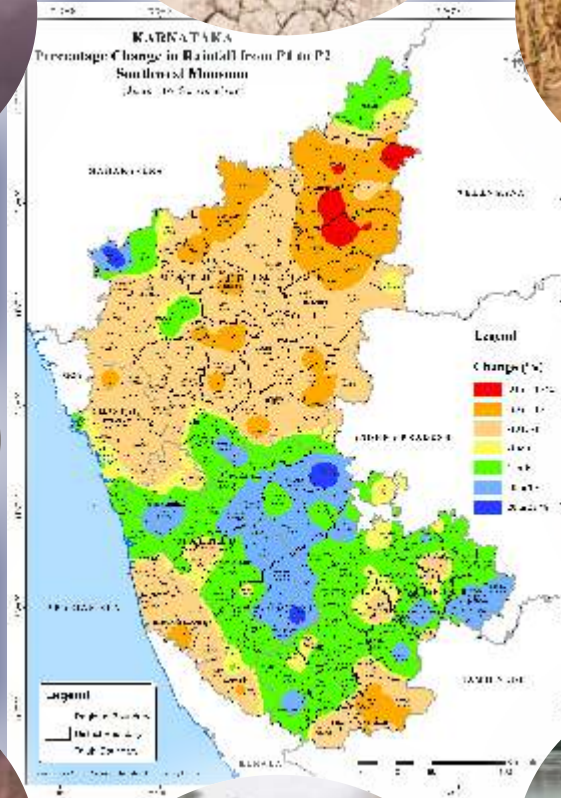




Climate Change Scenario in Karnataka: A Detailed Parametric Assessment



Karnataka State Natural Disaster Monitoring Centre
Major Sandeep Unni Krishnan Road, Yelahanka Bangalore - 560 064, Karnataka

JUNE 2020

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Karnataka State Natural Disaster Monitoring Centre (KSNDMC)

(Autonomous body affiliated to Revenue Department (Disaster Management), Government of Karnataka)

Major Sandeep Unnikrishnan Road, Yelahanka, Bengaluru 560064

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“Climate Change Scenario in Karnataka: A Detailed Parametric Assessment”

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FOREWORD

The life on Earth is shaped by the climatic factors and the historical records shows that the Earth's climate has changed in the past and resulted in significant transformations in ecosystems. One of the important consequences of climate change is the occurrence of Extreme weather events, especially in the tropical regions. High impact weather events such as Drought, Flood, Storms and Heatwaves have tremendous adverse impact on socio-economic condition of the community. Thus, unraveling the features of climate change in the past is key to understand the present and future climate scenarios. This study is an important contribution towards analyzing the past climate over Karnataka.

Karnataka State has been experiencing extreme weather events like Drought, Flood, and Hailstorm very frequently in the recent decades. At times, some parts of the state experiences both Drought and Flood within a season. Such events have caused colossal loss to human lives, livestock, crops, critical infrastructure, public and private properties. While the affected community loses its livelihood, the people are forced to migrate in large scale and undergone a lot of social and economic hardship.

This study is to assess the climate change-scenario and its consequences in terms of the severity and magnitude of the extreme weather events in the State. The long term rainfall and weather parameters data series for the last 58 years has been considered for the analyses. The parameters viz variations in intensity and amount of rainfall, number of rainy days, occurrence of dry spells (≥ 3 weeks), mean monthly temperature & relative humidity, have been analysed. The results of this study reveals both intrinsic and extrinsic characteristic of rainfall distribution in the state and its resultant effect in different regions.

It gives me immense pleasure to pen this Foreword for an excellent technical report on Climate change-assessment scenario in Karnataka. The report documented precisely the region-wise variations in climatic parameters and associated disasters. Technical insight into some of the major extreme weather events occurred in the state has also been provided.

I heartily congratulate Dr. G.S. Srinivasa Reddy, Director, KSNDMC and his team for bringing out this excellent publication. This book is a worthy reference material for Administrators, Academicians, Non-Governmental Organization and all other stakeholders for planning and implementing programs to minimize the impact of climate change.

Vandita Sharma, I A S

ABOUT THE KSNDMC

Karnataka state Natural Disaster Monitoring Centre (KSNDMC), is an autonomous registered society affiliated to the Revenue Department (Disaster Management), Govt. of Karnataka. It is the nodal Centre to monitor all the natural disasters in the state. This Centre was established, in 1988, as a Drought Monitoring Cell (DMC) and later in 2007 it was renamed as Karnataka state Natural Disaster Monitoring Centre with broad mandate to monitor different disasters like Droughts, Floods, Earthquakes, Landslides, Hailstorms in the state. The pioneering and path breaking initiatives with proactive approach, adopted towards the Disaster monitoring, is a unique model in the country.

The KSNDMC has been serving as a common platform to various response players to achieve synergy in the field of natural disaster management by providing timely proactive Science & Technology based inputs. To monitor the weather and understand its spatial and temporal variability, the KSNDMC has installed a dense network of weather monitoring stations which comprises Solar Powered GPRS enabled 747 Telemetric Weather Stations (TWS) covering all the Hoblis and 6500 Telemetric Rain Gauge Stations (TRG) covering all the Grampanchayaths. The data from these TWS and TRGs are being automatically transmitted every 15 minutes to a dedicated server and used in various analysis, generating daily, weekly and monthly reports and forecasting of weather over the state.

The Grampanchayath level weather forecast, generated in association with Space Applications Centre (SAC), ISRO, Ahmedabad, is first of its kind in the country. The Forecast, Early Warnings, Reports and weather related Advisories are being disseminated to all the stakeholders through ICT enabled information dissemination system which includes Email, SMS, Social Media Platforms. An interactive Help Desk “VARUNA MITRA” (24x7x365) is operational at KSNDMC throughout the year for providing weather updates directly to the farming community. Every day thousands of farmers are utilizing the weather information and advisories provided through VARUNA MITRA for planning their agricultural activities.

The Centre also provides data and technical inputs for implementing the Weather Based Crop Insurance Scheme in the state. Various other sectors like Agriculture and Horticulture based sectors, Irrigation, Fisherman community, Transport sector, Energy sector are also the beneficiaries of the services of KSNDMC. Services are also being provided to State and District level Disaster Management Authority in Karnataka.

The center has been active in capacity building program through guiding M. Tech students, delivering talks on disaster related activities and imparting training to participating students/faculty member from various schools/colleges.

The KSNDMC has been providing technical guidance and support to Government of Bihar, Orissa and Uttarakhand for developing and installing a robust disaster monitoring network and associated activities in the respective states.

Dr. G.S. Srinivasa Reddy
Director

Karnataka State Natural Disaster Monitoring Centre

EXECUTIVE SUMMARY

The Earth's climate, a dynamic system, is of vital importance for all forms of life. Several studies have shown that the climate system is continually varying, at different time-scales. The Climate change refers to changes in factors such as Temperature, Humidity, Air pressure, Wind, Clouds and Precipitation patterns over time. The imprints of Climate change are observed clearly across the world.

Understanding the features of climate change in the past is key to comprehend the present and future climate scenarios. In that context, this study has been carried out to decipher the variations in climate factors over Karnataka in the past. The long-term climate data series for the last 58 years (1960 to 2017) has been considered for the study. A major shift in climatic factor has been observed around the year 1990. Thus by taking 1990 as the central change point, the data series has been divided into two sub-series P1 (1960-1990) and P2 (1991 to 2017) for further parametric analysis. The variations in amount of rainfall, rainy days, frequency of rainfall events, occurrence of dry spells (≥ 3 weeks), number of below normal rainfall years, fluctuations in temperature and relative humidity were examined.

The results show that there is a considerable shift in rainfall pattern over Karnataka. The quantum, intensity and distribution of Rainfall has varied across the regions in the state from P1 to P2 periods. The amount of Annual rainfall and number of rainy days have increased in SIK and Malnad regions. At the same time, there is a reduction in amount of annual rainfall and marginal increase in number of rainy days observed in NIK and Coastal regions from P1 to P2. The Kodagu, Kalaburagi, Yadgir, Dakshina Kannada, Uttara Kannada districts shows a reduction in the amount of annual rainfall and an increase in rainfall over Shivamogga and Hassan districts.

The analysis of Taluk level rainfall data shows that, the Challakere Taluk in SIK region has an increase in amount of rainfall in all seasons and annually, while Vijapura Taluk in NIK region has a decrease in rainfall during all seasons and annually. The Shivamogga Taluk in Malnad region showed statistically insignificant increase in Southwest, Northeast and Annual rainfall. On the other hand, the Udupi Taluk in Coastal region showed significant decrease in pre-monsoon and Southwest monsoon season rainfall. Among the regions, SIK and Malnad regions showed statistically insignificant increase in all seasons and annual rainfall. While NIK and Coastal regions showed marginal decrease in Southwest monsoon rainfall from P1 to P2.

Parts of Vijayapura, Bagalkote, Raichur, Koppal, Ballari, Gadag, Dharwad, Belagavi, Haveri, Davanagere, Chitradurga, Chikkamgaluru, Bengaluru and Ramanagara districts showed higher inter-annual variability (CV %) in rainfall. Remaining districts showed less variability (CV) from P1 to P2. Very Light and Light rainfall events have increased in all the regions. Moderate and Heavy rainfall events did not show any distinct pattern. However, in the last two decades the extreme rainfall events have occurred in different regions of the state. Also, the number of years with below normal rainfall have increased in NIK, whereas it has decreased in other regions from P1 and P2. Consequently, the NIK and SIK are more prone to severe drought compare to Malnad and Coastal regions. Frequency of occurrence of drought has increased in recent years.

The analysis of Temperature and Relative Humidity data series for the period 2002 to 2018 shows a steady increasing trend in average Temperature, while the Relative Humidity showed a decreasing trend commonly in most of the regions in the state.

The imprints of changes in climatic condition are in the form of high impact weather events. The occurrence of Extreme weather events has increased both in terms of frequency and intensity across the state in the last decades. The data shows that the Hydro-Meteorological disasters such as Drought, Flood, Hailstorm, Cyclone, Heatwave, Thunderstorm and Lighting events have occurred in the state more frequently in recent years.

The extreme weather events have caused loss of human life, livestock, critical infrastructure, private and public property. Also, these events have caused increase in hunger, malnutrition, vulnerability to diseases, loss of livelihoods of the community.

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Chapter 1. INTRODUCTION

The Earth's climate can be defined as a state of systemic interaction between Atmosphere, Hydrosphere, Geosphere and Biosphere. Also, the Earth's climate is a dynamic system with both spatial and temporal variability. Several studies across the world have demonstrated that the climate system is continually varying, at different time-scales, due to the interactions between the components as well as external factors. The changes in climate at smaller timeframes, such as a month, a season or a year, is considered as Climate Variability. Whereas the changes in Climatic factors that occur over a longer period of time, typically over decades or longer is termed as Climate Change. The term "Climate Change", was proposed by the World Meteorological Organization (WMO) in 1966 to encompass all forms of climatic variability on time-scales longer than 10 years, regardless of cause. Overall, the Climate Change refers to changes in Temperature, Humidity, Air pressure, Wind, Clouds and Precipitation patterns over time.

It is essential to note that, the Earth's climate is largely driven by the Planet's energy budget, and most of that energy comes from the Sun. This solar energy is distributed around the globe, mainly through winds and ocean currents, goes towards weather, keeping the temperature of the Earth at a favorable level for life and powers the entire Biosphere. Thus, understanding the Earth's energy budget also helps to comprehend the climate, its spatial and temporal variability and foresee the effects climate change on constituents of the Biosphere.

Climate change is now affecting every country on every continent. It is disrupting national economies and affecting lives, costing people, communities and countries dearly. People are experiencing the significant impacts of climate change, which include changing weather patterns, rising sea level and more extreme weather events.

1.1 Causes of climate change:

There are many "Natural" and "Anthropogenic" (human-induced) factors that contribute to the climate change. It is abundantly clear from the evidence in the Geological records that Earth's Climate has been changing at different frequencies of time-scale. However, the rapid rate and the magnitude of climate change occurring now, is of great concern.

Earth's atmosphere contains various gases that act as a blanket to trap heat received from the Sun and prevent it from escaping back into space. This process is known as the Greenhouse Effect, and the gases are referred to as Green-House Gases (GHG). The main GHGs in nature are Carbon dioxide(CO_2), Methane (CH_4) and Nitrous oxide (N_2O). Without the greenhouse effect, the planet would be too cold to support life. Over the years, the amount of GHGs trapped in Earth's atmosphere has increased significantly, causing worldwide temperatures to rise.

Natural processes on Earth constantly create and destroy GHGs. The decay of plant and animal matter, for example, produces CO_2 , which is then absorbed by the plants during photosynthesis. This natural cycle keeps the level of CO_2 in the atmosphere fairly stable. Further, Volcanic activity also affects the climate because eruptions discharge GHGs and other pollutants into the Atmosphere. Several studies on Climate change recognize that these natural factors continue to play a role in climate change but contend that the impact of these factors alone does not explain the substantial rise in Earth's temperature.

Over the last few decades, it has become increasingly clear that there is a significant Human contribution to climate change (Battarbee, 2008). The increase in atmospheric CO_2 and CH_4 during the Holocene, especially between 8000 to 5000 years BP, as largely the result of Anthropogenic activity (Ruddiman & Thompson 2001). First humans reversed a natural decrease in Atmospheric CO_2 concentrations through forest clearance for

various activities like creating human settlements and development of Agriculture. In the next phase, human reversed the natural CH_4 decrease through the intense cultivation using flood irrigation method. As a result, the changes in CO_2 and CH_4 concentration in the atmosphere caused anthropogenic warming sufficient enough to counter natural cooling (Ruddiman, 2005a; Oldfield 2005; Birks 2008). Therefore, now, the term “Climate Change” is often used to refer specifically the anthropogenic climate change and at times it is synonymous with Anthropogenic Global warming.

The Global warming is a contributing factor to climate change and it is the effect of increase in concentration of GHG on Earth’s average surface temperature. The GHGs in the Atmosphere absorb heat radiation. Human activity, in the recent past, has increased GHGs in the Atmosphere since the Industrial Revolution, leading to more heat retention and an increase in surface temperatures.

Atmospheric aerosols alter climate by scattering and absorbing solar and infrared radiation and they also have the potential to change the microphysical and chemical properties of clouds. Finally, land-use changes, such as deforestation have led to changes in the amount of sunlight reflected from the ground back into space, the surface albedo.

Earth’s vegetation releases and absorbs more than 2 hundred Billion Metric Tons of CO_2 annually. Human activities, such as the burning of fossil fuels, add an extra 7 Billion Metric Tons of CO_2 per year. Over time, these additions have had a dramatic effect on the atmosphere. In the past 150 years, the concentration of CO_2 in the Atmosphere has risen by more than 30 percent.

Increased levels of other GHGs such as N_2O and CH_4 have also resulted from human activities. Several agricultural and industrial activities, such as the use of certain fertilizers in agriculture, produce N_2O . The CH_4 emissions come from the production of fossil fuels, from landfills and from livestock. These gases cause even more harm than CO_2 , even though they are less in quantity, because they have a much greater effect per pound on Earth’s temperature. The CH_4 , for example, is 21 times more potent than CO_2 .

The Anthropogenic activity has created and released GHGs that do not occur in nature. These include Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6). These gases, released during such industrial processes as aluminum production and electrical transmission, have thousands of times greater effect on the planet’s Temperature than CO_2 .

1.2 Effects of Climate Change

Globally the Earth’s climate is warmer today than at any time during the last 140 years. There are stronger evidences for a human influence on the global climate, although the precise magnitude of the influence is still uncertain. Global mean surface temperature could rise between 1.4° and 5.8°C in the next 100 years. Globally averaged precipitation is projected to increase, but at the regional scale both increases and decreases are projected. Which indicate that the intensity and frequency of extreme weather events are expected to increase. The global warming threat is real and the consequences of the climate change phenomena are many, and serious.

Climate change will continue to ‘work through’ for many decades, because the lead times in climate change are very long. The tropical and developing countries like India, would be more vulnerable to climate change, because of their already more extreme climate, the fragility of the food security of the people, their inadequate and vulnerable infrastructure, population density in marginal lands, and other factors.

Even small temperature increase in arid and semi-arid tropical regions could well lower agricultural productivity. The water scarcity will dramatically increase vulnerability and threaten food supplies. In addition, vector-borne diseases such as malaria and dengue fever and water-borne diseases such as cholera could increase.

The annual mean area-averaged surface warming is projected to be between 3.5° and 5.5°C over the Indian subcontinent by the end of the 21st Century (Ial, 2003). This warming would be more pronounced in winter than during monsoon season. During winter, India may experience between 5 and 25% decline in rainfall.

The decline in wintertime rainfall is likely to be significant and may lead to droughts during the dry summer months. More intense rainfall spells are also projected in a warmer atmosphere, increasing the probability of extreme rainfall events.

Since the Indian economy is intrinsically linked with the annual monsoon cycle, a better understanding of the future behavior of the monsoon and its variability is warranted for disaster mitigation and for developing adaptation strategies to cope with climate variability and climate change. A quantitative assessment of the magnitude of climate change over the Indian subcontinent, with some confidence and accuracy, is also crucial to evaluate the social and economic consequences expected and to formulate appropriate, though flexible, policy options.

This report presents the observed variability and changes in key climatic factors, especially Rainfall, over Karnataka as inferred through the statistical techniques. Also, an assessment of the magnitude of climate change over Karnataka and its implications on the monsoon rainfall and its variability, including plausible changes in extreme weather events has been attempted.

Chapter 2. KARNATAKA AN OVERVIEW

Karnataka state is located between 11.50 to 18.50 °N Latitude and 74.25 to 78.50 °E Longitude and covers an area of about 19.1 M ha which accounts for 5.8 % of the total geographical area of the country. The state is bounded by Goa in the Northwest, Maharashtra in the North, Andhra Pradesh in the East, Tamil Nadu in the South and Kerala in the Southwest. It has four major regions namely 1) North Interior Karnataka, 2) South Interior Karnataka, 3) Malnad region and 4) Coastal region. It has four administrative divisions namely 1) Mysore division, 2) Gulbarga division, 3) Belgaum division and 4) Bengaluru division. The state is composed of 30 districts divided into 176 Taluks (Fig.1). These Taluks are further divided into 747 Hoblies. It is home to 61.5million people (2011 Census) accounting for 5.05% of India's population. The state's population has grown by 15.7% during the last decade. Of the total population in the state 51% constitute males, 49% females while child (age 0-6) population is 12%.

Karnataka State has sub-Humid to humid climate on the West Coast and Western Ghats region and semi-arid to arid (very warm) climate in central, southern and northern districts of plateau region. The year is divided into four seasons viz., Winter (January-February), Summer (March to May); South-West Monsoon (June to September) and North East monsoon (October to December).

The state receives a normal annual rainfall of about 1150 mm in which about 73 % of the rainfall occurs during the SW Monsoon season, 15 % during NE monsoon and 10% during Pre-Monsoon season. There is a substantially high variability in spatial and temporal distribution of the rainfall over the state. Taluk wise Normal rainfall of the state vary from 477 mm to 4747 mm. Rainfall contribution is very high, from Southwest Monsoon Season (around 80% of the state rainfall), it is seen that the annual rainfall is lowest (477mm) in the eastern parts of Chitradurga district and highest (4747mm) over the Western Ghats. More than 2/3rd of the state receives less than 750 mm of rainfall. Taluk wise Annual variability (CV) of the rainfall ranges from 16 to 40%. The atmospheric temperature in the state ranges from 23°C to 43°C in summer and 9°C to 27 °C in winter.

2.1 Agro-climatic zones

Karnataka State is divided into four regions namely South Interior Karnataka, North Interior Karnataka, Malnad and Coastal Karnataka. These are further divided into ten Agro-Climatic Zones by UAS, Bengaluru under NARP program (Fig.2). Among these ACZ zones, there are five dry zones (2, 3, 4, 5 & 6) with relatively low rainfall and more erratic distribution. Similarly, along the eastern part of the hill zones to the west of the dry zones with relatively more rainfall with less erratic distribution and a small portion in the north-eastern part of the State were also identified as transitional zones (1, 7 & 8). The hill and Coastal belts cover the two distinct zones (9 & 10). The districts/Taluks covered under each ACZ are presented in Table.1. The five dry zones cover major area (107 taluks) while the three transitional zones cover 35 taluks in the state. The hill and Coastal zones cover 21 and 13 taluks respectively.

These 10 Agro-climatic zones are grouped in to three categories as under:

- a) Dry Zones:** North Eastern Dry Zone (2), Northern Dry Zone (3), Central Dry Zone (4), Southeastern Dry Zone (5) and Southern Dry Zone (6)
- b) Transitional Zones:** North-Eastern Transition Zone (1), Southern Transition Zone (7) and Northern Transition Zone (8)
- c) Hill and Coastal Zones:** Hilly Zone (9) and Coastal Zone (10)

Out of the total 19.1 M hectares in Karnataka the net cultivated area (2010-11) was 10.5 M hectares with

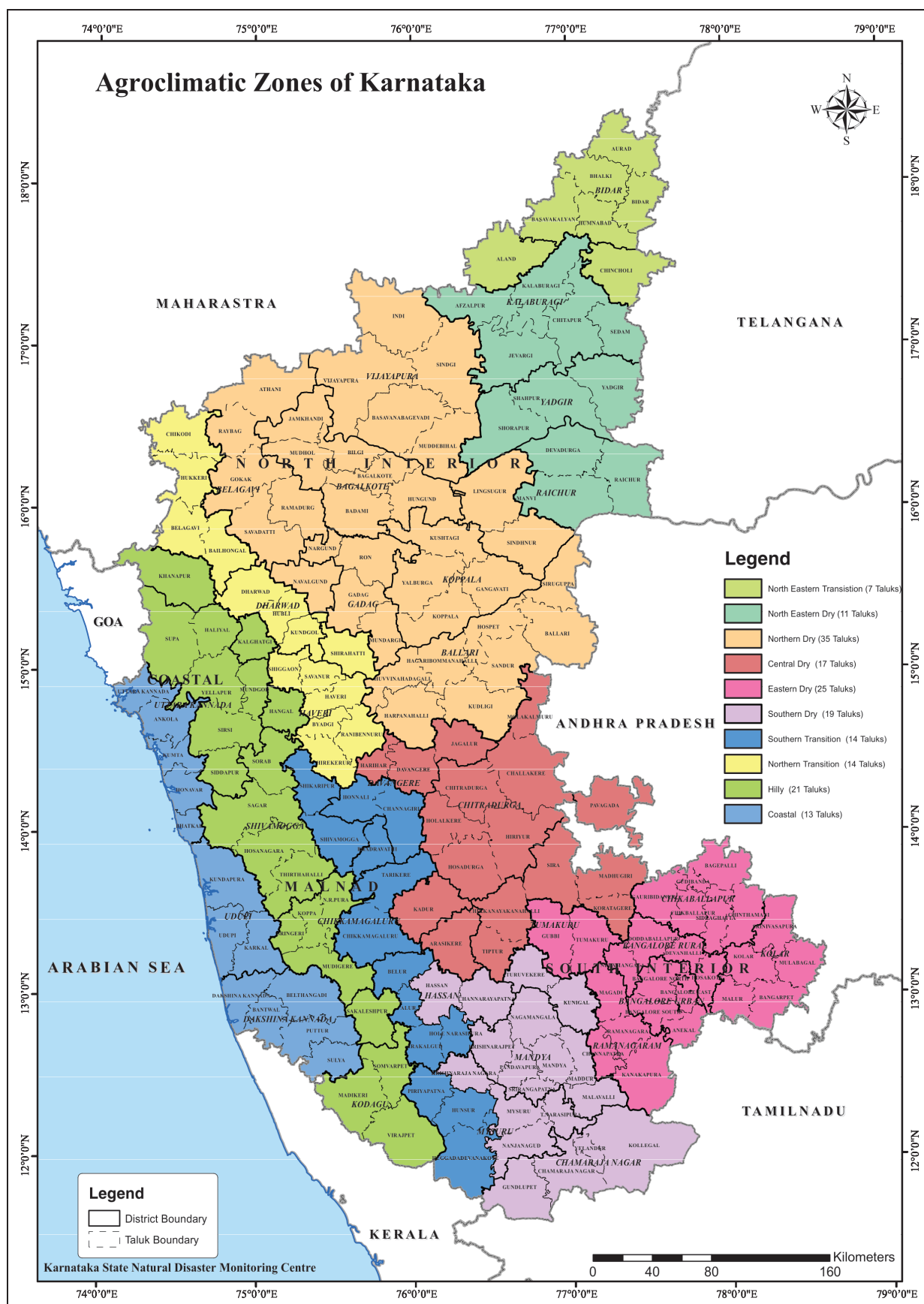


Fig. 2. Agroclimatic zones in Karnataka state

7.8 M land holdings of 1.55 ha average area. The small and marginal holdings account 76% of the total holdings in the state which occupy about 40% of the operated area (Agricultural Census 2010-11). Of the total cultivated area, the net irrigated area is about 4.09 M hectares (33%) and the net rainfed cultivated area is about 6.41 M hectares in the state. The Karnataka state has the second largest rain-fed agriculture area after Rajasthan. As, about 55% of total food grain and 74% of oilseeds production come from rain-fed agriculture in Karnataka, the rain-fed agriculture plays an important role in total food grain production in the state.

The state has three cropping seasons namely i) Kharif (6.92 Mha), ii) Rabi (3.03Mha), iii) Summer (0.59 Mha). Among the agricultural crops cereals (49%), pulses (24%), oilseeds (15%), cotton (6%), sugarcane (5%), tobacco (1%) occupy major area in the state. About 2.1Mha (17%) of the cultivated area is occupied by different horticultural crops such as Mango, Banana, Pomegranate, Papaya, Vegetables, Plantation crops like Coconut, Arecanut, Coffee, Cardamom and Pepper.

Major Reservoirs: There are three reservoirs in the state for hydroelectric generation, namely Linganamakki, Supa and Varahi. Other major reservoirs are Hemavathi, Harangi, KRS and Kabini in Cauvery river basin and six reservoirs Bhadra, Tungabhadra, Ghataprabha, Malaprabha, Almatti and Narayanapura in Krishna river basin. Majority of these reservoirs in Cauvery and Krishna basins are used for irrigation/drinking purposes. Additionally, there are 3580 minor irrigation tanks. Due to siltation, majority of these reservoirs& tanks have limited storage capacity and a few of them get dried up during summer season.

2.2 Hydro-Meteorological Disasters

The Karnataka state is prone to different kinds of natural hazards (disasters) such as drought, flood, cyclone, hailstorm and landslide. As a consequence of high spatial and temporal variability in rainfall, the state is more vulnerable to Hydro-Meteorological Disasters. Nearly 80% of the taluks in the State are drought prone and Successive droughts are a regular phenomenon in the state. Droughts and floods are observed in different regions of the state simultaneously. Droughts are typically wide spread and at times affect 92% (in 2003) of the taluks (162) in the state.

