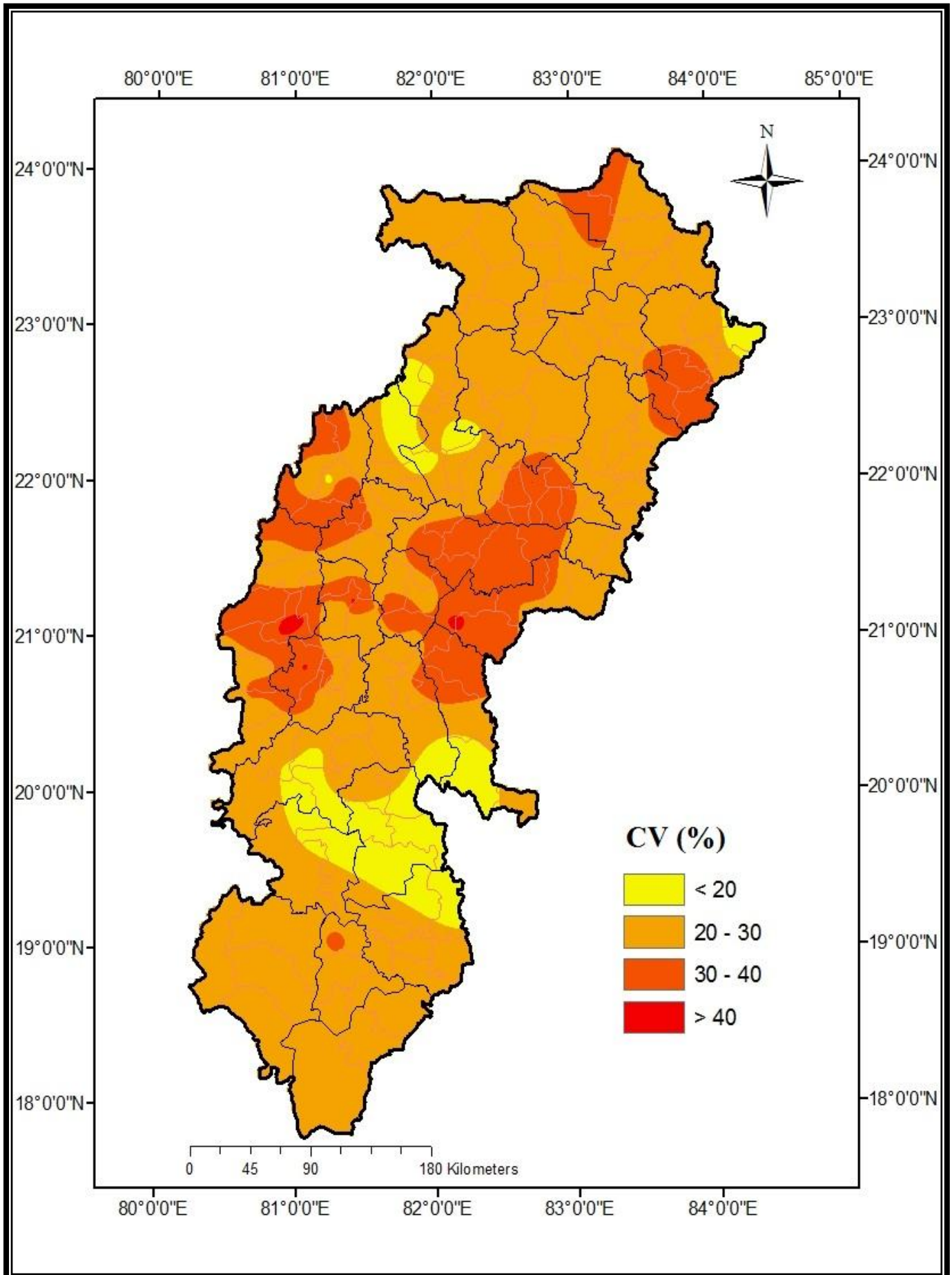


Fig. 4.5: Variability (CV %) in southwest monsoon rain in Chhattisgarh state

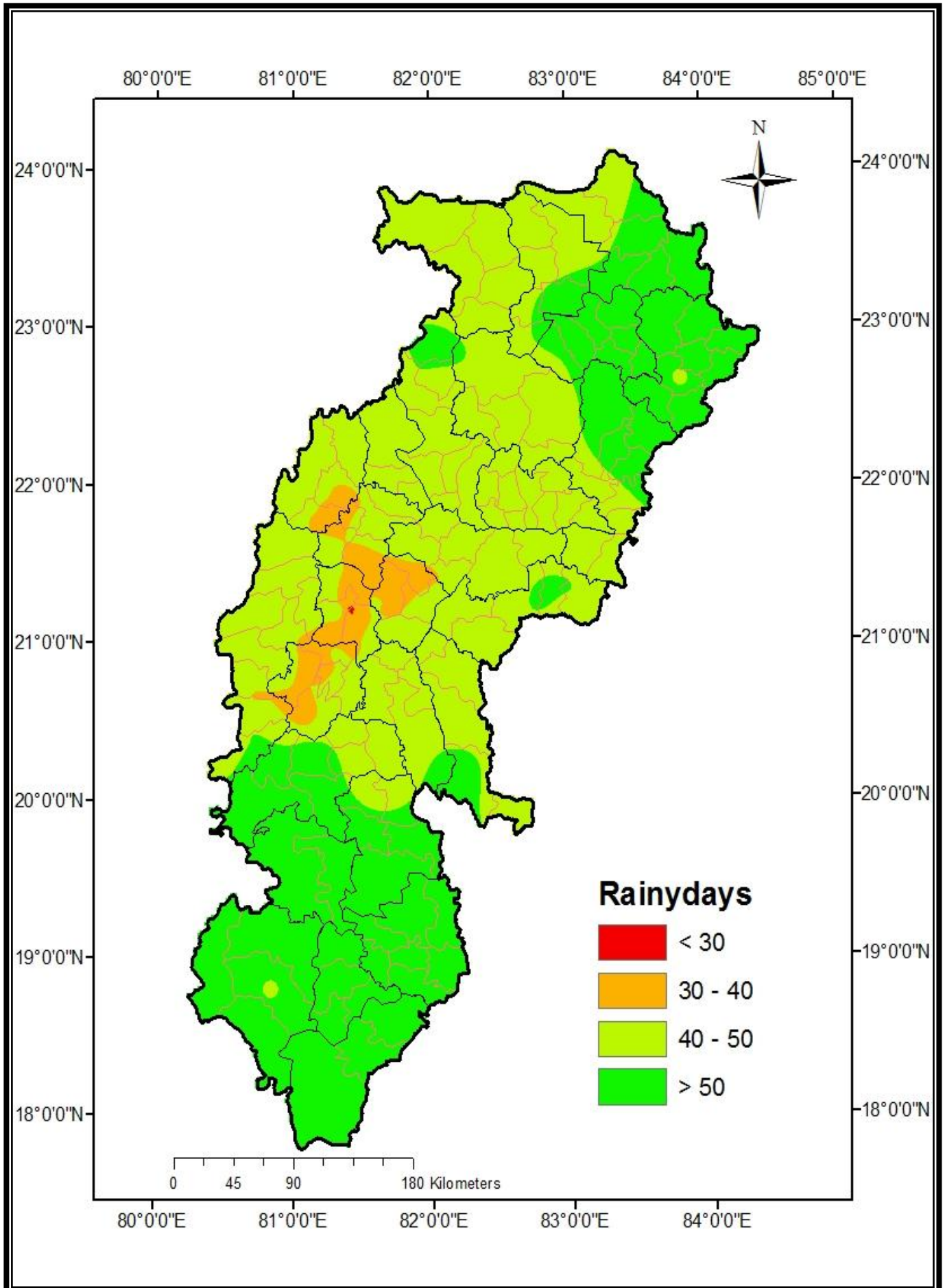


Fig. 4.6: Number of rainy days during southwest monsoon in Chhattisgarh state

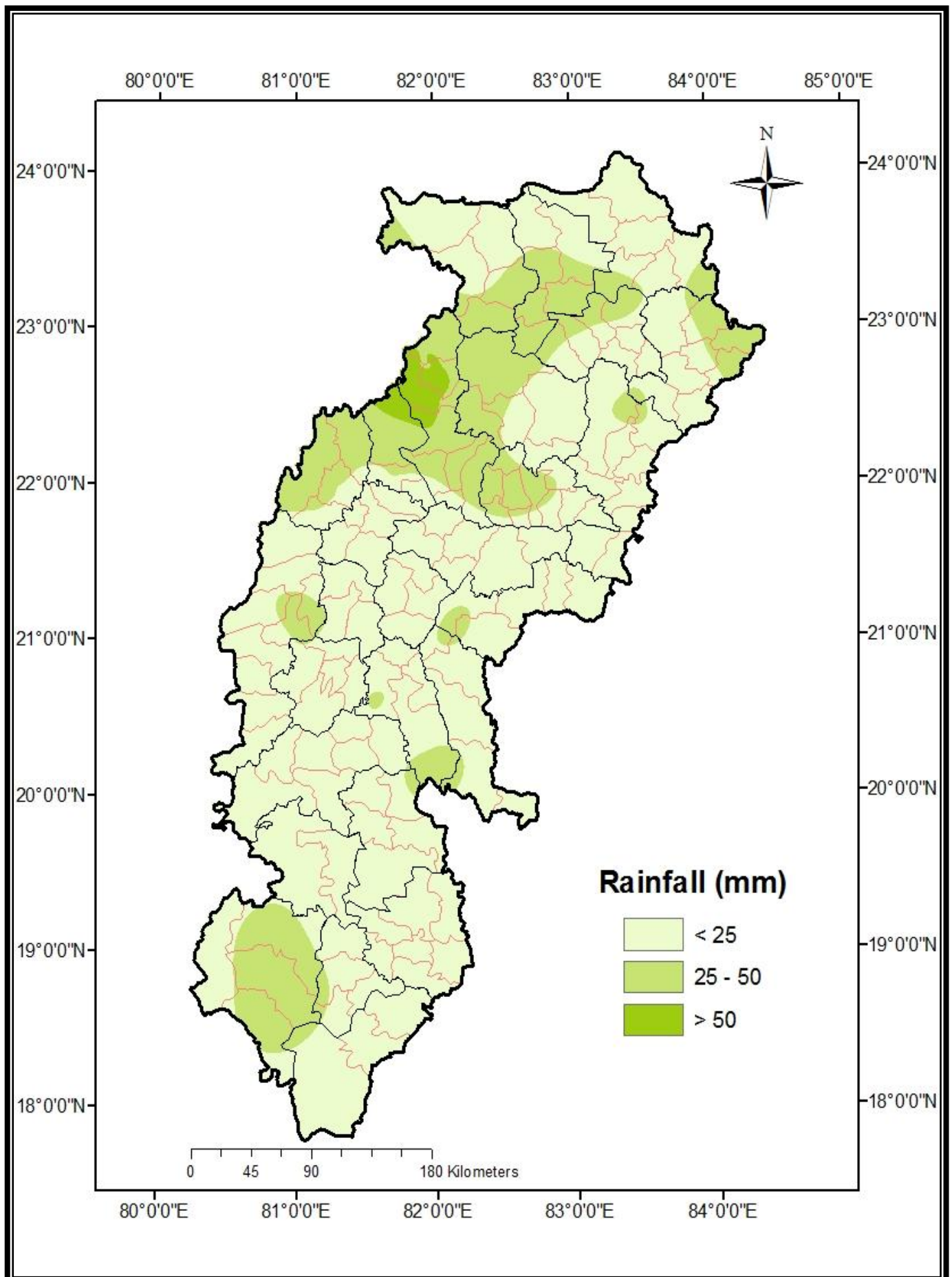


Fig. 4.7: Winter season rain (mm) in Chhattisgarh state

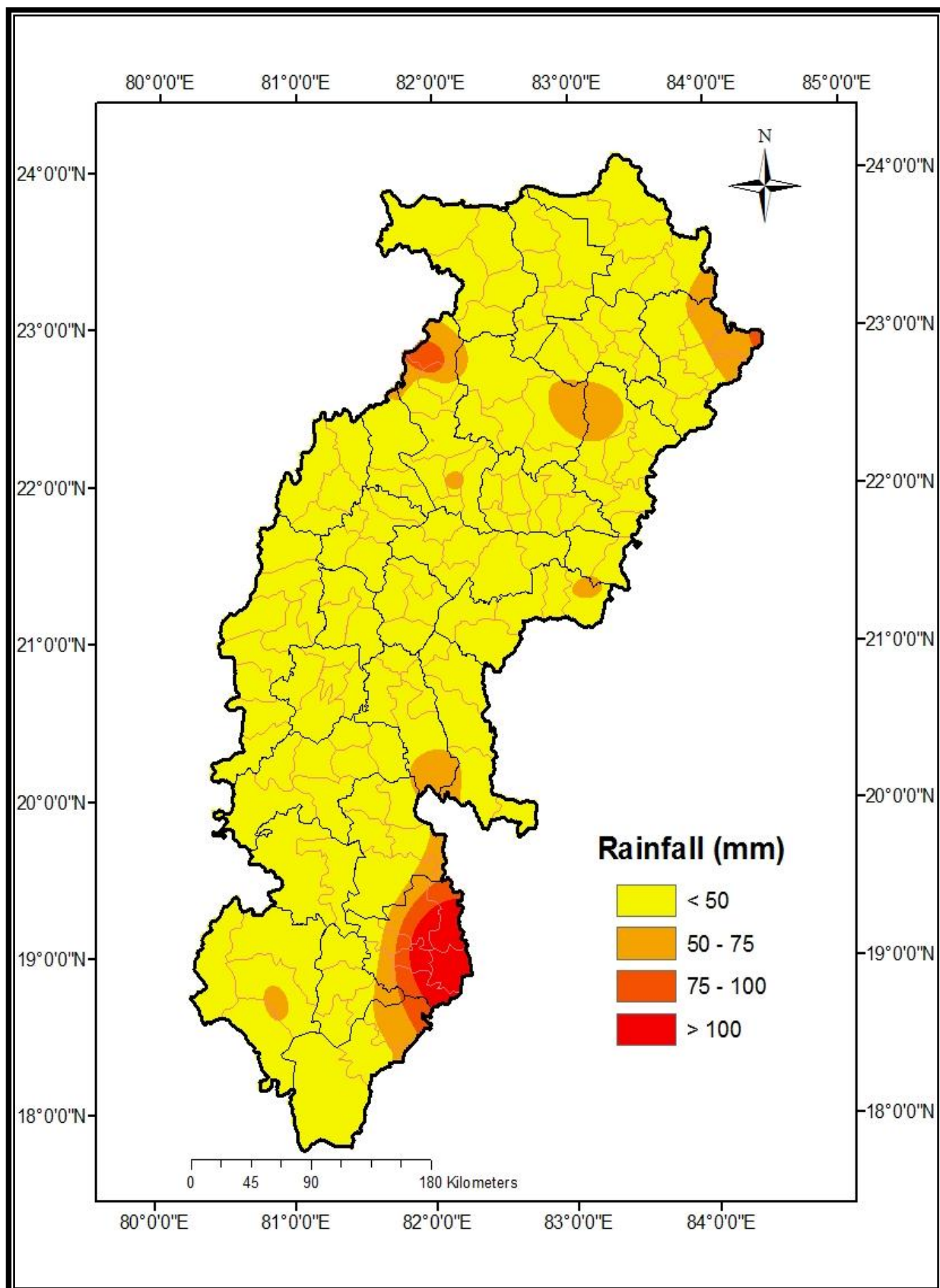


Fig. 4.8: Summer season rain (mm) in Chhattisgarh state

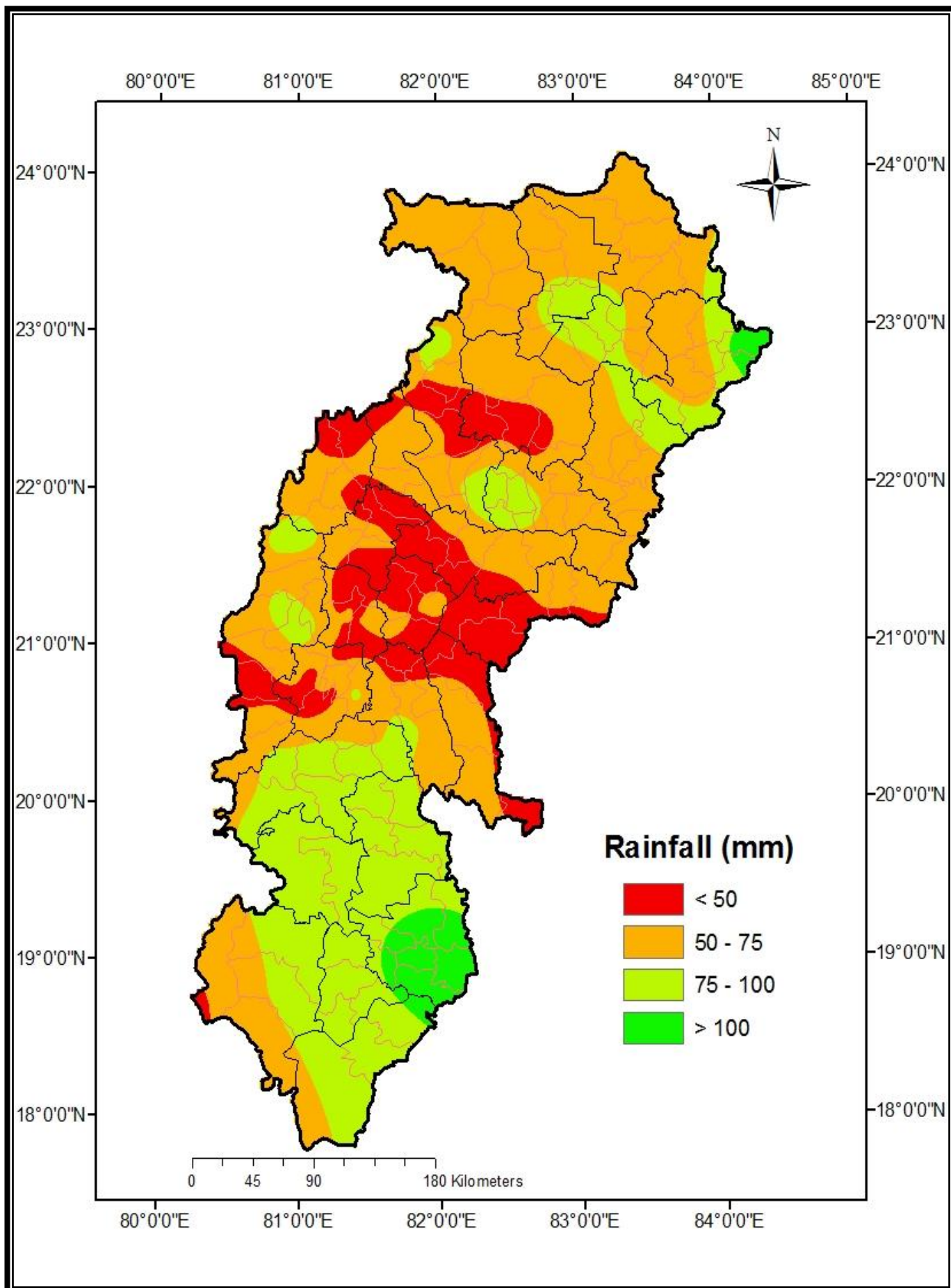


Fig. 4.9: Post-monsoon rain (mm) in Chhattisgarh state

4.2 Annual and seasonal average temperature and their trends

The air temperature over five major stations of Chhattisgarh state varies seasonally and annually depending upon their latitude, altitude and location with respect to geographical features such as water bodies, mountains and types of vegetation. In this study five major stations Raipur, Bilaspur, Ambikapur, Jagdalpur and Pendra are selected for the analysis of average annual and seasonal temperature and their trends results of this analysis are shown in Table 4.3 and Table 4.4.

4.2.1 Annual and seasonal average temperature

Average annual maximum temperature of Raipur is found high with a value of 32.6°C followed by Jagdalpur 31.1°C, Pendra 30.1°C, Ambikapur 29.8°C and lowest value found at Bilaspur 28.8°C. On the other hand, annual average minimum temperature found high at Raipur 20.6°C and lowest found at Bilaspur district 15.6°C. During winter season highest maximum temperature found at Jagdalpur 29.5°C and lowest maximum temperature found at Ambikapur 25.3°C but highest average minimum temperature found at Raipur 14.1°C and lowest minimum temperature found at Ambikapur 10°C. In summer season results shows highest maximum temperature at Raipur 38.8°C and lowest maximum temperature found at Pendra 35.8°C but highest minimum temperature found at Raipur 23.8°C and lowest minimum temperature found at Ambikapur 20.4°C. For the analysis of SWM temperature results found highest maximum temperature at Bilaspur 32.4°C and lowest average maximum temperature found at Jagdalpur 29.8°C but highest average minimum temperature found at Bilaspur 24.8°C and lowest found at Jagdalpur 22.4°C. During post-monsoon season highest average maximum temperature found at Bilaspur 32.1°C and lowest found at Ambikapur 26.7°C, Bilaspur station observed highest minimum temperature 19.7°C and lowest observed at Ambikapur 12.8°C. During peak summer season day time maximum high temperature reaches at 46.7°C in the month of May and June.

4.2.2 Annual and seasonal temperature trend

Annual and seasonal temperature trend analysis over the five given stations *viz.* Ambikapur under northern hills zone, Raipur, Bilaspur and Pendra are coming under Chhattisgarh plains region and Jagdalpur under Bastar plateau agroclimatic

zone. Temperature of these five stations fluctuated by its location, elevation and other geographical features of the station. Analysis of trend in annual and seasonal temperature data conducted for the given period of this study. Mean annual and seasonal temperature trend in the given period examined by using a linear regression model, the rate of change is defined by the slope of regression line for the given period.

Temperature trend analysis results found for Ambikapur indicate that minimum temperature during winter and summer season observed significantly increasing @ 10 % level, minimum temperature trend during post-monsoon season and annual basis found increasing @ 5 % level of significance with the regression slope 0.017°C and 0.008°C respectively during the period of study 1951-2013 shown in Fig. 4.10.

Temperature analysis results found for Jagdalpur condition during winter season have shown that maximum temperature showing increasing trend at 5 % level of significance and maximum temperature during post-monsoon season had shown increasing trend @ 1 % level of significance and the slope is found $0.008^{\circ}\text{C}/\text{yr}$ during 1910-2013. Minimum temperature of Jagdalpur during winter season found decreasing trend @ 5 % level of significance and the rate of change is found $-0.011^{\circ}\text{C}/\text{yr}$ during the period of study Fig. 4.11.

Maximum temperature trend result shown in Fig. 4.12 for Raipur condition during different season and annual basis indicate that during winter season maximum temperature trend is found increasing at 5 % level of significance and during summer and SWM season also found increasing trend @ 10 % level of significance but during post-monsoon season and annual basis trend is found increasing at 1 % level of significance. Rate of change of annual maximum temperature found $0.006^{\circ}\text{C}/\text{yr}$ during the period of study. Minimum temperature during winter and summer season results found significantly decreasing trend at 1 % level, only SWM trend found increasing trend at 5 % level of significance and annual minimum temperature trend found decreasing at 5 % level of significance with the slope of regression line is -0.006°C over the study period (1901-2013).

At Bilaspur station Fig. 4.13 shows, maximum temperature trend found increasing pattern during winter, post-monsoon season and annual basis at 1 %

level of significance and the rate of change is observed 0.099°C , 0.085°C and 0.067°C during the study period (1983-2013). But during summer season maximum temperature trend showed significantly increasing trend at 10 % level. Only summer season minimum temperature trend found significantly increasing pattern at 10 % level.

At Pendra, seasonal and annual maximum temperature trend found increasing pattern at 1 % level of significance and the slope of regression line found between 0.01°C to 0.017°C for the period of 1904-2013 whereas minimum temperature during winter, post-monsoon (PM) season and annual found increasing trend at 1 % level of significance and during SWM season result found increasing trend @ 5 % level of significance. Minimum temperature during post-monsoon season the slope is found 0.009°C during the period of study given in Fig. 4.14.

Table 4.3: Annual and seasonal average temperature ($^{\circ}\text{C}$)

Station Name		Winter	Summer	SWM	PM	Annual
Ambikapur	MaxT	25.3	36.1	31.1	26.7	29.8
	MinT	10.0	20.4	23.2	12.8	16.6
Jagdalpur	MaxT	29.5	36.6	29.8	28.3	31.1
	MinT	12.6	21.5	22.5	15.0	18.7
Raipur	MaxT	28.8	38.8	32.3	29.2	32.6
	MinT	14.1	23.8	24.5	16.4	20.6
Bilaspur	MaxT	27.6	37.9	32.4	32.1	28.8
	MinT	12.2	21.9	24.8	19.7	15.6
Pendra	MaxT	25.6	35.8	30.5	26.8	30.1
	MinT	12.0	21.9	23.1	14.3	18.7

Table 4.4: Annual and seasonal trend in temperature (°C)

Station Name		Winter	Summer	SWM	PM	Annual
Ambikapur	MaxT	(0.000) Inc-NS	(0.01) Inc-NS	(0.002) Inc-NS	(0.012) Inc-NS	(0.006) Inc-NS
	MinT	(0.010) Inc*	(0.008) Inc*	(-0.001) Dec-NS	(0.017) Inc**	(0.008) Inc**
Jagdalpur	MaxT	(0.005) Inc**	(-0.001) Dec-NS	(-0.002) Dec-NS	(0.008) Inc***	(0.001) Inc-NS
	MinT	(-0.011) Dec**	(-0.002) Dec-NS	(0.001) Inc-NS	(-0.008) Dec-NS	(-0.004) Dec-NS
Raipur	MaxT	(0.007) Inc**	(0.007) Inc*	(0.004) Inc*	(0.008) Inc***	(0.006) Inc***
	MinT	(-0.016) Dec***	(-0.015) Dec***	(0.003) Inc**	(-0.003) Dec-NS	(-0.006) Dec**
Bilaspur	MaxT	(0.099) Inc***	(0.058) Inc*	(0.045) Inc-NS	(0.085) Inc***	(0.067) Inc***
	MinT	(-0.020) Dec-NS	(-0.067) Dec*	(-0.035) Dec-NS	(-0.040) Dec-NS	(-0.041) Dec-NS
Pendra	MaxT	(0.012) Inc***	(0.013) Inc***	(0.010) Inc***	(0.017) Inc***	(0.014) Inc***
	MinT	(0.006) Inc***	(0.003) Inc-NS	(0.001) Inc**	(0.009) Inc***	(0.004) Inc***

Note: Values in parenthesis is slope of regression line indicating rate of change/year during the period of study

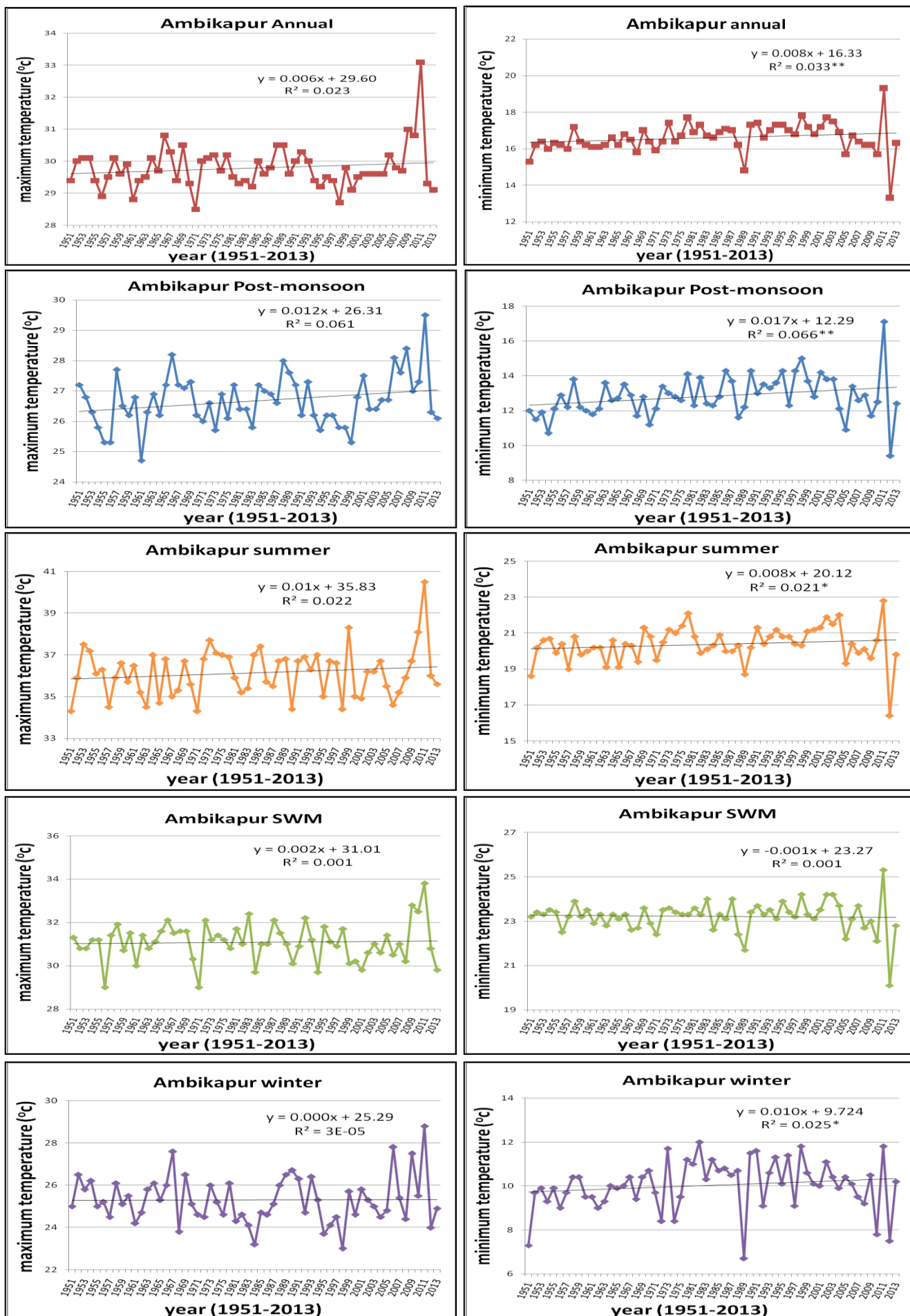


Fig. 4.10: Annual and seasonal maximum and minimum temperature trend of Ambikapur