Floods affect crops, human settlements in several districts of the state. Cyclones, Coastal erosion are limited to Coastal districts while landslides are common in western-Ghats areas. The seismic activity is observed in Coastal and Malnad regions of the state. The type of disaster, cause, extent and impacts of the commonly occurring disasters in the state are as under (Table-1)

2.3 Drought Vulnerability in Different Regions

Karnataka is one of the 16 states in India, which is frequently affected by drought and flood simultaneously in different regions. A systematic drought vulnerability study carried out by KSNDMC indicate that, the Coastal and Malnad regions have less vulnerable area than South Interior and North Interior Karnataka. The magnitude of drought situation in SIK is less as compared to NIK.

Table 1. Drought vulnerability area in different regions

Region / DVI class	1	2	3	4	5	Total
	Area(ha)					
South Interior Karnataka	344065	1858889	2188158	462424	976063	5829599
North Interior Karnataka	245676	598452	1490014	1879711	4621684	8835537
Malnad	1805000	580644	126971	143913		2656528
Coastal	1520780	342376				1863156
Total	3915522	3380363	3805146	2486052	5597752	19184820

Note : DVI class: 1-Very Slight, 2-Slight, 3-Moderate, 4-High, 5-Very High

Chapter 3. DATA AND METHODOLOGY

The Variations in total precipitation can be caused by a change in the frequency of precipitation events, or in the intensity of precipitation per event, or a combination of both. In order to improve the understanding of precipitation behavior as an indicator of climate changes, the precipitation data series must be analysed (Brunetti et al 2001).

The Rainfall, Temperature and Relative Humidity data series for the last 58 years, from 1960 to 2017, have been considered for the analysis. Definitions of rainfall and weather parameters, laid out by IMD have been followed. The rainfall, measured from 08.30 hrs to 08.30 hrs of consecutive days (24 hrs) is represented as Daily rainfall. The mean rainfall over a specified area / location averaged for a long period Normal rainfall.

3.1 Rainfall:

The Taluk-wise daily rainfall data, for the period 1960 to 2017, has been used for deriving weekly, monthly, seasonal and annual data series. Further rainfall normal was calculated through long period averaging. The rainfall parameters and their variations over the years have been analyzed.

3.1.1 Change point detection

The Rainfall data series, from 1960 to 2017, has been analyzed to determine the point of significant change or mean change point year. The Mean change points are computed by using the mean change point function in Matlab Computer Application. For the sake of equal number of years in each period, the total period has been divided into the following two periods

Period-1 (P1) - 1964-1990 (27 years)

Period-2 (P2) - 1991-2017 (27 years)

3.1.2 Amount of rainfall

The mean rainfall is calculated for both P1 and P2 periods independently and subtracted from P2 to P1 and converted into percentages. To find out taluk wise variations, four selected taluks are identified one from each region (Table 2)

Table 2. List of Taluks selected from each Region for Rainfall Analysis.

Sl. No	Region	District	Identified Taluks
1	SIK	Chitradurga	Chalkere
2	NIK	Vijayapura	Vijayapura
3	Malnad	Shivamogga	Shivamogga
4	Coastal	Udupi	Udupi

For the calculation of percentage change in the mean rainfall, the mean rainfall of P2 is subtracted from that of P1 and expressed as percentage change. Further the mean rainfall change during P1 and P2 is statistically tested for significance. To find the extent of change, a statistically independent 't' test was used for comparing two means for all the taluks. A t-test is an inferential statistic used to determine if there is a significant difference between the means of two groups, which may be related in certain features. The 'p' values, thus obtained from the 't' test, are categorized as follows.

- i) 90% significantly increasing,
- ii) 90% significantly decreasing
- iii) Insignificant based on p-value at 10% level of significance.

3.1.1 Coefficient of Variation (CV (%))

The coefficient of variation (CV %) is a statistical measure of the dispersion of data points in a data series around the mean. The Rainfall CV is used to understand the inter annual variability of rainfall. This parameter indicate the amount of variability inherent in rainfall data over a long period of time from the mean value. A low ratio indicates a high degree of dependability, and high ratio indicates an erratic behavior. The **coefficient of Variation (CV %)** is calculated for all the taluks as follows.

$$CV = \frac{SD\ of\ the\ rainfall}{Meanrainfall} \times 100$$

Further, the percentage change of CV is calculated between two periods P1 and P2.

3.1.2 Rainy days

Average number of Rainy days have been computed for all the taluks. Mean variation in average number of rainy days for two periods P1 and P2 is tested by using 't' test to find the significance.

3.1.3 Intensity of rainfall (rainfall events)

The amount of rainfall received in a day or in 24 hrs indicates the intensity of rainfall. The intensity of Rainfall has been categorized into four categories. They are, Very Light Rainfall (VLR), Light Rainfall (LR), Moderate Rainfall (MR) and Heavy Rainfall (HR). Frequency of these different rainfall categories over the years of two periods P1 & P2 are computed annually and tested mean variation of significance between two periods by performing 't' test.

3.1.4 Dry spell

If the weekly cumulative rainfall is less than 50 % of the normal, for a given place during a standard week, then it is considered as a Dry Week. Consecutive Dry weeks is termed as Dry Spell. The frequency of dry spell with ≥ 3 dry weeks was calculated for the P1 and P2 period and the percentage of years with ≥ 3 weeks dry spell are calculated for the SW Monsoon season.

3.1.5 Below normal Rainfall years

The percentage departures of rainfall against the normal are calculated for all the years and categorized into Normal, Below Normal and Above Normal years. Then the percentage of Below Normal years are calculated for SW monsoon season.

3.1.6 Occurrence of Drought

Karnataka state has been subjected to Drought condition during successive years. The KSNDMC is the nodal Agency in the state to identify the Taluks with Drought condition and assist the State Government for notifying those Taluks as Drought affected. The Drought condition is assessed by following the scientific parameters prescribed by Govt of India. The KSNDMC has all the relevant data pertinent to Drought in Karnataka.

The Taluk-wise data on Drought declaration from 2001 to 2018 has been analyzed by using the linear trend method for understanding the changes in Drought occurrence.

3.2 Temperature and Relative Humidity

For studying variations in temperature and relative humidity pattern, district average Temperature and Relative Humidity values for the period of 2002-2018 were considered. The following linear equation is used for finding the magnitude of change in Temperature and Relative Humidity.

$$y = bx + c$$

Where 'y' is dependent parameter and 'b' is slope, 'x' is independent data series and 'c' is the constant. The slope b is calculated by fitting linear trend method. Slope represents the magnitude change per year. From negative or positive 'b', it can be classified as increasing and decreasing trend in Temperature and Relative Humidity over the years.

District wise monthly spatially averaged minimum and maximum temperature and relative humidity were collected for the period of 2002-2018 from KSNDMC and further converted into district, region and state wise annual Min and Max Temperatures from the monthly weather data. Region and state wise Min and Max Temperature are considered among the districts of particular region for each year.

- i. Change in Temperature
- ii. Change in Relative Humidity (RH)

Chapter 4. ANALYSIS OF CLIMATIC PARAMETERS

The Rainfall, Temperature and Relative Humidity data series for the last 58 years, from 1960 to 2017, have been analysed for determining the change point detection in Time Series, Trend and Coefficient of Variation (CV) etc. The results of statistical analysis at 95% confidence level for annual, seasonal, monthly and daily rainfall data using different techniques is given in this Chapter. Andrew & Annamalai (2012), have shown that the changing climatic conditions have a bearing on the monsoon rainfall pattern over India. Thus, the variations in the rainfall pattern in the last 58 years' time series, observed herein, has been considered as an indicator of Climate Change in the region.

4.1.1 Change point detection

The objective of the change-point detection is to discover abrupt changes, in the property, lying behind time-series data (Liu et al. 2012). The analysis of regional and state annual rainfall data series of the last 58 years (1960 -2017) shows that there is no statistically significant definite trend in Annual rainfall pattern and the moving average, except a few aberrantly above normal rainfall events in some years (Fig 3).

The mean change point of rainfall over the state is observed in the year 2001 (Fig 4). However, at the regional level, the South Interior Karnataka (SIK) and Malnad regions shows mean change point of rainfall during 1991, while the Coastal region shows during 1988 (Fig.5). So the year 1990 has been considered as mean change point year in Rainfall data Time Series. Based on this change point, the rainfall data series for the last 58 years was divided into two sub-series i.e P1 (1960-1990) and P2 (1991-2017) for further analysis.

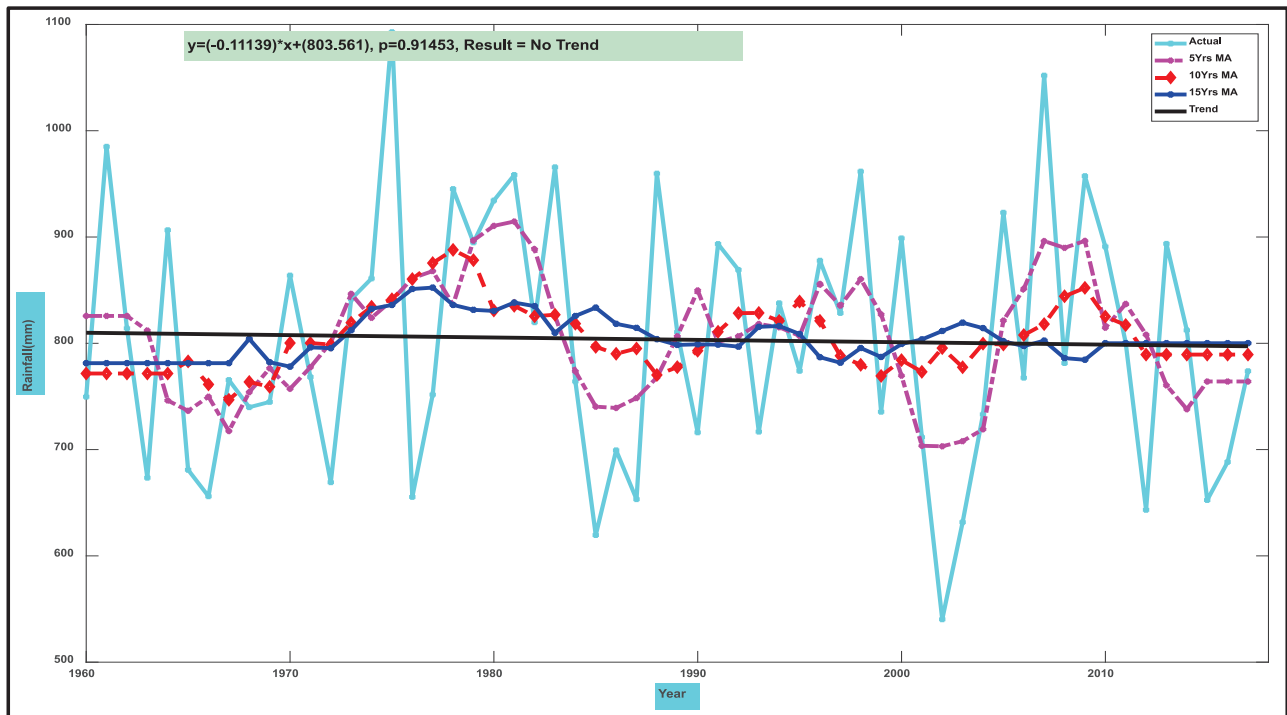


Fig. 3. State Rainfall Pattern and Moving Average of Southwest Monsoon Rainfall (mm)

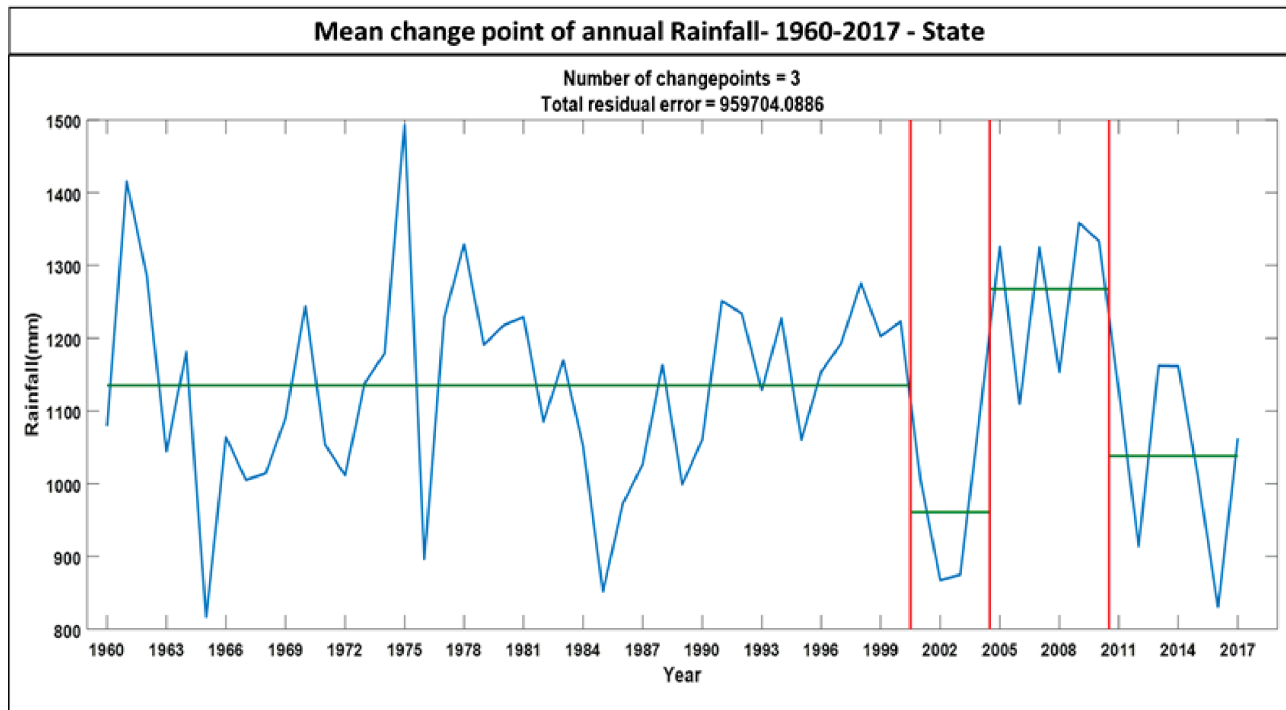


Fig. 4. Mean change point at State level.

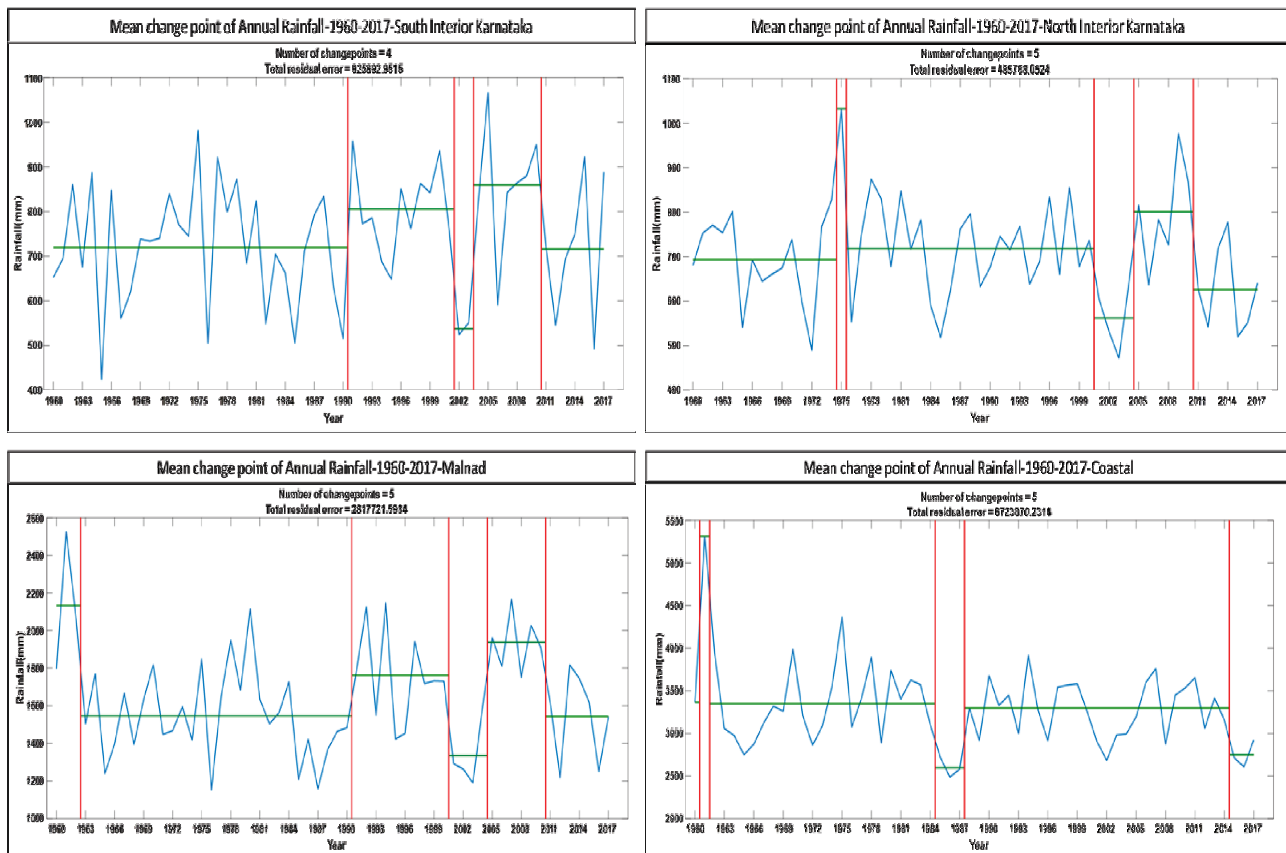


Fig. 5. Mean change points at Regional level.

4.1.2 Mean Rainfall

The analysis of mean rainfall variation at state, regional and district level, during P1 and P2, shows both positive (Increase) and negative (Decrease) shifts (Table-3). The observed positive change in rainfall (mm) at district level varies between 4 mm (Belagavi district) and 119mm (Shivamogga district), whereas the negative shift observed ranges from -314 (Dakshina Kannada) to -7mm (Bengaluru Rural district).

An increase in mean rainfall is observed in Shivamogga, Hassan, Kolar, Mysuru, Chitradurga and Bengaluru Urban districts. A decrease in mean rainfall is observed in Kalaburagi, Yadgir, Bagalakote, Vijayapura and Dakshina Kannada districts from P1 to P2. However, an increase in mean rainfall (at 90 % significant level) is observed in Shivamogga and Hassan districts. Similarly, a decrease in mean rainfall is observed in Yadgir, Kalburgi and Dakshina Kannada districts.

4.1.3 Weekly and Monthly Mean Rainfall

The State level weekly mean rainfall pattern shows a considerable decrease in 38th week from P1 to P2. Whereas the monthly mean rainfall of the state shows an increase during the months of June and October.

The region-wise weekly mean rainfall pattern shows that, the SIK region shows a decrease of weekly rainfall in the 38th week, while the monthly rainfall shows an increase in all the months except in September. Further, the SW-Monsoon and Annual rainfall also shows an increase in SIK region from P1 to P2.

The NIK region shows a rainfall decrease in the 38th week and the monthly rainfall also decreased in the months of July and September. The SW-Monsoon season as well as Annual rainfall also shows a decreasing trend in the region from P1 to P2.

In Malnad region, a decrease in weekly mean Rainfall is observed in 27th and 33rd Week, while the 35th and 36th Weeks shows an increasing trend in the region. The SW-Monsoon season and annual rainfall shows an increase in mean rainfall from P1 to P2.

In Coastal region, the weekly mean rainfall shows a decreasing trend in majority of the weeks from P1 to P2. The SW-Monsoon and Annual Rainfall also show a decreasing trend.

In all the regions and state as a whole, a significant decrease of weekly rainfall in 38th Week, observed suggests is a clear shift in the weekly rainfall from P1 to P2 (Fig-6).

To ascertain the significance of change in the mean annual rainfall and seasonal rainfall, an independent 't' test was performed on rainfall data series for P1 and P2 periods for all the taluks in the state (Table 4).

Table 4. Taluk level changes in Rainfall pattern from P1 to P2.

Region	Total No. of Taluks	Pre-monsoon			South west			North east			Annual		
		Increase 90% sig	Decrease 90% sig	Insignificant	Increasing 90% sig	Decreasing 90% sig	Insignificant	Increasing 90% sig	Decreasing 90% sig	Insignificant	Increasing 90% sig	Decreasing 90% sig	Insignificant
		Number of Taluks											
SIK	62	12	2	48	6	1	55	19	0	43	23	1	38
NIK	69	9	1	59	2	8	59	5	0	64	4	6	59
Malnad	25	5	0	20	4	0	21	6	0	19	10	0	15
Coastal	19	2	0	17	1	3	15	3	0	16	2	1	16
Total	175	28	3	144	13	12	150	33	0	142	39	8	128

Table 3. The Districts, Regional and State level variations in amount of rainfall.

S.No	District	Southwest Monsoon Rainfall				Annual Rainfall			
		P1 (mm)	P2 (mm)	Change (mm)	Change (%)	P1 (mm)	P2 (mm)	Change (mm)	Change (%)
1	Bengaluru Urban	465	499	34	7	836	943	107	13
2	Bengaluru Rural	457	450	-7	-2	820	858	38	5
3	Ramanagara	440	455	15	3	843	903	60	7
4	Kolar	376	418	42	11	715	841	126	18
5	Chikkaballapura	398	410	12	3	706	752	46	6
6	Tumakuru	394	407	13	3	733	766	33	4
7	Chitradurga	292	323	31	11	533	638	105	20
8	Davanagere	375	392	17	4	616	674	58	9
9	Chamarajanagara	342	302	-40	-12	823	757	-66	-8
10	Mysuru	346	373	27	8	730	806	76	10
11	Mandya	323	329	6	2	707	767	60	9
12	Ballari	401	380	-21	-5	625	629	4	1
13	Koppala	389	376	-13	-3	577	615	38	7
14	Raichur	476	437	-39	-8	672	656	-16	-2
15	Kalaburagi	641	532	-109	-17	830	729	-101	-12
16	Yadgir	651	510	-141	-22	872	730	-142	-16
17	Bidar	624	652	28	5	796	859	63	8
18	Belagavi	544	548	4	1	758	777	19	2
19	Bagalkote	380	343	-37	-10	592	573	-19	-3
20	Vijayapura	438	403	-35	-8	641	610	-31	-5
21	Gadag	383	348	-35	-9	618	611	-7	-1
22	Haveri	480	486	6	1	744	778	34	5
23	Dharwad	491	470	-21	-4	747	750	3	0
24	Shivamogga	1318	1437	119	9	1595	1761	166	10
25	Hassan	579	640	61	11	951	1058	107	11
26	Chikkamagaluru	1414	1438	24	2	1758	1849	91	5
27	Kodagu	2093	2035	-58	-3	2541	2520	-21	-1
28	Dakshina Kannada	3392	3078	-314	-9	3901	3712	-189	-5
29	Udupi	3583	3478	-105	-3	4038	4039	1	0
30	Uttara Kannada	2444	2427	-17	-1	2744	2762	18	1
Region wise and State									
31	SIK	375	390	15	4	719	777	58	8
32	NIK	492	462	-30	-6	708	699	-9	-1
33	Malnad	1201	1254	53	4	1548	1652	104	7
34	Coastal	2872	2764	-108	-4	3250	3214	-36	-1
35	State	805	799	-6	-1	1102	1135	33	3

Bold values are significant at 90% Confidence level

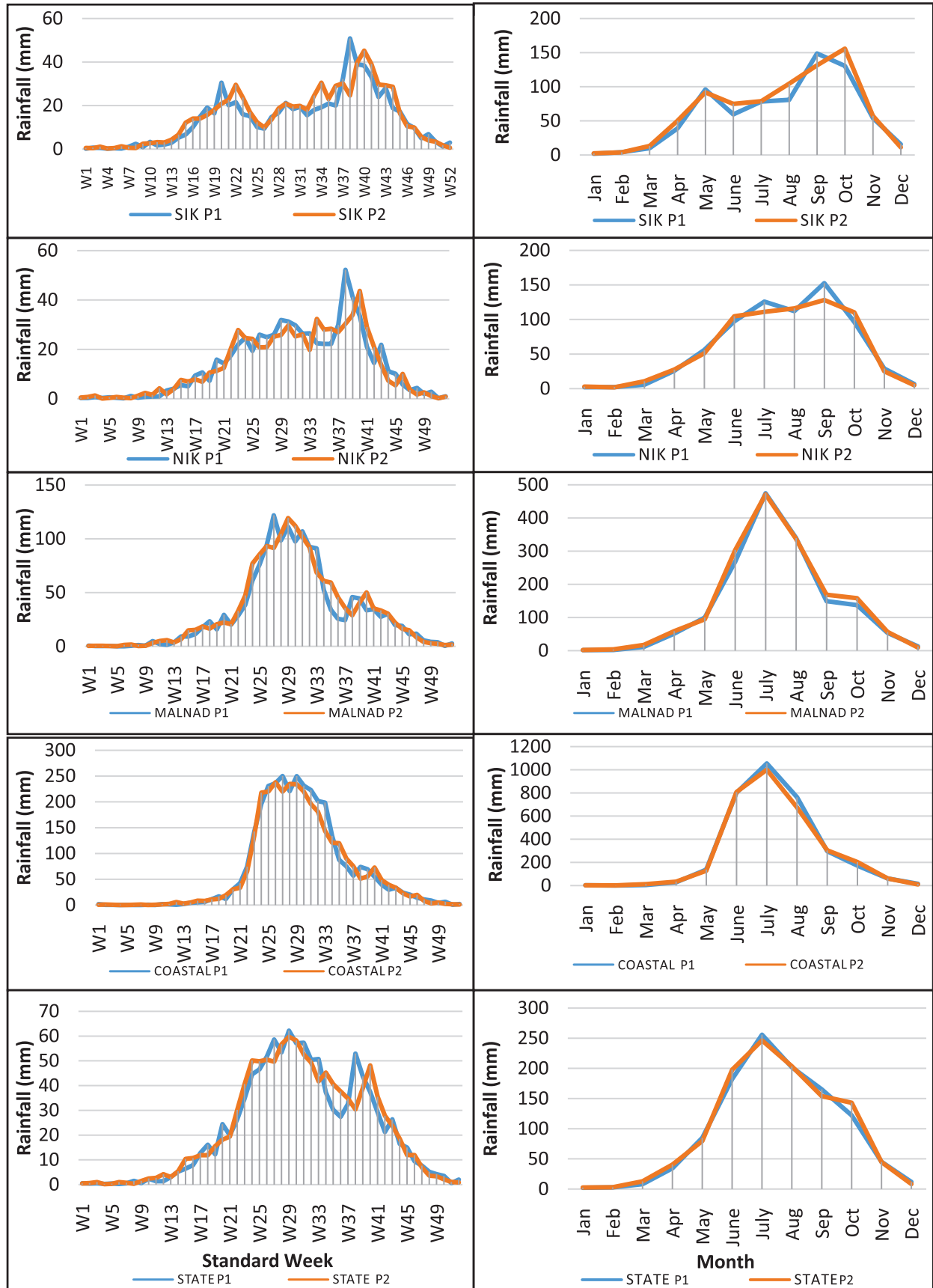


Fig. 6. Weekly and monthly Mean rainfall pattern for P1 and P2.