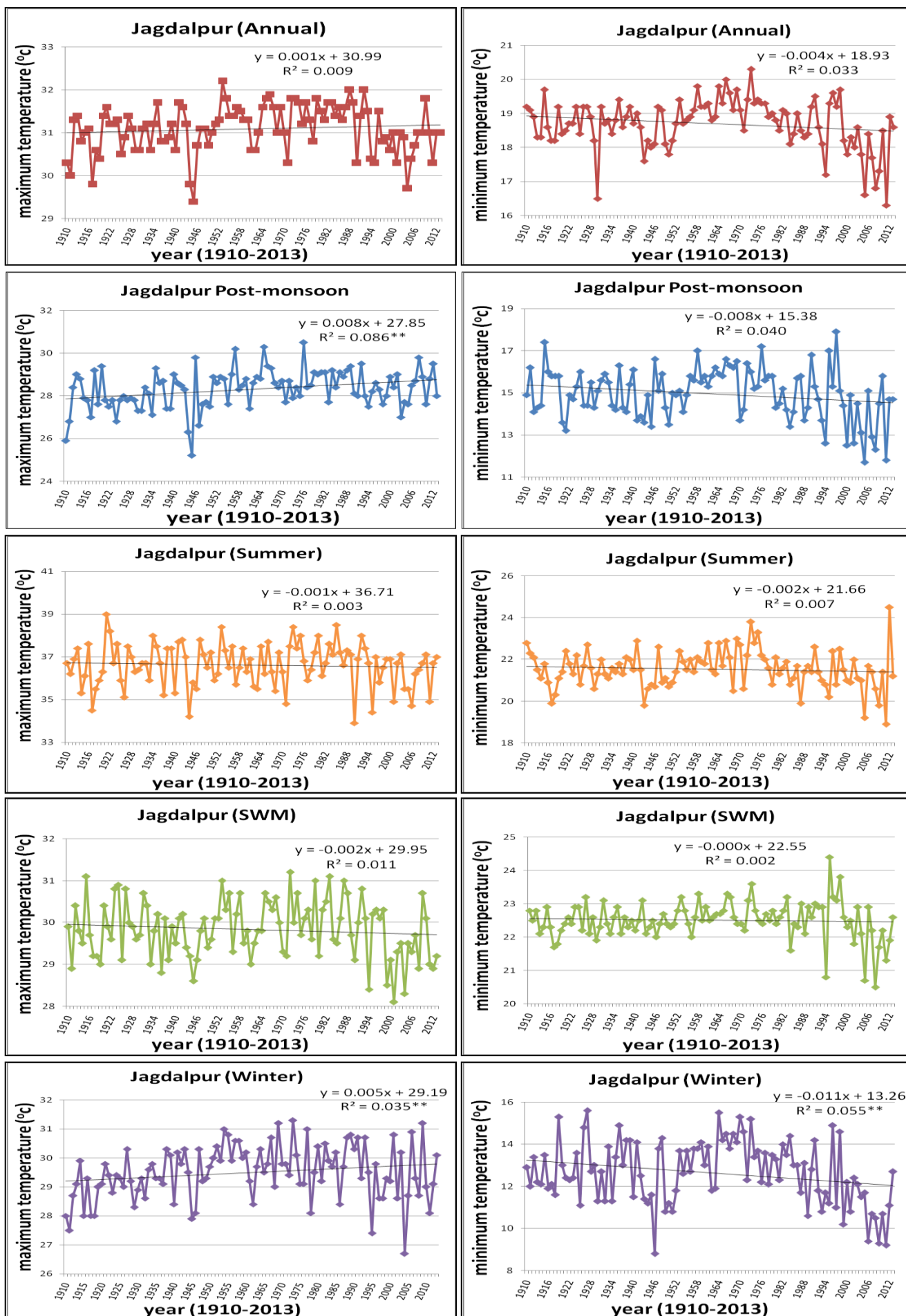


Fig. 4.11: Annual and seasonal maximum and minimum temperature trend of Jagdalpur

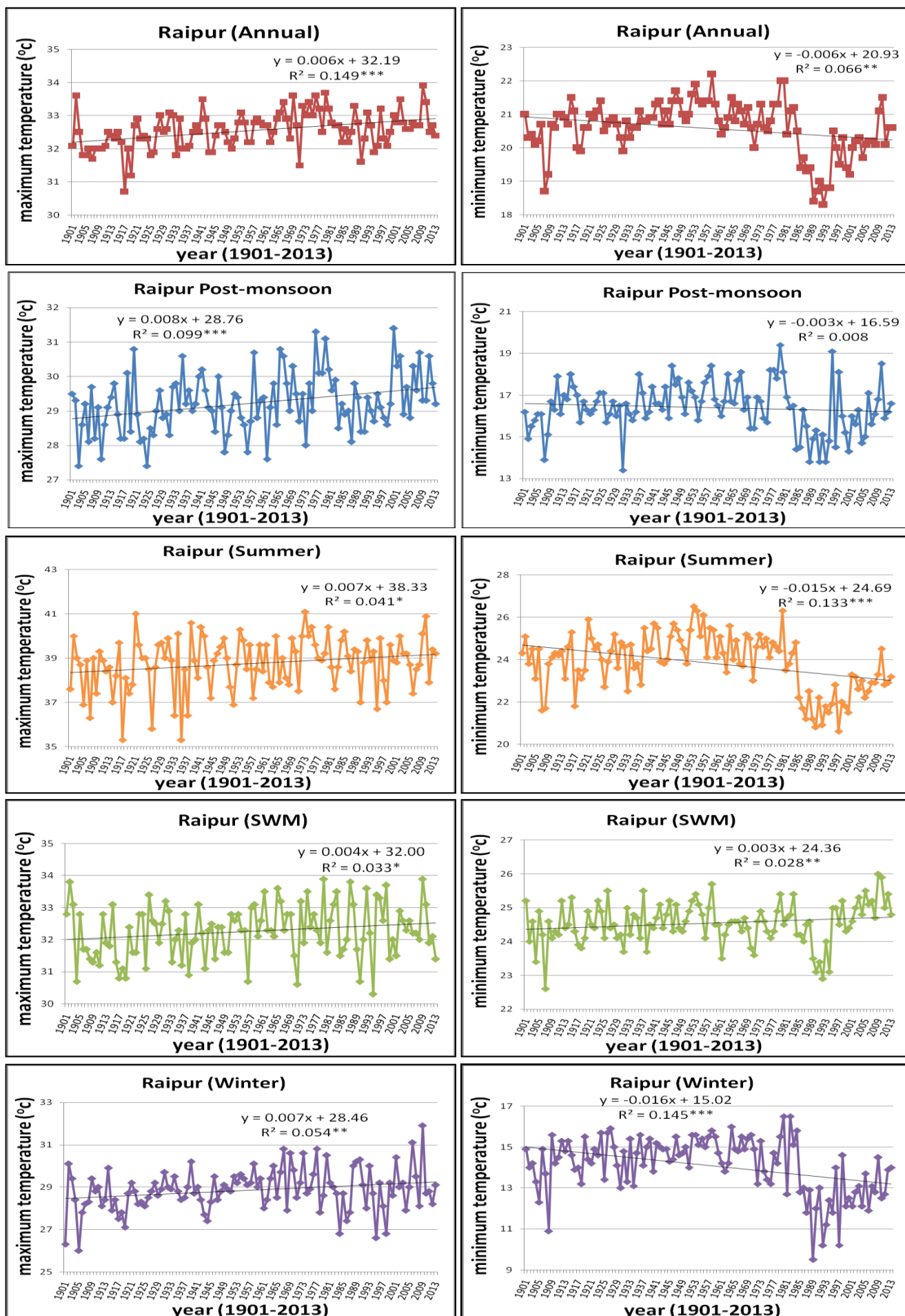


Fig. 4.12: Annual and seasonal maximum and minimum temperature trend of Raipur

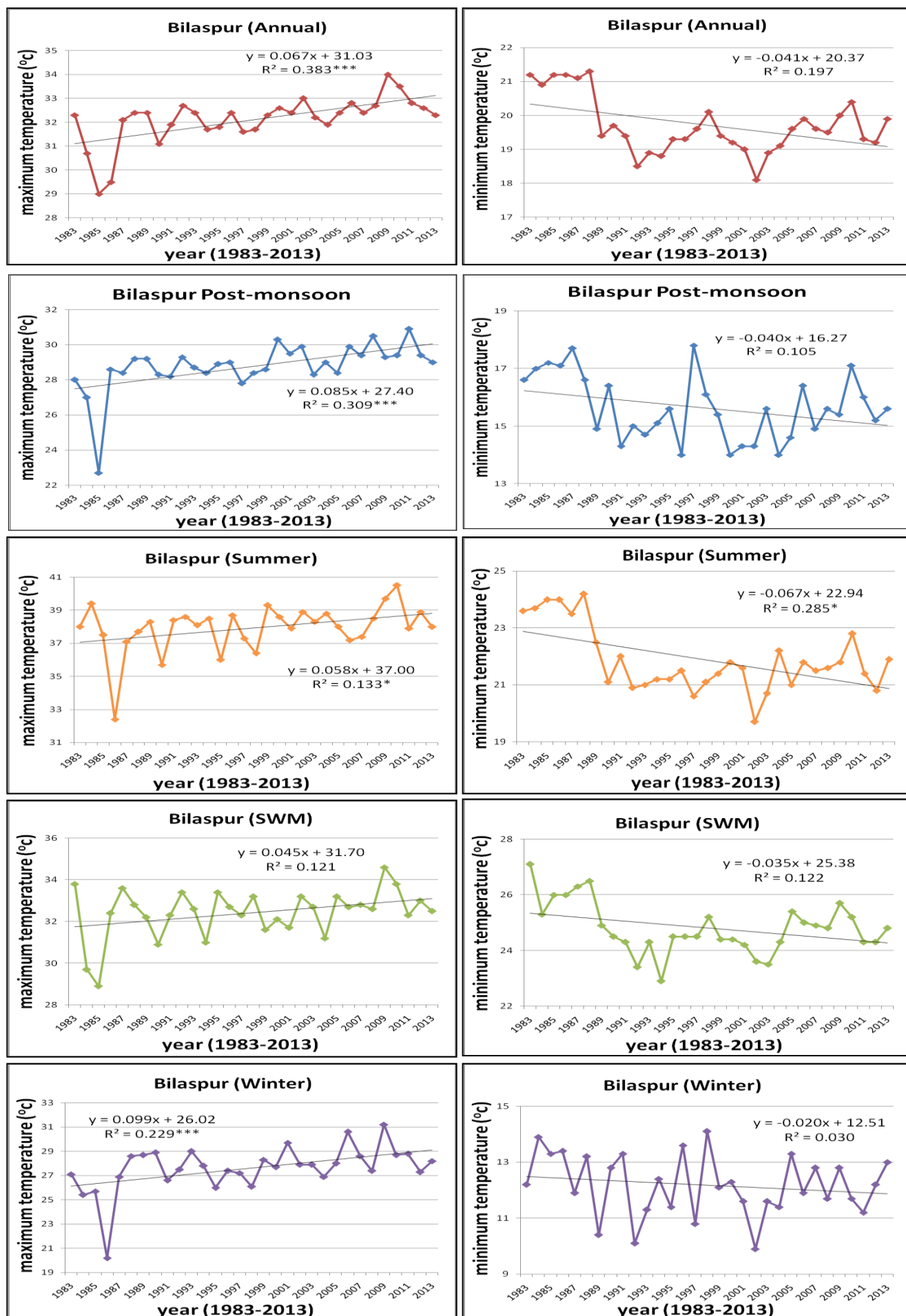


Fig. 4.13: Annual and seasonal maximum and minimum temperature trend of Bilaspur

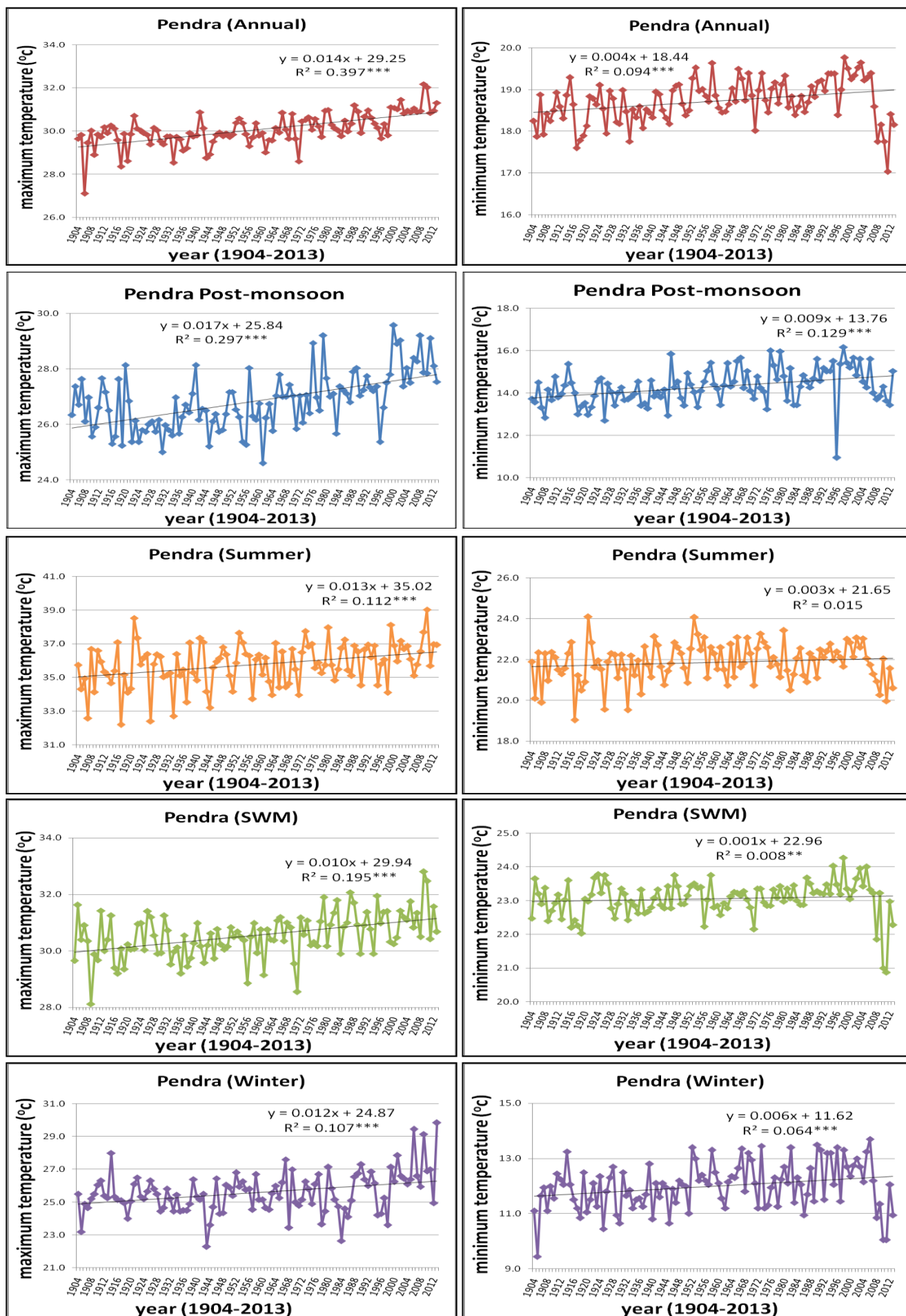


Fig. 4.14: Annual and seasonal maximum and minimum temperature trend of Pendra

4.3 Annual and seasonal PET and relative humidity

Potential evapotranspiration (PET) is an important variable in drought identification to determine evaporative demand of the atmosphere. The PET concept was first introduced in the late 1940s and beginning of 1950s by Penman. It is defined as “the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile”. Potential evapotranspiration (PET) is a vital part of the hydrological cycle and it has been used in dry and wet condition analysis of climate such as drought and aridity.