At state level, there is an increase in annual rainfall in 39 taluks and decrease in 8 taluks. The Pre-monsoon rainfall shows an increase in 28 taluks a decrease in 3 taluks. Increase in SW-Monsoon in 13 Taluks and decrease in 12 Taluks, an increase in 33 Taluks during NE-Monsoon season is observed.

Regionally, in SIK region there is a statistically significant increase (90% significance level) in annual rainfall in 23 taluks and decrease in 1 taluk. Seasonally, an increase in pre-monsoon rainfall in 12 taluks and decrease in 2 taluks is observed. There is an increase in rainfall in 6 taluks and decrease in 1 taluk during the SW monsoon season and Rainfall increase in 19 taluks during NE-Monsoon season.

In NIK region, there is an increase in Annual rainfall in 4 taluks and decrease in 6 taluks (at 90% significance level). An increase in Pre-monsoon rainfall is observed in 9 taluks and decrease in 1 taluk. The increase in rainfall in 2 taluks and decrease in 8 taluks during SW monsoon season and an increase in 5 taluks during NE-Monsoon has been observed.

In Malnad region, there is an increase in annual rainfall in 10 taluks at 90% significance level. In 5 taluks, an increase in pre-monsoon rainfall is observed. There is an increase in both southwest monsoon and northeast monsoon seasonal rainfall in 4 and 6 taluks respectively.

In Coastal region, annual rainfall is increasing in 2 taluks and decrease in 1 taluk (90% significance level). The results shows an increase in pre-monsoon rainfall season in 2 taluks. There is an increase in Southwest monsoon seasonal rainfall in 1 taluk and decrease in 3 taluks. Also, there is an increase in Northeast monsoon seasonal rainfall in 3 taluks.

The data series P1 and P2 has been analyzed to determine the variations in quantum of rainfall in one of the Taluks selected from each region in the state. The results are given in Table 5.

Table 5. The variations in quantum of rainfall (mm) in one of the Taluks selected from each region.

Taluk /Region	Pre-Monsoon			South-West Monsoon			North-East Monsoon			Annual		
	P1	P2	Change	P1	P2	Change	P1	P2	Change	P1	P2	Change
Chalalkere (SIK)	84	120	36	215	279	64	114	157	43	414	556	142
Vijayapura (NIK)	77	76	0	454	386	-68	141	144	3	671	606	-66
Shivamogga (Malnad)	130	125	-6	641	638	-3	177	199	22	948	962	14
Udupi (Coastal)	178	195	17	3371	3180	-191	241	293	52	3790	3668	-122
SIK	148	163	15	375	390	15	196	225	29	719	777	59
NIK	85	95	10	492	462	-29	131	142	11	708	699	-9
Malnad	153	175	22	1201	1254	53	193	223	29	1548	1652	104
Coastal	140	176	35	2872	2764	-108	238	274	35	3250	3214	-37
State	123	139	16	805	799	-6	174	197	23	1102	1135	33

The Challakere Taluk in SIK region shows a significant increase in Annual and SW-Monsoon seasonal rainfall from P1 to P2. On the contrary, the Vijapura Taluk, in NIK region, shows a decrease in Annual and SW-Monsoon rainfall. The Shivamogga Taluk in Malnad region shows statistically insignificant increase in Annual and SW-Monsoon rainfall. The Udupi Taluk in Coastal region shows a significant decrease in Pre monsoon and SW-Monsoon rainfall.

Among the regions, SIK and Malnad regions showed insignificant increase in Annual rainfall and seasonal rainfall, while NIK and Coastal regions showed a marginal decrease in SW-Monsoon rainfall.

State as whole, there is a marginal increase in pre-monsoon, Northeast monsoon and Annual rainfall, whereas Southwest monsoon rainfall shows a decreasing trend.

The SW-Monsoon seasonal rainfall (mm) has varied in the state from P1 to P2 (Fig-8). Most of the taluks in SIK and Malnad regions shows an increase in the amount of rainfall and majority of the taluks in NIK and Coastal regions shows a decrease in the amount of rainfall from P1 to P2. The significant change in the SW Monsoon rainfall from P1 to P2 taluks are given in Fig-8.

4.1.4 Change in Coefficient of variation (CV%)

The Rainfall Coefficient of variation (CV %) in rainfall explains the extent of year to year variation within the time series. Thus, the CV of SW-Monsoon rainfall at Taluk level was computed for P1 and P2 series to know the inter-annual variability of rainfall (Table 6 and Fig.9).

Table 6. CV (%) and its change from P1 to P2

Taluk/Region	CV (%) SW-Monsoon Rainfall (P1)	Change (%)
Chalkere (SIK)	38	11
Vijayapura (NIK)	34	8
Shivamogga (Malnad)	50	-20
Udupi (Coastal)	17	-1
SIK	27	-2
NIK	21	1
Malnad	18	4
Coastal	15	-2
State	15	0

The CV (%) of SW-Monsoon rainfall for Chalkere and Vijayapura taluks shows 11% and 8% increase from P1 to P2 respectively. Whereas Shivamogga taluk shows 20% decrease of rainfall CV. The remaining taluks and regions have shown a statistically insignificant change in CV of Rainfall.

At the District level, the increase in CV %, observed in parts of Vijayapura, Bagalkote, Raichur, Koppal, Ballari, Gadag, Dharwad, Belagavi, Haveri, Davanagere, Chitradurga, Chikkamagaluru, Bengaluru and Ramanagara districts, indicates that the inter-annual variability of rainfall has increased over these districts. Remaining taluks of the state have shown a decrease in CV (%) from P1 to P2, indicating a decrease in inter-annual variability of rainfall from P1 to P2. (Sreenivasa Reddy. et al. 2019).

4.1.5 Change in rainy days

The imprints of climate change can also be observed in terms of shifting weather patterns. The areas with steady amount of rainfall are now experiencing more extreme precipitation events. The regions are experiencing long spells of little to no rainfall between heavy rainfall events. As per the guidelines of IMD, a rainy day is defined as that a day which receives rainfall amount of more than 2.5 mm. The bulk of the monthly, seasonal, and annual rainfall at a station is contributed by a small percentage of the total number of rain days with large rain amounts. The variations in heavy rainfall, total rainfall and dry days (<2.5 mm of rainfall) are strongly related to changes in maximum temperature and cloud cover (Suppiah and Hennessy1998).

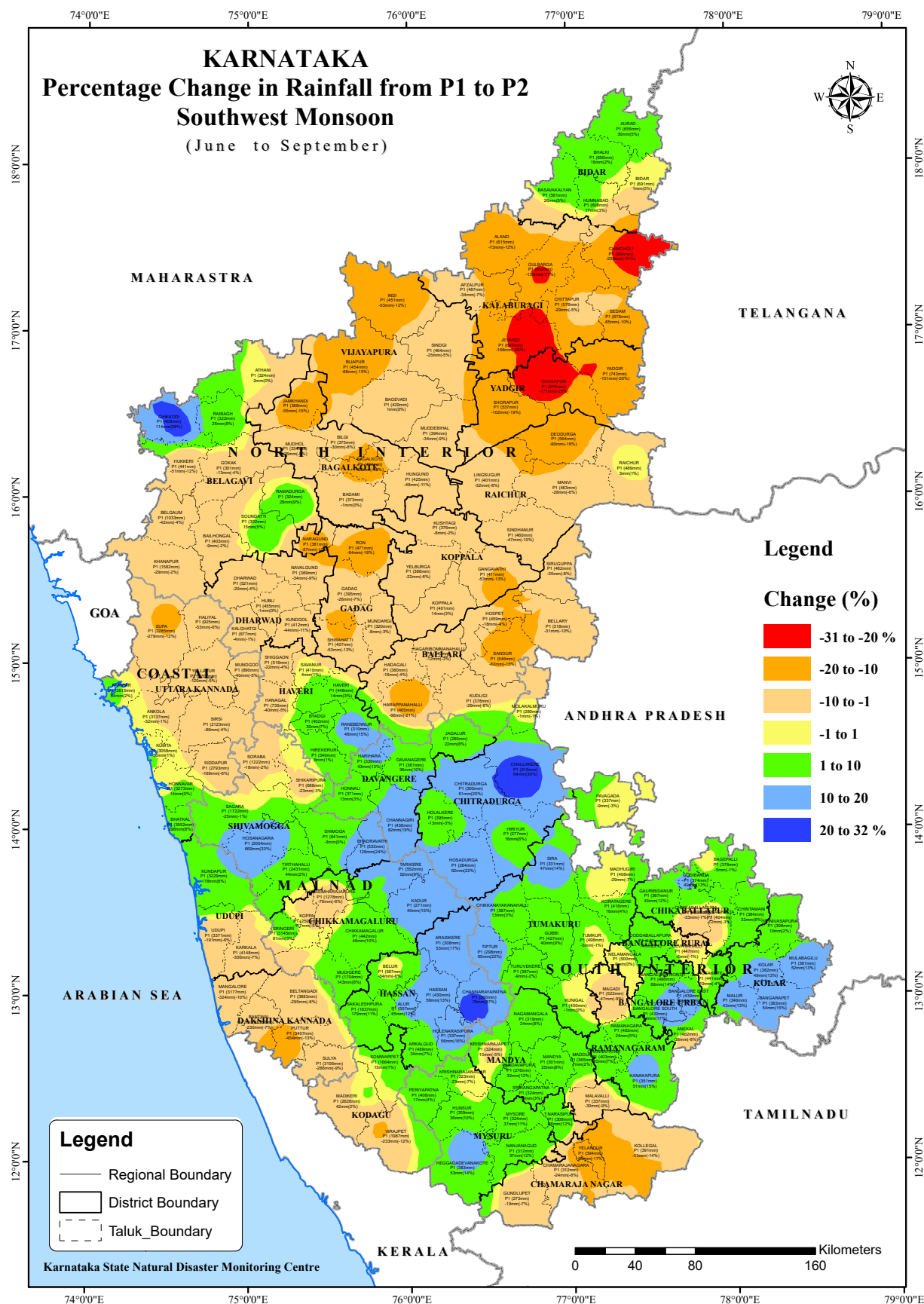


Fig. 7. Percentage change in the Southwest Monsoon Rainfall from P1 to P2

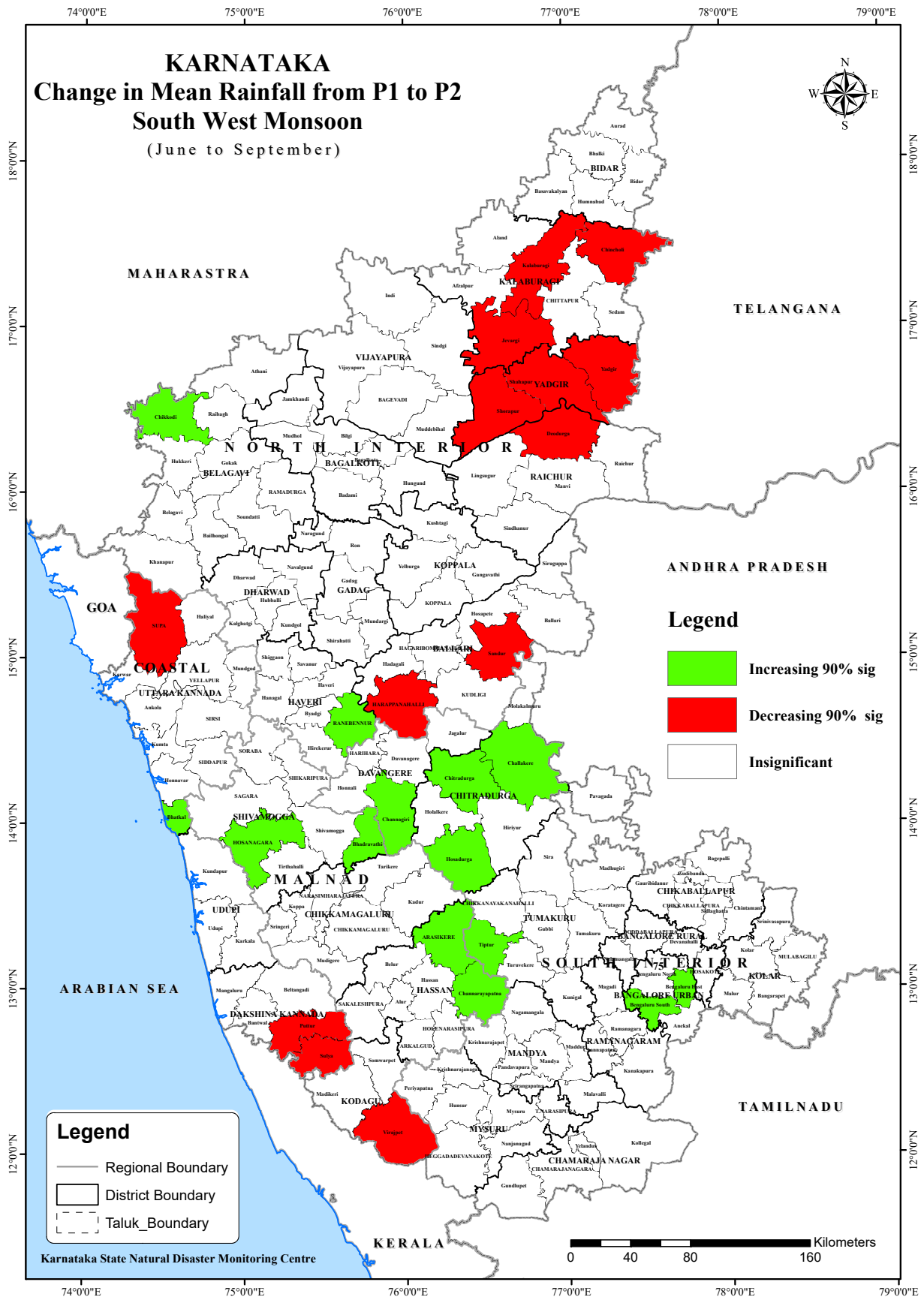
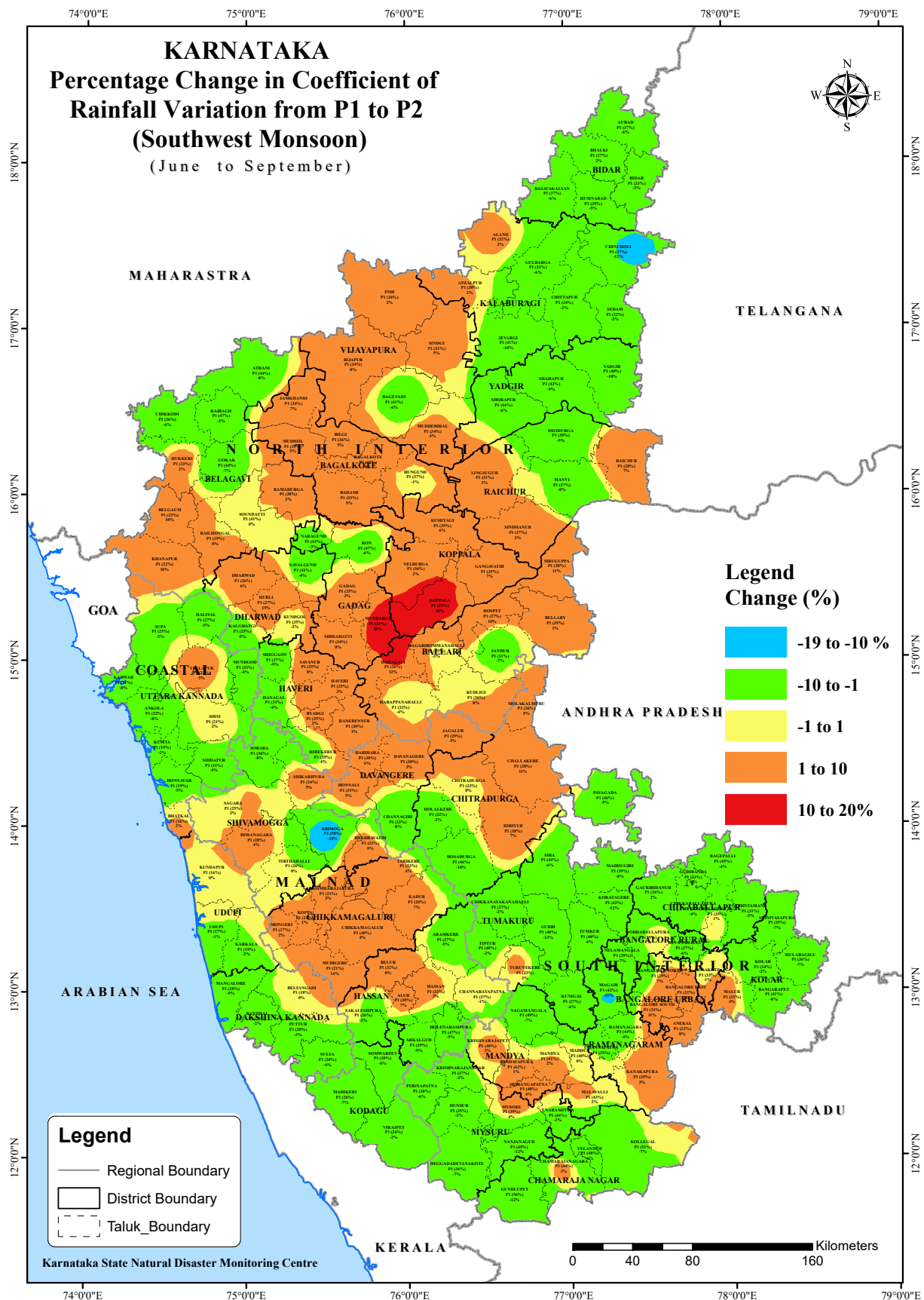


Fig. 8. Change (90% significance) in the SWMonsoon rainfall (mm) from P1 to P2



Computation of the rain days can provide the information regarding frequency and intensity of rain events during different weather conditions. For example, the drought season may be marked by both fewer rain days and less rain per day as compared to periods of normal and above-normal rainfall. Therefore, statistical features of the daily rainfall distribution over an area is important in understanding the rainfall climatology (Nandargi & Mulye 2012).

The rainfall data series for the P1 and P2 periods have been analyzed to decipher the variations in number of rainy days between P1 and P2. The monthly seasonal and annual trend in rainy days have also been computed.

The result shows that there is no significant change in monthly average rainy days in the state from P1 to P2 (Fig.10). The monthly mean rainy days have increased in SIK and Malnad region in most of the months during P2. In NIK region, there is an increase in monthly mean rainy days during June, August and October, whereas in the month of July, it has decreased during P2. In Coastal region, March, April and October months shows an insignificant increase in mean rainy days, whereas there is no significant change in rainy days in other months.

Change in average rainy days at Taluk level for all the seasons and annual has been tested for significance, classified and presented in Tables 7 and 8. A significant increase in average mean rainy days, during the Pre-Monsoon season, is observed in SIK (42 taluks), NIK (23 taluks), Malnad (13 taluks) and Coastal (14 taluks) regions. An insignificant changes observed in the remaining taluks.

During the SW-Monsoon season, SIK (19 taluks), NIK (3 taluks), Malnad (8 taluks) and Coastal (1 taluk) have shown a significant increase in average mean rainy days. An insignificant change is observed in the remaining taluks (Fig 11 & 12).

During the NE-Monsoon season, SIK (25 taluks), NIK (10 taluks), Malnad (6 taluks) and Coastal (4 taluks) regions have shown a significant increase in average mean rainy days. An insignificant change is observed in remaining taluks.

The mean annual rainy days in SIK (46 taluks), NIK (20 taluks), Malnad (15 taluks) and Coastal (10 taluks) have shown a significant increasing trend. An insignificant change is observed in the remaining taluks from P1 to P2.

Table 7. Region-wise variations in seasonal mean rainy days.

Region	Total No. of Taluks	Pre-monsoon			South west			Northeast			Annual		
		Increase (90% sig)	Decrease (90% sig)	Insignificant	Increase (90% sig)	Decrease (90% sig)	Insignificant	Increase (90% sig)	Decrease (90% sig)	Insignificant	Increase (90% sig)	Decrease (90% sig)	Insignificant
		No. of taluks											
SIK	62	42	0	20	19	0	43	25	0	37	46	0	16
NIK	69	23	0	46	3	0	66	10	0	59	20	0	49
Malnad	25	13	0	12	8	0	17	6	0	19	15	0	10
Coastal	19	14	0	5	1	0	18	4	0	15	10	0	9
Total	175	92	0	83	31	0	144	45	0	130	91	0	84

Season-wise variations in regional and state level Average rainy days from P1 to P2 for selected taluks are given in Table 7.

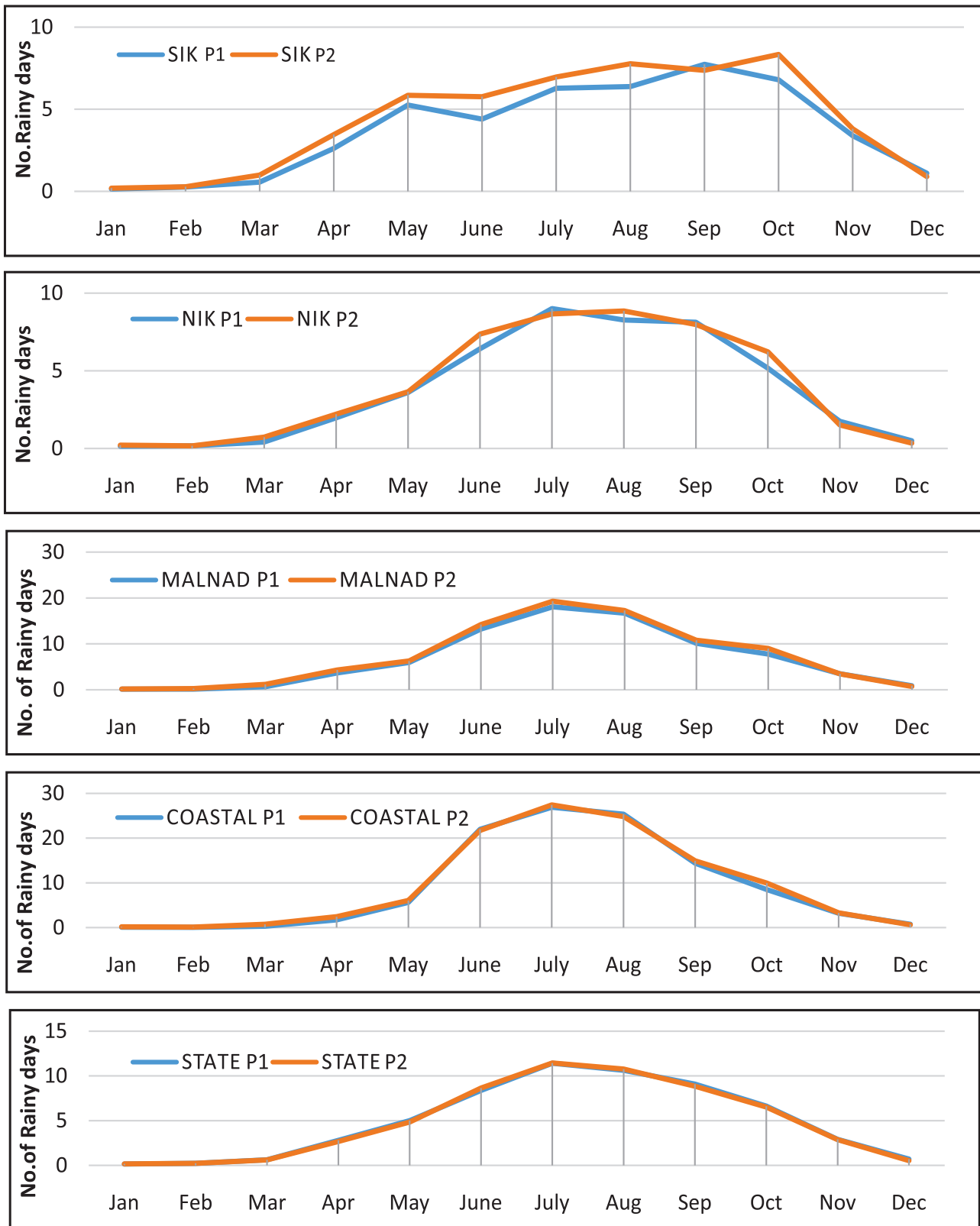


Fig. 10. Regional and State level monthly average rainy days pattern for P1 and P2.

The average annual rainy days shows an increasing trend in Challakere (28 to 34), Shivamogga (64 to 70), Udupi (111 to 117) taluks and SIK (45 to 52), Malnad (81 to 87) regions. The Vijayapura taluk showed 3 days decrease (42 to 39). While NIK, Coastal regions and state annual average rainy days have not changed significantly from P1 to P2 (Table 8). The Changes in average Rainy days at Taluk level is given in Fig. 11 and 12.

Table 8. Change in number of rainy days in selected taluks of different regions.

Taluk/ region	Pre-Monsoon			South-west Monsoon			North-east Monsoon			Annual		
	P1	P2	Change	P1	P2	Change	P1	P2	Change	P1	P2	Change
Challakere (SIK)	5	7	2	15	18	3	7	9	2	28	34	6
Vijayapura (NIK)	6	6	0	28	25	-3	8	8	0	41	38	-3
Shivamogga (Malnad)	8	8	0	46	51	5	10	11	1	64	70	5
Udupi (Coastal)	7	9	2	93	94	1	12	14	3	111	117	6
SIK	9	11	2	25	28	3	11	13	2	45	52	7
NIK	6	7	1	32	33	1	7	8	1	46	48	2
Malnad	11	12	2	58	62	3	12	13	1	81	87	6
Coastal	8	10	2	89	89	0	12	14	1	109	112	3
State	9	9	0	39	40	0	10	10	0	59	58	1

4.1.6 Change in category of rainfall events.

The variations in these rainfall events from P1 to P2 are tested for significance (Table 9). The rainfall in a day is classified into four categories, based on the amount of rainfall in each event.