Potential evapotranspiration given in Table 4.5 during winter season found very low at Ambikapur and Pendra station 191 mm because the temperature range is very low at both the stations during winter season but in this season 243 mm PET observed at Jagdalpur. PET range observed from 526 mm to 604 mm at Pendra and Raipur during summer season. Lowest PET found at Bilaspur 456 mm and highest observed 552 mm at Raipur during southwest monsoon season. PET range observed for post-monsoon season 298 mm at Ambikapur and Pendra to 339 mm at Raipur. Annual PET ranged from 1518 mm at Pendra to 1723 mm at Raipur shown in Fig. 4.15 which is comparatively high than the other stations due to industrialization, lack of vegetation and urbanization and this higher value will ultimately cause lower water level in ground.

Relative humidity has been shown in Fig. 4.16 for four given stations *viz.* Ambikapur, Bilaspur, Jagdalpur and Raipur. In this analysis results revealed that annual RH-1 is varying from 78 % at Ambikapur to 82 % at Raipur and Bilaspur but RH-2 is ranging from 41 % at Raipur to 50 % at Jagdalpur. During summer season RH-1 found less between 55 % at Ambikapur and 67 % at Jagdalpur whereas RH-2 also observed less and varies from 22 % at Raipur to 32 % at Jagdalpur. During winter, SWM and post-monsoon season RH-1 is not varying much and difference is less for all given stations varied from 83 % to 90 %. RH-2 range observed 35 -40 % at Raipur and Jagdalpur during winter season. RH-2 observed at Raipur and Jagdalpur during southwest monsoon 65-72% and 43-55 % during post-monsoon (PM) season Table 4.6.

Table 4.5: Average annual and seasonal PET (mm)

seasons	Ambikapur	Bilaspur	Jagdapur	Raipur	Pendra
Winter	191	219	243	229	191
Summer	540	535	557	604	526
SWM	508	456	493	552	503
PM	298	313	337	339	298
Annual	1537	1523	1630	1723	1518

Table 4.6: Average annual and seasonal relative humidity (%)

Seasons	Ambikapur		Bilaspur		Jagdapur		Raipur	
	RH-1	RH-2	RH-1	RH-2	RH-1	RH-2	RH-1	RH-2
Winter	83	39	86	38	83	40	83	35
Summer	55	25	64	27	67	32	56	22
SWM	86	69	88	68	87	72	85	65
PM	87	45	89	48	87	55	90	43
Annual	78	44	82	45	81	50	78	41

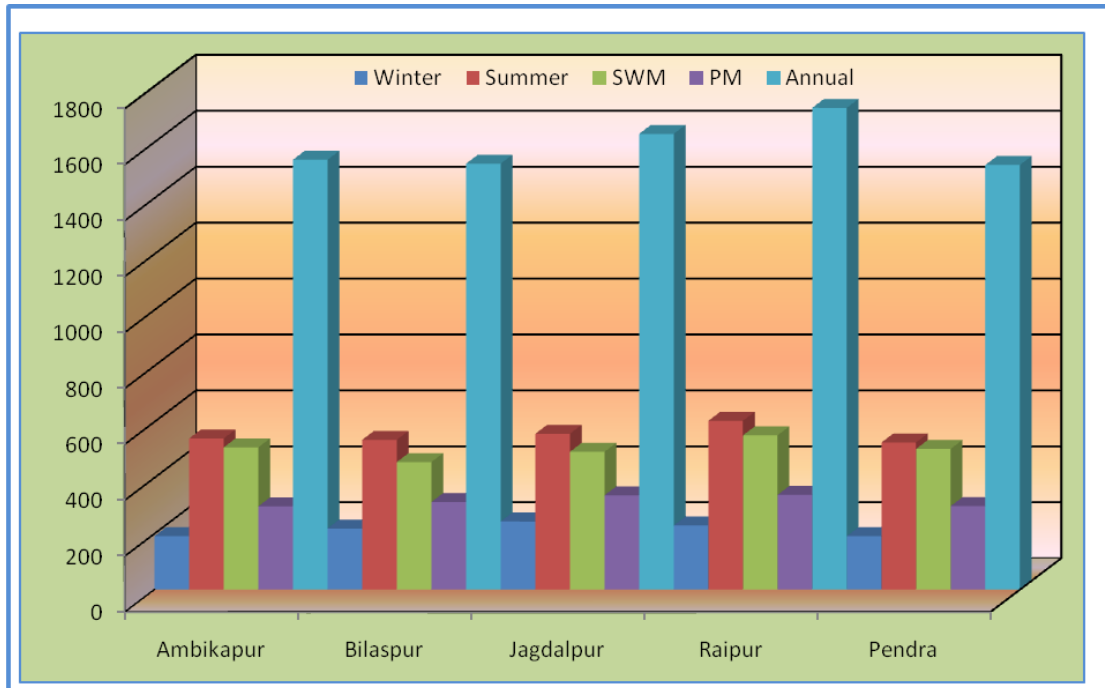


Fig. 4.15: Average annual and seasonal PET (mm)

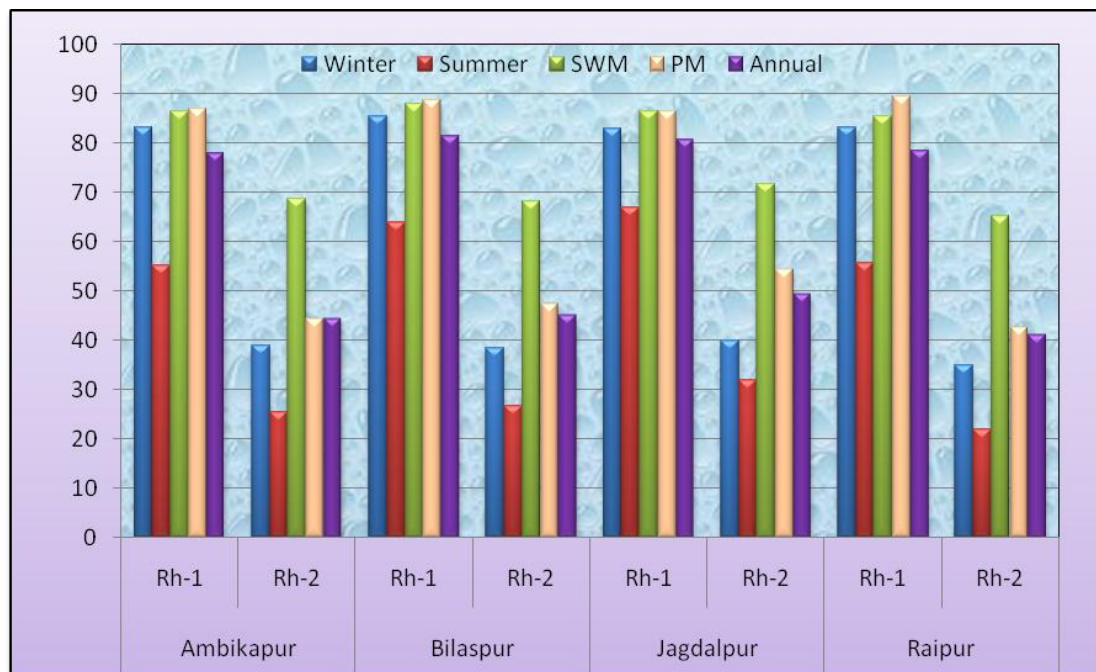


Fig. 4.16: Annual and seasonal average morning (RH-1) and afternoon (RH-2) relative humidity percentage

4.4 Area, production and productivity of major *kharif* crops

The productivity level of crops has to be enhanced and sustained and this is possible only when efficient locations have been identified for the crops. This information would help to replace the uneconomical crop in the identified areas. These uneconomical crops will be replaced by the crops with good potential to achieve the sustainability and self sufficiency. District wise area, production and productivity furnished in Table 4.7 for the 16 parent district and productivity zones has been shown by productivity zones maps in Fig. 4.17 to 4.20 for rice, maize, pigeonpea and soybean crops.

4.4.1 Rice (*Oryza sativa*)

Chhattisgarh state average area under rice cultivation during *kharif* season found approximately 37.63 lakh ha on the basis of available database. This area has fluctuated from 36.81 lakh ha during 1999 to 38.32 lakh ha found during 2013 and average rice production is found 4973 thousand tonnes. During 2000 and 2002 rice production found very less. Year 2002 incidentally was declared as an All-India drought year but highest production found to be 7503 thousand tonnes during 2012. Koriya district is having lowest area 69 thousand ha and production 81 thousand tonnes for the rice cultivation but Raipur district has the highest area and production 508 thousand ha and 651 thousand tonnes respectively. Janjgir-champa and Dhamtari district found highest productivity 1815 kg/ha and 1769 kg/ha respectively but Kawardha district found as low productivity district of 1093 kg/ha. In this study 16 parent districts of Chhattisgarh state are categorized under the different productivity zones based on their area and yield shown in Fig. 4.17. Raipur, Durg and Bilaspur district is characterized under high area and medium productivity zone and Rajnandgaon, Bastar, Dantewara and Mahasamund districts characterized as medium area and medium productivity zone but Kawardha, Korba and Koriya district characterized under low area and low productivity zone.

4.4.2 Maize (*Zea mays*)

For Chhattisgarh region after rice, maize is the second principle crop widely grown in Chhattisgarh state covering around 99 thousand ha area (according to the available database) with 142 thousand tonnes average production.

Lowest cultivated area observed is 91 thousand ha during 1999 but highest area observed is 107 thousand ha during 2011 and 2012. Lowest production 70 thousand tonnes found during 2001 and highest production 208 thousand tonnes found during 2012. Mahasamund district is found to have very low area of 0.15 thousand ha and production of 0.16 thousand tonnes but Surguja district covers large area of 37 thousand ha for the maize cultivation with 50 thousand tonnes production. Dhamtari, Kanker and Bastar district found as highest productivity district with 1806, 1787 and 1722 kg/ha but Durg is found to be low productivity district with yield of 1062 kg/ha. In this study, Bastar, Jashpur and Kanker district categorized as high area and high productivity zone and Bilaspur and Korba district categorized under medium area and medium productivity zone but Raipur, Durg, Rajnandgaon and Mahasamund district comes under low area and low productivity zone shown in Fig. 4.18.

4.4.3 Pigeonpea (*Cajanus cajan*)

Approximately 51 thousand ha area covered by pigeonpea cultivation during *Kharif* season with 28 thousand tonnes production of Chhattisgarh state, Surguja district is found to possess highest area 14.5 thousand ha and average production found to be 8.1 thousand tonnes but Dhamtari district found with lowest area of 0.26 thousand ha and production is found 0.09 thousand tonnes. Bastar district is found to be high productivity district with 675 kg/ha but Dhamtari district is found to be low productivity district with 363 kg/ha. In this study Surguja, Durg and Kawardha district categorized as high area and medium productivity zone. Jashpur, Rajnandgaon and Koriya district comes under medium area and medium productivity zone but Mahasamund and Dhamtari district categorized under low area and low productivity zone.

4.4.4 Soybean (*Glycine max*)

Chhattisgarh state occupies 51.8 thousand ha by soybean during *kharif* season with an average production found to be 51.8 thousand tonnes. Kawardha district is found to possess highest area of 19.41 thousand ha with 21.21 thousand tonnes production this is followed by Durg district 16.31 thousand ha and Rajnandgaon 13.88 thousand ha and average production is found 14.6 thousand

tonnes and 13.46 thousand tonnes respectively. Dhamtari district found as highest productivity district with 1289 kg/ha but Raigarh district found as lowest productivity district 592 kg/ha. All parent districts are categorized in different productivity zones in which Kawardha district is coming under high area and high productivity zone, Durg and Rajnandgaon categorized under high area and medium productivity zone but Surguja, Raigarh, Koriya and Kanker districts categorized under low area and low productivity zones.