Table 9. Change in category of rainfall in different regions from P1 to P2

Region	Total No. of Taluks	VLR(0.1 to 2.5mm)			LR(2.6 to 15.5mm)			MR(15.6 to 64.4mm)			HR(>=64.5mm)		
		Increase (90% sig)	Decrease (90% sig)	Insignificant	Increase (90% sig)	Decrease (90% sig)	Insignificant	Increase (90% sig)	Decrease (90% sig)	Insignificant	Increase (90% sig)	Decrease (90% sig)	Insignificant
		Number of Taluks											
SIK	62	61	0	1	49	0	13	3	2	57	13	7	42
NIK	69	67	0	2	38	0	31	2	14	53	3	13	53
Malnad	25	24	0	1	13	0	12	6	1	18	3	1	21
Coastal	19	19	0	0	9	0	10	5	0	14	1	4	14
Total	175	171	0	4	109	0	66	16	17	142	20	25	130

VLR=Very Light Rainfall, LR=Light Rainfall, MR=Moderate Rainfall, HR=Heavy Rainfall

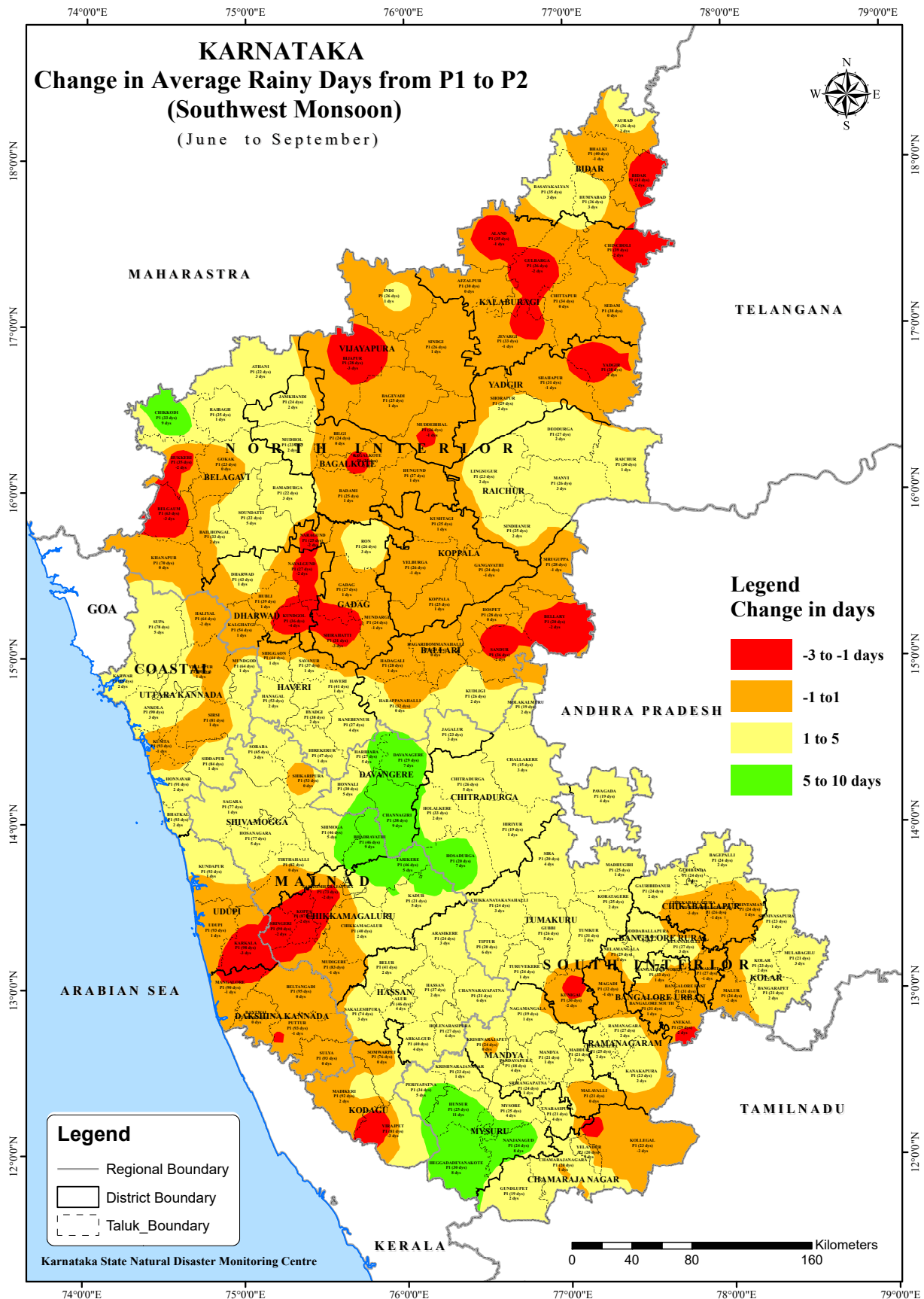


Fig. 11. Change in the Southwest monsoon Average rainy days from P1 to P2.

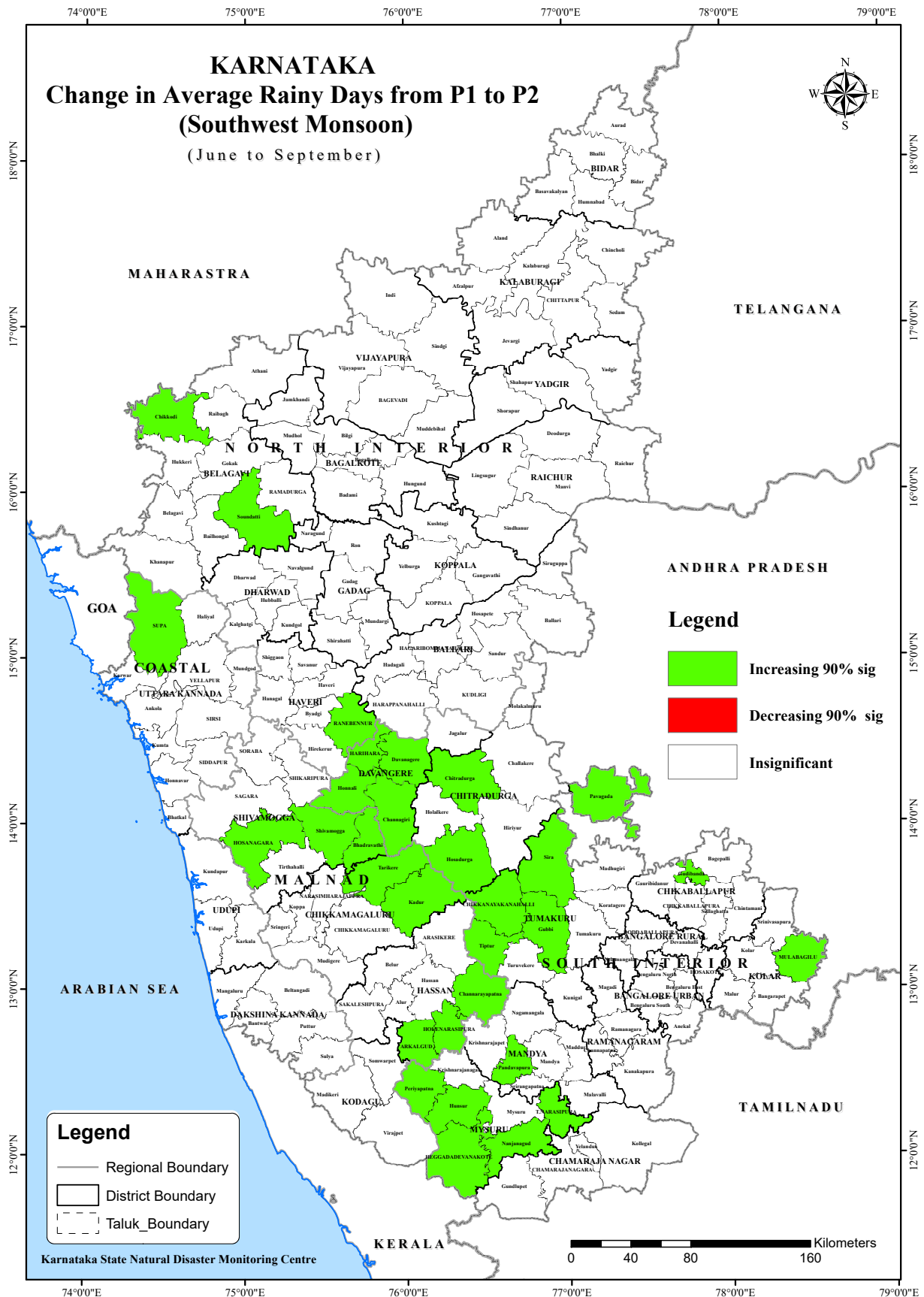


Fig. 12. Significant Change in the Southwest monsoon season Average rainy days from P1 to P2.

Majority of the taluks in different regions shows a significant increase in frequency of Very Light and Light rainfall events (Fig 13).

The Moderate and Heavy rainfall events in NIK region shows a significant decrease in 14 taluks. The Heavy rainfall events have a significant increase in 10 taluks and a decrease in 9 taluks of SIK region. In Malnad region, the Heavy rainfall events have significant increase in 3 taluks and a decrease in 1 taluk. In Coastal region, Heavy rainfall events have a significant increase in 1 taluk and a decrease in 4 taluks. The remaining taluks showed an insignificant change in Heavy rainfall events from P1 to P2.

The number of rainfall events in selected taluks are given in Table.10

Form Table 10, it is observed that there is a significant increase in VLR events in (from 110 to 478), moderate rainfall events (from 307 to 411) in Challakere taluk. A significant increase in light rainfall events is observed also in Shivamogga (from 777 to 900) and Udupi (from 557 to 686) taluks.

Heavy rainfall events showed a significant increase in Challakere (from 6 to 20), a decrease in Vijayapura (from 26 to 17) and Udupi (from 485 to 405) taluks was observed.

In remaining categories, no significant change were observed in these taluks.

The changes in Taluk level Mean heavy rainfall days is given in Fig. 14 and significant change (at 90%) is in Fig. 15.

Table 10. Number of rainfall events in selected taluks of different Region in P1 & P2

Taluk	VLR (0.1 to 2.5mm)			LR(2.6 to 15.5mm)			MR (15.6 to 64.4mm)			HR (≥64.5mm)		
	P1	P2	change	P1	P2	change	P1	P2	change	P1	P2	change
Chelakere	110	478	368	307	411	104	434	488	54	6	20	14
Vijayapura	812	694	-118	481	429	-52	610	589	-21	26	17	-9
Shivamogga	628	1050	422	777	900	123	927	953	26	31	29	-2
Udupi	342	653	311	557	686	129	1967	2070	103	485	405	-80

Bold values are significant at 90%

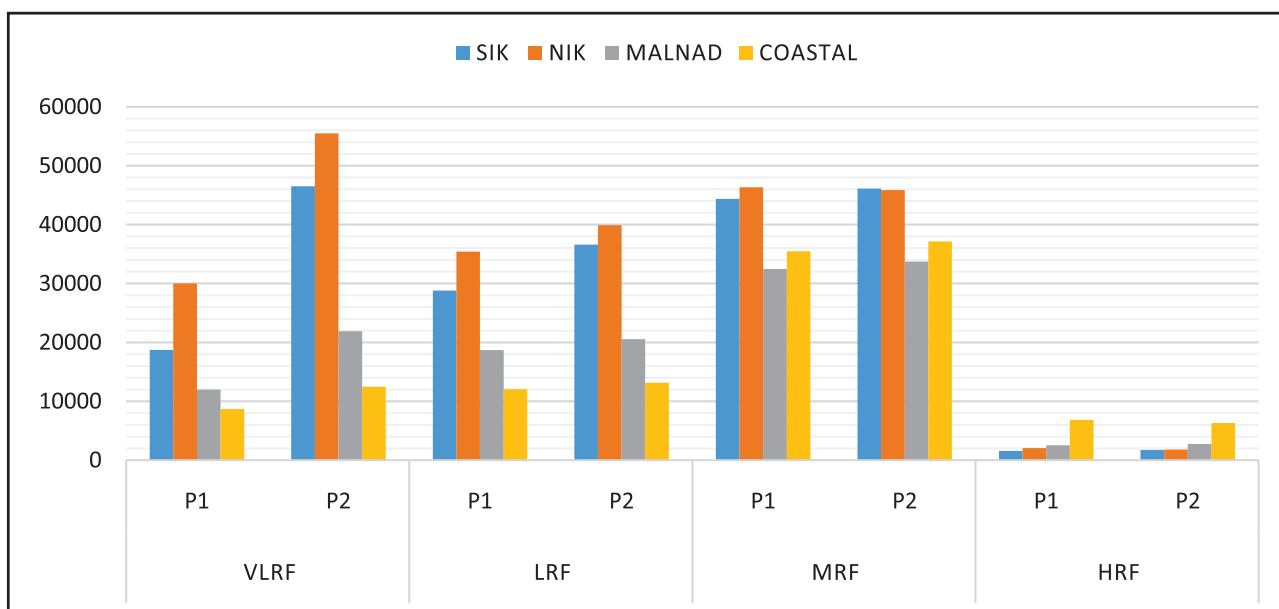


Fig. 13. Region wise category of rainfall events for P1 and P2

It is observed that there is an increase in Very Light Rainfall (VLR) and Light Rainfall (LR) events in all the regions from P1 to P2 (Table 9).

Moderate rainfall (MR) events have increased in SIK, Malnad and Coastal regions. Whereas MR has decreasing trend in NIK from P1 to P2.

Heavy Rainfall (HR) events have increased in SIK (1590 to 1737) and Malnad (2525 to 2773). Whereas the HR events have decreased in coastal region (6844 to 6300) and NIK (2042 to 1793).

4.1.7 Dry spell pattern (≥ 3 weeks)

A day, from 08.30 hrs to 08.30 hrs of consecutive days, having < 2.5 mm of rainfall is considered as a Dry Day and a week having rainfall 50% less than the normal is considered as a Dry Week. The Dry spell, is defined as an extended period of dry days / weeks. Therefore, a dry spell, is a continuous period with precipitation less than the normal for that period (Tebaldi et al. 2006; Sushama et al. 2010).

The Dry Spell, characterized with deficit rainfall, will have immense adverse impact on agriculture activity as well as Hydrological status (soil moisture, stream flow, groundwater, and reservoir storage) of the region. It is a very important parameter to assess the drought intensity and spread. If the dry spell exists initially during the monsoon, it affects the growth and yield of the crop.

The rainfall time series for P1 and P2 have been analyzed to delineate the taluk-wise dry spell pattern during the SW-Monsoon, compute the percentage of years with ≥ 3 weeks dry spell occurrence in the season (Fig-16).

4.1.8 Change in below normal Rainfall years.

The Departure of SW-Monsoon rainfall from Normal was calculated for P1 and P2 periods and categorized into Normal, Below Normal and Above Normal categories. To ascertain the drought pattern, Taluk-wise change in below normal years are calculated for P1 and P2 periods and presented in Fig-17.

The results shows an increase in below normal rainfall years for most of the Taluks in NIK from P1 to P2. and the period ranged from 1 to 5 years, while in Vijayapura, Kalaburagi, Jevargi, Shahapur and Chincholi taluks, it ranged from 5 to 10 years.

There is a decrease in the range of 1 to 5 years in number of below normal rainfall years in majority of the taluks of SIK and Malnad regions.

4.2. Change in Temperature ($^{\circ}\text{C}$) and Relative Humidity (RH %)

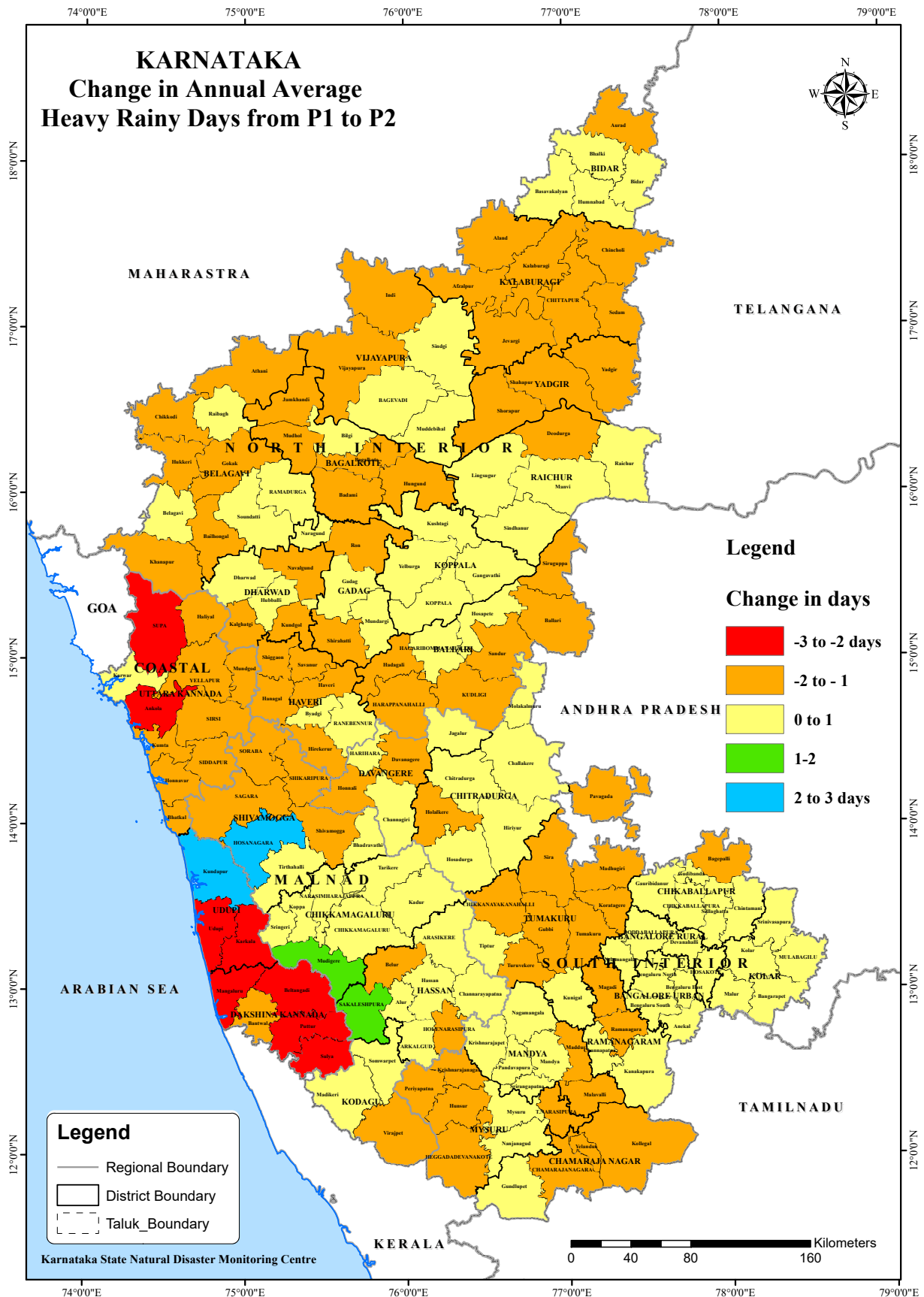
Besides the rainfall and its variation in different regions, the Temperature and Relative Humidity are also the prime indicators of climate change. So it is important to see the changes in the Temperature and Relative Humidity over the years.

The Temperature and Relative Humidity data from 2002 to 2018 has been considered for the analysis. Further monthly Temperature and Relative Humidity data is converted to annual data by averaging the minimum and maximum Temperature and Relative Humidity.

The trend of linearity is fitted and graphically presented in the figures 18, 19, 20 and 21. For finding the significance of the trend over the period, Man-Kendall statistical test and Sen's slope method have been applied and the results are presented in Table. 11.

It is evident that, the average annual temperatures showed an increasing trend (significant at 95% level) in Bengaluru Urban, Bengaluru rural, Ramanagara, Kolar, Chikkaballapur, Tumkuru, Mandya districts of SIK region, Ballari district of NIK region, Dakshina Kannada of Coastal region (Figs 18, 19, 20, and 21).

Average relative humidity showed a significant decreasing trend in Chitradurga, Davanagere, Mysuru, Mandya districts from SIK region, Ballari, Koppala, Belagavi, Haveri, Gadag, Dharwad from NIK region,



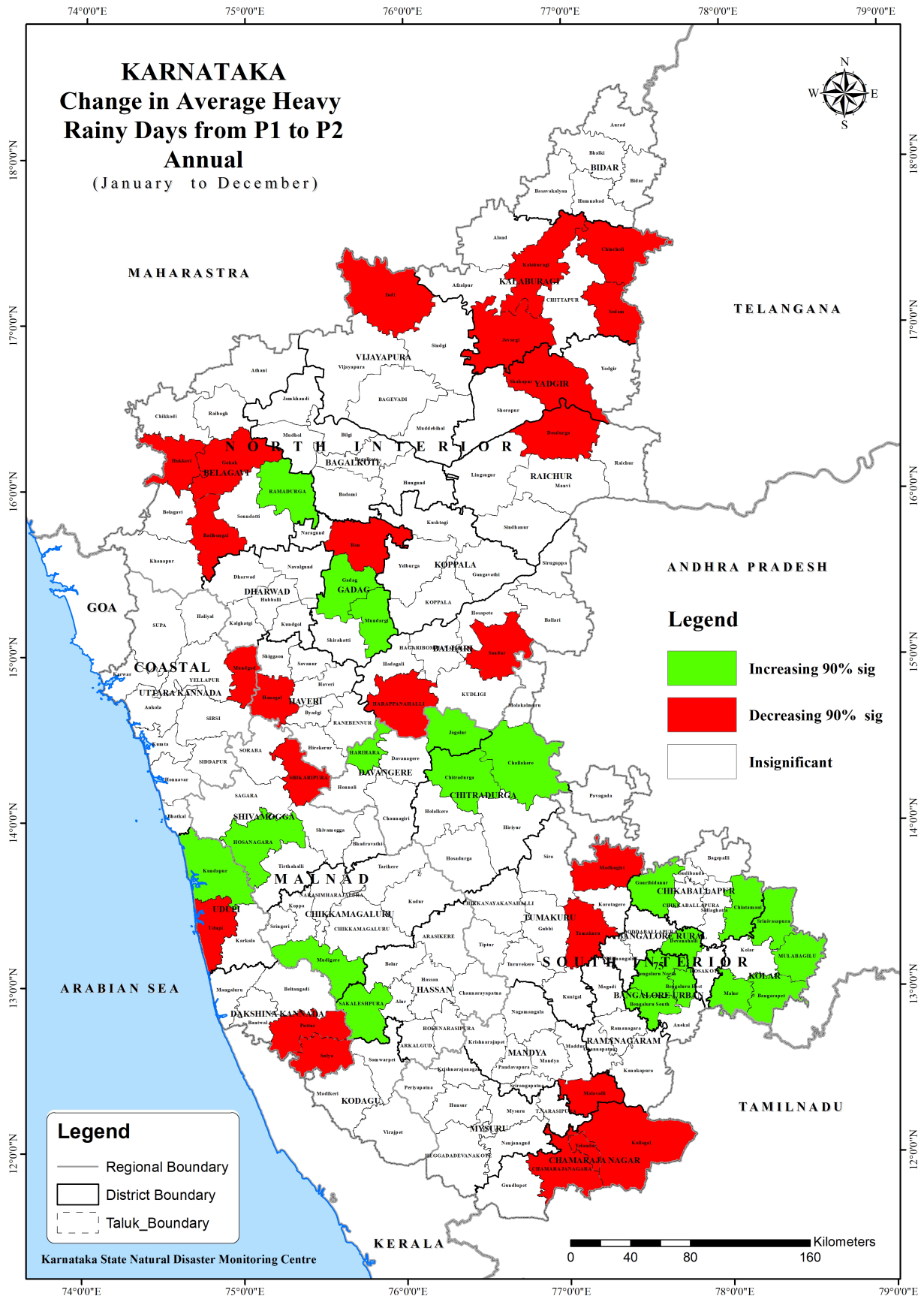


Fig. 15. Significant Change in the Annual Heavy Rainfall days from P1 to P2

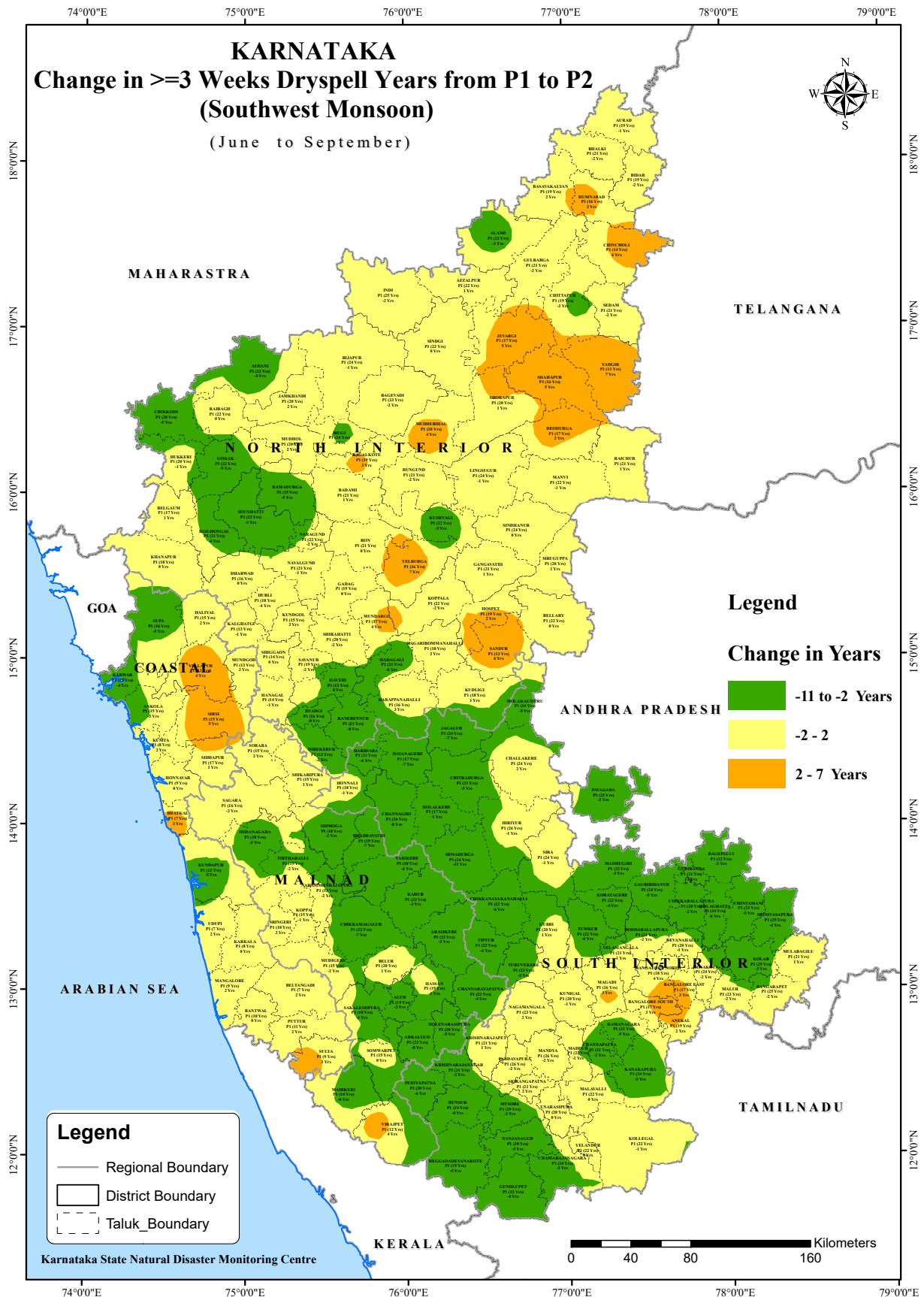


Fig. 16. Change in ≥ 3 weeks dry-spell in Southwest Monsoon Season from P1 to P2

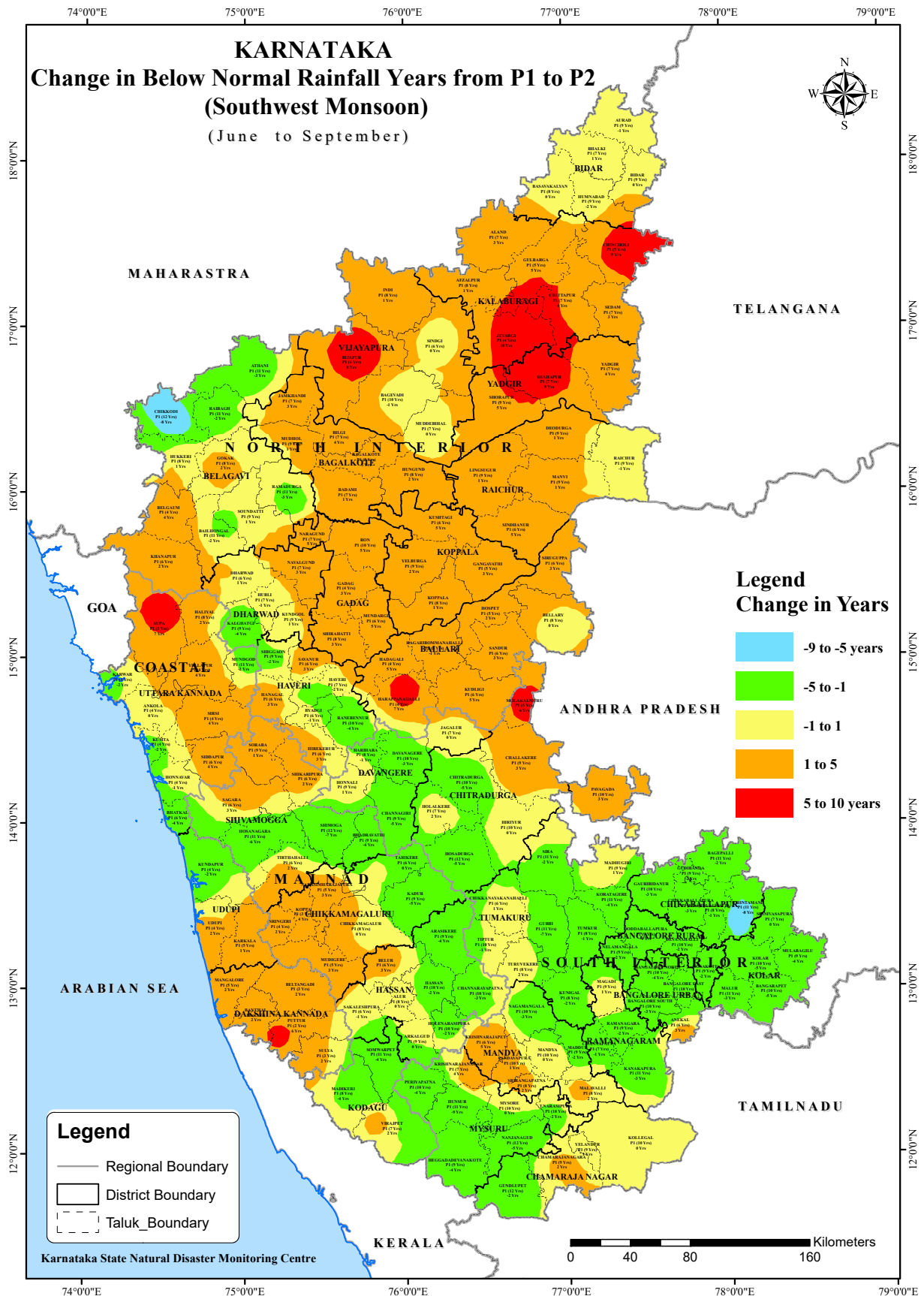


Fig. 17. Taluk-wise change in below normal years from P1 to P2.

Shivamogga, Hassan, Kodagu from Malnad region and Uttara Kannada district from Coastal region. Among the regions Malnad and Coastal regions showed a significant decreasing trend.

Table 11. Trend in Temperature and Relative Humidity over the years (2002-2018)

District\Region	Sen slope for Temperature and RH					
	Change in Temperature(°C)/ year			Change in RH(%)/ year		
	Avg.	Min	Max	Avg.	Min	Max
Bengaluru Urban	0.10	0.19	-0.01	0.40	-0.40	1.48
Bengaluru Rural	0.12	0.21	-0.01	0.31	-0.54	1.15
Ramanagara	0.13	0.09	0.08	0.12	-0.91	1.81
Kolar	0.12	0.26	-0.04	0.24	-0.10	0.66
Chikkaballapura	0.10	0.13	0.05	0.29	-0.26	0.99
Tumakuru	0.12	0.06	0.18	-0.32	-1.45	1.12
Chitradurga	-0.05	-0.15	0.04	-1.00	-2.11	0.24
Davanagere	0.07	0.06	0.11	-1.04	-2.74	0.49
Chamarajanagara	-0.02	0.03	-0.11	-0.51	-1.41	1.30
Mysuru	0.13	0.05	0.22	-1.38	-3.44	0.66
Mandya	0.18	0.20	0.10	-1.57	-3.25	0.43
Ballari	0.15	0.04	0.02	-0.54	-1.99	0.93
Koppala	0.12	0.15	0.24	-0.49	-1.36	0.45
Raichur	0.00	-0.03	0.02	-0.14	-0.86	0.65
Kalaburagi	0.00	0.02	0.03	0.34	-0.16	1.00
Yadgir	-0.04	-0.08	-0.01	0.18	-0.57	0.79
Bidar	-0.11	-0.09	-0.03	-0.34	-1.46	0.58
Belagavi	-0.01	-0.02	-0.08	-0.68	-1.75	0.57
Bagalkote	0.02	-0.03	-0.03	-0.24	-1.35	0.86
Vijayapura	-0.06	-0.03	0.06	-0.22	-1.10	0.65
Gadag	0.07	0.05	-0.11	-0.43	-1.86	1.19
Haveri	0.01	-0.07	0.01	-0.42	-1.01	0.10
Dharwad	-0.04	-0.01	0.06	-0.47	-1.69	0.74
Shivamogga	-0.01	-0.09	-0.08	-0.86	-2.26	0.38
Hassan	0.07	-0.03	-0.03	-0.60	-1.98	0.79
Chikkamagaluru	0.07	0.08	0.04	-0.57	-2.21	0.97
Kodagu	-0.04	-0.08	0.09	-1.00	-2.58	0.52
Dakshina Kannada	0.12	0.21	0.01	-0.42	-1.27	0.34
Udupi	0.01	0.10	-0.02	-0.52	-1.11	0.19
Uttara Kannada	0.09	0.11	0.04	-0.82	-1.83	0.14
SIK	0.13	0.25	0.01	0.02	-0.47	0.71
NIK	-0.07	-0.08	-0.09	-0.08	-0.60	0.44
Malnad	0.06	0.04	0.06	-0.79	-2.14	0.45
Coastal	0.05	0.11	-0.02	-0.57	-1.29	0.21
State	0.02	0.06	-0.03	-0.12	-0.44	0.24

Note: Bold value values indicate significance at 95%



Fig. 18. Region-wise Temperature pattern in the state.

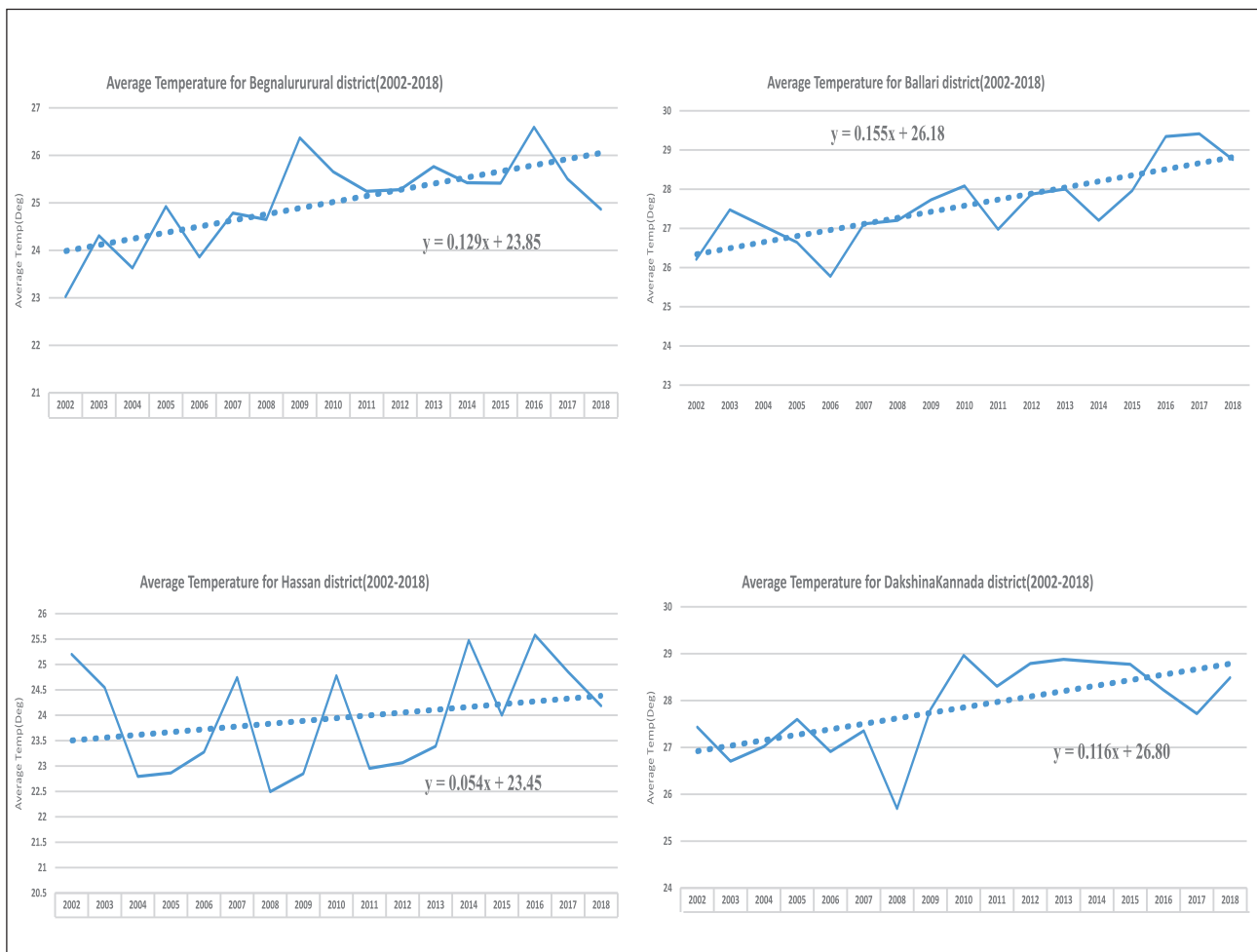


Fig. 19. Temperature pattern for the selective districts in the state.



Fig. 20. Region-wise Relative Humidity (RH%) pattern.



Fig. 21. Relative Humidity pattern for selective districts.

Monthly average temperatures for selected districts during P1 and P2 periods were calculated. These Monthly average temperatures showed a significant increase during P2 period as compared to P1 period in Dakshina Kannada and Chitradurga districts, while insignificant increase is observed in majority of the months during P2 in Vijayapura district. In case of Shivamogga district, monthly average temperatures show an insignificant increase during January, February, November and December months, whereas in other months an insignificant decrease is observed in P2 period (Fig.22).

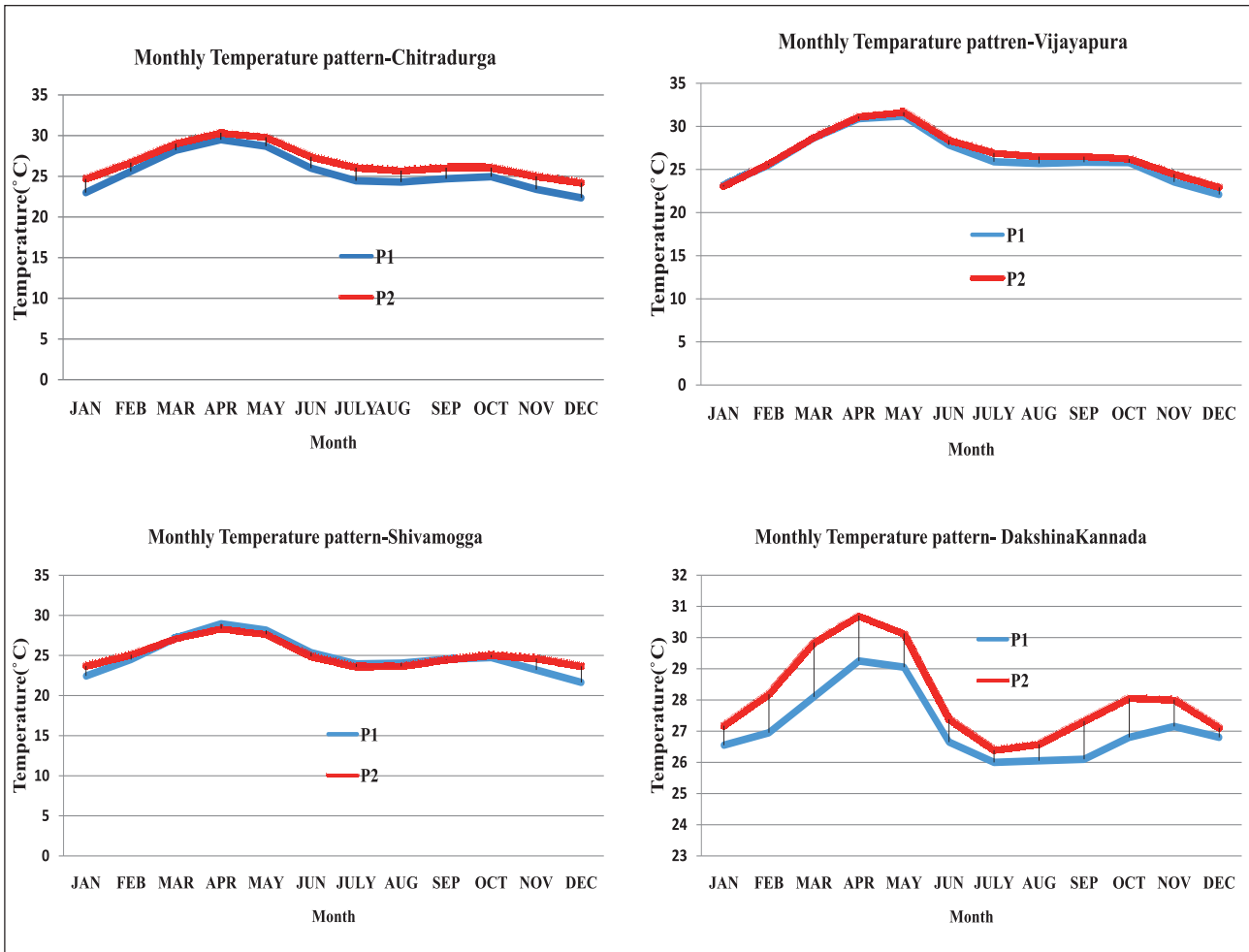


Fig. 22. Monthly average Temperature pattern for selected districts during P1 (1901-1978, Source IMD-1984) and P2 (2002-2018).

Chapter 5. Analysis of Rainfall Pattern in the last 30 Years (1989-2018)

The Rainfall data series for the last 30 years (1989-2018) has been analysed to investigate the variability and changes in rainfall pattern over Karnataka. The Monthly, seasonal and annual time-series has been considered for the analysis.

5.1. Mean Rainfall

The Mean monthly rainfall of South-West Monsoon months, June to September, display similar spatial distribution pattern with a gradual decrease from west to East wherein highest rainfall is in coastal districts and lowest rainfall in central Karnataka. Spatial distribution of mean rainfall is higher in Coastal and adjacent districts of Malnad region with ranging from 250 to 1180mm in June, 250 to 1344mm in July, 250 to 996mm in August, 250 to 430mm in September. The Southwest monsoon seasonal rainfall ranges from 750 to 3866mm and Annual rainfall from 1000 to 4600mm. The mean rainfall is lower in the districts of central parts of SIK and NIK regions which ranges from 60 to 100mm in June, 50 to 100mm in July, 55 to 100mm in August, 82 to 100mm (in the parts Haveri, Davanagere, Chitradurga Mysuru and Chamarajanagara districts) in September. The Southwest monsoon seasonal rainfall in this part of the state ranges from 250 to 500mm and Annual Rainfall from 500 to 1000. (Fig-23).

5.2 Coefficient of variation:

The coefficient of rainfall variation (%) is lower in Coastal and adjacent Malnad districts which ranges from 20 to 50% in June, 20 to 40% in July and August, 40 to 60% in September. The CV in Southwest monsoon season ranges from 13 to 30% and annually from 12 to 20%. The highest CV% in coastal districts is observed in the month of September.

The CV is higher in central parts SIK and NIK regions which ranges from 80 to 93% (in the parts Chitradurga and Tumkuru districts) in June, 80 to 103% in July, 60 to 90% in August. The CV in Southwest monsoon season ranges from 30 to 52% and annually from 30 to 40 %.(Fig-24).

District, Regional and state level Mean Rainfall and its CV% for the Months of June, July, August and September, SW Monsoon Reason and Annual are given in Table 12.

Table 12. District, region and State of monthly, seasonal and annual mean rainfall and CV of rainfall

S.No	District Name	June		July		August		September		Pre_Monsoon		Soutwest Monsoon		Northeast Monsoon		Annual	
		Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)
1	Bengaluru Urban	89	57	93	62	132	56	174	47	197	39	488	30	235	46	920	25
2	Bengaluru Rural	71	61	92	60	125	52	152	49	168	37	439	26	226	46	833	25
3	Ramanagara	75	58	84	68	125	51	159	54	196	37	444	32	245	44	885	25
4	Kolar	71	63	83	67	101	58	156	49	158	38	411	25	251	44	821	23
5	Chikkaballapura	69	57	85	56	103	50	145	45	122	40	402	27	210	46	734	22
6	Tumakuru	74	48	78	60	105	58	139	56	152	34	397	28	200	40	749	20
7	Chitradurga	64	53	63	51	85	58	103	59	127	45	316	33	177	42	621	26
8	Davanagere	86	47	97	49	101	39	100	55	112	45	384	27	162	51	659	24
9	Chamarajanagara	57	58	59	64	74	66	105	62	200	29	295	39	248	40	743	26
10	Mysuru	86	49	93	46	88	47	99	56	205	32	367	28	220	44	791	22
11	Mandya	58	64	57	70	83	63	124	59	187	42	321	38	244	40	752	24
12	Ballari	83	48	68	49	102	45	122	60	102	47	376	27	145	47	622	20
13	Koppala	84	60	60	60	94	65	132	60	89	47	370	36	143	61	603	29
14	Raichur	89	67	88	52	110	51	140	53	73	62	427	29	140	62	640	24
15	Kalaburagi	106	48	129	52	145	44	161	45	83	49	540	25	114	52	736	19
16	Yadgir	101	61	116	50	142	54	152	49	79	57	512	29	136	58	727	23
17	Bidar	133	44	183	57	188	40	159	59	91	62	663	27	118	61	872	22
18	Belagavi	138	39	167	40	122	39	113	49	88	40	539	25	134	48	762	21
19	Bagalkote	91	54	58	47	71	60	117	59	88	47	337	35	133	56	558	27
20	Vijayapura	95	57	76	56	93	56	136	52	83	52	400	32	124	59	607	25
21	Gadag	83	54	64	57	79	53	115	61	118	46	340	35	140	55	598	25
22	Haveri	116	40	148	43	118	37	93	52	132	37	475	26	155	56	762	22
23	Dharwad	120	47	126	43	107	39	109	52	136	44	461	25	142	52	740	21
24	Shivamogga	339	33	548	39	382	30	155	54	127	37	1425	23	193	53	1745	22
25	Hassan	151	46	204	44	153	36	131	48	193	38	637	25	218	45	1048	22

S.No	District Name	June		July		August		September		Pre_Monsoon		Southwest Monsoon		Northeast Monsoon		Annual	
		Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)	Rainfall (mm)	CV (%)
26	Chikkamagaluru	329	33	538	36	409	26	171	42	186	36	1448	20	223	48	1856	19
27	Kodagu	516	33	770	36	558	35	225	47	226	43	2069	22	261	37	2556	19
28	Dakshina Kannada	911	25	1093	27	768	21	312	50	265	54	3084	15	371	37	3720	12
29	Udupi	1039	21	1192	30	865	27	388	52	231	69	3484	14	337	38	4052	13
30	Uttara Kannada	705	18	864	29	589	29	255	48	136	64	2413	14	200	44	2749	13
Region and State																	
31	SIK	73	46	80	48	100	46	129	46	163	30	381	26	216	36	760	20
32	NIK	106	37	112	35	114	33	127	44	97	38	458	21	135	46	691	16
33	Malnad	298	33	462	37	337	27	160	41	176	34	1256	20	218	42	1650	19
34	Coastal	812	18	976	27	680	24	291	48	185	59	2759	13	267	37	3211	12
35	State	198	21	244	26	202	21	150	35	141	32	794	14	190	32	1125	12

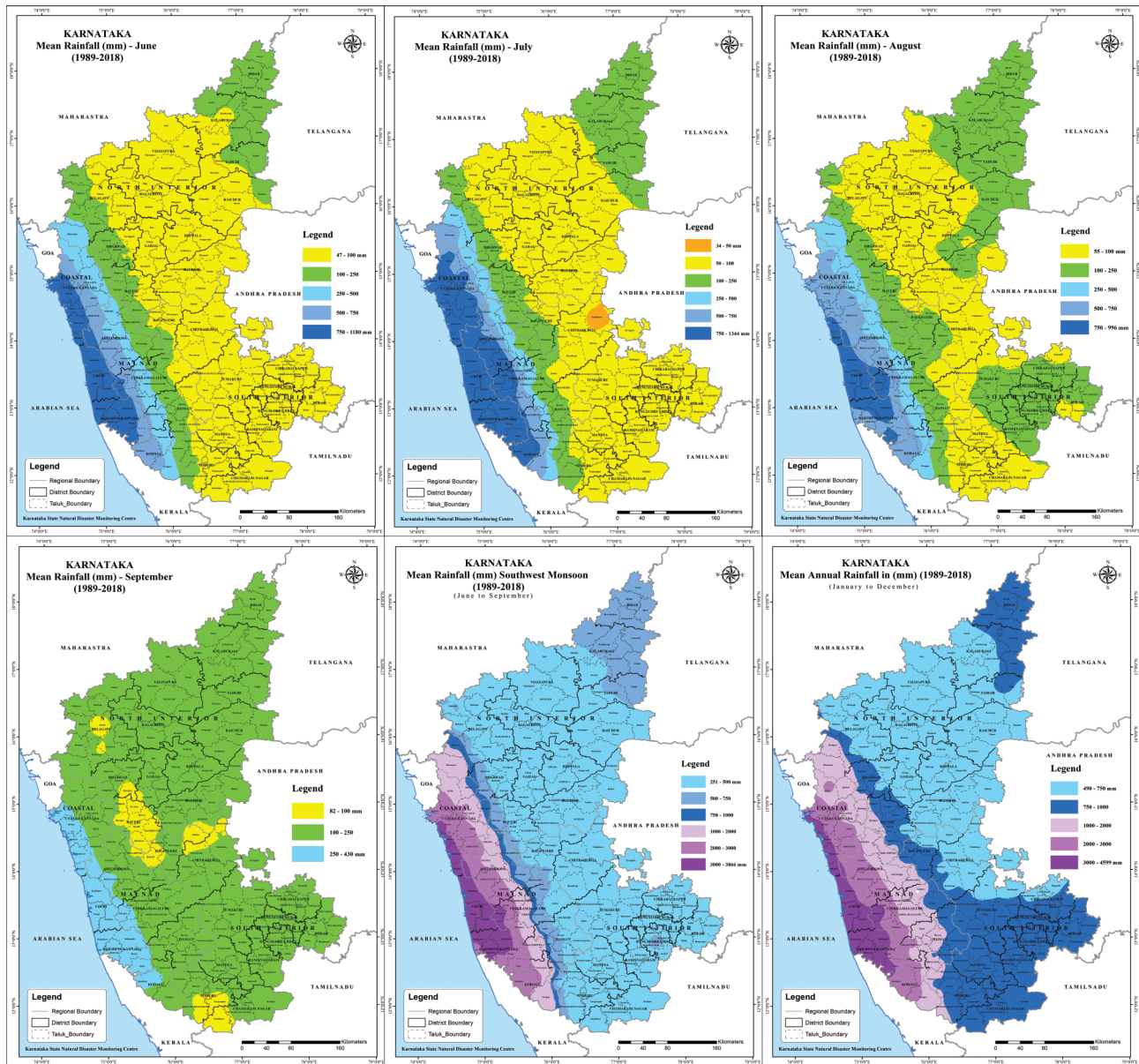


Fig. 23. June, July, August, September, Southwest Monsoon season and Annual Mean Rainfall (1989-2018).