Table 4.7: District wise average area (000 ha), production (000 tonnes) and productivity (kg/ha) of Chhattisgarh state

District	Rice			Maize			Pigeonpea			Soybean		
	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity	Area	Production	Productivity
Raipur	508	651	1281	1.5	1.8	1175	2.9	1.1	379	0.609	0.703	1154
Durg	436	585	1341	0.3	0.3	1062	5.5	2.9	531	16.309	14.602	895
Rajnandgaon	262	320	1223	1.4	1.6	1136	3.9	2.2	559	13.882	13.459	969
Bastar	260	334	1287	16.7	28.7	1722	1.0	0.7	675	0.030	0.034	1129
Bilaspur	317	448	1413	4.4	5.7	1308	4.2	2.5	601	1.338	1.628	1216
Surguja	307	351	1142	36.9	49.7	1349	14.5	8.6	594	0.050	0.037	739
Raigarh	233	276	1185	1.0	1.4	1443	2.0	1.2	578	0.034	0.020	592
Mahasamund	240	300	1249	0.1	0.2	1071	0.8	0.3	380	0.013	0.015	1138
Dhamtari	131	232	1769	0.3	0.5	1806	0.3	0.1	363	0.026	0.033	1289
kawardha	92	101	1093	2.9	3.2	1093	5.2	2.8	539	19.406	21.208	1093
Janjgi-Champa	253	459	1815	0.4	0.6	1365	1.1	0.7	619	0.030	0.038	1244
Korba	109	121	1110	4.8	6.0	1245	1.1	0.6	493	0.002	0.002	825
Jashpur	179	205	1145	6.3	9.4	1504	3.7	2.2	584	0.030	0.031	1014
Koriya	69	81	1175	8.3	10.8	1305	3.2	1.8	549	0.009	0.006	704
Kanker	165	263	1594	6.7	12.1	1787	0.6	0.4	588	0.016	0.013	794
Dantewara	200	244	1221	6.9	9.8	1424	0.9	0.5	565	0.017	0.018	1078
State	3763	4973	1322	99	142	1434	51	28	557	51.8	51.8	1001

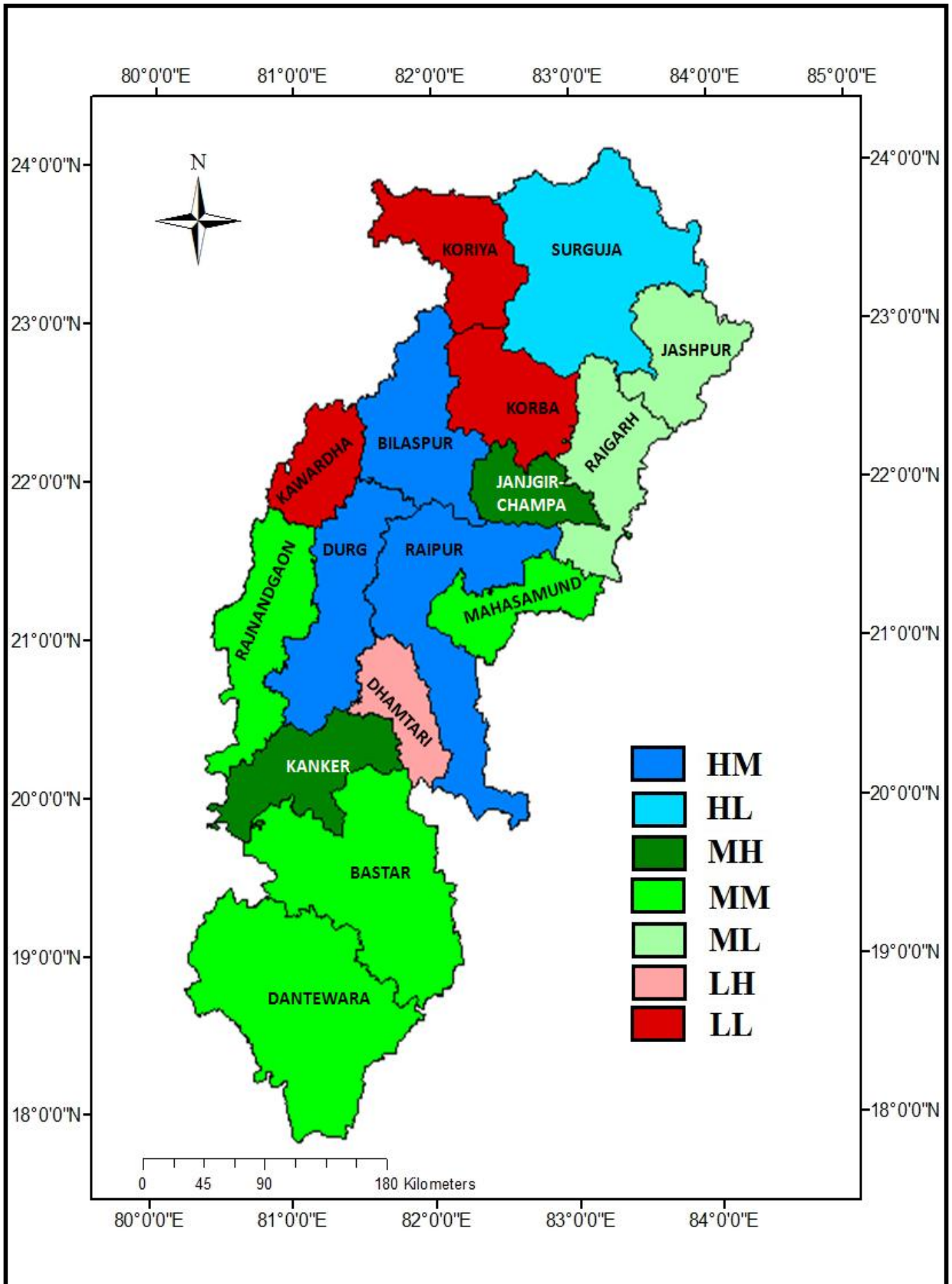


Fig. 4.17: Productivity zones of rice in Chhattisgarh state

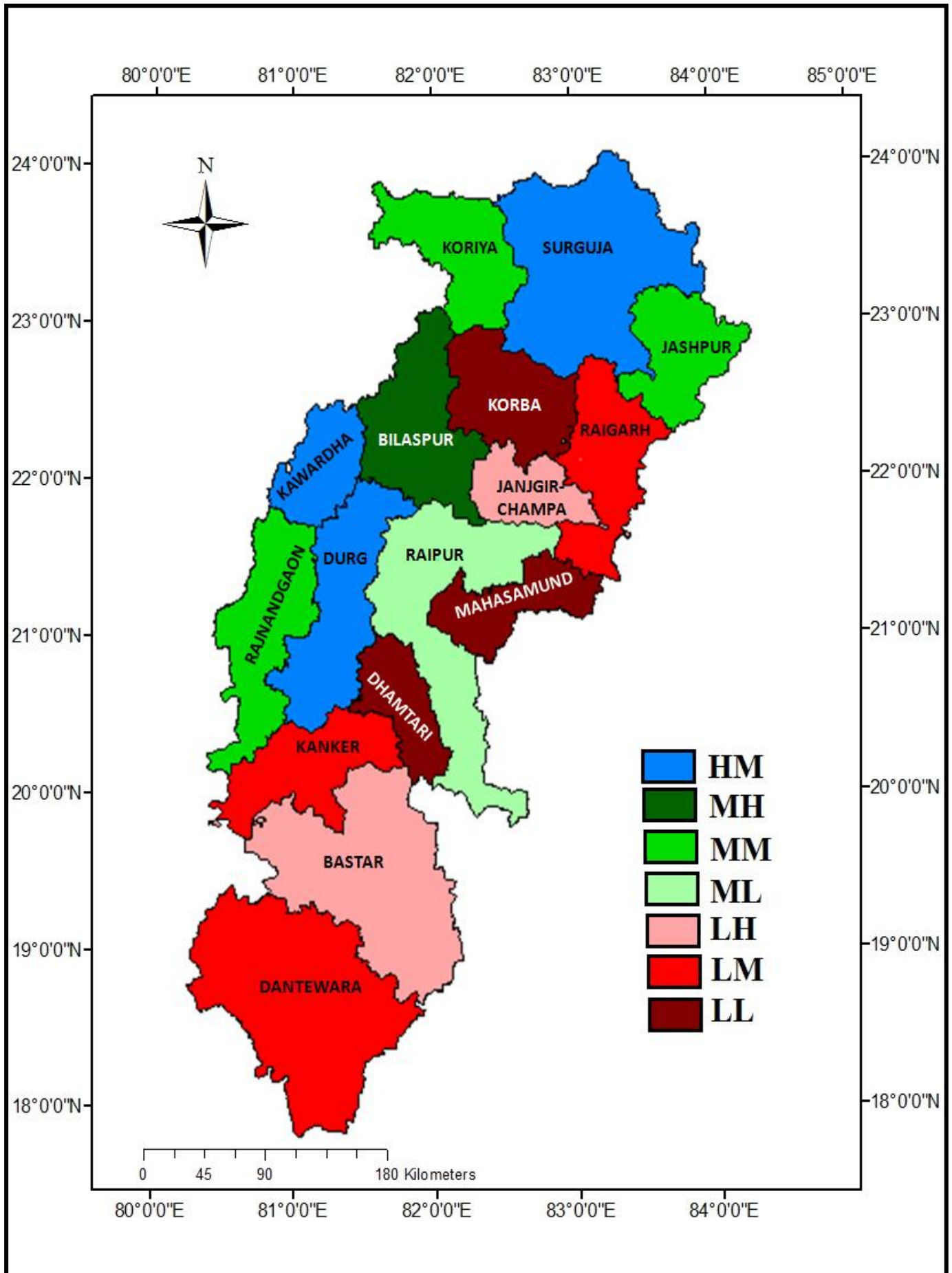


Fig. 4.19: Productivity zones of pigeonpea in Chhattisgarh state

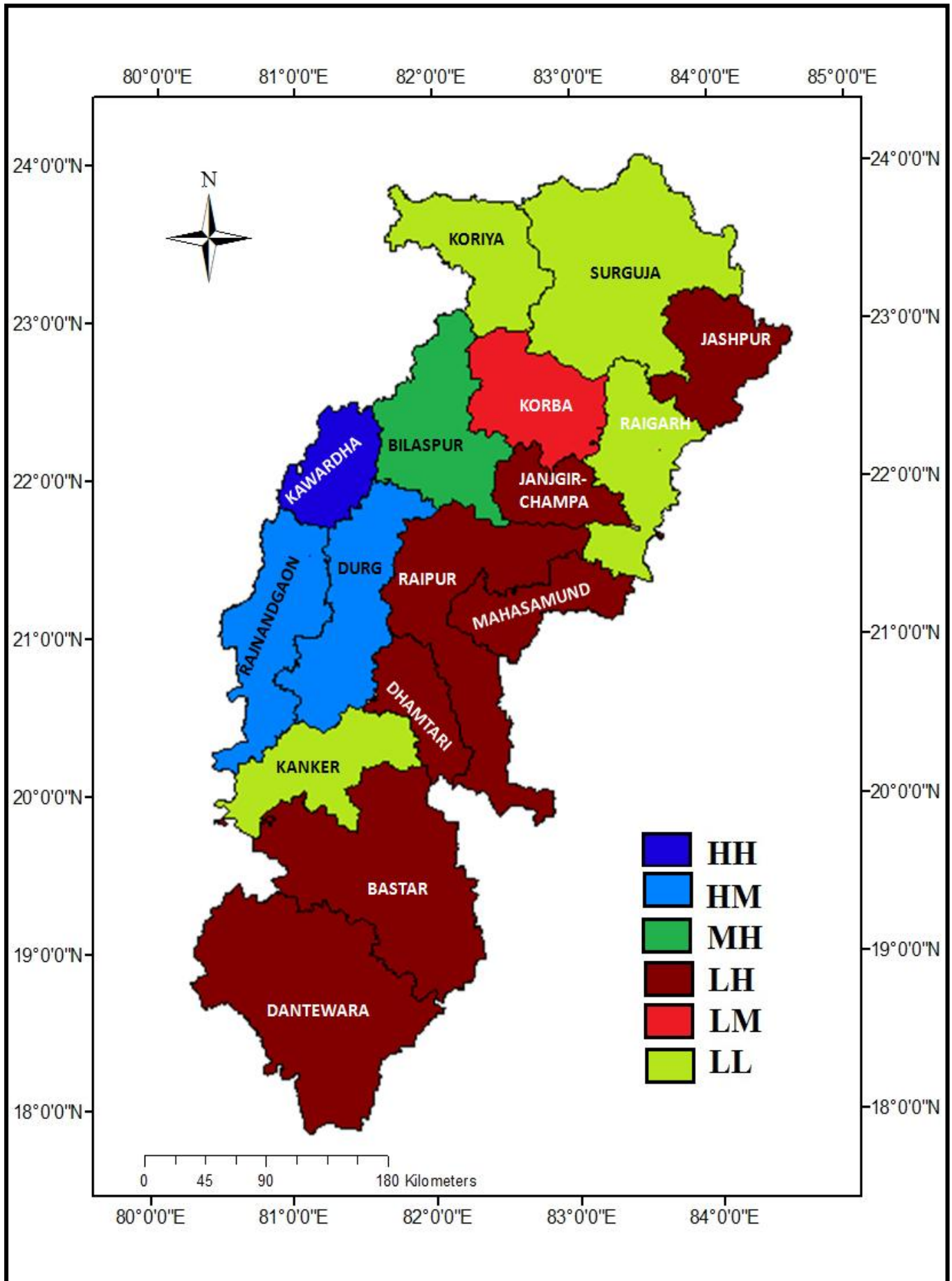


Fig. 4.20: Productivity zones of Soybean in Chhattisgarh state

CHAPTER - V SUMMARY AND CONCLUSIONS

In the present study entitled “Agroclimatic analysis of Chhattisgarh state with respect to sustainable crop production” was carried out at department of agrometeorology IGKV Raipur. Chhattisgarh state is part of eastern India, where more than 80 per cent of the population depends on agriculture for their livelihood. At present the state has 27 districts and the state has been divided into three agro-climatic zones (Northern hills, Bastar plateau and Chhattisgarh plains). Based on the results obtained from the study some of the important points are summarized in present chapter.

The present study was undertaken to assess the normal rainfall pattern, amount, variability and rainy days of Chhattisgarh state and temperature trend pattern of major five stations, relative humidity of four stations and PET of five stations worked out in annual and seasonal basis and also utilized long term area, production and productivity for major *kharif* crops (rice, maize, soybean and pigeonpea) data of 16 parent districts to categorize the productivity zone of Chhattisgarh state. The result has been presented by graphs and maps using arcGIS software. This study has been worked out to improve the crop suitability assessment to identify area for sustainable crop production in rainfed agro-ecosystem.

Chhattisgarh state bounded by Madhya Pradesh, Uttar Pradesh, Jharkhand, Orissa, Andhra Pradesh and Maharashtra, the state receives rainfall mainly from SWM approximately 90 % (1050 ± 123 mm) of annual rainfall received by SWM season with 12 % CV. Normal rainfall of the state worked out from 84 rain gauge stations is observed 1167 ± 147 mm with a variability of 13 %. Maximum amount of rainfall found in Bastar plateau ACZ and minimum amount of rainfall observed in Chhattisgarh plain ACZ. The maximum average rainfall recorded during SWM period and annual basis at Surajpur district 1311 and 1411 mm and annual minimum rainfall recorded at Kawardha district 885 mm due to low rainfall Kawardha district experiencing from drought.

The annual rainfall is received with 56 ± 8 rainy days with a variability of 14 %. Highest number of rainy days observed in Bastar district 76 and lowest found in Bemetara and Durg district 43 numbers of rainy days. Highest number of rainy days also observed in Bastar plateau followed by northern hills. During SWM average rainfall received by 48 ± 5 numbers of rainy days with a variability of 11 %.