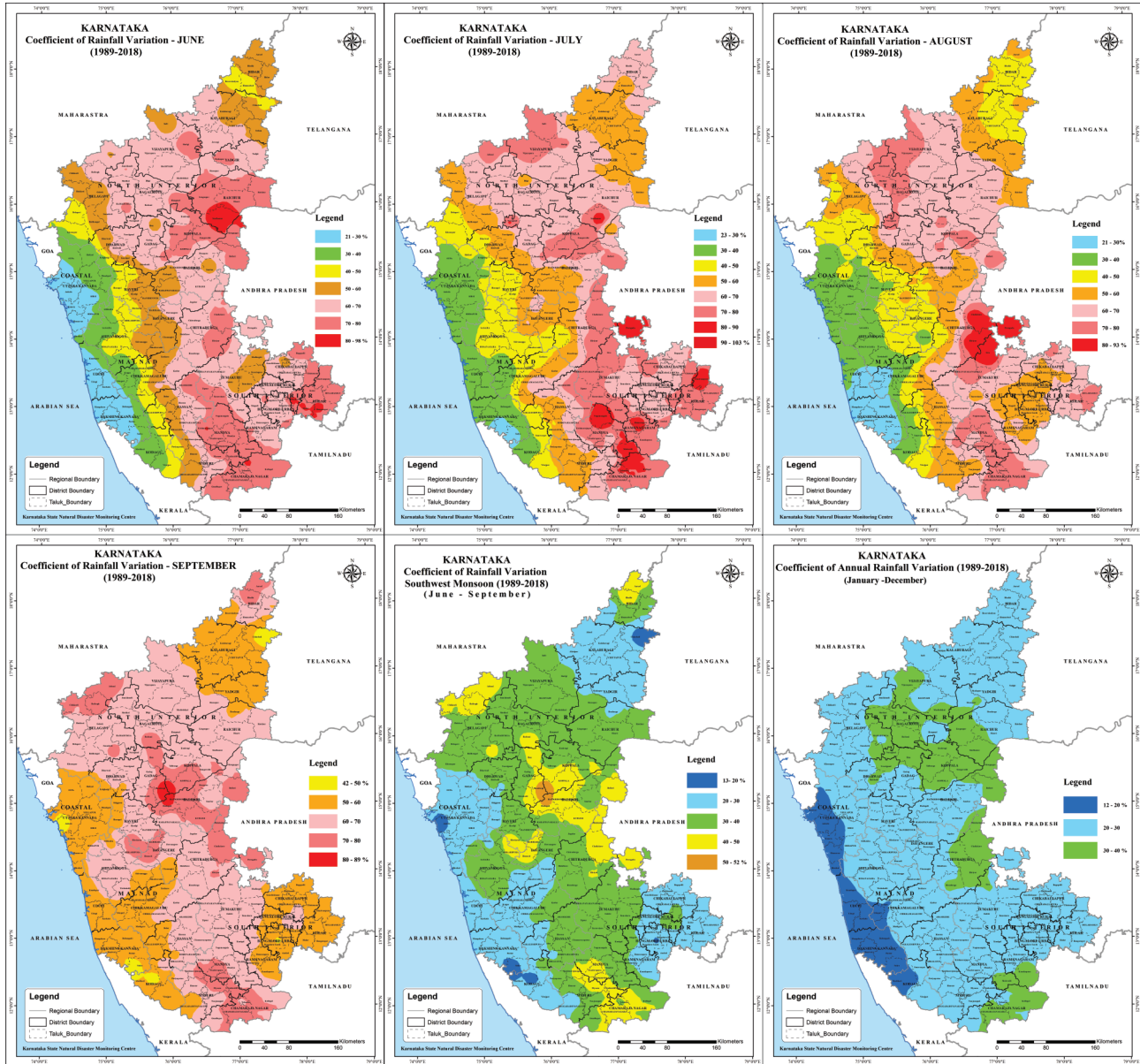


Fig. 24. June, July, August, September, Southwest Monsoon season and Annual Coefficient of Rainfall Variation (1989-2018).

5.3 Mean Rainy days:

The Mean rainy days are highest in coastal and malnad districts as similar to rainfall pattern and decreases towards eastward. Spatial distribution of mean rainy days are higher in Coastal and adjacent districts varying with 15 to 24 days in June, July and August, 10 to 16 days in September, 50 to 95 days in southwest monsoon and 75 to 126 days in annual. Lesser rainy days record at central parts of SIK and NIK regions with varying 3 to 5 days in June (particularly in the parts of Chitradurga, Kolar, Mandya and Chamarajanagara districts), 3 to 10 days in July and August, 5 to 10 days in September, 17 to 50 days in Southwest monsoon and 33 to 50 days in annual.(Fig-25)

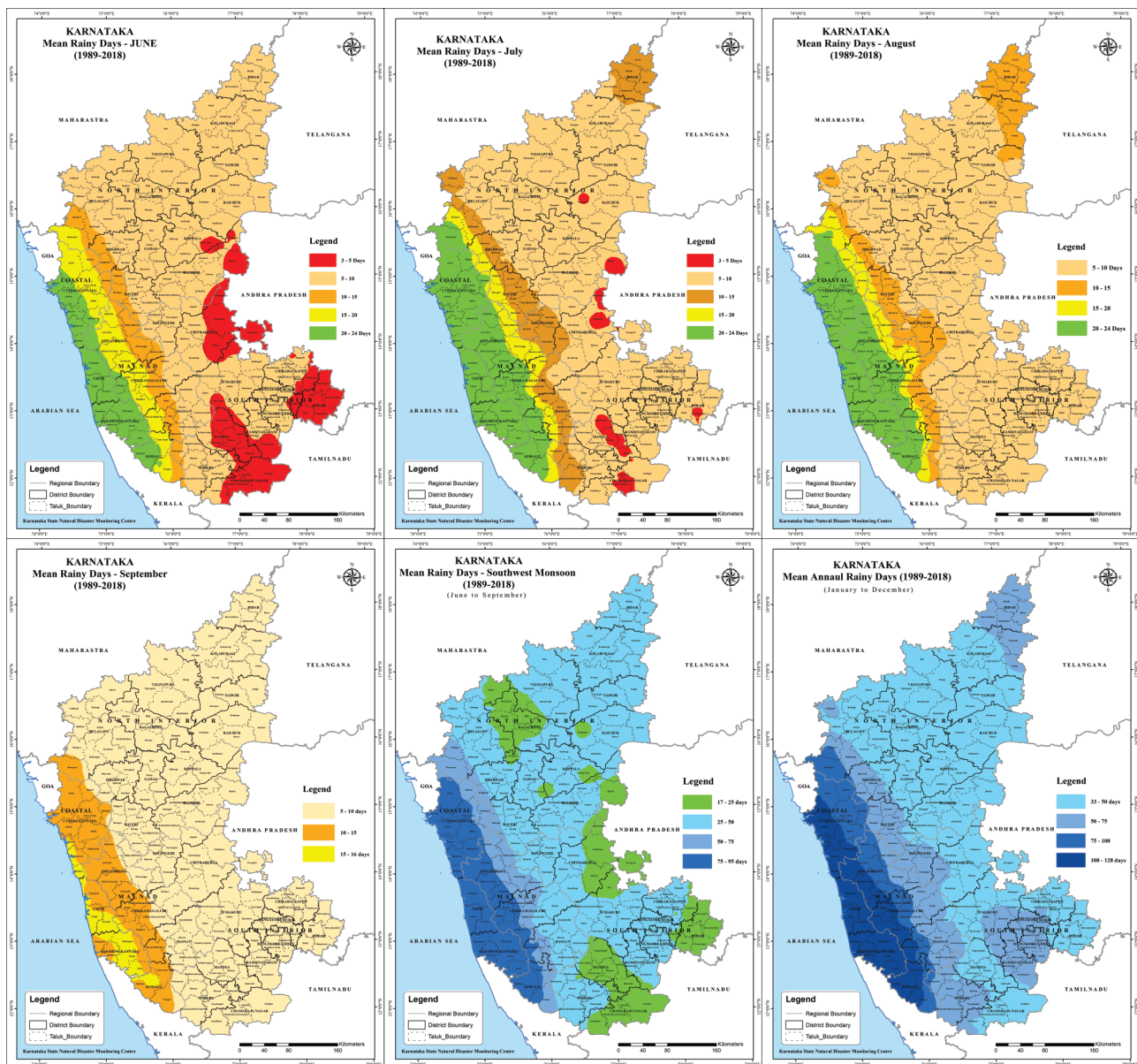


Fig. 25. June, July, August, September, Southwest Monsoon and Annual Mean Rainy Days (1989-2018).

5.4 Mean Dry days:

The Mean dry days are less in the Coastal and adjacent Malnad districts with ranging 5 to 15 days in June, 2 to 5 days particularly in coastal districts in July, 3 to 10 days in August, 13 to 20 days in September, 20 to 60 days in SW Monsoon, 230 to 280 days Annually. Mean dry days are higher in most of the taluks of SIK and NIK regions which ranges from 20 to 26 days in June, 20 to 27 days in July, 20 to 26 days in August, 20 to 24 days in September, 80 to 104 in Southwest monsoon and 300 to 332 days in Annually. (Fig-26)

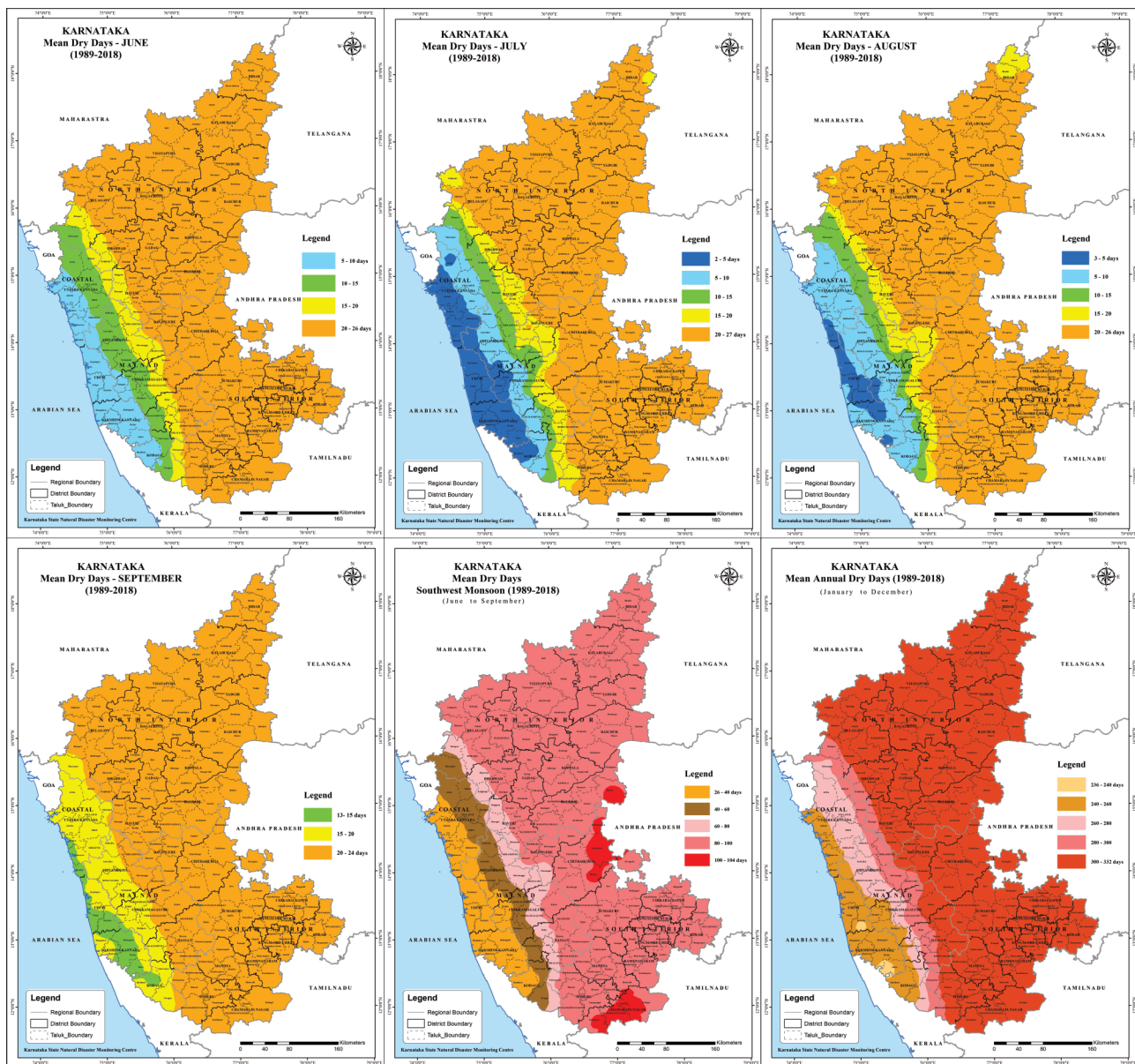


Fig. 26. June, July, August, September, Southwest Monsoon and Annual Mean Dry Days (1989-2018).

5.5 Mean Heavy rainy days

The Spatial distribution of mean Heavy rainfall days show that heavy rainfall days are more in Coastal region varying 10 to 18 days in SW Monsoon and 10 to 20 days in annually least number of Heavy Rainfall days are record with 1 to 5 days in the taluks of SIK and NIK regions in Southwest monsoon and annually

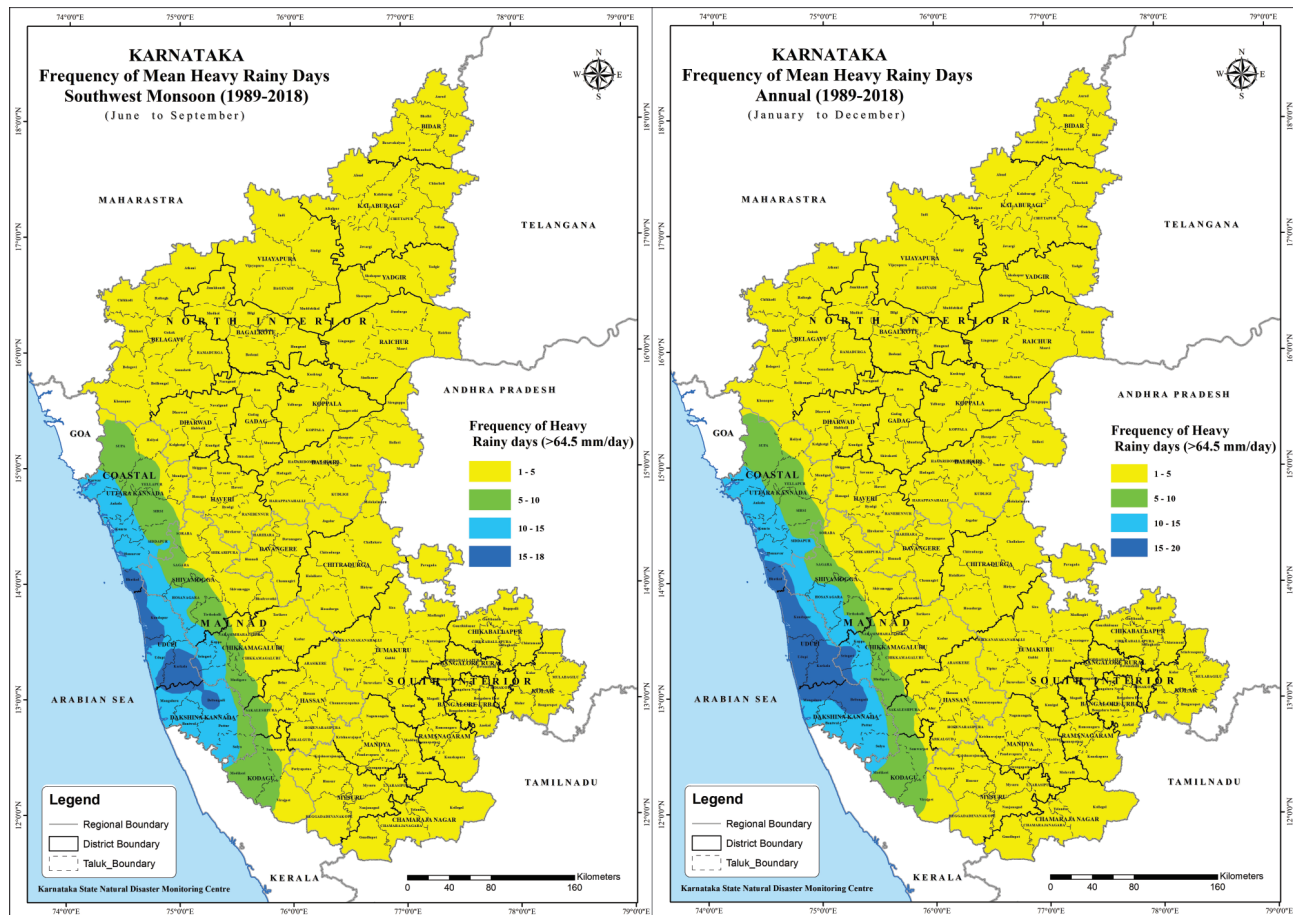


Fig. 27. Southwest monsoon season and Annual Frequency of Mean Heavy rainy days (1989-2018)

5.6 Rainfall Trend:

The rainfall show a decreasing trend in majority of the taluks over the state in June and July. Increasing Rainfall trends are observed in August (particularly in SIK and NIK regions) and September months in majority of taluks over the state. Both decreasing and increasing trends are observed in the Southwest monsoon and Annual rainfall. Rainfall trend show a significant decrease in parts of Udupi and Dakshina Kannada districts in Southwest monsoon and annually (Fig-28).

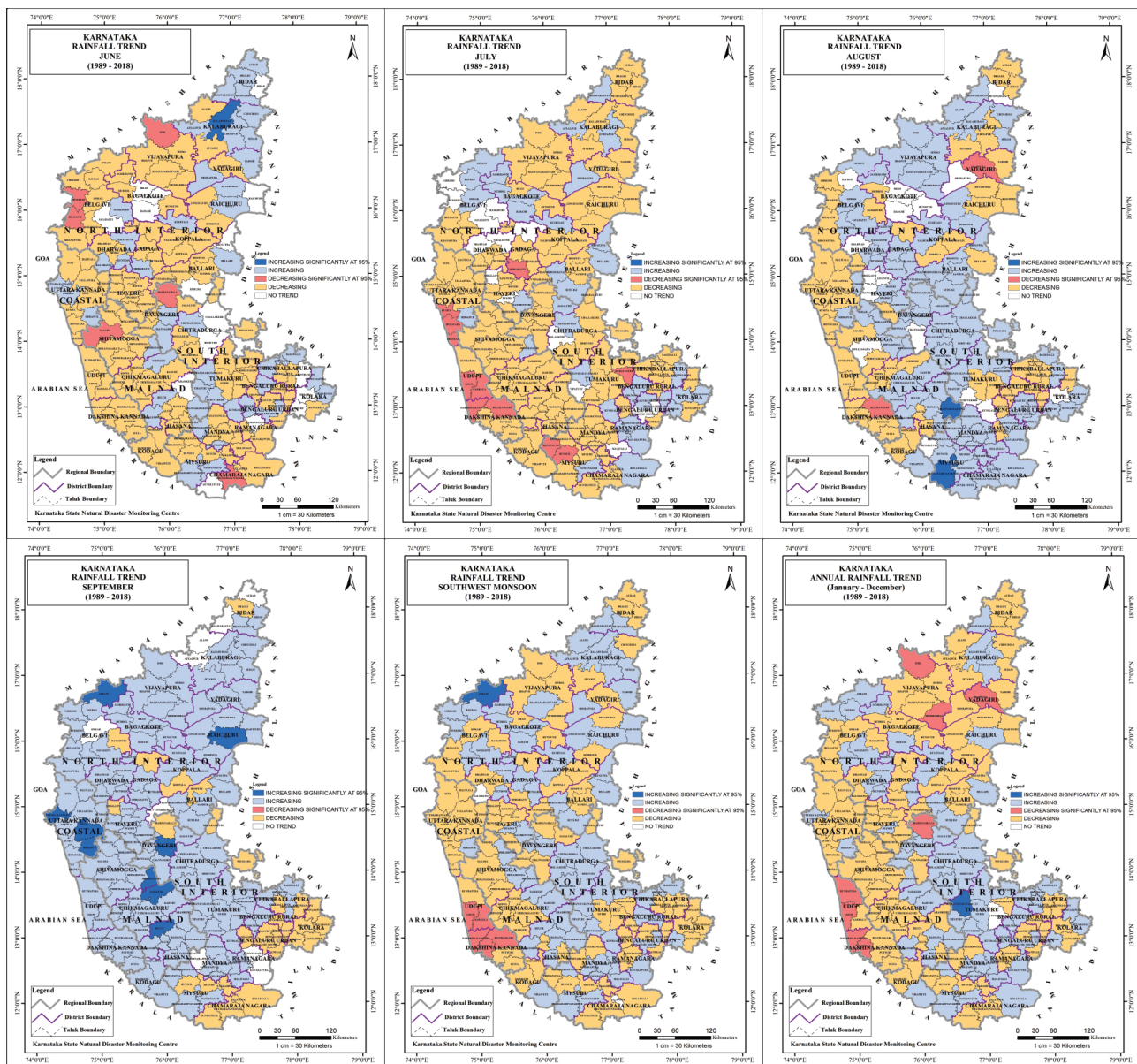


Fig. 28. June, July, August, September, SW Monsoon and Annual Rainfall Trends (1989-2018).

5.7 Rainy days trend

Trends of mean rainy days in majority of taluks over the state show an increasing trend in September, Southwest monsoon season and annually (Fig-29).

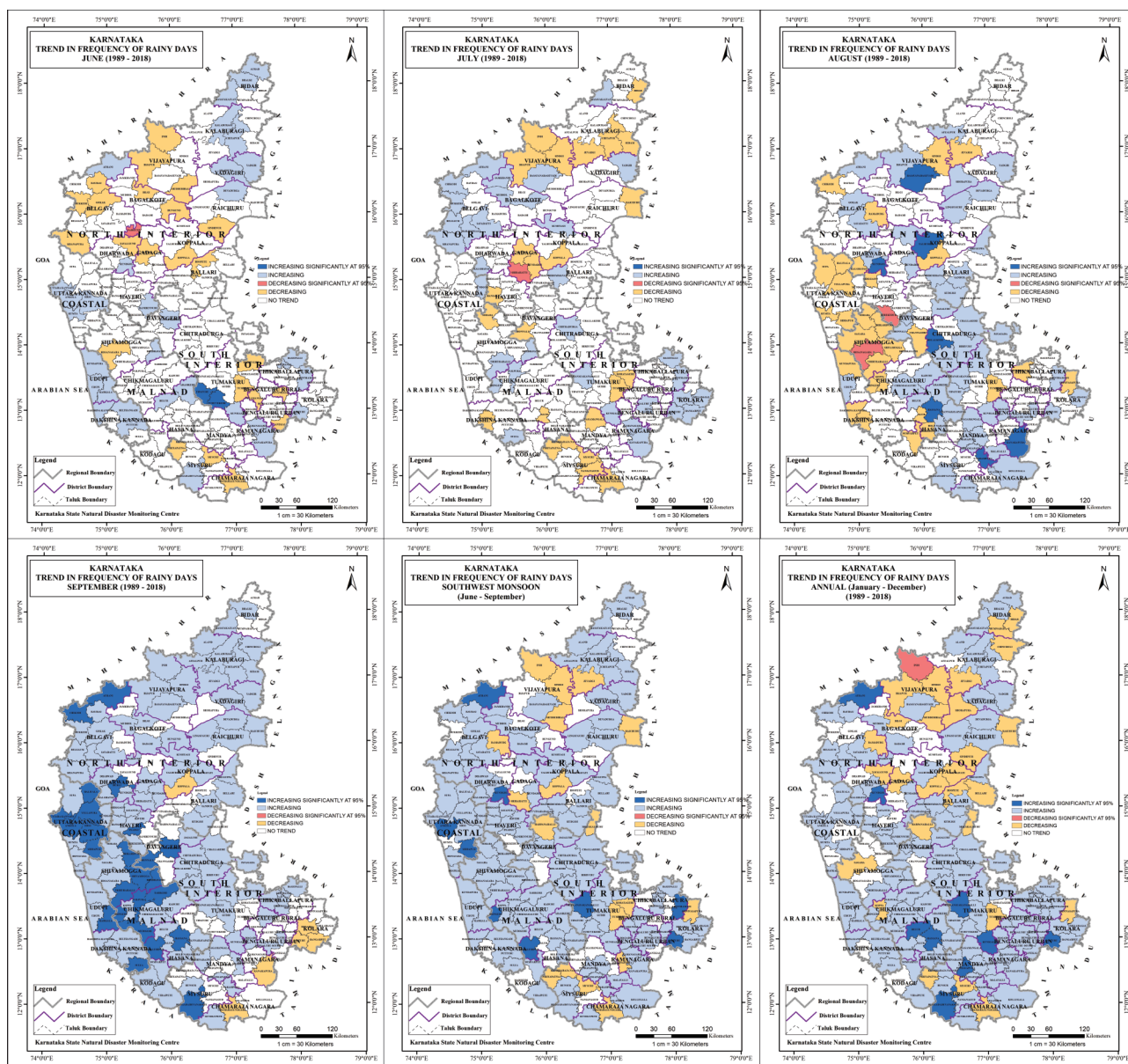


Fig. 29. June, July, August, September, SW Monsoon and Annual Rainy days Trends (1989-2018).

5.8 Heavy rainfall days trends

Heavy rainy days trends show a decreasing trend over parts of Coastal and adjacent taluks in June, July, August, Southwest monsoon season and annually. No trend is observed in the remaining taluks of the state (Fig-30).

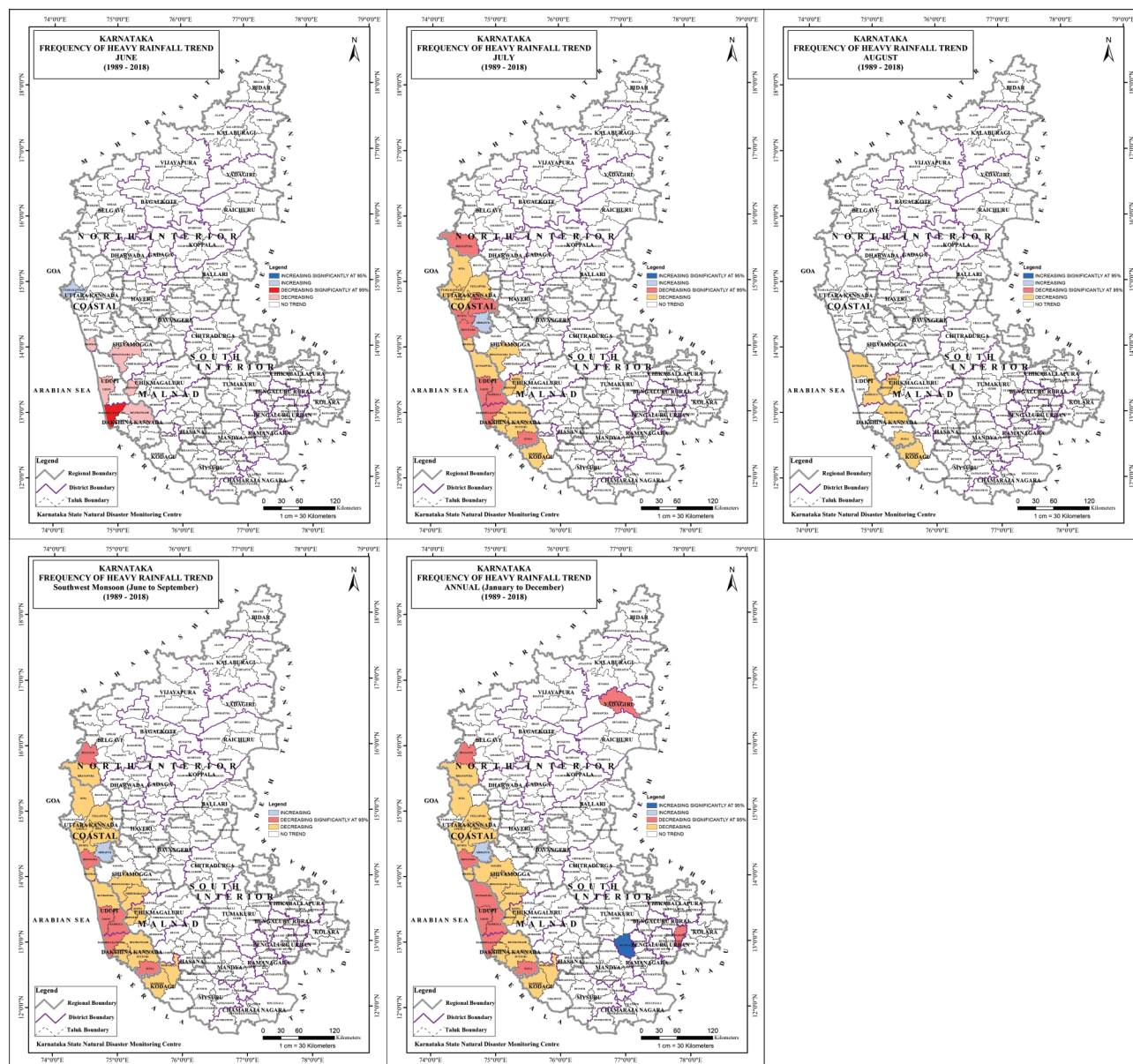


Fig. 30. June, July, August, SW Monsoon and Annual Heavy Rainfall days Trends (1989-2018).

Chapter 6. IMPACT OF CLIMATE CHANGE

Tropical regions like India are considered to be more vulnerable to climate change impacts, in the form of Extreme Weather events (IPCC 2014; INCCA 2010). In the recent decades the extreme weather events have generated enormous pressure on economies, shattered infrastructure and made the poor more vulnerable.

The Climate change had a serious adverse impact on various sectors in different regions across India. There are evidences of increase in the intensity and frequency of Extreme weather events such as heavy and /or high intensity rainfall, Drought due to extended dry spells, Heat waves, Thunderstorms and Tropical Cyclones which can be attributed to the climate change. The adverse impacts such as hunger, malnutrition, vulnerability to diseases, loss of income and livelihoods are commonly observed. Natural hazards like floods & landslides of Uttarakhand in 2013, Chennai floods in 2015 and the drought in 2015 and 2016 across India, floods in Karnataka during 2018 and 2019 are some of the glaring examples.

The following are some of the direct and indirect impacts of extreme weather events.

Extreme Weather Events	Impact
Drought (Hydrological, Meteorological and Agricultural).	Crop loss, Malnutrition and Hunger. Diseases or epidemics outbreak, Drinking water scarcity in Rural and urban areas, Loss of Biodiversity, Loss of livelihood, Migration, Child labor
Flood (riverine and urban floods.).	Loss of life , Critical Infrastructure, Property
Hailstorm	Crop loss, Property loss
Tropical cyclone	Loss of life, Critical Infrastructure, Property, Loss of livelihood, Migration, Diseases outbreak
Heat waves or cold wave.	Loss of life, Crop loss, Drinking water scarcity in Rural and urban areas
Storm surges, Coastal Erosion, Saline water intrusion	Loss of life and coastal Biodiversity, Critical Infrastructure, private property loss
Landslides and mudflow.	Loss of life, Critical Infrastructure, Property Loss of Biodiversity,

6.1 Extreme Weather Events in India.

Drought: The details of the monsoon rainfall deficit and the area affected (%) in the country from 1951 to 2015 is given in (Table-13). The data indicate that the rainfall deficit ranged from -7.1 to -26 %, while the affected area was up to 42% in 1985 and 10% in 2002. During 2015, as Maharastra received rainfall 50% less than the normal, the state Government declared 37% of the villages in the state as drought affected. Most of the villages in Marathwada region of the state and Latur district was worst affected due to consecutive droughts causing acute surface and ground water scarcity (Mahapatra, 2016). Nevertheless, the government introduced water trains to tackle the grave situation and relief for the affected population.

Uttarakhand Flood in 2013: The Uttarakhand state was hit by very heavy rainfall causing flash floods on 16th June, 2013. It caused havoc in five districts of the state. Almost 160 people died and 4021 people went missing. Many people were stranded due to damaged roads, landslides and flash floods.

Table 13. Drought affected area in India since 1951 (Source: Ministry of A&FW, GoI)

Year	Rainfall deficit (%)	Area affected (%)
1951	-18.7	34
1965	-18.2	37
1966	-13.2	34
1972	-26	40
1974	-12	33
1979	-18	35
1982	-14.5	29
1985	-7.1	42
1987	-25	18
2002	-19	10
2014	-12	25
2015	-14	39

Chennai Floods in 2015: For a city tagged indubitably as India's "water scarcity capital" Chennai's water woes took a surprising turn towards the end of 2015 when torrential rains hit the city with unanticipated flood consequences. Chennai floods were the outcome of torrential rainfall events and due to the disturbance of natural drainage systems that caused the inundation of the city.

6.2 Extreme Weather events in Karnataka.

The Karnataka has experienced several extreme weather events in the last decades. Consequently, the state has been frequently confronted with various Hydro-meteorological disasters such as Drought, Flood, Hail-storm, cyclone, landslides, heat waves etc, which has caused enormous damage to life, property, crops and critical infrastructure. The Drought is the most common and recurring Hydro-Meteorological Disasters in the state.

6.2.1 Drought

Karnataka is the most drought-prone state after Rajasthan in India. The entire rainfed area in Karnataka state has been regularly affected by drought. Nearly 80% of Taluks in the state are drought-prone. In the last two decades (2001-2019), the state has experienced drought of various severity for 15 years, only year 2005, 2010 and 2017 were exceptions (Fig-31). Some of the Taluks were Drought affected consecutively for more than 5 years. The variation in spatial and temporal distribution of SW monsoon rainfall is the main reason for the recurrence of Drought in the state. The drought can be short-lived or can last for months or years, having a substantial effect on the agriculture, human population, livestock, and ecosystem in the affected region. Drought has a devastating impact on the economy in general and more particularly in regions where the first-order economic activities such as agriculture constitute the primary source of livelihoods.

Recently, during the year 2016, out of 176 Taluks in the state, 139 Taluks were Drought affected in Kharif and 162 Taluks in Rabi season. Similarly, during the year 2018, about 100 taluks were Drought affected in Kharif and 156 taluks in Rabi. This indicates the high vulnerability of state to drought.

The District in NIK region are the ones which are subjected to severe Drought condition successively. Consequently, the socio-economic condition of the Farming community has suffered immensely.

According to the Ministry of Agriculture and Farmers Welfare (MoAFC&W), Government of India (GoI) 16 districts of the state, the majority of which are from NIK, experienced drought for a period of 10 years during the last 15 years (2001–15). The Drought causes crop loss, drinking water scarcity, fodder scarcity, loss of livelihood, unemployment to rural agricultural laborers, large scale migration etc. Increased incidence of droughts reduces crop productivity, affecting nutrition and consequently, resistance to infections.

Drought has its implications on several aspects such as infant mortality, maternal mortality, malnutrition among children and women, high incidence of childhood diseases, and inadequacies in water supply and sanitation and ultimately results in a low Human Development Index (HDI) ranking (PPMSD, 2014; Shivashankar & Ganesh Prasad, 2015). Due to a very low HDI, some districts are categorized as Aspirational Districts by the GoI (NITI, 2018 a,b) with some of these identified by UNICEF (2016) for their intervention in the areas of health, education, nutrition, water, sanitation, and child protection as well. An in-depth understanding about direct and indirect impacts of drought on children and their health, nutrition, protection, education, and other related issues provide insights for concerned stakeholders to devise an effective recovery, mitigation measures, and intervention for achieving long-term climate and disaster resilience.

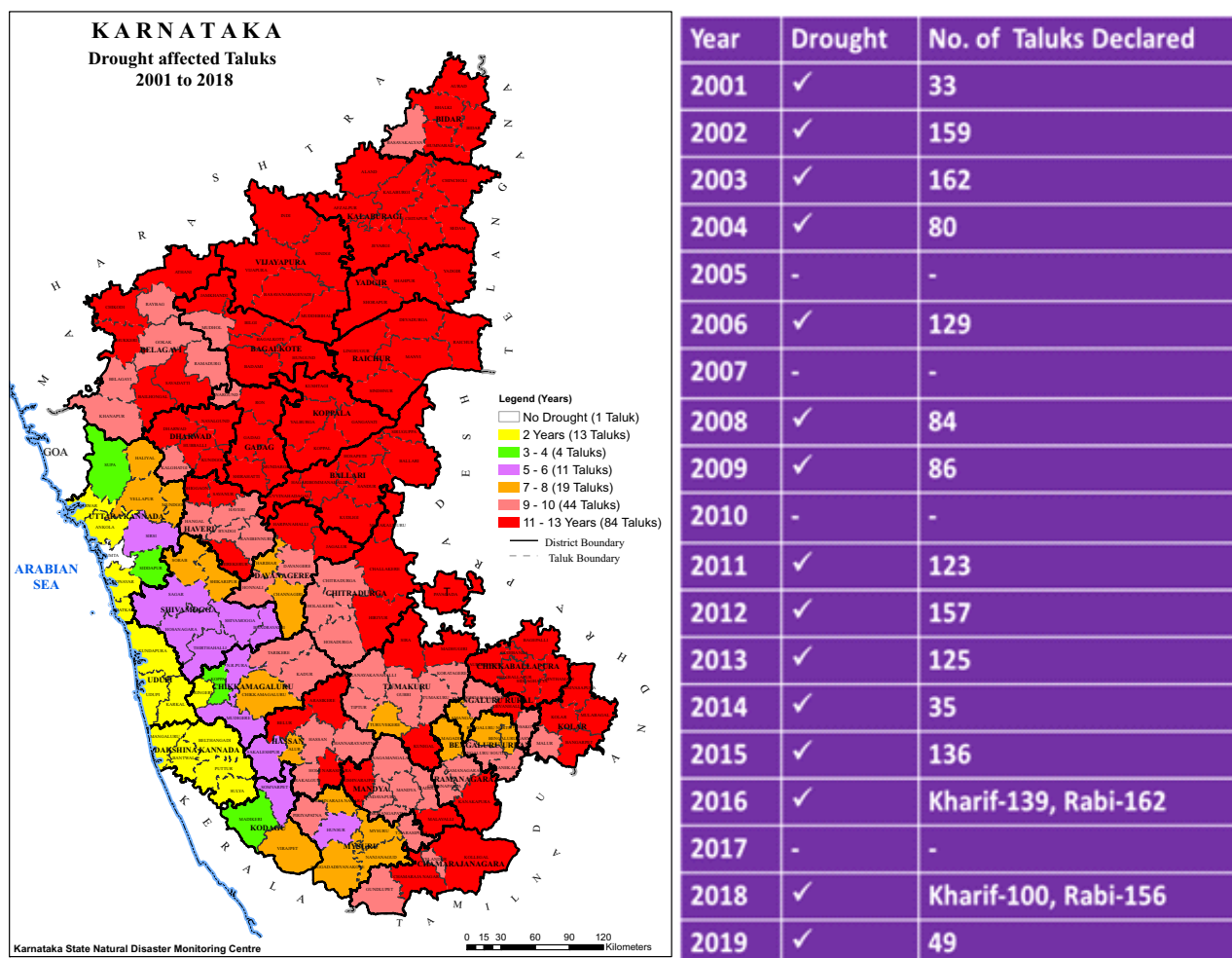


Fig. 31. The Drought affected Taluks in the state from 2001 to 2019.

6.2.2 Floods in Karnataka.

Floods have been a devastating Hydro-Meteorological Natural Disaster recurring both in riverine areas and Urban areas in Karnataka. They have been causing loss of life and property and thereby causing huge social and economic losses in the state. The Flood is a high-water stage in which the water over flows its natural course and flows onto adjoining areas along its course causing severe damage. High intensity and / or heavy rainfall followed by inadequate carrying capacity of rivers to hold the excess water within their banks has led to floods. Also, huge amount of water released from the reservoirs located in the upper catchment is yet another major factor for the Floods.

The Karnataka experienced severe floods during 2005, 2009, 2018 and 2019. As a result of an atmospheric

depression in Bay-of-Bengal and consequent rainfall in adjoining parts of Karnataka, Andhra and Maharashtra, the State experienced catastrophic floods in the districts of North Interior Karnataka in October 2009, which caused immense damage to people's livelihood, property and critical infrastructure in 7 districts in the region.

6.2.3 Floods & Landslides in Malnad & Coastal districts in 2018

During the SW Monsoon season 2018, the State experienced events of flood. Many parts of Malnad and Coastal Karnataka particularly in Kodagu, Hassan, Chikkamagaluru, Shivamogga, Belgaum, Dharwar and Coastal Districts of Dakshina Kannada, Udupi and Uttara Kannada, resulting in flash floods which in turn caused landslides, mudflows, inundation in low lying areas and marooned the people residing in these areas. The rainfall was so severe that several hilly terrains slid, blocking or damaging the roads and bridges, approaches to scattered settlement in the Western Ghats especially in Kodagu District, marooned the inhabitants in villages and towns.

The main trigger of landslides has been prolonged incessant high intensity rainfall (>300mm in 24h), which drives an increase in pore water pressures with in the soil. This coupled with the rapid ground water level changes along the slopes triggered landslides. The impact of unprecedented rainfall was such that it changed the geomorphology, course of river sand drainage of the region. The entire fertile top soil has been washed away and trees were uprooted adversely affecting the local ecology.

There was loss of 67 human life and numerous livestock. The wide trail of destruction due to the extreme rainfall events have not only left thousands of people homeless but has also led to total loss of livelihood. The worst affected are plantation workers and small and marginal land holders. The critical infrastructure like roads, schools, hospitals etc, public properties like houses and commercial complex were severely damaged. National Highways, viz, NH-275, NH-75 and NH-234 and State highways and major district roads Kodagu and village roads and forest roads have been severely damaged due to rain induced landslide and incessant rainfall.

The floods and associated landslides and mudflows caused extensive damage to Agriculture, Horticulture, high value plantation crops. The Coffee estates have been devastated and lost their geographic identity due to massive landslides. High value plantation crops such as Coffee, Black Pepper and Cardamom have been irreversibly damaged, causing a deadly blow to coffee planters, spice growers especially the small and marginal farmers. The plantations that stood with the slaughter of nature have also been infested with insects and fungal diseases.

6.2.4 Flood in Karnataka during SW Monsoon Season 2019.

In 2019, the entire State was experiencing severe drought situation as a result of deficit rainfall and prolonged dry spell during pre-monsoon period (March-May) and Southwest Monsoon (June-July). Thirteen districts were in deficit rainfall category and water in reservoirs was just 43% of the total capacity at the end July 2019.

However, from 3rd to 10th August 2019, the State received 224 mm of rainfall with an overall departure of (+) 279 %, from normal which is the highest for Karnataka for the corresponding period in the last 118 years. Some districts received rainfall more than 700% departure from normal during this period. The distribution of the rainfall has been skewed and the excessive rainfall has been confined to parts of North Interior Karnataka, Malnad and Coastal region. Such was the intensity of the rain that, the State which was grappling with the drought situation was confronted with devastating floods in the space of just one week (Fig-32).

The situation was further compounded by record discharge of water of up to 9 lakh Cusecs for many days from the dams in the Upper Krishna basin and Bhima Basin in Maharashtra. The Cumulative inflows and outflows of the major Reservoirs Viz., Almatti and Narayanapura in Krishna Basin and KRS and Kabini in Cauvery Basin were unprecedented for this period in the State. The outflow from Narayanapura dam was



Plate 1. Impact of floods in Kodagu district in 2018.

Table 14. Regional and State level rainfall statistics for flood period in 2019.

Region	South West Monsoon Rainfall Pattern 2019 (1st June to 10th Aug'19)			Rainfall Pattern (3rd to 10th Aug'19)		
	Normal (mm)	Actual (mm)	%DEP	Normal (mm)	Actual (mm)	%DEP
South Interior Karnataka	181	190	5	22	68	210
North Interior Karnataka	300	322	7	34	103	208
Malnad	1111	1268	14	119	604	409
Coastal	2271	2493	10	230	744	224
STATE	551	624	13	59	224	279

consistently more than 6.25 lakh Cusecs for 7 to 8 days, which is highest since the construction of the dam. The Bhima river, a tributary of Krishna, also carried upto 3 lakh Cusecs, which is a historic high. The cumulative effect of heavy rainfall and enormous outflow of water from the reservoirs caused deluge in and around the downstream areas of these rivers. The reservoirs which were less than half their capacities at the end of July, attained full reservoir level with record outflows within a span of 10 days. The record rainfall coupled with high discharges from reservoirs has caused extreme flooding and landslides in 103 taluks of 22 districts.

The devastating floods and landslides caused loss of life and enormous damage to crops and critical infrastructure. 87 human lives are lost due to floods and landslides. Many villages flattened due to landslides/mudslides. While the people of the affected districts went through immense hardship, the loss of shelter has been a devastating experience. Around 2.47 lakh houses were damaged, out of which about 1.79 lakh houses were severely/fully damaged.

About 8.88 lakh hectares of agriculture, horticulture and plantation crops was damaged and large swathe of the fields are heavily silted due to change in river course and inundation. Landslides and mudslides in the multiple locations destroyed around 10,615 ha of agriculture and horticulture areas completely.

Critical infrastructure, such as roads, bridges/culverts, electrical infrastructure, schools, hospitals and anganwadis, etc, have been ravaged due to floods. About, 22,000 km of State Highway, Major district roads, village and urban roads have been damaged; 2913 bridges/culverts have been damaged. Large chunk of hills (mudslips) have slid over roads in multiple locations, the quantum of debris is humongous and will require coordinated efforts from multiple agencies to restore the roads. The flood and landslides have disrupted electricity supply in many villages; 59,598 poles, 14098 transformers and 3619 power supply lines have been severely damaged. 10988 government building such as primary schools, Anganwadi, community assets, PHCs and Panchayathghars have been damaged.

The impact of unprecedented rainfall was such that it changed the geo-morphology, course of river and drainage of the region. The entire fertile top soil has been washed away which is likely to adversely affect the local ecology.

The wide trail of destruction due to the extreme event has not only left thousands of people homeless but has also led to a loss of livelihood due to large scale destruction of private and public properties. The estimated crop loss due to flood and landslides is Rs.15,119.00 crores. The estimated total loss were to the tune of Rs. 38451.11 crores.

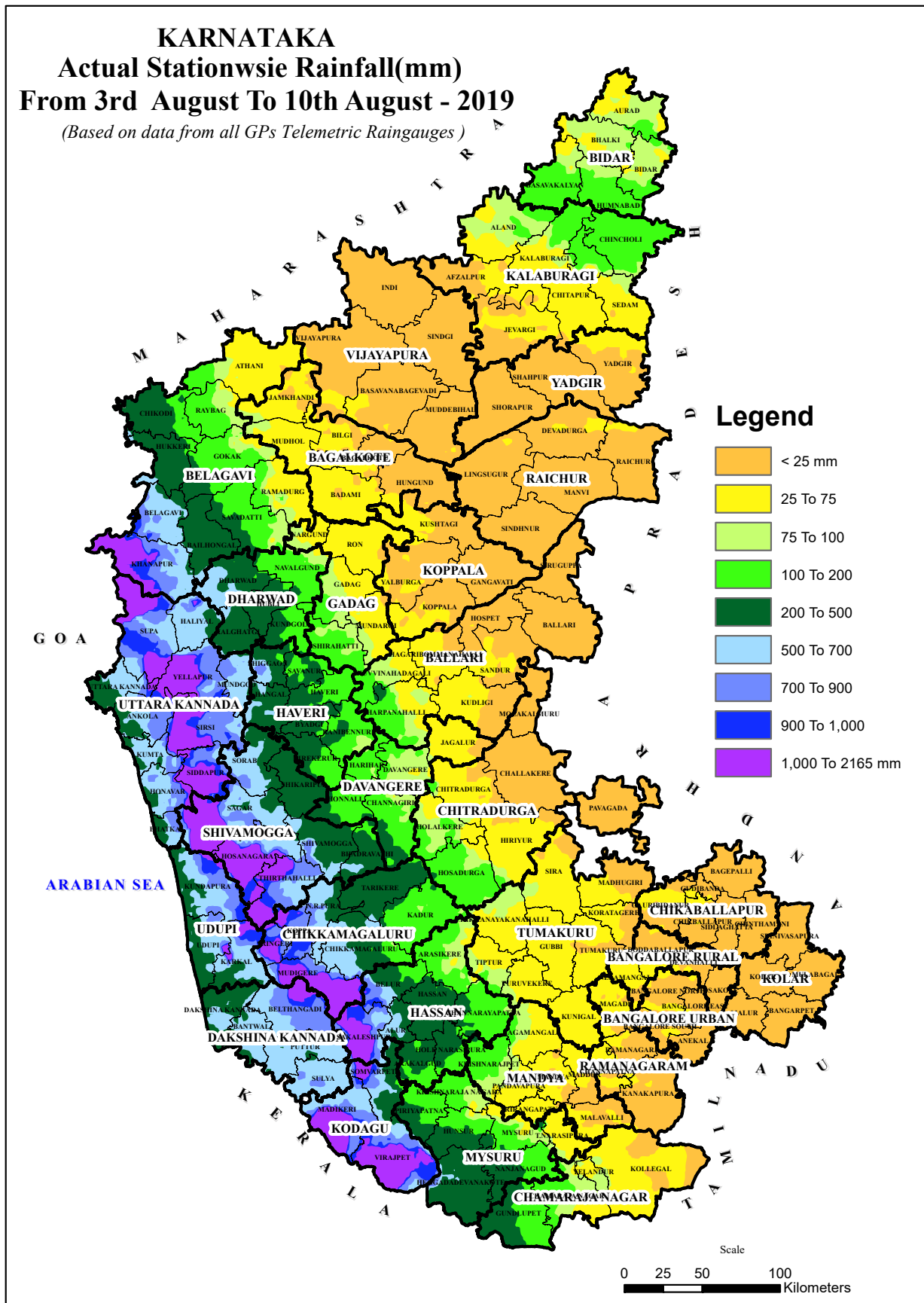


Fig. 32. The rainfall pattern in Karnataka during 3-10 August 2019.

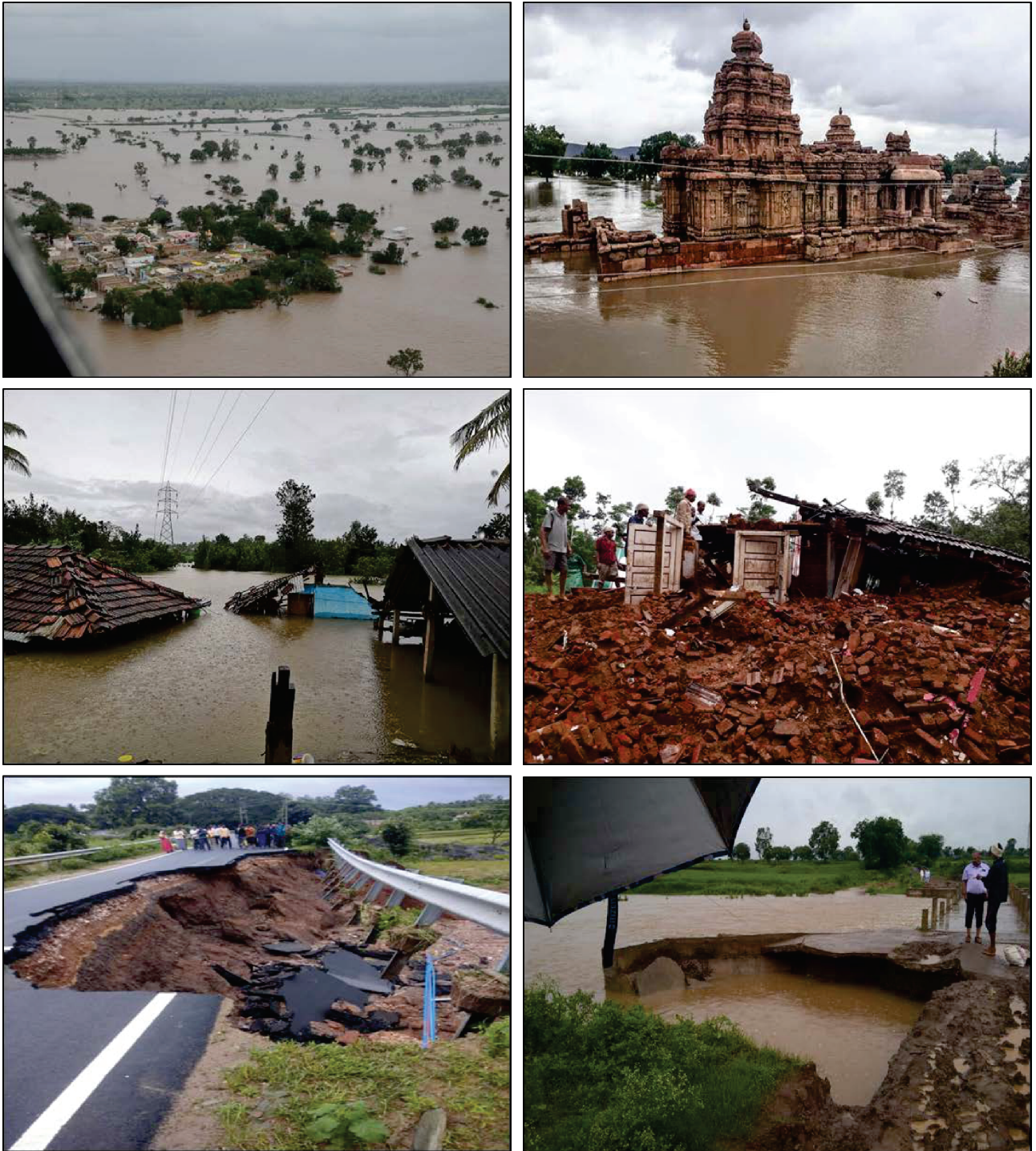


Plate 2. The infrastructure damage caused by the extreme rainfall in Karnataka during 3-10 Aug 2019.



Plate 3. Rescue & Relief operations during floods in Karnataka 3-10 August, 2019.

6.2.5 Hail storms

Hail storms are also one of the major disasters over the State in the recent years. During Pre Monsoon (March to May) the frequency of Hail storms associated with Thunder storm activity and Gusty winds with intensified rainfall is damaging not only infrastructure, crops (Plate-4). Human lives and livestock. Loss is mainly over Northern part of the State every year since 2014. North Interior Karnataka being a part of semi-arid region and continuously experiencing Hailstorm events in majority of the areas.

For example, under the influence of Moisture incursion from Arabian Sea, low level wind confluence and upper level divergence in the atmosphere during pre-monsoon period 2015, the hailstorm accompanied with high intensity rainfall and gusty winds with thunderstorm activity had taken place in 8 districts of North Interior Karnataka Viz., Bidar, Kalaburgi, Yadgir, Bellary, Raichur, Koppal, Vijayapura and Gadag.