In this study of minimum and maximum temperature trend analysis has been worked out for the five major stations *viz.* Ambikapur, Jagdalpur, Raipur, Bilaspur and Pendra in which minimum and maximum temperature trend found slightly increasing at Ambikapur. Maximum temperature trend also found slightly increasing whereas minimum temperature trend found slightly decreasing at Jagdalpur station on annual and seasonal basis. Bilaspur station maximum temperature trend found increasing pattern during winter, post-monsoon season and annual basis at 1 % level of significance and the rate of change is observed 0.099°C , 0.085°C and 0.067°C during the study period (1983-2013). During post-monsoon season and annual basis trend is found increasing at 1 % level of significance with $0.008^{\circ}\text{C}/\text{yr}$ and $0.006^{\circ}\text{C}/\text{yr}$ during the period of study. At Pendra seasonal and annual maximum temperature trend found increasing pattern at 1 % level of significance and the slope of regression line found between 0.01°C to 0.017°C for the period of 1904-2013.

During *kharif* season rice, maize, soybean and pigeonpea are major crops grown in Chhattisgarh state. 37.63 lakh ha of the state covered by rice, 99 thousand ha by maize, 51.8 thousand ha by soybean and 51 thousand ha area covered by pigeonpea with the state average production of 49.73 lakh tonnes, 99 thousand tonnes, 51.8 thousand tonnes and 28 thousand tonnes respectively. Maximum productivity of rice is found 1815 kg/ha at Janjgir-Champa and 1769 at Dhamtari. Whereas the highest productivity of maize 1806 kg/ha found at Dhamtari and 1722 kg/ha at Bastar district. In case of pulses crops the highest productivity of pigeonpea found to be 675 kg/ha at Bastar and highest productivity of soybean found 1289 kg/ha at Dhamtari district. Productivity zones of these *kharif* season crops have been classified based on the area and productivity of particular crops.

Potential evapotranspiration (PET) analyzed over the five major stations of Chhattisgarh state. PET results revealed that the highest PET found at Raipur on annual (1723 mm) and seasonal basis as compared to other stations whereas lowest annual (1518) and seasonal PET observed at Pendra. During summer season PET is found highest than the other seasons due to increasing temperature. Annual and seasonal morning (RH-1) and afternoon relative humidity (RH-2) analyzed over four stations in which annual RH-1 range is observed at Raipur 78 % to Bilaspur 82 %. RH-1 and RH- 2 observed lowest during summer season but highest RH-1 observed during post-monsoon season and highest RH-2 found during SWM season. Afternoon relative humidity range observed from 41 % at Raipur to 50 % at Jagdalpur.

SUGGESTIONS FOR FUTURE RESEARCH WORK

1. This study can be useful for further agroclimatic analysis based on the rainfall and rainy days distribution in Chhattisgarh state.
2. In the era of climate change rainfall pattern and temperature trend analysis will be analyzed. This study can be helpful for these types of weather variability analysis in future research works.
3. In this study the productivity zones of *kharif* crops viz. rice, maize, soybean and pigeonpea have been worked out, this study can also be useful to set the cropping pattern based on the productivity to get the efficient production from particular districts.

REFERENCES

- Ahonsi, G.E. and Kazeem, K.M. 2014. Dew point temperature, relative humidity and sunshine hours in Jos, Nigeria: Their relationship and Predictive model. *Environmental Research Journal*, 8(1): 17-20
- Akpan, S.U. And Okoro, B.C. 2013. Developing rainfall intensity–duration–frequency models for Calabar city, south-south, Nigeria. *American journal of engineering research (AJER)*, 2(6): 19-24
- Anonymous. 2010. State level Agriculture statistics, Directorate of Agriculture, Raipur, Chhattisgarh, India
- Bapuji Rao, B., Sandeep, V.M., Rao, V.U.M. and Venkateshwarlu, B. 2012. Potential evapotranspiration estimation for Indian conditions: Improving accuracy through calibration coefficients. *Tech. Bull. No.1/2012. All India Co-ordinated Research Project on Agrometeorology, Central Research Institute for Dryland Agriculture, Hyderabad. 60pp.*
- Bhargava, N., Bhargava, R., Tanwar, P.S., and Sharma, A. 2013. Rainfall spatial analysis using GIS. *International Journal of Advanced Research in Computer and Communication Engineering*, 2(5): 2197-2200
- Bhelawe, Sanjay., Nain, A.S. and Singh, R. 2013. Delineation of agro-climatic zones of Chhattisgarh. *Journal of Agricultural Issues*, 18(1-2): 77-78
- Bhowmik, S.K. Roy and Das, A.K. 2007. Rainfall analysis for Indian monsoon region using themerged rain gauge observations and satellite estimates:Evaluation of monsoon rainfall features. *J. Earth Syst. Sci*, 116(3): 187–198
- Borgohain, A. 2013. Trend of area, production and productivity of rice crop in Assam. *International Journal of Research in Commerce, Economics and Management*, 3(5): 130-135
- Chaudhary, J.L. 1994. Crop planning through rainfall analysis in Bastar district of Madhya Pradesh. *Fertilizer News*, 39(7): 43-49
- Chaudhary, J.L. 1999. Agro-climatic studies of Bastar district in Chhattisgarh region with special reference to production of rice. *Fertilizer News*, 44(3): 33-38
- Chaudhary, J.L., Sharma, G.K. and Thakur, D.S. 2013. Analysis of weather parameters of Bastar plateau agro-climatic zone for strategic crop planning. *Journal of Agricultural Issues*, 18(1&2): 70-76

- Chaudhry, J.L. and Tomar, G.R. 1999. Agro-climatic analysis of stable rainfall period in undivided Bastar district of Chhattisgarh region of Madhya Pradesh, India. *Oryza*, 36(1): 66-69
- Das, P. K., Chakraborty, A. and Seshasai, M. V. R. 2014. Spatial analysis of temporal trend of rainfall and rainy days during the Indian summer monsoon season using daily gridded (0.5 degrees x 0.5 degrees) rainfall data for the period of 1971-2005. *Meteorological Applications*, 21(3): 481-493
- Dhekale, B.S., Mahdi, S.S., Garde, Y.A. and Sahu, P.K. 2014. Parametric and nonparametric regression models for area, production and productivity trends of rice (*Oryza sativa*) crop. *International Journal of Agricultural and Statistical Sciences*, 10(1): 211-216
- Dhakre, D. S. and Sharma, A. 2010. Growth analysis of area, production and productivity of maize in Nagaland. *Agricultural Science Digest*, 30(2): 142-144
- Eludoyin, O.M. 2014. A perspective of the diurnal aspect of thermal comfort in Nigeria. *Atmospheric and Climate Sciences*, 4: 696-709
- Fischer, G., Velthuizen. H.V., Shah. M. and Nachtergaele, F. 2002. Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results. International Standard Book Number 3-7045-0141-7, 1-119
- Gates, G. M., 1988. "Climate and the climate system", M.E. Schlesinger (Ed.) physically based and simulation of climate and climate change, part I, kluwer academic Publisher, 3-21.
- Goswami, B., Mahi, G.S. and Saikia, U.S. 2006. Effect of few important climatic factors on phenology, growth and yield of rice and wheat. *Agric. Rev.*, 27(3): 223 – 228
- Gupta, V. K., Agrawal, K. K., Upadhyay, A. P. and Shanker, U. 2000. Effect of rainfall, number of rainy days and length of rainy season on productivity of rice (*Oryza sativa* L.) crop at Jabalpur. *Journal of Agrometeorology*, 2(1): 61-64
- Hadgu, G., Tesfaye, K., Mamo, G. and Kassa, B. 2013. Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. *Academia Journal of Agricultural Research*, 1(6): 088-100
- Haris, A.A., Chhabra, V. and Biswas, S. 2011. Trends in paddy production and productivity in the Gangetic plains of Bihar as influenced by rainfall pattern. *Agricultural Situation in India*, 68(7): 323-327

- Hiremath, D.B. and Shiyani, R.L. 2013. Analysis of vulnerability indices in various agro-climatic zones of Gujarat. *Ind. Jn. of Agri. Econ.*, 68(1): 122-137
- Hobbins, M.T. and Ramirez, J.A. 2004. Trends in pan evaporation and actual evapotranspiration across the conterminous U.S. Paradoxical or complementary. *Geophysical Research Letters*, 31: 1-5
- Jain, S.K., and Kumar, V. 2012. Trend analysis of rainfall and temperature data for India. *Current science*, 102(1): 37-49
- Jhajharia, D., Yadav, B. K., Maske, S., Chattopadhyay, S. And Kar, A. K. 2012. Identification of trends in rainfall, rainy days and 24 h maximum rainfall over subtropical Assam in Northeast India. *Comptes Rendus Geoscience*, 344(1): 1-13
- Kaloo, M.J., Patidar, R. and Dr. Choure. T. 2014. Production and Productivity of Rice in Jammu and Kashmir: An Economic Analysis. *International Journal of Research*, 1(4): 464-473
- Karabulut, M., Gurbuz, M. and Korkmaz, H. 2008. Precipitation and temperature trend analyses in Samsun. *J. Int. Environmental Application & Science*, 3(5): 399-408
- Khalkho, D., Patil, S.K., Patel, S., Pali, G.P. and Nag, S.K. 2013. Cadastral level mapping for efficient natural resources management of Turenar cluster villages using remote sensing and GIS technologies. *Journal of Agricultural Issues*, 18(1&2): 55-60
- Kirono, D.G.C. and Kent, D.M. 2010. Assessment of rainfall and potential evaporation from global climate models and its implications for Australian regional drought projection. *International Journal of Climatology*, 31(9): 1295–1308
- Kokilavani, S. and Geethalakshmi, V. 2013. Identification of efficient cropping zone for rice, maize and groundnut in Tamil Nadu. *Indian Journal of Science and Technology*, 6 (10): 5299-5301
- Koshal, A.K. 2014. Changing current scenario of rice-wheat system in Indo-Gangetic plain region of India. *International Journal of Scientific and Research Publications*, 4(3): 1-13
- Kumar, S. and Bourai, V.A. 2012. “Economic analysis of pulses production their benefits and constraints” (A Case Study of Sample Villages of Assan Valley Of Uttarakhand, India). *IOSR Journal of Humanities and Social Science (IOSRJHSS)*, 1(4): 41-53

- Kumar, V. and Jain, S. K. 2011. Trends in rainfall amount and number of rainy days in river basins of India (1951-2004). *Hydrology Research*, 42(4): 290-306
- Manickam, V., Kotapati, S.S. and Iyyanki, V.M.K. 2013. Analysis of precipitation concentration index and rainfall prediction in various agro-climatic zones of Andhra Pradesh, India. *Int. Res. J. Environment Sci.*, 2(5): 53-61
- McMahon, T.A., Peel, M. C., Lowe, L., Srikanthan, R. and McVicar, T.R. 2013. Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. *Hydrol. Earth Syst. Sci.*, 17: 1331–1363
- Mummigatti, U.V., Naveen, N. E. And Ningalur, B. T. 2013. Rainfall and rainy day trends at Dharwad, Karnataka. *International Journal of Agricultural Sciences*, 9(1): 237-241
- Nandargi, S. And Mulye, S.S. 2011. Relationships between rainy days mean daily intensity and seasonal rainfall over the Koyna catchment during 1961-2005. *The Scientific World Journal*, 2012:1-10
- Nazaripour, H. and Daneshvar, M. R. M. 2014. Spatial contribution of one-day precipitations variability to rainy days and rainfall amounts in Iran. *International Journal of Environmental Science and Technology*, 11(6): 1751-1758
- Owiti, Z. and Zhu, W. 2012. Spatial distribution of rainfall seasonality over EastAfrica. *Journal of Geography and Regional Planning*. 5(15): 409-421
- Pali, A.K., Sinha, B.L., Sahu, R.K. and Sinha, J. 2013. Rainfall analysis for effective crop and water resources planning for Raipur region of Chhattisgarh. *Journal of Agricultural Issues*, 18(1&2): 49-54
- Pandey, V., Kumar, M. and Sekh, A.M. 2001. Agroclimatic features of LASPEX sites. *Journal of Agrometeorology*, 3(1&2): 39-55
- Pereira, A.R., 1982. Crop planning for different environments. *Agr. Meteorol.*, 27: 71-77
- Rao, V.U.M., Rao, A.V.M.S., Rao, G.G.S.N., Satyanaryana, T., Manikandan, N., Venkateswarlu, B. and Ramamohan, I. 2011. Weather Cock software. Central Research Institute for Dryland Agriculture, Hyderabad.
- Rao, V.U.M. and Rao, B. Bapuji and Venkateswarlu, B. 2013. Agroclimatic Atlas of Andhra Pradesh. Central Research Institute for Dry Land Agriculture, Hyderabad, 1-270

- Rao, V.M., Om Prakash, Sharma, A., Hermon, R.R., Rao, P.K., Prasad, N.S.R., Kumar, T.P. and Srinivas Kumar, S.S.R.S. 2008. Agro-climatic planning and information bank (APIB) for Uttarakhand state, India. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7. Beijing, : 1451- 1456
- Rathod, I.M. and Aruchamy, S. 2010. Spatial analysis of rainfall variation in Coimbatore district Tamilnadu using GIS. International Journal of Geomatics and Geosciences, 1(2): 106-118
- Reddy, S.J., 1983. Agroclimatic classification of the semi-arid tropics I. A method for the computation of classificatory variables. Agr. Meteorol., 30: 185-200
- Roohi, R., Ahmad, S. and Ashraf, A. (2002). Characterization and classification of agro-climates of Pakistan. Pakistan J. Agric. Res., 17(3): 245-258
- Sahin, S. 2012. An aridity index defined by precipitation and specific humidity. Journal of Hydrology, 444-445: 199-208
- Sen, P. K., Radhika, P. and Seema. 2013. A study on trends in area, production and productivity of soybean in Kota District of Rajasthan. Journal of Research ANGRAU, 41(4): 82-84
- Sharma, G.K. and Chaudhary, J.L. 2014. Time trends in temperature of Bastar plateau agroclimatic zone of Chhattisgarh. Mausam, 65(1): 29-36
- Sharma, M.A. and Singh J.B. 2010. Use of probability distribution in rainfall analysis. New York Science Journal, 3(9): 40-49
- Skidmore, A.K., Bijker, Wietske., Schmidt Karin and Kumar Lalit. 1997. Use of remote sensing and GIS for sustainable land management. ITC Journal, (3-4): 302-315
- Soman, M.K. and Kumar, K.K. 1990. Some aspects of daily rainfall distribution over India during the south-west monsoon season. International Journal of Climatology, (10): 299-311
- Stafford, J.M., Wendler, G. and Curtis, J. 2000. Temperature and precipitation of Alaska: 50 year trend analysis. Theoretical and Applied Climatology, 67(1-2): 33-44
- Subramaniam, A.R. and Raju, P.A.N., 1988. Rainfall variability and crop production in north coastal Andhra. Fertilizer News, 33: 39-49
- Taher, S. and Alshaikh, A. 1998. Spatial analysis of rainfall in southwest of Saudi Arabia using GIS. Nordic Hydrology, 29 (2): 91-104

- Tirkey, A.S., Pandey A.C. and Nathawat M.S. 2012. Groundwater level and rainfall variability trend analysis using GIS in parts of Jharkhand state (India) for sustainable management of water resources. *Int. Res. J. Environment Sci.*, 1(4): 24-31
- Trenberth, K.E., 2011. Changes in precipitation with climate change. *Climate research*, 47: 123–138
- Tsiros, E., Domenikiotis, C. and Dalezios, N. R. 2008. Sustainable production zoning for agroclimatic classification using GIS and remote sensing. *Quarterly Journal of the Hungarian Meteorological Service*, 113(1–2): 55–68
- Waghmare, S.K., Raghuwanshi, R.S. and Sharma, N. P. 2002. Growth and variability in area, production and productivity of maize in Satpura Plateau of Madhya Pradesh. *JNKVV Research Journal*, 36(1/2):118-119.
- Wart, J.N., Bussel, L.G.J.V., Wolf, J., Licker, R., Grassini. P., Nelson, A., Boogard, H., Gerber, J., Mueller, N.D., Cleassens, L., Ittersum, M.K.V. and Cassman, K.G. 2013. Use of agro-climatic zones to upscale simulated crop yield potential. *Field Crops Research*, 143: 45-55

APPENDIX - A

Table: Rainfall data availability period for 84 stations of Chhattisgarh state

No.	Districts	Stations	Latitude	Longitude	Database period	Missing years	Available years
1	Balod	Balod	20.730000	81.200000	1964-2013	1971, 1994	48
2	Balod	Admabad	20.701636	81.236548	1960-1999	1971, 1998	38
3	Balod	Dondi	20.485808	81.083744	1993-2013		21
4	Balod	Dondi lohara	20.790105	81.057526	1993-2013		21
5	Balod	Gundardehi	20.946957	81.288709	1993-2013		21
6	Balod	Gurur	20.685154	81.403171	1993-2013		21
7	Balod	Gondli dam	20.738404	81.114091	1965-2007	1971	42
8	Balod	Kharkhara dam	20.811162	80.976448	1974-2008		35
9	Balodabazar	Balodabazar	21.656917	82.159196	1960-2013	1969-71, 2004, 2005, 2006, 2007, 2012	46
10	Balodabazar	Simga	21.630000	81.700000	1981-2013	2007	32
11	Bemetara	Bemetara	21.714025	81.535615	1962-2013	1971	51
12	Bemetara	Berla	21.525541	81.477329	1994-2013	2009-11	17
13	Bemetara	Nawagarh	21.905556	81.606944	1994-2012	1995, 1997-98, 2001, 2005-7	12
14	Durg	Dhamdha	21.460311	81.330315	1993-2012		20
15	Durg	Patan	21.035765	81.545638	1993-2013		21
16	Durg	Bhilai	21.208877	81.378063	1960-1998	1971	38
17	Durg	Gondi	21.214100	81.397800	1965-1980	1970-71, 1974, 1976-79	9
18	Durg	Khapri	21.237897	81.316561	1960-2007	1971	49
19	Durg	Bhatagaon Durg	21.459670	81.332699	1960-1999	1962, 1971	38
20	Dhamtari	Chhati	20.779491	81.667884	1983-2008		26
21	Dhamtari	Dhamtari	20.708320	81.530155	1960-2013	1961, 1969, 1971	51
22	Dhamtari	Gangrel	20.616533	81.578330	1979-2013	1987-1996	25
23	Dhamtari	Madamsilli	20.553105	81.663777	1960-2005		46

Conti....

No.	Districts	Stations	Latitude	Longitude	Database period	Missing years	Available years
24	Dhamtari	Sondur	20.224510	82.103062	1981-2007	1988, 1989-2001, 2002, 2003, 2003, 2004, 2005 , 2006 , 2007	7
25	Mahasamund	Bagbahara	20.982230	82.398350	1984-2013		30
26	Mahasamund	Basana	21.279419	82.831339	1990-2013		24
27	Mahasamund	Mahasamund	21.108978	82.102316	1960-2013	1969-1971, 1972 ,1973, 2001, 2002, 2003, 2007	45
28	Mahasamund	Pithora	21.249629	82.518218	2001-2013		13
29	Mahasamund	Saraipali	21.330258	82.998412	1981-2013	1988-1989	31
30	Mahasamund	Bhalukona	21.194499	82.958221	1960-2007	1971, 1991-2006	31
31	Kanker	Charama	20.494451	81.373326	1981-2013	1984, 2006-2007	30
32	Kanker	Kanker	20.267228	81.493327	1981-2013	1984, 2005-2008	28
33	Gariaband	Gariaband	20.633333	82.066667	1960-2013	1968,1969, 1970-71, 1987	49
34	Gariaband	Deobhog	19.900836	82.655096	1981-2013	2007	32
35	Gariaband	Rajim	21.000450	81.822710	1981-2013	2007, 2012	31
36	Raipur	Raipur	21.251384	81.629641	1960-2013		54
37	Raipur	Arang	21.200000	81.970000	1982-2013	2007, 2012	30
38	Raipur	Neora	21.558569	81.841562	1981-2013	2007	33
39	Raipur	Bhatagaon RPR	21.215024	81.624058	1960-2007	1971, 1999	46
40	Raipur	Gudhiyari	21.261852	81.622603	1974-2002	1999-2000	27
41	Raipur	Kendri	21.100424	81.729470	1960-1995	1971	35
42	Raipur	Tara	21.235922	81.641405	1964-2001	1970-71, 1995, 1997, 1999-2000	32
43	Mungeli	Mungeli	22.057970	81.685929	1960-2013	1970-71, 2004-7	48
44	Kawardha	Kawardha	21.994987	81.252592	1963-2013	1964-65, 1970, 1971, 1972, 1973, 1991-98, 1999, 2000	35
45	Kawardha	Pandariya	21.214100	81.309550	2003-2013	2003, 2007	9
46	Kawardha	Bodla	21.968050	81.285900	1974-2013	1976, 1992-99	31
47	Kawardha	Chhirpani	22.221144	81.213326	1981-2008	1990-94	23
48	Rajnandgaon	Amba. Chowki	20.778076	80.747292	1961-2013	1970-74	48
49	Rajnandgaon	Chhuriya	20.639340	80.737060	1998-2013		16
50	Rajnandgaon	Dongargaon	20.973439	80.858222	1997-2013		17

Conti....

No.	Districts	Stations	Latitude	Longitude	Database period	Missing years	Available years
51	Rajnandgaon	Khairagarh	21.421187	80.975751	1962-2013	1971	51
52	Rajnandgaon	Mohala	20.575908	80.746395	1975-2013		39
53	Rajnandgaon	Rajnandgaon	21.100702	81.038579	1962-2013	1971	51
54	Rajnandgaon	Gandai	21.670000	81.100000	1962-2013	1971	51
55	Bilaspur	Bilaspur	22.067650	82.167400	1960-2013	1962, 1970-71, 1975	50
56	Bilaspur	Pendra	22.777430	81.956209	1981-2013	1996, 1997	31
57	Bilaspur	Pendra Road	22.768143	81.948026	1999-2013		15
58	Bilaspur	Kota	22.295529	82.021437	1981-2013		33
59	Bilaspur	Bhaisajhar	22.281140	82.092458	1983-1993		11
60	Bilaspur	Kenda	22.537429	82.067952	1981-1993		13
61	Bilaspur	Khodri	22.665328	81.933021	1981-1993		13
62	Korba	Kanki	22.228420	82.657121	1960-2013	1970-1971, 1991-1999	43
63	Janjgir Champa	Akaltara	22.025788	82.428955	1997-2013		17
64	Janjgir Champa	Champa	22.005912	82.682995	1960-2013	1970-71, 1992-1996	47
65	Janjgir Champa	Janjgir	22.102670	82.924480	1960-2013	1970-71	52
66	Raigarh	Dharamjaigarh	22.511150	83.193900	1975-2013		39
67	Raigarh	Gharghoda	22.183800	83.330450	1960-2013	1962, 1970-1971, 1976	50
68	Raigarh	Lailunga	22.374740	83.606370	1999-2013		15
69	Raigarh	Sarangarh	21.589394	83.074214	1960-2013	1970-1971	52
70	Jashpur	Bagicha	23.038800	83.644600	1974-2013		40
71	Jashpur	Jashpur Nagar	22.834026	84.145697	1960-2013	1962, 1970-1971	51
72	Jashpur	Kunkuri	22.677018	83.829515	1978-2013	1995-1998	32
73	Jashpur	Pathalgaon	22.556054	83.459927	1960-2013	1970-1971	52
74	Koriya	manendragarh	23.219643	82.197605	1974-2013		40
75	Surajpur	Pratappur	22.936400	83.192800	1999-2013	2004-2008, 2010	9
76	Balrampur	wadrafnagar	23.484465	83.211301	2003-2013	2004-2007	7
77	Surguja	Ambikapur	23.136883	83.143574	1981-2013		33

Conti....

No.	Districts	Stations	Latitude	Longitude	Database period	Missing years	Available years
78	sukma	sukma	18.396480	81.670920	1972-2013	1985, 1986, 1988, 1989, 1990, 2005, 2006, 2012	33
79	Bastar	Jagdapur	19.083546	82.027617	1980-2013		34
80	Dantewara	Dantewara	19.074540	81.292700	1973-2013	1976, 1989, 2000, 2001, 2003-2007	33
81	Narayanpur	Narayanpur	20.288680	81.115450	1972-2013	1989, 2002-2007	35
82	Kondagaon	Kondagaon	19.576539	81.666955	1999-2013	2002, 2004-2007	10
83	Bijapur	Bhopalpatanam	18.782540	80.361570	1999-2012	1999, 2000, 2001, 2002, 2004-2007	6
84	Bijapur	Bijapur	18.791667	80.816667	1960-2012	1962, 1970-1971, 1974-75, 1977, 1979, 1999, 2000-2002, 2004-2010	35

APPENDIX – B

Table: Annual and seasonal average rainfall (mm) of 84 stations of Chhattisgarh state with its SD and CV percentage

No.	Districts	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1	Balod	Balod	18	39	214	21	33	159	901	338	38	59	71	119	999	376	38
2	Balod	Admabad	9	19	207	15	27	180	898	249	28	45	56	124	967	261	27
3	Balod	Dondi	1	7	458	0	0	0	984	273	28	55	61	111	1040	290	28
4	Balod	Dondi lohara	10	30	315	4	13	316	813	332	41	42	53	125	869	349	40
5	Balod	Gundardehi	9	27	298	4	13	293	928	206	22	46	62	136	988	220	22
6	Balod	Gurur	15	50	323	17	43	260	1190	306	26	78	96	123	1301	336	26
7	Balod	Gondli dam	9	18	207	12	26	208	827	277	34	50	53	105	898	300	33
8	Balod	Kharkhara dam	20	35	171	28	39	139	964	322	33	65	57	88	1076	343	32
9	Balodabazar	Balodabazar	12	18	150	19	31	162	869	272	31	50	58	116	950	301	32
10	Balodabazar	Simga	15	24	166	13	29	226	989	198	20	50	56	112	1067	212	20
11	Bemetara	Bemetara	16	29	186	19	30	158	991	302	30	56	61	108	1082	316	29
12	Bemetara	Berla	7	30	412	4	12	282	737	186	25	39	53	134	788	207	26
13	Bemetara	Nawagarh	1	4	346	5	16	346	942	235	25	27	30	110	974	232	24
14	Durg	Dhamdha	2	7	352	8	23	274	878	254	29	45	42	94	933	272	29
15	Durg	Patan	8	20	266	10	41	423	1110	237	21	48	55	116	1175	254	22
16	Durg	Bhilai	11	25	222	22	30	136	952	247	26	55	67	123	1040	263	25
17	Durg	Gondi	5	14	300	13	28	214	524	235	45	44	71	161	586	260	44
18	Durg	Khapri	6	16	270	6	14	242	916	345	38	45	64	144	972	374	39
19	Durg	Bhatagaon Durg	5	14	264	11	26	231	965	243	25	40	53	132	1021	267	26
20	Dhamtari	Chhati	17	29	171	29	40	140	949	275	29	49	52	105	1044	296	28
21	Dhamtari	Dhamtari	18	26	146	39	45	116	939	267	28	60	67	111	1055	293	28

Conti....

No.	Districts	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
22	Dhamtari	Gangrel	30	31	105	37	35	96	1029	293	28	51	60	118	1147	315	27
23	Dhamtari	Madamsilli	16	20	128	38	43	111	1074	295	27	74	77	103	1203	325	27
24	Dhamtari	Sondur	28	18	63	54	46	84	1068	145	14	66	70	107	1215	214	18
25	Mahasamund	Bagbahara	9	22	243	6	18	290	905	304	34	32	49	154	952	330	35
26	Mahasamund	Basana	2	5	342	3	16	490	1120	340	30	59	65	110	1184	350	30
27	Mahasamund	Mahasamund	31	132	431	27	61	227	868	350	40	45	61	137	970	350	36
28	Mahasamund	Pithora	17	29	171	12	25	213	1183	361	31	38	42	111	1250	365	29
29	Mahasamund	Saraipali	22	32	146	51	48	94	1184	306	26	70	69	99	1327	339	26
30	Mahasamund	Bhalukona	15	31	215	22	35	160	940	216	23	43	56	131	1019	221	22
31	Kanker	Charama	14	21	155	21	50	242	1056	250	24	68	76	112	1159	305	26
32	Kanker	Kanker	20	27	137	39	74	189	1008	286	28	79	88	111	1146	343	30
33	Gariaband	Gariaband	15	27	179	34	57	166	1125	365	32	62	79	129	1236	382	31
34	Gariaband	Deobhog	2	8	372	10	30	286	1018	262	26	37	56	151	1067	275	26
35	Gariaband	Rajim	17	37	225	9	25	280	1053	292	28	40	46	115	1118	312	28
36	Raipur	Raipur	23	27	122	53	59	111	1073	288	27	64	62	97	1212	302	25
37	Raipur	Arang	13	36	287	6	15	236	1045	296	28	51	59	115	1115	324	29
38	Raipur	Neora	10	23	231	7	16	221	831	292	35	45	56	125	894	324	36
39	Raipur	Bhatagaon RPR	15	21	142	40	69	174	1101	334	30	65	77	119	1221	370	30
40	Raipur	Gudhiyari	5	18	366	1	6	420	867	258	30	39	59	150	913	284	31
41	Raipur	Kendri	7	18	272	16	29	181	979	369	38	53	67	128	1054	382	36
42	Raipur	Tara	4	13	294	2	8	422	786	250	32	44	60	137	836	264	32
43	Mungeli	Mungeli	26	34	135	29	32	111	928	219	24	71	61	86	1055	252	24
44	Kawardha	Kawardha	37	47	127	49	46	95	842	157	19	62	60	96	991	175	18
45	Kawardha	Pandariya	23	40	175	9	21	230	921	178	19	49	49	100	1002	215	21
46	Kawardha	Bodla	24	41	167	12	30	249	686	231	34	51	53	103	774	252	33
47	Kawardha	Chhirpani	32	42	130	30	38	125	661	221	33	49	57	117	772	240	31

Conti....