Table. 15. District-wise Maximum Wind speed (km/hr) recorded during 8-16 April 2015.

Sl.No.	District	Max Wind speed (km/hr) recorded during 08th - 16th April, 2015	Max Wind speed recorded Date	As per Climatological Table, mean Wind speed for April month (km/hr)
1	Ballari	43.6	14th April, 2015	6.0
2	Bidar	24.1	08th April, 2015	11.1
3	Kalaburagi	26.6	12th April, 2015	8.4
4	Koppala	54.7	13th April, 2015	10.1
5	Raichur	21.2	12th April, 2015	10.1
6	Yadgir	25.2	12th April, 2015	8.4
7	Gadag	17.3	11th April, 2015	10.0
8	Vijayapura	45.7	12th April, 2015	6.5



Plate 4. Impact of Hailstorms on horticultural crops in Karnataka

The paddy crop grown in Tungabhadra reservoir command area and Narayanapur reservoir command area which were almost in harvesting stage and horticulture crops like Mango, Grapes, Pomegranate, Sappota etc., were subjected to heavy hailstorm associated with high velocity wind. Consequently, the State suffered an unprecedented hailstorms related loss to the tune of Rs. 422.36 Crores.

6.2.6 Cyclone :

India has a long coastline of about 7,516 km. Broad-scale assessment of the population at risk suggests that an estimated 32 crore people, which accounts for almost one third of the country's total population, are vulnerable to cyclone related hazards. The average annual frequency of tropical cyclones in the north Indian Ocean (Bay of Bengal and Arabian Sea) is about 5 (about 5-6 % of the Global annual average) and about 80 cyclones form around the globe in a year. The frequency is more in the Bay of Bengal than in the Arabian Sea, the ratio being 4:1.

The Karnataka state has about 320 Km of coastline, in the western part bordering the Arabian Sea. Though historically, Karnataka State was not experiencing any major Cyclone event but in the last decade as the frequency of cyclonic storm in the Arabian has increased, the Cyclone risk has increased in the coastal and adjoining areas of the state. There were about 16 Cyclonic storms developed in the Arabian Sea in the last 10 years, in which 5 of them were in 2019 and 1 in 2020.

The human population settled and the critical infrastructure, private properties all along the 320 km coastline and the adjoining areas are highly vulnerable to cyclone risk.

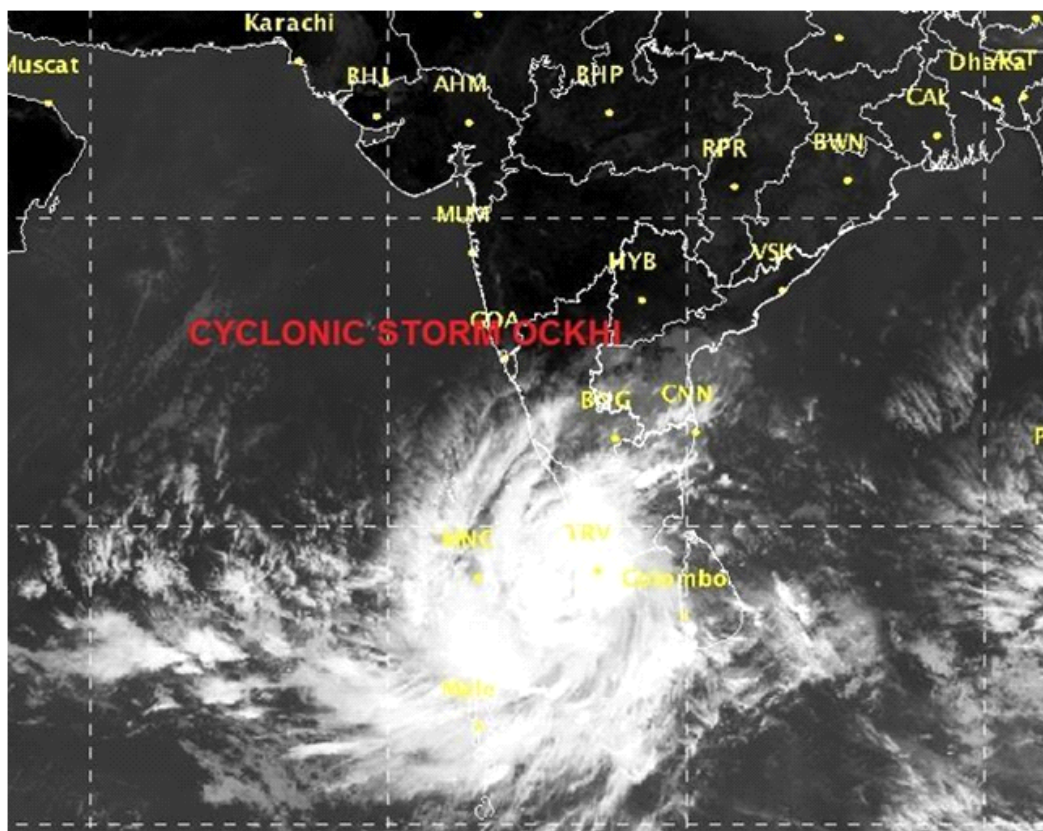


Plate 5. The Satellite Image of the Tropical Cyclone Ockhi in the Arabian Sea in 2017.

The Karnataka state has been implementing the National Cyclone Risk Mitigation Project (NCRMP) Phase II. Under this project a robust Early Warning Dissemination System with Last Mile connectivity is being designed and implemented all along the coast line and its 5 km buffer zone. Apart from the early warning

Table 16. The List of Tropical Cyclones developed in Arabian Sea & Bay of Bengal since 2011.

Year	Name of the Cyclone	Arabian sea / Bay of Bengal	Duration
2011	Keila	Arabian Sea	29 Oct 2011 – 4 Nov 2011
	Thane	Bay Of Bengal	25 Dec 2011 – 31 Dec 2011
2012	Nilam	Bay Of Bengal	28 Oct 2012 – 1 Nov 2012
	Murjan	Arabian Sea	23 Oct 2012 – 26 Oct 2012
2013	Viyaru	Bay Of Bengal	10 May 2013 – 17 May 2013
	Phailin	Bay Of Bengal	4 Oct 2013 – 14 Oct 2013
	Helen	Bay Of Bengal	19 Nov 2013 – 23 Nov 2013
	Lehar	Bay Of Bengal	19 Nov 2013 – 28 Nov 2013
	Madi	Bay Of Bengal	07 Dec 2013 – 12 Dec 2013
2014	Nanauk	Arabian Sea	11 Jun 2014 – 14 Jun 2014
	Hudhud	Bay Of Bengal	8 Oct 2014 – 14 Oct 2014
	Nilofar	Arabian Sea	25 Oct 2014 – 31 Oct 2014
2015	Ashobaa	Arabian Sea	08 Jun 2015 – 12 Jun 2015
	Komen	Bay Of Bengal	26 Jul 2015 – 2 Aug 2015
	Chapala	Arabian Sea	28 Oct 2015 – 4 Nov 2015
	Megh	Arabian Sea	5 Nov 2015 – 10 Nov 2015
2016	Roanu	Bay Of Bengal	19 May 2016 – 23 May 2016
	Kyant	Bay Of Bengal	23 Oct 2016 – 27 Oct 2016
	Nada	Bay Of Bengal	30 Nov 2016 – 01 Dec 2016
	Vardah	Bay Of Bengal	6 Dec 2016 – 13 Dec 2016
2017	Maarutha	Bay Of Bengal	15 Apr 2017 – 17 Apr 2017
	Mora	Bay Of Bengal	28 May 2017 – 31 May 2017
	Ockhi	Bay Of Bengal	29 Nov 2017 – 6 Dec 2017
2018	Sagar	Arabian Sea	16 May 2018 – 20 May 2018
	Mekunu	Arabian Sea	21 May 2018 – 27 May 2018
	Daye	Bay Of Bengal	19 Sep 2018 – 22 Sep 2018
	Luban	Arabian Sea	6 Oct 2018 – 15 Oct 2018
	Titli	Bay Of Bengal	8 Oct 2018 – 13 Oct 2018
	Gaja	Bay Of Bengal	10 Nov 2018 – 19 Nov 2018
	Phethai	Bay Of Bengal	13 Dec 2018 – 18 Dec 2018
2019	Pabuk	Bay Of Bengal	31 Dec 2018 – 8 Jan 2019
	Fani	Bay Of Bengal	26 Apr 2019 – 5 May 2019
	Vayu	Arabian Sea	10 Jun 2019 – 17 Jun 2019
	Hikaa	Arabian Sea	22 Sep 2019 – 25 Sep 2019
	Kyaar	Arabian Sea	24 Oct 2019 – 3 Nov 2019
	Maha	Arabian Sea	30 Oct 2019 – 7 Nov 2019
	Bulbul	Bay Of Bengal	5 Nov 2019 – 11 Nov 2019
	Pawan	Arabian Sea	4 Dec 2019 – 7 Dec 2019
2020	Amphan	Bay of Bengal	16 May 2020 – 21 May 2020
	Nisarga	Arabian Sea	1 Jun 2020 – 3 Jun 2020

system, the connecting roads to the nearest highways, bridges, saline embankments are also being built in the vulnerable area. In order to provide shelter to the affected and displaced community during the Cyclone or Tsunami, the Multi-Purpose Cyclone Shelters with basic amenities are also being built in these areas.

6.2.7 Heat Waves

Heat Wave is a period of abnormally high temperatures, more than the normal maximum temperature that occurs during the summer season. Heat Waves typically occur between March and May. The extreme temperatures and resultant atmospheric conditions adversely affect people as they cause physiological stress, sometimes resulting in death. As such there is no universal definition for heat wave. It is generally defined as a prolonged period of excessive heat. The bordering States of North Interior Karnataka, i.e., Telangana and Andhra Pradesh, have been experiencing severe heat wave in the past several years and many deaths have been reported.

As large parts of Karnataka are under arid to semi-arid condition, the state is experiencing the Heat-wave like condition in the recent years (Fig. 34). Karnataka has been experiencing higher than normal temperatures particularly in districts belonging to North Interior Karnataka and these districts are prone to high temperature for a longer duration in a year.

Coastal and South Interior Karnataka are less prone to heat wave when compared to NIK. However, temperature is not the sole criteria for heatwave, Relative Humidity and other meteorological factors determine the heat wave conditions.

During the summer heat wave in the years of 2014 to 2019 in neighboring States of Andhra Pradesh and Telangana (then undivided Andhra Pradesh) unprecedentedly high day and night-time temperatures resulted in more than 2500 deaths. The vast majority of these were among older people. Karnataka though reported less mortality due to heat wave during the same period, but the parts of North Interior Karnataka remains vulnerable to heat wave as many of these are bordering the districts of Telangana and Andhra Pradesh.

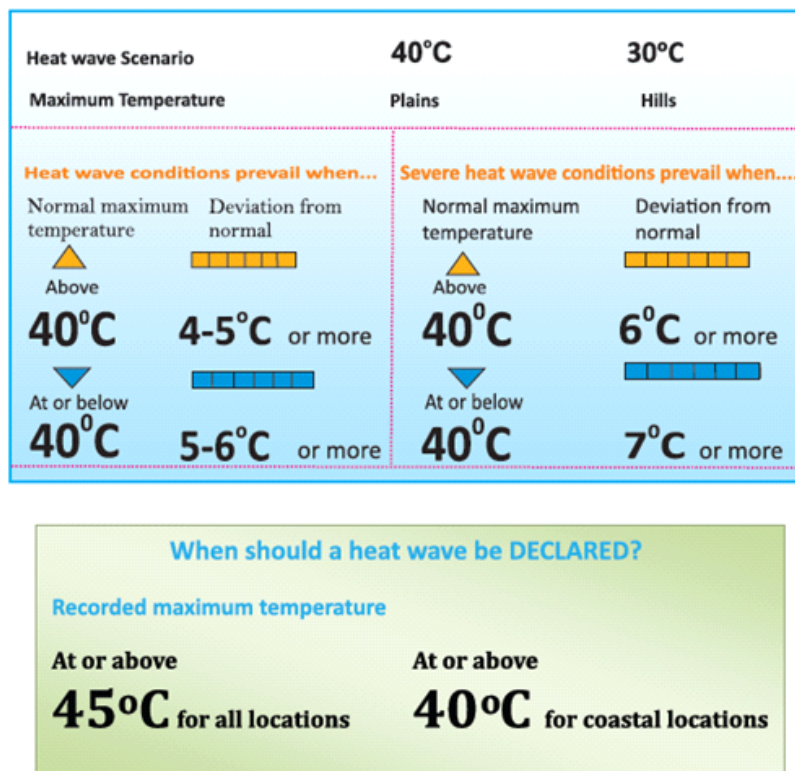


Fig. 33. Criteria for Heat Waves(IMD)

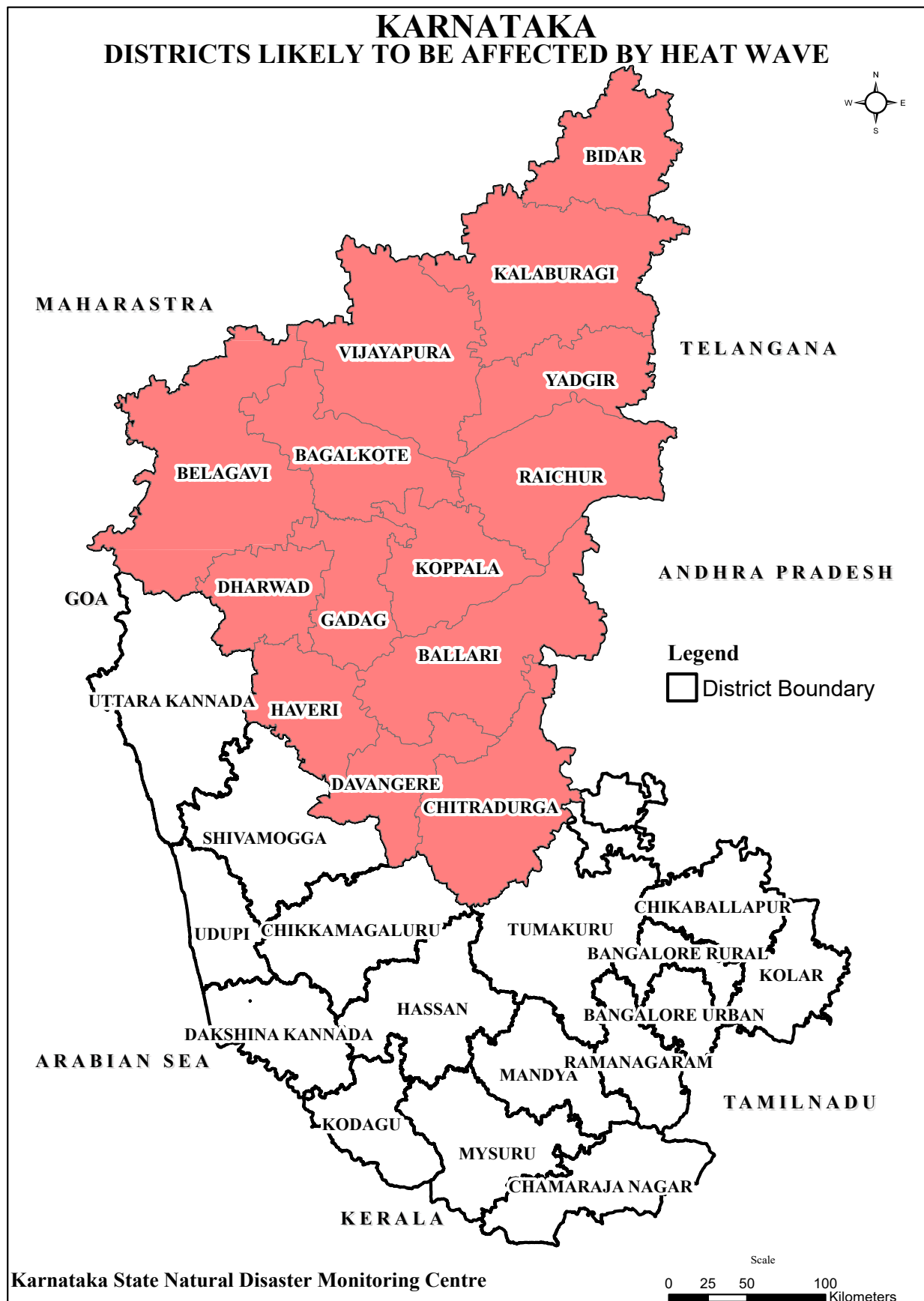


Fig. 34. Heatwave prone districts in Karnataka.

The definition and criteria for identifying and the declaration of Heat Wave condition followed by the Indian Meteorological Department IMD is as follows.

- The maximum Temperature of a station is at least 40°C for Plains and at least 30°C for Hilly regions.
- When normal maximum temperature of a station is less than or equal to 40°C,
Heat Wave: Departure from normal is 5°C to 6°C and
Severe Heat Wave: Departure from normal is 7°C or more
- When normal maximum temperature of a station is more than 40°C
Heat Wave: Departure from normal is 4°C to 5°C and
Severe Heat Wave: Departure from normal is 6°C or more
- When actual maximum temperature remains 45°C or more for all locations irrespective of normal maximum temperature and for coastal locations when actual maximum temperature remains above 40°C, it is considered as the heat wave condition in that region.

The homeless, rickshaw pullers, building and road construction workers, traffic policemen and farmers are the people worst affected by heat waves as they work all day, even in the afternoon when the heat is at its peak. Poverty makes a heat wave all the more unbearable. The health and nutrition of the poor being low to start with, resistance, of the poor people, to heat stress is low. In addition to providing them with shelter, food and water, working hours on construction sites should be reduced during summer.

Heat wave also causes forest wild fires. Number of forest wild fires have increased in Karnataka state in recent years.

In order to mitigate the impact of Heatwave on the community in the vulnerable areas, the KSNDMC has been Issuing Heat Wave bulletins for the State. When the maximum temperatures observed are above normal, the diurnal variations of Temperature are low over the region/ district and satisfying the heat wave criteria for a given period during the summer, the KSNDMC issue Heat wave bulletins. The duration of maximum temperature in a day for a particular area also given weightage while issuing the bulletin.

As the temporal distribution of the maximum temperature in areas of Telangana and Maharashtra states bordering Karnataka influences the temperature pattern in the adjoining area of Karnataka State, the observed

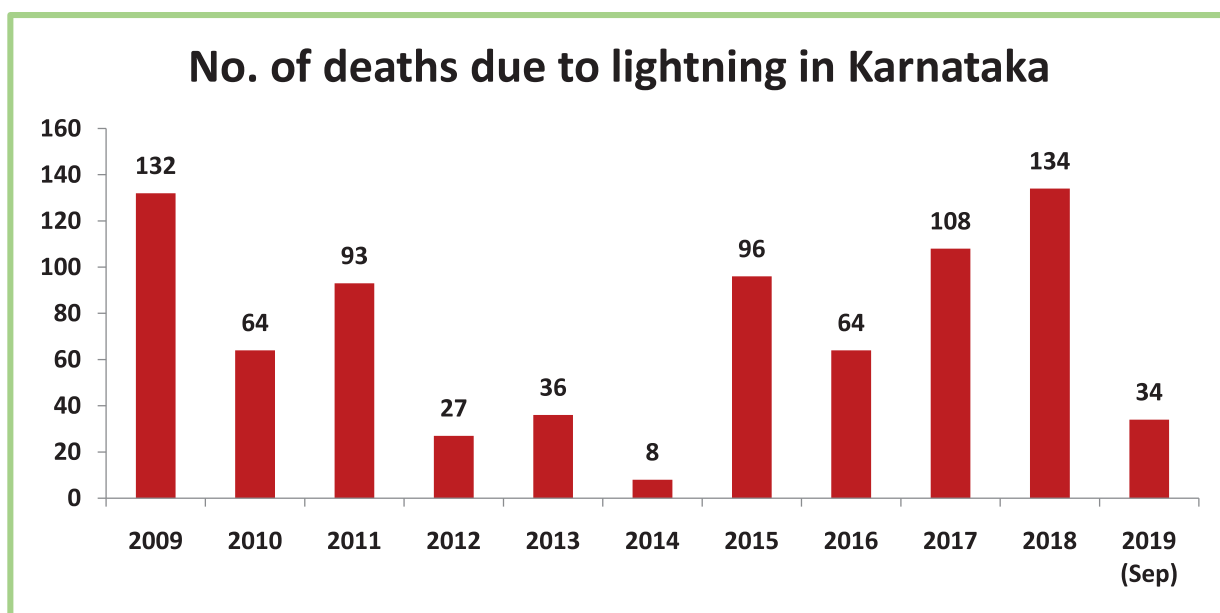


Fig. 35. Year wise number of deaths due to lightning in Karnataka from 2009-2019.

Maximum Temperature for the last 48-72 hrs and the Temperature forecast for the next 48 hrs are also taken into consideration while issuing the heat wave bulletin for the State and suggesting mitigation measures for the respective authorities.

6.2.8 Lightning

Lightning is a sudden electrostatic discharge that occurs during a thunderstorm. This discharge occurs between electrically charged regions of a cloud called intra-cloud lightning (IC), between Cloud to Cloud (CC lightning), or between a cloud and the ground (CG lightning). The charged regions in the atmosphere temporarily equalize themselves through this discharge referred to as a flash. A lightning flash can also be a strike, if it involves an object on the ground. Lightning creates light in the form of black body radiation from the very hot plasma created by the electron flow, and sound in the form of thunder. Lightning may be seen and not heard when it occurs at a distance. A huge amount of energy (about 1 billion joules) is released during a lightning strike. Due to this there is a loss of life and property across the world every year.

Lightning strikes have been causing loss of life and property in Karnataka (Fig-35). The records available with Revenue Department (Disaster Management) GOK shows that more than 600 people have died due to lightning strikes in Karnataka since 2009. Apart from the loss of life, there is huge loss of livestock as well as infrastructure due to lightning strikes in the state every year.

Monitoring the Dangerous Thunderstorm movements and providing early warning to the vulnerable community and also guiding the community through awareness about the safety measures to be taken to protect themselves from the lightning strikes is the only way. Thus, KSNDMC has installed a Lightning detection Sensors network in the state and providing lightning strike related early warning to the community. A **Mobile App "SIDILU"** has been developed for disseminating the information about Lightning Strikes in the state. Apart from the Early Warning, the App also provides the advisory about the safety measure in the form of Do's and Don'ts to the public which will help public to secure themselves during the Lightning activity in their location.

Apart from disseminating the Early Warning through **"SIDILU" Mobile App** the Early Warning will also be disseminated through **SMS** to the mobile phones of the Panchayat Development Officers (PDOs) and Revenue Inspectors of the respective Grampanchayaths. Early Warning about the lightning strikes is being disseminated to the public through 24 x 7 Interactive Help Desk **"VARUNA MITRA"** as well. The lightning related early warning and advisories, customized to Grampanchayath level, is also being disseminated directly through SMS to the farers.

Apart from providing Early Warning about the Lightning strikes, for creating awareness in the general public the KSNDMC has developed Audio-Visual clips explaining the impact of lightning strikes and related safety measures and being made available to the public through Mass media.

CONCLUSION

The study of long-term climate data series for the last 58 years (1960 to 2017) shows that there has been a considerable shift in rainfall pattern over Karnataka. The quantum, intensity and distribution of Rainfall has varied across the regions in the state from P1 (1960-1990) to P2 periods (1991-2017). The amount of Annual rainfall and number of rainy days have increased in SIK and Malnad regions. Alongside, there is a reduction in amount of annual rainfall and marginal increase in number of rainy days observed in NIK and Coastal regions. The Kodagu, Kalaburagi, Yadgir, Dakshina Kannada, Uttara Kannada districts shows a reduction in the amount of annual rainfall and an increase in rainfall over Shivamogga and Hassan districts from P1 to P2.

An increase in seasonal and annual rainfall in Challakere taluk and a decrease in rainfall in Vijapura taluk in NIK is observed. Similarly, there is a marginal increase in seasonal and Annual rainfall in Shivamogga taluk in Malnad region and on the contrary there is a marginal decrease in rainfall in Udupi taluk in Coastal region. Among the regions, SIK and Malnad regions showed statistically insignificant increase in all seasons and annual rainfall. While NIK and Coastal regions showed marginal decrease in southwest monsoon rainfall from P1 to P2.

The CV (%) representing the inter-annual variability of Rainfall is high in Parts of Vijayapura, Bagalkote, Raichur, Koppal, Ballari, Gadag, Dharwad, Belagavi, Haveri, Davanagere, Chitradurga, Chikkamagaluru, Bengaluru and Ramanagara districts. Very Light and Light rainfall events have increased in all the regions. Moderate and Heavy rainfall events did not show any distinct pattern. Also, the number of years with below normal rainfall have increased in NIK, whereas it has decreased in other regions from P1 and P2. Consequently, the NIK and SIK are more prone to severe drought compare to Malnad and Coastal regions. Frequency of occurrence of drought has increased in recent years.

The analysis of Temperature and Relative Humidity data series for the period 2002 to 2018 shows a steady increasing trend in average Temperature, while the relative humidity showed a decreasing trend commonly in most of the regions in the state.

The effects of variations in climatic factors are observed in the form of high impact weather events in the state. The occurrence of Extreme weather events has increased both in terms of frequency and intensity across the state in the last decades. The data shows that the Hydro-Meteorological disasters such as Drought, Flood, Hailstorm, Cyclone, Heatwave, Thunderstorm and Lighting events have occurred in the state more frequently in recent years. The extreme weather events have caused loss of human life, livestock, critical infrastructure, private and public property.

The high spatial and temporal variability of rainfall distribution has been the cause of recurring and widespread Drought in Karnataka. At times, the drought has affected about 90% (as in the year 2003) of the Taluks in the state. Agriculture and allied sectors, on which the majority population of State depends for employment and livelihood, is the most affected by the recurrence of Drought. The Drought causes crop loss, drinking water scarcity, fodder scarcity, and unemployment to rural agricultural laborers. Increased incidence of droughts reduces crop productivity, affecting nutrition and consequently, increase in hunger, malnutrition, vulnerability to diseases, and loss of livelihoods of the community.

The recurrence of droughts and floods because of changing rainfall patterns caused by climate change would be detrimental to surface and groundwater recharge and also pose a great challenge to the water security.

The risk of Cyclone in the Arabian Sea, storm surges and sea-level rise has made the population settled along the coastline in the state, exceedingly vulnerable to the impacts of these disasters and potential loss of land due to erosion, loss of critical infrastructure and property.

Therefore, the concerned stakeholders has to plan and implement a far-reaching sector specific mitigation and adaptation measures and interventions for achieving long-term climate resilience, sustainable economic growth, and also achieving the Sustainable Development Goals (SDG). Creating awareness amongst the public about the Climate Change, its impacts and adaptation strategies should also be included in the programs.

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