No.	District	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
48	Rajnandgaon	Amba. Chowki	13	23	176	22	39	180	1070	284	27	42	47	112	1147	301	26
49	Rajnandgaon	Chhuriya	9	21	235	4	14	312	1038	380	37	22	26	116	1074	386	36
50	Rajnandgaon	Dongargaon	10	21	200	26	66	249	1046	404	39	63	60	95	1146	383	33
51	Rajnandgaon	Khairagarh	19	31	168	22	31	142	902	225	25	71	66	92	1014	240	24
52	Rajnandgaon	Mohala	15	27	182	18	32	180	1124	281	25	77	93	122	1233	341	28
53	Rajnandgaon	Rajnandgaon	38	94	247	37	38	105	997	407	41	86	93	108	1158	374	32
54	Rajnandgaon	Gandai	17	32	185	21	31	148	851	311	37	77	105	137	966	323	33
55	Bilaspur	Bilaspur	32	38	119	54	80	148	1046	289	28	72	60	83	1204	295	24
56	Bilaspur	Pendra	57	56	98	100	91	91	1023	223	22	72	76	106	1252	251	20
57	Bilaspur	Pendra Road	40	49	121	90	65	72	1033	215	21	86	112	129	1250	279	22
58	Bilaspur	Kota	46	83	180	49	86	178	938	262	28	59	55	93	1091	284	26
59	Bilaspur	Bhaisajhar	36	34	94	25	31	121	755	97	13	30	21	69	847	95	11
60	Bilaspur	Kenda	48	48	100	42	35	83	874	209	24	43	35	82	1007	239	24
61	Bilaspur	Khodri	70	77	111	34	28	81	874	155	18	46	49	107	1024	181	18
62	Korba	Kanki	17	33	196	30	41	135	1018	261	26	46	56	122	1111	274	25
63	Janjgir Champa	Akaltara	36	45	126	26	38	147	1222	299	24	93	95	102	1376	381	28
64	Janjgir Champa	Champa	29	38	132	30	34	115	973	386	40	73	100	137	1104	425	39
65	Janjgir Champa	Janjgir	24	32	137	24	34	140	1092	316	29	65	67	103	1204	342	28
66	Raigarh	Dharamjaigarh	23	24	107	75	189	253	1115	316	28	68	67	99	1280	302	24
67	Raigarh	Gharghoda	19	29	155	32	38	117	1136	264	23	58	54	94	1244	287	23
68	Raigarh	Lailunga	23	44	190	28	32	115	1053	326	31	88	115	130	1192	383	32
69	Raigarh	Sarangarh	18	25	139	38	56	149	940	243	26	58	55	95	1053	270	26
70	Jashpur	Bagicha	21	30	142	40	60	149	1150	296	26	64	66	103	1275	315	25
71	Jashpur	Jashpur Nagar	38	43	113	65	55	84	1396	274	20	106	88	83	1605	310	19
72	Jashpur	Kunkuri	11	21	196	23	42	179	978	347	35	58	67	115	1070	384	36
73	Jashpur	Pathalgaon	27	48	179	40	52	131	1173	321	27	83	79	95	1323	358	27

Conti....

No.	District	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
74	Koriya	manendragarh	25	40	162	20	44	218	1113	261	23	67	71	107	1225	311	25
75	Surajpur	Pratappur	12	22	193	10	21	208	1311	382	29	78	71	92	1411	368	26
76	Balrampur	wadrafnagar	13	22	176	9	19	215	1009	304	30	63	53	84	1094	351	32
77	Surguja	Ambikapur	47	41	88	48	47	96	1170	321	27	83	61	73	1348	342	25
78	sukma	sukma	6	16	271	49	53	108	1199	261	22	88	74	85	1342	268	20
79	Bastar	Jagdapur	22	22	98	143	71	49	1129	232	21	113	93	82	1408	289	21
80	Dantewara	Dantewara	14	37	260	6	13	208	1170	355	30	91	75	83	1282	334	26
81	Narayanpur	Narayanpur	15	28	188	29	55	190	1235	245	20	88	69	79	1366	289	21
82	Kondagaon	Kondagaon	18	23	126	27	26	93	1121	173	15	85	79	93	1252	196	16
83	Bijapur	Bhopalpatanam	11	18	157	9	17	190	1258	333	26	51	59	116	1329	362	27
84	Bijapur	Bijapur	42	90	213	52	59	113	1075	261	24	77	60	78	1247	280	22

APPENDIX - C

Table: Annual and seasonal average rainy days of 84 stations of Chhattisgarh state with its SD and CV percentage

No.	Districts	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
1	Balod	Balod	1	2	170	2	2	139	40	13	32	3	3	100	46	15	33
2	Balod	Admabad	1	1	186	1	2	174	42	9	23	3	3	98	47	10	21
3	Balod	Dondi	0	0	458	0	0	0	39	9	24	2	2	88	41	10	24
4	Balod	Dondi lohara	0	1	316	0	1	357	35	10	28	2	2	108	38	11	28
5	Balod	Gundardehi	1	2	293	0	1	318	41	9	23	2	3	116	44	9	21
6	Balod	Gurur	0	1	290	0	1	271	45	8	17	4	4	107	50	9	19
7	Balod	Gondli dam	1	1	197	1	2	209	40	9	23	3	3	92	45	11	24
8	Balod	Kharkhara dam	1	2	133	2	3	121	45	8	19	3	3	80	52	10	19
9	Balodabazar	Balodabazar	1	2	155	2	3	141	44	9	21	3	3	86	50	10	21
10	Balodabazar	Simga	1	2	169	1	2	241	44	8	18	3	2	81	49	9	19
11	Bemetara	Bemetara	1	2	171	1	2	173	43	9	20	3	3	106	48	10	21
12	Bemetara	Berla	0	1	412	0	1	289	36	8	23	2	2	88	39	9	24
13	Bemetara	Nawagarh	0	1	346	0	1	346	41	8	19	2	2	101	43	8	18
14	Durg	Dhamdha	0	1	262	1	2	286	40	9	22	3	3	101	43	9	22
15	Durg	Patan	0	1	262	0	2	402	42	9	22	3	3	106	46	11	23
16	Durg	Bhilai	1	2	184	2	3	151	44	8	18	3	3	101	49	10	21
17	Durg	Gondi	0	1	300	1	2	211	25	13	54	3	4	118	29	15	52
18	Durg	Khapri	0	1	237	1	2	256	41	10	25	2	3	111	44	11	25
19	Durg	Bhatagaon Durg	0	1	225	1	2	207	44	8	19	3	3	111	48	10	21
20	Dhamtari	Chhati	1	2	144	2	3	125	46	9	20	4	3	93	53	12	22
21	Dhamtari	Dhamtari	1	2	124	3	3	107	42	11	26	3	3	92	50	14	27
22	Dhamtari	Gangrel	2	2	93	3	3	91	45	11	25	3	3	90	54	13	25

Conti....

No.	Districts	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
23	Dhamtari	Mademsilli	1	2	114	3	3	102	47	9	19	5	4	85	55	12	22
24	Dhamtari	Sondur	2	2	73	5	3	57	51	6	12	3	3	98	62	10	16
25	Mahasamund	Bagbahara	1	1	199	0	1	262	48	9	18	2	3	130	52	10	19
26	Mahasamund	Basana	0	0	359	0	1	490	52	9	17	4	3	83	56	8	15
27	Mahasamund	Mahasamund	2	4	262	2	2	124	43	11	25	3	3	95	49	9	18
28	Mahasamund	Pithora	1	1	135	1	2	224	45	8	19	3	3	92	49	11	22
29	Mahasamund	Saraipali	1	2	119	4	4	88	50	10	20	4	3	75	60	12	20
30	Mahasamund	Bhalukona	1	2	197	2	3	142	45	10	21	3	3	99	50	10	20
31	Kanker	Charama	1	1	151	1	3	256	46	9	19	4	3	85	52	12	23
32	Kanker	Kanker	1	2	118	2	4	186	45	8	18	5	4	94	53	14	26
33	Gariaband	Gariaband	1	2	158	2	3	141	45	11	25	4	3	85	52	12	23
34	Gariaband	Deobhog	0	1	316	1	2	294	46	10	21	2	2	101	49	11	22
35	Gariaband	Rajim	1	1	203	1	2	298	45	7	17	3	3	96	49	9	19
36	Raipur	Raipur	2	2	98	4	4	95	47	8	17	4	3	81	57	10	17
37	Raipur	Arang	0	1	230	1	1	216	44	8	18	3	3	104	48	10	21
38	Raipur	Neora	1	1	197	1	2	237	41	8	19	2	3	115	45	11	24
39	Raipur	Bhatagaon	1	1	123	3	3	117	41	9	21	3	3	91	48	11	23
40	Raipur	Gudhiyari	0	1	406	0	0	381	39	11	27	2	2	107	42	12	29
41	Raipur	Kendri	0	1	227	1	2	168	42	9	22	3	3	93	47	9	20
42	Raipur	Tara	0	1	286	0	1	330	37	9	23	2	3	118	40	10	24
43	Mungeli	Mungeli	2	3	125	3	3	99	46	9	19	4	3	82	55	11	20
44	Kawardha	Kawardha	3	3	123	4	3	77	45	8	18	4	3	82	56	10	18
45	Kawardha	Pandariya	1	2	145	0	1	163	46	5	12	3	3	85	51	8	17
46	Kawardha	Bodla	2	3	146	1	2	192	38	11	28	3	2	77	45	12	28
47	Kawardha	Chhirpani	3	4	140	3	3	107	45	11	24	4	4	90	55	12	21
48	Rajnandgaon	Amba. Chowki	1	2	162	1	2	152	46	11	24	2	3	113	51	12	24

No.	Districts	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
49	Rajnandgaon	Chhuriya	0	1	204	0	1	310	39	8	20	2	2	118	42	9	21
50	Rajnandgaon	Dongargaon	0	1	173	1	3	225	43	7	16	3	3	93	48	7	14
51	Rajnandgaon	Khairagarh	1	2	149	2	2	126	43	9	21	4	3	77	50	11	21
52	Rajnandgaon	Mohala	1	2	148	1	2	150	49	10	21	4	4	95	55	12	22
53	Rajnandgaon	Rajnandgaon	2	4	172	3	3	98	42	13	32	5	4	95	52	14	26
54	Rajnandgaon	Gandai	1	2	161	2	2	138	40	11	27	4	3	90	47	13	28
55	Bilaspur	Bilaspur	2	3	104	4	4	97	48	9	19	4	3	75	58	10	17
56	Bilaspur	Pendra	4	3	76	7	5	64	52	9	16	4	3	81	68	11	17
57	Bilaspur	Pendra Road	3	3	81	7	4	57	54	8	15	5	3	71	69	10	15
58	Bilaspur	Kota	3	5	141	4	4	105	48	9	18	4	3	67	60	8	14
59	Bilaspur	Bhaisajhar	4	4	104	3	2	82	46	8	17	4	3	73	57	11	20
60	Bilaspur	Kenda	4	4	114	5	4	82	47	11	25	4	4	99	59	17	30
61	Bilaspur	Khodri	4	4	101	3	2	80	40	8	19	3	3	91	51	10	20
62	Korba	Kanki	1	2	160	2	3	125	46	10	21	3	3	103	52	11	22
63	Janjgir Champa	Akaltara	2	2	127	2	2	138	50	8	15	4	4	89	57	10	17
64	Janjgir Champa	Champa	2	2	113	3	3	99	44	14	32	4	4	85	53	17	32
65	Janjgir Champa	Janjgir	2	2	121	2	2	125	47	10	21	4	4	95	54	12	22
66	Raigarh	Dharamjaigarh	2	2	116	4	9	199	51	12	23	4	3	81	61	12	19
67	Raigarh	Gharghoda	1	2	143	3	3	118	52	10	19	4	3	76	60	12	20
68	Raigarh	Lailunga	1	2	145	3	3	118	59	9	16	4	5	114	67	12	18
69	Raigarh	Sarangarh	1	2	122	3	3	105	44	8	17	4	3	77	52	9	18
70	Jashpur	Bagicha	2	2	146	3	4	125	60	11	19	4	4	97	68	15	22
71	Jashpur	Jashpur Nagar	3	3	88	5	4	77	64	9	14	6	4	68	79	12	15
72	Jashpur	Kunkari	1	2	180	2	3	169	49	13	26	4	3	93	55	16	28
73	Jashpur	Pathalgaon	2	2	126	3	3	99	57	10	17	4	3	83	66	12	18
74	Koriya	manendragarh	2	3	156	1	2	151	46	9	19	4	4	97	53	11	21

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No.	Districts	Stations	Winter			Summer			SWM			NEM			Annual		
			Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
75	Surajpur	Pratappur	1	1	155	1	2	198	52	6	12	5	4	12	58	11	18
76	Balrampur	wadrafnagar	1	1	198	1	1	198	48	10	21	4	3	72	53	13	24
77	Surguja	Ambikapur	4	3	70	5	3	70	54	9	17	6	4	69	68	11	16
78	sukma	sukma	0	1	292	3	4	120	56	10	18	5	4	83	65	11	18
79	Dantewara	Dantewara	1	1	191	0	1	206	54	10	19	5	4	79	60	11	19
80	Narayanpur	Narayanpur	1	1	180	2	3	152	57	8	14	5	4	67	65	10	15
81	Kondagaon	Kondagaon	1	1	142	3	2	75	54	7	12	5	4	75	63	7	11
82	Bastar	Jagdapur	2	2	106	11	3	30	57	8	15	7	4	59	76	11	15
83	Bijapur	Bhopalpatanam	1	1	167	1	1	182	53	10	20	3	3	89	57	11	19
84	Bijapur	Bijapur	3	6	187	4	4	97	50	8	15	4	3	72	61	11	19

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S.No.	Degree	Year	Name of board
1	10 th	2006	CGBSE RAIPUR
2	12 th	2008	CGBSE RAIPUR
3	B.Sc. Horticulture	2013	IGKVV RAIPUR
4	M.Sc. (Ag) Agrometeorology	2015	IGKVV RAIPUR

Professional Experience (If any) :

Membership of Professional Societies (If any) :

Awards / Recognitions (If any) :

Publications (If any): In numbers only


 Signature